BK-94-146

Taxy 13

Department of Veterans Affairs

20090519 180

Rehabilitation R&D Progress Reports 1992-1993



Vol 30-31, December 1994
Veterans Health Administration
Rehabilitation Research and Development Service

TO THE READERSHIP

Traditionally, each issue of the *Rehabilitation R&D Progress Reports* covers work accomplished during the year prior to its publication. Therefore, Vol. 29, published in 1992, covered work done in 1991. Due to reorganization and the installation of additional computerized equipment for further refinement of the publication, there was no *Progress Reports* published in 1993.

In order to keep our readers informed of progress being made in the field of rehabilitation research and development, the current issue (Vol. 30–31) covers both 1992 and 1993.

The next issue (Vol. 32) will be published in 1995 and will cover reports of work accomplished in 1994.

Thank you for your patience. We regret the delay, and any inconvenience it may have caused, and we look forward to receiving your input for the 1994 issue.

PUBLICATIONS MANAGEMENT

ON THE COVER

This striking and imposing eagle guards the entrance to the Department of Veterans Affairs, Rehabilitation Research and Development Service in Baltimore, Maryland.

Historically, this magnificent federal building, which has been declared a national historic monument, was dedicated in 1933 by order of the then Secretary of the Treasury of the Federal Government in Washington, DC. Geographically, it is located on South Gay Street just off Pratt Street, the main thoroughfare of Baltimore's beautiful Inner Harbor.

In 1987, the Washington, VA Central Office, Rehabilitation Research and Development Service expanded into the field to house the operations of a number of its Service's functions: publications, evaluation of research and development prototypes, evaluation of non-VA commercial devices and wheelchair compliance testing, and the support group for peer review of rehabilitation research and development proposals submitted for funding support. (A detailed description of each of these Sections may be found in Section II of this issue.) Progress reports of funded projects are reported in this publication along with non-VA reports.

It is indeed an honor for the Rehabilitation Research and Development Service, directed by John W. Goldschmidt, M.D., to be housed in this historic building.

THE EDITOR

Cover design by Frank Vanni; photograph by Nick Lancaster, Scientific and Technical Publications Section, Rehabilitation Research and Development Service, Department of Veterans Affairs.

Department of
Veterans Affairs

AD-A286323

Rehabilitation R&D Progress Reports

1992-93

Rehabilitation R&D Progress Reports
is a publication of
The Department of Veterans Affairs
Veterans Health Services and Research Administration

VA Rehabiliation Research and Development Service
Scientific and Technical Publications Section (117A)
103 South Gay Street
Baltimore, MD 21202-4051

GUIDELINES FOR SUBMITTING PROGRESS REPORTS FOR THE YEAR 1994 to be published in 1995.

PUBLICATION

The *Rehabilitation R&D Progress Reports* is published annually.

SUMMARY OF REQUIREMENTS

GENERAL INFORMATION

Each report must include the following information:

1. Full names, titles, and addresses of the principal investigator and co-authors and location of the research activity, including zip or postal codes.
2. Telephone number of the principal investigator.
3. Full name and address of the sponsoring organization(s), as well as the specific funded program. Include name of organization's director, if applicable (not necessary for VA facilities).
4. Complete and accurate recent publications resulting from this research (i.e., exact title, author(s), publication title, volume, issue number, date, and page numbers). Incomplete citations will be deleted.
5. A list of key words.
6. A suggested category listing (based on categories included in this book).

TEXT

Text of reports may not exceed 600 words. The *Progress Reports* are published solely as statements of investigators on the current status of their work, and not as short research papers. Reports must be typed, double-spaced format, with clearly marked page numbers. Two hard copies are required. A copy of the same material on diskette (nonreturnable) must be included. We use files saved in pure ASCII format under MS-DOS, either 5 1/4-inch or 3 1/2-inch diskettes.

1. ORGANIZATION: The text should contain a brief summary of the **Purpose, Methodology, Progress, Results (Preliminary** or **Final)** over the past year, and may contain a brief statement of **Future Plans/Implications,** if appropriate. **Recent Publications Resulting from This Research** may include citations from the previous year only (i.e., 1994), and must be published or accepted for publication. Information on **Patents** and **Awards** may also be included. Because of space limitations we will print only up to a total of 6 citations for any one Progress Report.
2. ILLUSTRATIONS: **Do not include figures, tables or photographs.**
3. EDITORIAL CHANGES: Since galley proofs are not sent on *Progress Reports* submissions, any editorial changes made to meet publication requirements will be final, and not subject to author review.

CORRESPONDENCE

Non-VA Investigators Address mail to:
Managing Editor
Rehabilitation R&D Progress Reports, 1995
Scientific and Technical Publications Section (117A)
VA Rehabilitation Research and Development Service
103 South Gay Street
Baltimore, MD 21202-4051 USA

VA Investigators Address mail to:
Program Analysis and Review Section (117A)
Rehabilitation R&D Progress Reports, Issue, 1995
Project Monitor (PA, SCI, Sensory, Geriatric [as appropriate])
VA Rehabilitation Research and Development Service
103 South Gay Street
Baltimore, MD 21202-4051 USA

CONTACTS

FTS 8(700)922-1800, FAX (410)962-9670, Commercial (410)962-1800

Department of Veterans Affairs

Rehabilitation R&D Progress Reports

1992-93

John W. Goldschmidt, M.D.
Director, Rehabilitation Research and Development Service
Veterans Health Administration
Department of Veterans Affairs

Tamara T. Sowell, *Editor*

Neil McAleer, *Co-Editor*

SCIENTIFIC AND TECHNICAL
PUBLICATIONS SECTION MANAGEMENT
Jon S. Peters, *Acting Program Manager*
Renee Bulluck, *Secretary*
Marcia Nealey, *Program Clerk*

PRODUCTION STAFF
Neil McAleer, *Managing Editor*
Barbara G. Sambol, *Senior Technical Publications Editor*
Donald L. Martin, *Technical Publications Editor*
June R. Terry, *Program Assistant*
Celeste Anderson, *Secretary*

INFORMATION RESOURCE UNIT
Frank L. Vanni, *Visual Information Specialist*
Nick Lancaster, *Scientific and Technical Photographer*

The opinions expressed in contributed material are those of the authors and those responsible for supplying the material, and are not necessarily those of the Department of Veterans Affairs.

Contents of *Rehabilitation R&D Progress Reports* are within the public domain, with the exception of material which was already under copyright when received and appears here with the permission of the copyright owner. Such copyrighted material is clearly identified as such on the page where it appears, and all such material in an issue is listed at or near this position in that issue.

Copyrighted material in this issue: NONE.

DISTRIBUTION/CIRCULATION POLICY

Rehabilitation R&D Progress Reports is distributed annually. The mailing list is intended to cover all professionals in the rehabilitation field who are either actively involved in research, contemplate such involvement, or need to remain familiar with the direction and methods of the current research and the clinical application of its results.

At present, the *Rehabilitation R&D Progress Reports* annual publication is distributed free of charge, both in the United States and in foreign countries. Additions will be made to the mailing list upon request.

BACK ISSUE ORDER FORM

The following back issues and reprints of the *Journal of Rehabilitation Research and Development* and *Rehabilitation R&D Progress Reports* are available on request, free of charge, when in stock. Check any you wish to receive.

____ Vol. 21 No. 2 (1984)
____ Vol. 24 No. 3 (1987)**Microstomia, Hip Replacement
____ Annual Supplement (*PR 1988*)
____ Vol. 26 No. 2 (1989)
____ Vol. 26 No. 3 (1989)
____ Annual Supplement (*PR 1989*)
____ Vol. 27 No. 1 (1990)
____ Vol. 27 No. 2 (1990)
____ Vol. 27 No. 3 (1990)
____ Vol. 27 No. 4 (1990)
____ Vol. 28 No. 2 (1991)
____ Vol. 28 No. 3 (1991)
____ Vol. 28 No. 4 (1991)
____ Vol. 29 No. 1 (1992)+*JRRD* Index: Vol. 28
____ Vol. 29 No. 2 (1992)
____ Vol. 29 No. 3 (1992)
____ Vol. 29 No. 4 (1992)
____ Vol. 29 Annual Supplement (PR 1991)
____ Vol. 30 No. 1 (1993)
____ Vol. 30 No. 2 (1993)
____ Vol. 30 No. 3 (1993)
____ Vol. 30 No. 4 (1993)
____ Vol. 31 No. 1 (1994)+*JRRD* Index: Vol. 30
____ Vol. 31 No. 2 (1994)
____ Vol. 31 No. 3 (1994)

Clinical Publications:
____ Clinical Supplement No. 2 (Choosing A Wheelchair System)
____ Clinical Guide (Physical Fitness/Lower Limb Loss)

* = Special issue on this subject
** = Clinical articles on this subject
+ = issue contains JRRD index

Name: _____ _____
Label ID Number:

Address: _____ _____
Street Apt. #

_____ _____
City State Zip Code

_____ _____
Country Postal Code

Please mail this form with your request to:
Publications Back Order Department
Scientific and Technical Publications Section
VA Rehabilitation R&D Service (117A)
103 South Gay Street
Baltimore, Maryland 21202-4051

You may also use Internet Mail to place an order and/or to be added to our mailing list. Our Internet Mail address: pubs@balt-rehab.med.va.gov

Fax orders and requests are also accepted at (410) 962-9670.

Rehabilitation R&D Progress Reports 1992-93

Contents

1	*Section I.*	***PROJECT PROGRESS REPORTS*** Progress reports are arranged in appropriate subject categories. Reports are numbered in brackets preceding the title. VA-sponsored reports are presented first and are followed by those of other sponsoring organizations in alphabetical order. (*See next page for a topical listing with project numbers.*)
454	*Section II.*	***SPONSOR INDEX WITH SELECTED PROGRAM SUMMARIES*** ***A. Department of Veterans Affairs*** ***B. Non-VA Sponsoring Organizations*** This section contains the name and location of all sponsoring organizations and an index of the titles and page numbers of the projects sponsored by each.
476	*Section III.*	***AUTHOR INDEX*** The names of all progress report investigators and directors of sponsoring orgnizations are listed with corresponding page numbers.
487	*JRRD On-Line*	Information on accessing Progress Reports and JRRD electronically.

Section I
Project Progress Reports

I. Amputations and Limb Prostheses

A. General

1 Additive Fabrication Technique for the CAM of Prosthetic Sockets
2 Prosthetic/Orthotic Materials
3 Resource Unit for Information and Education
4 Short Range Telemetry of Surface Myoelectric Signals

B. Upper Limb

1. General

5 New Control Applications for Upper-Limb Prostheses: Direct Muscle Attachment for Position-Servo Control
6 Direct Muscle Attachment: Multifunctional Control of Hands and Arms
7 VV59 Prosthetic Hand Enhancements: Cosmetics, Electronics, and New Larger Size
8 Biomechanical Study to Improve Grip in Children's Terminal Devices
9 Prosthetic Arm Design and Simulation System: PADSS
10 EPP-Type Position-Servo Control of Electric Elbows for Children
11 Electromechanical Prosthetic Hands and Visual Feedback
12 Myoelectric Control Strategies
13 Improving Prosthetic Prehension

B. Upper Limb

2. Above-Elbow

14 Triphasic Patterns in Above-Elbow Amputees
15 Liberty MyoSelector: An Adaptable Scheme to Select Multiple Functions
16 New Boston Elbow: Increased Capabilities
17 MyoArray: A Diagnostic Tool to Test and Train Amputees to Use Myoelectric Prostheses
18 Development of a Prosthesis for Elbow Disarticulation Amputees

B. Upper Limb

3. Below-Elbow

19 EMG Pattern Recognition

C. Lower Limb

1. General

20 Clinical and Laboratory Study of Amputation Surgery and Rehabilitation
21 Application of Ultrasound and Computer Techniques to Lower Limb Prosthetic Socket Design
22 Computerized Methods in Prosthetics and Orthotics
23 Functional Biomechanical Characterization and Functional Design Specification: Lower-Extremity Prosthetics
24 Dynamic Response Prosthetic Feet and Their Role in Human Ambulation
25 Dundee Limb Fitting Centre Lower Limb Amputee Survey

C. Lower Limb

2. Above-Knee

26 Computer-Aided Socket Design and Computer-Aided Manufacturing for Above-Knee Prosthetics
27 Femoral Displacement in Above-Knee Sockets
28 Modification of the Van Nes Prosthesis
29 Pediatric Above-Knee Endoskeletal Running Prosthesis

C. Lower Limb

3. Below-Knee

30 Efficiency of Dynamic Elastic Response Feet
31 Prosthetic Design for Dysvascular Below-Knee Amputees
32 Gait Initiation in Below-Knee Amputees: Analysis of Safe Function
33 New CAD/CAM Methods to Enhance Prosthesis Design
34 Practical Applications of New CAD and CAE Techniques to Socket Design
35 Comparison of CAD/CAM and Conventional Techniques for the Fabrication of Trans-Tibial Sockets with Supracondylar Suspension
36 Comparison of Van Nes Rotationplasty and Syme's Amputation

II. Biomechanics

A. Bone and Joint Studies

37 Maintenance and Adaptation of Bone Tissue: The Importance of Mechanical Stimuli
38 Determination of Bone and Joint Loads from Bone Density Distributions
39 Upright Posture: How Limb Biomechanics Limits the Ability to Stand
40 Strength of Human Cortical Bone with Simulated Metastatic Lesions
41 Biomechanics of Cervical Diagnostic Maneuvers: A Pilot Study
42 Optimum Implant Stiffness for Lumbar Fusion: A Pilot Study

43 Correlation of Streaming Potentials with Stages of Bone Repair/Remodeling
44 Study to Investigate the Benefits of Physiotherapy and External Supports on the ACL Deficient Knee
45 Skeletal Muscle Characteristics during Submaximal Activation
46 Skeletal Muscle Reaction to Growth and Immobilization
47 Quantitative Functional Anatomy of the Upper Extremity
48 Kinematic and Dynamic Analysis of the Shoulder Mechanism

B. Human Locomotion and Gait Training

49 Comparative Study of Stabilogram-Diffusion Analysis and Traditional Posturographic Analyses
50 Bicycle Ergometry to Improve Ambulation in Hemiplegic Stroke Patients
51 Initiation of Human Walking
52 Computational Posturography: In Numero Experiments on Postural Control
53 Integration of Visual Input into the Aged Postural Control System
54 Age-Related Changes to Open-Loop and Closed-Loop Postural Control Mechanisms
55 Effects of Visual Input on Open-Loop and Closed-Loop Postural Control Mechanisms
56 Random Walking during Quiet Standing
57 Integrated Assessment of Factors Affecting Functional Capacity for Locomotion
58 Restoration of Gait for the Stroke Patient
59 Computer-Aided Movement Analysis in a Rehabilitation Context
60 Effects of Head Injury on Open-Loop and Closed-Loop Postural Control Mechanisms
61 Feigning Postural Instability
62 Postural Control Adaptability during Prolonged Spaceflight
63 Development of a Direct Ultrasound Ranging System for the Quantification of Ambulation
64 Assessment of Variability in Human Walking
65 Hard-Wired Central Pattern Generators for Quadrupedal Locomotion
66 Effects of Noise on a Locomotor Central Pattern Generator Model
67 Group-Theoretic Approach to Rings of Coupled Biological Oscillators
68 Coordination of Muscles in Gait

C. Other

69 Effects of Head Positioning on Pressure Generation in the Pharynx during Normal Swallowing: A Pilot Study
70 Development of a Low-Dimensional Representation of Lifting Dynamics: A Pilot Study
71 Contralateral vs. Ipsilateral Cane Use

III. Functional Assessment

72 Effects of Sensory-Neural Deficits on Balance and Posture in Individuals with Multiple Sclerosis: A Pilot Study
73 Development of a Predictive Model of Driving Performance in Stroke Patients
74 Functional Analysis of Feeding and Interaction Disorders with Young Children Who Are Profoundly Disabled

IV. Functional Electrical Stimulation

A. General

75 Selective Neural-Muscular Stimulation Using Magnetic Fields and Implantable Coils
76 Rehabilitation of the Colon after Spinal Cord Injury: A Pilot Study
77 High Charge Density, Bipolar Electrodes for Chronic FNS
78 Implantable Electrodes Using Iridium Oxide Film Technology
79 Management of Central Ventilatory Insufficiency through Abdominal and Thoracic Stimulation: A Pilot Study
80 Electrical Activation of the Diaphragm for Ventilatory Assist
81 Evaluation and Optimization of FES Techniques for Exercise

B. Upper Limb Applications

82 Functional Neuromuscular Systems for Upper Extremity Control

C. Lower Limb Applications

83 FES-Aided Paraplegic Gait Using a Controlled-Brake Orthosis
84 Development of an On-Line Correction Capability for FNS Locomotion: Computer Simulation of Paraplegic Gait through Multiple Gait Cycles
85 Development of an On-Line Correction Capability for FNS Locomotion: Mathematical Models for Muscle Control
86 Development of an On-Line Correction Capability for FNS Locomotion: A Fuzzy Logic Rule Base for Gait Phase Detection and Correction
87 Development of an On-Line Correction Capability for FNS Locomotion: State Estimation of Electrically Stimulated Muscle Using the EMG Surface Response
88 Restoration of Standing Pivot Transfer for Quadriplegic Patients Using a Totally Implanted FNS System
89 Functional Paraplegic Walking with Electrical Stimulation
90 Restoration of Muscle Activity Through FES and Associated Technology: The Raft Project, A Concerted Action

91 Biomechanical Analysis of Paraplegic Walking with Orthoses and FES
92 Estimation of Electrical Stimulus: Torque Relationship in Quadriceps Muscle for FES Application on Paraplegic Patients
93 Novel FES System Improving Locomotion Abilities in SCI Subjects by Enhanced Voluntary Control Based on Sensory Integration and Extended Sensory Perception

V. Geriatrics

94 Optokinetic Testing for Diagnosis and Rehabilitation of Balance Disorders
95 Upper Body Motion Analysis for Amelioration of Falls in the Elderly
96 Influences on Long Bones: Development, Growth, and Aging
97 Effects of Expectation, Reward, and Activity on Subtypes of Schizophrenia
98 Age-Related Changes in the Triceps Surae Stretch Reflex and Postural Control
99 Knowledge-Based System for Selecting Elopement Control Devices
100 Environmental and Behavioral Factors in Falls among the Elderly
101 Evaluation of Interventions to Prevent Elopement among Nursing Home Patients
102 Design of New Toilet Prototypes for Elderly and Disabled Veterans
103 Applicability of Accessibility Codes to Meet the Needs of Elderly People
104 Balance Training in Elderly Fallers and Nonfallers
105 Effects of Strength Changes for Older Adults
106 Restraint of Ambulatory Nursing Home Residents with Cognitive Impairments
107 Effects of Age and Resistance Training on Skeletal Muscle
108 Quantitative Posturography: Age-Related Changes in Postural Stability
109 Effect of Chair Design on Chair Rise Performance in Disabled Old Adults
110 Effects of Muscle Strength on Balance during Movement in the Elderly
111 Do Changes in Strength Improve Balance and Function in Elderly Men and Women?
112 Synchronized Electrical Stimulation Therapy in Elderly Incontinent Men: A Pilot Study
113 Manipulating Joint Compliances and Ground-Reaction Forces to Predict Falling Potential: A Pilot Study
114 Behavioral Treatment of Urinary Incontinence
115 Effects of Aging on the Bone Tissue of the Femoral Neck on Men and Women
116 Swallowing Dysfunction in Elderly Head and Neck Cancer Patients
117 Swallowing Physiology Related to Normal Aging
118 Age-Related Changes in Sensory-Motor Performance
119 Attention in Early Dementia
120 Later Life Effects of Early Life Disability: Comparisons of Age-Matched Controls on Indicators of Physical, Psychological, and Social Status
121 Evaluation of Adaptive Device Use by Older Adults with Mixed Disabilities
122 Use of Technology to Promote Rehabilitation of Older Persons: Reducing the Barriers to Independence
123 Role of Training to Enhance Utilization of In-Home Support: A Comparison Between Older Hispanics and Anglos With A Disability
124 Policy and Funding Alternatives to Promote Community and Supportive Services for Older Persons with a Disability
125 Analysis of Policy Barriers to Accessing Technology Services for Individuals Aging with a Disability
126 Analysis of Policy Barriers to Accessing Technology Services for Individuals Aging with a Spinal Cord Injury
127 Polio Disability: Personal Meaning, Well-Being, and Age
128 Discussing CPR/DNR Choices with Geriatric Inpatients: The Psychological Impact on the Patient
129 Caregiver Health
130 Psychosocial Factors and Health in the Elderly

VI. Head Trauma and Stroke

131 Computer-Assisted Treatment of Hemi-Inattention in R-CVA Patients
132 Neuroactivation SPECT Imaging for Assessment of Rehabilitation Potential Following Cerebral Infarction
133 Integrating Trauma and Rehabilitation (ITR)
134 Orthokinetic Orthosis: Systematic Replication of a Clinical Efficacy Study of Orthokinetics Treatment for a Patient with Upper Extremity Hemiparetic Movement Dysfunction in Post-Acute CVA
135 Musical Attention Training Program
136 Reducing Motor Disability in Hemiparetic Stroke by Manipulation of Sensory Input from the Paretic Upper Limb: A Quantitative Evaluation
137 Predictive Value of Cognitive/Behavioral Measures in Patients after Stroke in Assessing Functional Outcome
138 Improving Vocational Outcomes of Individuals Who Have Sustained a Stroke
139 Effectiveness of a Telephone Support Group for Stroke Caregivers
140 Effects of Aerobic Exercise on Young Persons Post-Stroke
141 Controlled Study of the Effects of EMG Feedback and Electrical Stimulation on Motor Recovery in Acute Stroke Patients

142 Course of Recovery of Cognitive-Communicative Problems in Right Brain Damaged Individuals
143 Co-Morbidities and Complications in Stroke: Incidence, Risk Factors, and Effects on Outcomes
144 Prevention of Thromboembolism in Stroke Rehabilitation Patients
145 Community Re-Entry and Functional Status of People Following Brain Injury Rehabilitation

VII. Independent Living Aids

A. General

146 Restoration of Sit-to-Stand Function in Elderly Patients Using FNS
147 Development of a Portable Biofeedback Cane: A Pilot Study
148 Development of a Miniature 'Shear' Sensing Transducer: A Pilot Study
149 Occupational Therapy Functional Assessment Compilation Tool (OT FACT)
150 Development of User-, Professional-, and Public-Accessible Database Interface Techniques
151 Assessing Individuals' Predispositions to the Use, Avoidance, or Abandonment of Assistive Technologies
152 Bedsore Biomechanics
153 Investigational Study of the Effect of Platelet-Derived Growth Factors on Non-Healing Pressure Ulcers

B. Robotics

154 Rehabilitation Engineering Research Center in Robotics
155 Improving the Functional Utility of Rehabilitation Robotics through Enhanced Sensory Feedback
156 Rehabilitation Robotics Information Program
157 Three-Dimensional Pointing Interface for the Manus Manipulator
158 Eye Position Interface for the MANUS Manipulator

C. Communication Methods and Systems

159 Recognition of Hand Gestures by People with Motor Impairments: A Pilot Study
160 Development of Extensions for Standard Computers and Operating Systems to Allow Access by Users with Motor Impairments
161 Effects of Gain and Movement Range on Performance Using Head-Controlled Computer Input Devices
162 Project LITERAAC: Literacy Intervention to Enhance Reading and Writing through Augmentative and Alternative Communication
163 Interface Training and Use by Persons with Cognitive Disabilities
164 Interface Training and Use by Young Children
165 General Input Device Emulating Interface (GIDEI) Standard
166 Development of Design Guidelines for Computers and Other Electronic Devices to Increase Usability by Persons with Disabilities
167 Recognition of Gestures for Expressive Communication
168 Flexible Abbreviation Generation
169 Compansion: A Rate Enhancement Method that Utilizes Natural Language Processing Techniques
170 Application of Natural Language Processing to AAC
171 Human Factors Studies in Eye Movements Related to AAC Head-Mounted Unit
172 Human Factors Studies in Eye Movements Related to AAC Head-Movement Studies
173 Augmentative Communication Information Program
174 Language Facilitation through Graphics and Graphical Animation
175 Spatialization and Spatial Metaphor in AAC
176 Speech Processing Program
177 Speech Synthesis Program
178 Development of an AAC Software Architecture
179 Development of AAC Systems Based on Personal Computers
180 Evaluation of Human-Systems Interaction in AAC
181 Enhancing Picture-Based Communication via Computer-Assisted Design and Instruction
182 Modeling of Performance with Computer Access and Alternative Communication Systems
183 WiVik 2REP: Rate Enhancement Package
184 WiViK 2 Scan: 1-5 Switch Scanning Access
185 Development of 'Talksbac', a Computer-Based Communication System

D. Private and Public Programs

186 Rehabilitation Engineering Research Center: Technology Evaluation and Transfer
187 Evolution of Independent Living Programs: A Longitudinal Study
188 Assisting Community-Based Rural Independent Living Programs
189 Life Satisfaction of People with Physical Disabilities: Relationship to Personal Assistance, Disability Status, and Handicap
190 Development of an Instrument to Measure Adequacy of Personal Assistance Service
191 Use of Personal Assistance Services by Persons with Spinal Cord Injury
192 Effect of Personal Assistance Services on the Long-Term Health of a Rehabilitation Hospital Population: Perceptions of Rehabilitation Professionals
193 Demonstrating a Model Approach to Independent Living Center-Based Assistive Technology Services
194 Increasing the Ability of Independent Living Centers to Serve the Hispanic Population
195 Increasing the Ability of Independent Living Centers

to Serve the Population of African Americans with Disabilities

196 Relationships among Age at Onset, Adequacy of Personal Assistance, Negative Health Incidents, and Health Care Utilization for Persons with Physical Disabilities

197 Applications of Technology to Enhance Quality of Life: A Multidisciplinary Consortium Approach

198 Applications of Technology: A Multidisciplinary Consortium and Service Delivery Model

199 Assessing the Capabilities of Independent Living Center Staff to Deliver ADA-Related Services

VIII. Muscles, Ligaments, and Tendons

A. Muscles

200 Effect of Chronic Theophylline Treatment on Quadriplegia

201 Pedaling Coordination: Identification of Muscle Control Strategies

202 Muscle Coordination of Multijoint Motor Tasks: An Interactive Computer Workstation Environment

203 Muscle Fiber Strengthening with Electrical Stimulation

204 Modelling of EMG Signals

205 Multichannel Surface EMG Signals

206 Estimation of Muscle Fiber Conduction Velocity

207 EMG and Mechanical Manifestations of Muscle Fatigue

208 Biochemical and Myoelectric Events during Fatigue

209 Skeletal Muscle Architectural Design: Implications for Tendon Transfer

210 Muscle Adaptability during Prolonged Spaceflight

211 Mechanism of Torque Generation in the Frog Hindlimb

212 Muscle Fiber Damage Due to Eccentric Contractions

213 Intraoperative Measurement of Human Muscle Sarcomere Length

B. Ligaments and Tendons

214 Physiological Basis of Strength Following Surgical Tendon Transfer

215 Combined Functional Loading and Laser Photostimulation of Regenerating Tendons

IX. Neurological and Vascular Disorders

A. General

216 Treatment of Muscle Spasticity Using Phenol Nerve Blocks

217 Development of Spastic Tolerant Stick Controller: A Pilot Project

218 Improvements to the Technique of Synchronization Evaluation

219 Effects of Hand Dominance on Motor Unit Firing Behavior

220 Neurosim: Investigations in Computational Neuroscience

221 Motor Unit Firing Rates during Sustained Isometric Contractions

222 Rank-Ordered Regulation of Motor Units

223 Common Drive of Motor Units: A Model for Motor Unit Control

224 Exercise Testing and Training of Multiple-Sclerosis Patients

225 Regrowth of Corticospinal Axons Following Co-Implantation of Carbon Filaments and Fetal CNS Tissue

226 Regrowth of Injured Axons on Non-Biological Substrates

227 Motor Unit Control Strategies during Sustained Isometric Contractions

228 Synchronous Behavior of Motor Unit Firings

229 Synchronization across Muscles

230 Neuromuscular Function in Postpolio Subjects: A Three-Year Follow-Up Study

231 Effect of a 12-Week Non-Fatiguing Muscle-Strengthening Exercise Program in Postpolio Patients

232 Vestibular Stimulation and Cerebral Palsy

233 Modelling of Force Production in the Muscle

234 Effect of Wax Therapy on the Plantar Skin in Leprosy

B. Low Back Pain

235 Database Development for a Clinical Back Analysis System

236 Muscle Performance in the Back Analysis System Compared to Lifting Tasks

237 Development of Test Protocols Related to the Behavior of Back Muscles

238 EMG Parameters of Lumbar Back Muscles

239 Back Assessment of Athletes from Varsity and Freshman Crew Teams

240 Normative Database Study of Back Muscle Function

241 Clinical Validation of the Back Analysis System for Treatment Outcome following Rehabilitation

242 Back Analysis System (BAS) Update

243 Secondary Prevention of Back Pain and the Development of Chronicity: The OIOC-NIOSH Model Clinic

244 Vermont Rehabilitation Engineering Research Center for Low Back Pain

C. Swallowing Disorders

245 Biomechanical Measurements and Classification of Dysphagia

D. Vascular Disorders

246 Predicting Ischemia in Use of the Lower-Limb Prosthesis: A Pilot Study

247 Noninvasive Measurement of Changes in Muscle Oxygent with Claudication

248 Omental Angiogenic Factor to Reverse Peripheral Vascular Insufficiency: A Pilot Study

249 Viscoelasticity of the Limb in Compartment Syndrome: A Pilot Study
250 Treatment of Dysphagia in Age-Related Disease: Stroke

X. Orthopedics

A. General

251 Multimodality Image Registration of the Cervical Spine
252 Suitability of Titanium Alloy as a Joint Replacement Bearing Surface
253 Mechanical Regulation of Skeletal Tissue in Normal and Prosthetic Joints
254 Cartilage Repair: Effects of Mechanical Loading
255 Development of Articulating Joints: The Role of Mechanical Forces
256 Hip Fracture Risk Assessment Using Automated 3-D Finite Element Modeling
257 Patient-Specific Finite Element Modeling of Bone from CT Scan Data
258 Vertebral Fusion by New Osteogenic Agents to Accelerate Rehabilitation
259 Biochemistry of Cartilage in a Model of Disuse and Different Types of Recovery
260 Predisposing Factors in Disc Prolapse
261 Changes in Blood Flow Associated with Intramedullary Nailing
262 Bone Substitute Material
263 Biochemical Analysis of Synovial Activation in Joint Dysfunction
264 Origin and Character of Regenerate Bone
265 Restoration of Oral Function with Maxillary Bone Grafts and Implants
266 Continuation of the Center for Retrieved Orthopedic Prostheses
267 Contact Pressure in the Hind Foot
268 In Vivo Measurement of Vertebral Displacement after Lumbar Fusion
269 3-D Analysis of Spinal Deformities by Means of the AUSCAN System
270 Orthopaedic Research Unit

B. Hip Implants

271 Influence of Collar Geometry in Femoral Components
272 Effect of Femoral Collar Geometry in Hip Replacement
273 Tissue Differentiation and Maintenance: The Influence of Mechanical Stimuli
274 Wear Debris Generation in Hip Modular Head and Neck Components
275 Pulsed Laser Deposition of Coating for Prosthesis-Bone Bonding
276 Optimized Surface Bonding and Stiffness of Femoral Endoprostheses
277 Coating/Surface Treatments for Prosthesis-Bone Bonding
278 Bone Cement Collar for Sealing the Femoral Canal around Noncemented Prostheses
279 New Strategies for Long-Term Performance of Femoral Prostheses
280 Calcium Phosphate Ceramic Coatings as Vancomycin Carriers
281 Fiber-Reinforced Polymer Femoral Components for Hip Arthroplasty
282 Effect of Autologous Bone Paste, Hydroxyapatite, and Bone Morphologic Protein on Bone Fixation into Porous Coated Devices

C. Knee Implants

283 All-Plastic Total Knee Replacement
284 Tibio-Femoral Contact Stress and Stress Distribution Evaluation of Total Knee Replacements

D. Arthritis

285 Diagnosis of Cartilage Degeneration: Quantitative Surface Spectroscopy

XI. Orthotics

286 Adjusted vs. Unadjusted Foot Orthoses in the Prevention of Foot Ulcers in Diabetics
287 Computer-Aided Design and Computer-Aided Manufacturing of Orthopedic Footwear
288 Biomechanical Optimization of Lower Limb Orthoses Using Dynamic Surface Polyelectromyography
289 Modular Custom-Fitting Ankle-Foot Orthosis
290 Analysis of a Paediatric Ankle-Foot Orthosis
291 Advanced Contracture Reduction Orthosis (CRO)
292 Lightweight, Cosmetic, Articulating Ankle-Foot Orthosis
293 Corrective Head Orthosis for the Treatment of Occipital Plagiocephaly

XII. Psychological and Psychosocial Disorders

294 Sexuality Issues among Women with Physical Disabilities

XIII. Sensory, Cognitive, and Communication Aids

A. Hearing Impairment

295 Computerized Adaptive Methods for Selecting Hearing Aids
296 Evaluation of Word-Recognition Performance with Sentence Materials
297 Evoked Otoacoustic Emissions for Ototoxic Monitoring in Adults
298 Programmable Hearing Aids: Evaluation and Prediction of Benefit
299 Effects of Presence vs. Absence of Prolonged Amplification on Audition

300 Effect of Lack of Amplification on Persons with Unilateral Hearing Loss
301 Early Detection of Hearing Loss from Ototoxic Agents by High-Frequency Auditory Evaluation
302 Evaluation of a Coping Strategies Program in Aural Rehabilitation: A Pilot Study
303 Basic Mechanisms and Rehabilitative Strategies for Presbycusis
304 Rehabilitation Engineering Research Center on Hearing Enhancement and Assistive Devices
305 Auditory Redundancy of Computer Information for Hearing-Impaired Individuals
306 Feature Extraction Methods for a Video Telephone for Deaf and Hard-of-Hearing People
307 Natural Language Processing Principles for Improving Deaf Writing
308 Sclection, Fitting, and Evaluation of Hearing Aids

B. Speech Impairment

309 Nonliteral Language Test and Training Workstation for Patients with Communicative Deficits: A Pilot Study
310 Computer-Assisted Speech Evaluation Expert System
311 Cortical Auditory Evoked Potentials and Behavioral Measures of Aphasia
312 Verification of the Equivalency of Language Comprehension Measures: A Pilot Study
313 Ideomotor Apraxia: Recovery and Treatment
314 Analysis of a Treatment for Apraxia of Speech in Adults with Aphasia
315 Evaluation of the IBM Voicetype Recognition System with Speech-Impaired Individuals
316 Refinement and Evaluation of a Computer-Based Program for Training Speech Rate with Neurologically Impaired Individuals
317 Cricopharyngeal Myotomy Study

C. Vision Impairment

318 Using Self-Monitoring to Improve Communicative Efficiency in Aphasia
319 Environmental Information Needs for Wayfinding by Special Populations
320 Design and Testing of an Electronic Travel Aid for Blind Persons
321 Relationship of Auditory Skills to the Mobility of Blind Individuals
322 Development of a Computer Model of Mobility Coverage for the Visually Impaired
323 Revision of the Text : Foundations of Orientation and Mobility
324 Functional Independence Measure for Blind Adults (FIMBA)
325 Development of a System to Assess Locomotion over Long Distances: A Pilot Study
326 Design and Evaluation of Liquid Crystal (LC) Dark-Adapting Eyeglasses for Persons with Low Vision
327 Adjustable Power Liquid Crystal Lenses to Assist Persons with Low Vision: A Pilot Study
328 Development and Validation of Criteria for Task Safety in Blind Mobility
329 Enhancement of Balance Testing
330 Adaptive Cane for Special Adult Groups: A Pilot Study
331 Evaluating the Efficacy of a Peripheral Vision Expander System: A Pilot Study
332 National Survey of the Impact of Low Vision Device Use among Veterans
333 Use of Microphotodiode Implants to Restore Retinal Function: A Pilot Study
334 Connected Speech Deviations of Aphasic and Non-Brain-Damaged Adults
335 Promoting Generalized Language Use: An Analysis of Treatment Variables
336 Reading Rehabilitation of Geriatric Patients Post Exudative Maculopathy
337 Can Improvement in Reading Rates in Patients with Macular Disease be Predicted Prior to Vision Rehabilitation?
338 Validating a Measure of Low Vision Functional Status
339 Braille Literacy: Training, Mentoring, and Technological Services Program for Blind Adults
340 Multi-Modal Computer Feedback
341 Measuring Needs of Elderly Patients for Low Vision Devices
342 Rehabilitation of Visually Impaired Older Persons
343 New Nystagmus Tester
344 Photorefractive Vision Screening Research
345 Improved Visual Evoked Potential Recording System
346 Early Intervention: Clinical Efficacy of Alternate Occlusion in Infantile Esotropia
347 Evaluation of Heads-Up Displays for Low Vision Applications
348 Impact of Vision Impairments on Everyday Tasks
349 Skill Card: Evaluation and Technology Transfer
350 Study of Driving and Visual Impairment
351 Identification of Differential Costs and Time Usage of Blind and Visually Impaired Persons
352 Identification of Skills, Knowledge, and Steps Necessary for Students with Visual Impairments Entering Postsecondary Institutions
353 Identification of Skills and Knowledge Necessary for People with Visual Impairments Beginning Jobs after Graduating from Postsecondary Institutions
354 Fax-Based Communication Augmentation System for the Print-Handicapped
355 Access to Computer-Music Software by Blind and Vision-Impaired Musicians
356 Digital Speech Recorder and Programmer
357 Assistive Devices for Blind Diabetics
358 New Approach to Specialized Job Adaptations: Knitting Machine Counter Example
359 Audible Stud Finder
360 Rolling Ruler
361 Computer Interfacing of Digital Multimeters
362 OEM Audible Carpenter's Level
363 Special Light Probe for a Multi-Line Telephone

364 Desktop Broadcasting
365 WiVox: Voice Output for Windows
366 Study to Assess the Feasibility of Contracting with a Nominee Agency for the Business Enterprise Program
367 Assessment of Psychometric Tests for the Visually Impaired
368 Talking Signs® Project
369 Ergonomic Low Vision Telescope Grip
370 Vision Research: A National Plan, 1994-1998
371 Voice-Enhanced Oven: Software Emulation
372 Investigating Use of the Universal Product Code by Visually Impaired Shoppers and Vendors

D. Deaf-Blind

373 Electronic Formboard
374 Auditory Arcade
375 Talking Keyboard
376 Investigating Some Basic Parameters of Multifinger Tactile Perception
377 Survey of Deaf-Blind Technology Needs
378 Dexter: The Fingerspelling Mechanical Hand for Deaf-Blind Persons
379 Vibrating Medication Reminder for the Deaf-Blind
380 Smith-Kettlewell Vibratory Battery Tester for the Deaf-Blind
381 Warning Device Allows Swimmers Who Are Deaf-Blind to Swim Independently

XIV. Spinal Cord Injury and Related Neurological Disorders

A. General

382 Management of the Musculoskeletal Complications of Spinal Cord Injury
383 Spinal Cord Injury-Induced Bone Loss
384 Wheelchair Exercise and Digital Echocardiography for the Detection of Heart Disease
385 Urinary Bladder Stimulation following Spinal Cord Injury
386 Advanced Technology Neural Information Sensors for Prosthetic Control by Quadriplegics
387 Device for Treatment of Peripheral Nerve Injury
388 Prokinetic Agents for Constipation in Spinal-Cord Injured (SCI) Patients: A Pilot Study
389 Improving Exercise Performance of Quadriplegics
390 Objective Assessment of Spasticity in Spinal Cord Injury
391 DC Field Effects on Axonal Transport in the Corticospinal Tract following Spinal Cord Injury
392 Effect of Serine Protease Inhibitors on Neurite Outgrowth
393 Carbohydrate Metabolism and Cardiovascular Risk Factors in Persons with Spinal Cord Injury
394 Effect of Supported Standing and Upper Body Exercise on Lower Extremity Spasticity in Persons with Spinal Cord Injury
395 Sodium Pump Expression in Spinal Cord Trauma: A Pilot Study
396 Understanding Leisure Behavior of People with Spinal Cord Injury
397 Return to Productivity, On Your Mark, Project Incubator, Bridge: Four Employment Demonstration Projects
398 Quantification of Spasticity by Pendulum Test and EMG Activity Analysis
399 Development of an Instrument to Predict Compliance with Self-Care Behaviors in a Spinal Cord-Injured Population Using the Theory of Reasoned Action
400 Immune Responses to Pneumococcal Vaccine in Spinal Cord Injury
401 Natural History and Clinical Course of Urinary Tract Complications in Patients with Spinal Cord Dysfunction
402 Collaboration between Medical Rehabilitation Programs and Independent Living Centers in Facilitating Independent Living by Persons with Recently Incurred Spinal Cord Injury
403 Adaptive Noise Cancellation Applied to Spinal Cord Monitoring
404 KeyREP: Keyboard Rate Enhancement Package
405 Cardiorespiratory Responses to Exercise Testing in Acute Spinal Cord Individuals
406 Spinal Cord Injury Occurring in Patients with Ankylosing Spondylitis: A Multicenter Study
407 Hand Grip Assistive Device Allows Quadriplegics to Play Tennis
408 Wheelchair Performance Capacity and Physical Strain in Spinal Cord Injured Subjects
409 3-D Optical Analysis of Chest Wall Motion

B. Treatment and Rehabilitation

410 Functional Electrical Stimulation of Spinal Cord Injury Patients
411 Management of Incontinence in SCI Patients with Penile Nerve Stimulation
412 Neuroprosthetic Control of Bladder and Bowel in SCI Patients: A Pilot Study
413 Effect of Exercise on Upper Extremity Recovery following Quadriplegia
414 Thin-Film Peripheral Nerve Electrode
415 Application of the Nursing Minimum Data Set to Spinal Cord Injury Care
416 Catheter Cleaning for Re-Use in Intermittent Catheterization
417 Proposal for a Survey of Attendant Care Arrangements for Indigent SCI Individuals in Louisiana
418 Assessment of Post-Traumatic Stress Disorder in Spinal Cord Injury
419 Consumer Perception of Resources Needed for Long-Term Recovery from Spinal Cord Injury
420 Factors Affecting Employment Status among Persons with Spinal Cord Injury

421 Treatment of Vesicosphincter Dyssynergia Using the Urolume Prosthetic Stent: Effect on the Maximum Urethral Pressure Gradient
422 Music Making in Rehabilitation for Persons with Spinal Cord Injuries
423 Intrathecal Baclofen for Treatment of Intractable Spinal Spasticity
424 Rehabilitation Research and Training Center: Complications of Spinal Cord Injury
425 Adjustment of Spinal Cord Injured Who Are Victims of Intentional vs. Unintentional Injuries
426 Baclofen Pump: Functional and Neuropsychological Impact
427 Longitudinal Analysis of Well-Being in Persons with Spinal Cord Injury and Their Caregivers
428 Clinically Derived Protocol for Changing Condom Catheters in Males
429 Problem-Solving Skills Training in the Treatment of Pressure Ulcers in Persons with Spinal Cord Injury
430 Pathologic Effects of Recurrent Bacteriuria in Patients with Spinal Cord Dysfunction
431 Ultrasound for Urinary Tract Surveillance of Persons with Spinal Cord Injury
432 Natural History and Clinical Course of Skin Complications (Excluding Pressure Ulcers) in Persons with Spinal Cord Injury
433 Functional Assessment of the Performance Capacity of the Wheelchair-User Combination during Rehabilitation
434 Psychosocial Adjustment of Spinal Cord Injured Who Are Victims of Gunshot Wounds

C. Spinal Cord Regeneration

435 Application of Electric Fields to Enhance Recovery following Spinal Cord Injury
436 Preparation of Genetically Modified BDNF and NT-3 Secreting Fibroblasts and Evaluation of Their Capacity to Enhance Regrowth of Injured Spinal Cord Fibers
437 Ion Channel Expression in Astrocytes
438 Physiological Effects of Glial Cell Transplantation in the Myelin-Deficient Spinal Cord
439 Studies on Secondary Injury in Anoxic White Matter
440 Molecular Organization and Pharmacology of Mammalian Axons
441 Transplants of Ensheathing Glia from Adult Olfactory Bulb Facilitate Axon Regeneration in the CNS

XV. Wheelchairs and Powered Vehicles

A. General

442 Development and Testing of Clinical Workstation for the Reduction of Wheelchair Propulsion Injuries
443 SCI Responses to Wheelchair Propulsion during Fatigue: A Pilot Study
444 Wheelchair Propulsion Performance in Young, Middle-Aged, and Elderly
445 Toward the Design of a New Bowel Care/Shower Chair: A Pilot Study
446 Ergonomics of Manual Wheelchair Propulsion
447 Assessment of Deficiencies in Assistive Technology for Personal Transportation Systems
448 Methodology for Evaluating Equipment Used when Assessing Individuals' Needs for Vehicle Modification and Adaptive Equipment
449 Testing Procedures for Wheelchair Lifts
450 Testing Procedures for Wheelchair Sacrament Systems
451 Evaluation of Structural Integrity and Dynamic Stability of Modified Vans
452 Wheelchair Research at the University of Pittsburgh RERC

B. Powered Controllers

453 Research in Curvilinear Synchronous Motors for Power Wheelchairs
454 NavChair Control System for Automatic Assistive Wheelchair Navigation
455 Cognitive Readiness for Powered Wheelchair Mobility
456 Determining the Appropriateness of Integrated Control of Assistive Devices
457 Robotic Workstation with Optoelectronic Control
458 Powered Wheelchair Controller with Dynamic Stability Checking
459 Smart Wheelchair Modules

C. Seating Systems

460 Design of a Videofluoroscopy Chair for SCI and Other Disabled Patients: A Pilot Study
461 Quality Implications of Information Capture, Transfer, and Use in a Cross-Discipline Rehabilitation Engineering Team
462 Clinical Analysis of a CAD/CAM System for Custom Seating
463 Consumer Involvement in Children's Seating Design
464 Custom Car Seats for School-Aged Children

XVI. Wound and Fracture Healing

A. Pressure Sores

465 Evaluation of Interface Pressure Measurement Instruments: A Pilot Study
466 In Vitro Test of an Artificial/Cellular Graft for Pressure Sore Repair: A Pilot Study
467 Skin Composition in Spinal Cord Injury
468 Toward Better Methods of Nerve Repair and Evaluation
469 Artificial Nerve Graft: Union of Cellular and Noncellular Components

470 Treatment of Pressure Ulcers
471 Histopathology of Denervated Skin following Spinal Cord Injury

B. Fracture Healing

472 Comparison of Events in Bone Healing Influenced by CCEF and PEMF Signals

C. Other

473 Diabetic Foot Ulcer Risk Factors and Pathophysiology of Wound Repair

XVII. Miscellaneous

474 Vocational Training Facility: Interactive Employment Training for Persons with Physical Disabilities
475 Research Program on Accessible Housing
476 Predicting Wayfinding Ability from Laboratory-Based Spatial Tasks
477 Feasibility of a Dynamic Dermofluorometer to Monitor Skin Fluorescence: A Pilot Study
478 Development of a Two-Needle Front End for Motor Unit Detection
479 Reconstruction Expansion as a Geometry-Based Framework for Choosing Proper Delay Times
480 Visualizing the Effects of Filtering Chaotic Signals
481 Holter System Development for Recording Plantar Pressures
482 Effect of Botox on Walking
483 Health Behavior in School-Aged Children with Physical Disabilities
484 Doctoral Training in Physical Therapy
485 Design of a Clinical Reference System for Positioning Electrodes on the Back
486 Electrode Array Signal Processing
487 Research Training in Rehabilitation Engineering
488 Medical Rehabilitation Payment Study
489 Health Care Utilization and Cost Experience of Working-Age Persons with Disabilities: An Analysis of the National Medical Expenditure Survey (NMES)
490 Operational Definition of Independence
491 Research Training in Engineering and Rehabilitation Technology
492 Impact of Waiting for Community-Based Services and the Roles of Formal and Informal Services on Adults with Mental Retardation Who Live with Their Families: A Longitudinal Perspective
493 Transferring Technology from the Research Laboratory to the Commercial Market
494 Implementation and Follow-Up of Rehabilitation Technology
495 Rehabilitation Technology Training: A Plan for Facilitating the Delivery of Technology
496 Gathering and Disseminating Information on Assistive Technology for Children
497 Developing a Consumer's Guide on Funding Assistive Technology
498 Mainstreaming Students with Assistive Technology into Regular Education
499 Assistive Technology Usage Outcome
500 Rehabilitation Engineering Center, Texas A&M
501 Adaptive Filters for Biological Signal Processing
502 VLSI Telemetry Implant for Myoelectric Control
503 Portable Force Feedback Display System
504 Cognitively Based Treatments of Acquired Dyslexia
505 USERNET: Collaborative Evaluation of Commercial Appliances and Products
506 Multimedia Summer Experience
507 Assessment of Rhizotomy Surgery for Children with Cerebral Palsy
508 Development of a Swimsuit for Individuals Who Are Incontinent
509 Leg Gaiters Provide Flotation for Swimmers with Lower Limb Paralysis
510 Disabled Swimmers Use Special Seat to Participate Independently in Aquabics Classes
511 Inshoe Pressure and EMG Measurement

I. Amputations and Limb Prostheses

A. General

[1] AN ADDITIVE FABRICATION TECHNIQUE FOR THE CAM OF PROSTHETIC SOCKETS

Dudley S. Childress, PhD; Joshua S. Rovick, PhD
Northwestern University, Chicago, IL 60611

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A711-DA)*

PURPOSE—Computer-aided design (CAD) and computer-aided manufacturing (CAM) are gaining increased usage in the provision of artificial limbs. The devices currently available for CAM of prosthetic sockets are modeled after techniques commonly used for hand fabrication. This development project explores an alternative method of automated fabrication specifically designed for CAM which is expected to expand the role and the capability of CAD/CAM in prosthetics.

The device is designed to build sockets in an entirely new way but with common prosthetics materials. Sockets are built using an additive, sequential technique wherein thin layers of plastic material are deposited upon one another to create the desired socket shape. The plastic is melted in an extrusion tool and forced through a nozzle to obtain a flowing bead of molten plastic. A computer-guided manipulator directs the flow of plastic to correspond to sectional profiles of the socket at varying intervals. The device operates automatically, building a typical B/K prosthetic socket in about 1 hour and 30 minutes.

PROGRESS—A laboratory prototype of the fabricator has been designed, built, and refined to achieve a working device capable of producing sockets from data supplied by the socket CAD programs. Software translators were written to convert CAD data files for the fabricating device. The device uses common thermoplastic materials such as polypropylene (either homopolymer or copolymer), polyethylene, ABS, etc. which are readily available from plastic suppliers.

Due to the novel method of socket production, mechanical tests have been, and are being, performed to evaluate the acceptability of the method in comparison to established techniques of socket provision. The tests measure the tensile strength and the fatigue resistance (durability) of parts fabricated using the device. Standard ASTM methods are used in the testing. Clinical tests are also underway to gage the performance of the sockets in real-world application.

RESULTS—Standardized tensile testing has been performed on specimens prepared from polypropylene homopolymer and copolymer. The specimens were loaded to evaluate the anisotropic (non-uniform) material characteristics of the fabrications and were compared with specimens made with conventional fabrication techniques and with material properties reported in the literature. Examination of the failed specimens and the tensile strength data indicate that the tensile strength of the experimental specimens is equivalent to the tensile strength of the material in general. The fabricating device and technique, in and of themselves, do not compromise the mechanical strength of the material, nor do they result in structural characteristics which facilitate tensile failure.

Standardized fatigue testing is underway to evaluate the endurance of the fabrications. Preliminary results for polypropylene homopolymer suggest

that fabrications made using the experimental system will have high resistance to fatigue and be appropriate for long-term use without failure. Testing of the polypropylene copolymer will follow that of the homopolymer. Typically the copolymer has even greater fatigue resistance than does the homopolymer.

One socket has been fit for a trans-tibial amputee. The socket was designed using commercial socket CAD software, made from polypropylene homopolymer using the experimental fabricator, and fit using an Iceross liner. The limb was worn for a period of 3 weeks and subjected to routine use for 25-30 hours per week. Use was then discontinued and the socket inspected for any obvious signs of damage, of which there were none. Further clinical fittings will follow successful outcome of the fatigue tests.

FUTURE PLANS—Construction of clinical prototypes and wider clinical evaluation of the sockets will follow the development work described in this report. Device commercialization is anticipated after completion of evaluations.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Additive fabrication technique for the computer-aided manufacturing of sockets. Rovick JS. Seventh World Congress of the International Society of Prosthetics and Orthotics, Chicago, IL, 1992.

New CAM technique for the direct automated fabrication of sockets. Rovick JS. Nineteenth Annual Meeting of the American Academy of Orthotists and Prosthetists, Las Vegas, NV, 1993.

Surface curvature analysis for enhanced computer-aided-design of prosthetic sockets. Chan RB, Rovick JS, Childress DS. In: Proceedings of the International Conference of the IEEE Engineering in Medicine and Biology, San Diego, 1993:15.

Additive fabricator for high-speed production of artificial limbs. Rovick JS. Fifth International Conference on Rapid Prototyping, Dayton, OH, 1994.

Plastic deposition fabricator for the cam of sockets: material strengths and clinical experience. Rovick JS, Uellendahl J. Twentieth Annual Meeting of the American Academy of Orthotists and Prosthetists, Nashville, TN, 1994.

[2] PROSTHETIC/ORTHOTIC MATERIALS

Dudley S. Childress, PhD; C.H. Chiu; E.P. Lautenschlager; J.L. Gilbert; E.H. Greener; K.E. Healy
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The overall purpose of this project is to characterize the physical and mechanical properties of the materials in the current prosthetic and orthotic armamentarium, and through this knowledge develop fabrication procedures which will lead to stronger, more durable devices that are better able to perform a specific task.

PROGRESS—In this report period efforts were concentrated on the commercially available material Subortholen™. Heat treatment and weathering-induced polymer degradation, which affect selected structural, physical, and mechanical aspects of this common orthotic and prosthetic thermoplastic, were investigated using the techniques of Fourier transform infrared (FTIR) spectroscopy, differential scanning calorimetry (DSC), X-ray diffraction (XRD), FTIR and optical microscopy, gel permeation chromatography (GPC), dynamic mechanical analysis (DMA), plus hardness and tensile testing. Results indicate that weathering induced chemical reactions began from pre-existing carbonyl groups and from unsaturated carbon double bonds within this ethylene and hexene copolymer. Massive chain scission reactions took place which resulted in changes in the structure of the polymer and in its physical and mechanical properties. Multiple regression statistics support the suggestion that the key factors which dominate the polymer degradation in this system are reaction zone thickness, cracking density, and changes in the molecular weight and crystallinity on the polymer surface.

To control the structural and physical properties and the weathering degradation resistance of

Suborthotlen, first its glass transition temperature had to be measured ($T_g = -115°C$). With this critical information, a heat ($= 140°C$)-and-below-T_g-quench (liquid nitrogen, $-196°C$) treatment was developed. This treatment was evaluated in comparison with a heat-and-above-T_g-quench (ice water) method and other currently used methods in orthotic and prosthetics clinics which involve either air-cooled or furnace-cooled processes. Results of these studies indicated that the clinical treatments significantly reduced both the ductility and strength of Subortholen. The heat-and-above-T_g-quench treatment produced greater ductility but reduced its strength. However, with the heat-and-below-T_g-quench treatment, both the ductility and strength of Subortholen were improved. This treatment also resulted in enhancement of resistance to cracking, to weathering degradation, and to impact on the material. These improvements endured approximately 10 days of artificial weathering (Q-U-W Accelerated Weathering Tester, Q-Panel Co., Cleveland, OH), which according to calibrations completed during the current reporting period, are equivalent to 6 to 8 years of Chicago weathering.

RESULTS—It may be concluded that the heat-and-below-T_g-quench treatment of Subortholen can improve the service life of prostheses and orthoses made from this material. Such a method, using other coolants, may also be suitable for routine improvements in the physical properties and weathering degradation resistance of other clinically used semi-crystalline thermoplastics, whose glass transition temperatures have been measured as follows: polypropylene, T_g of $-10°C$; Durr-Plex™ (polyethylene terephthalate), T_g of $-40°C$; Surlyn™ (ethylene methacrylic acid copolymer), T_g of $-80°C$; and Uvex™ (cellulose acetate butyrate), T_g of $-25°C$.

[3] RESOURCE UNIT FOR INFORMATION AND EDUCATION

Dudley S. Childress, PhD; Else M. Tennessen, MS
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The Resource Unit for Information and Education (RU) is a clearinghouse for data available to consumers, service providers, research professionals, manufacturers, and others. An information service only, the Unit does not endorse or recommend any product, service, or clinician.

PROGRESS—RU information databases contain over 2,000 entries about prosthetics, orthotics, and disabling conditions, with information on amputation and disability management, amputee support groups, state-of-the-art research, general disabilities, recreational resources, self-help groups, prosthetic/orthotic schools and organizations, publications, and manufacturers. The RU's *1992-1993 Prosthetic-Orthotic Resource Directory*, published in late 1992, is a direct result of these databases.

A Help Line, available on both voice and FAX/TDD lines, disseminates information directly as well as directing callers to other information clearinghouses or professionals when these are better able to service their request. Information requests are filled by sending clients printed materials as well as listings of publications and relevant organizations.

In 1992, the RU helped host the VII World Congress of ISPO (International Society for Prosthetics and Orthotics) in Chicago. This triennial congress enjoyed a record attendance of over 2,000 for its lectures and workshops on state-of-the-art advancements and practices in prosthetics and orthotics. Copies of the Proceedings are available for a nominal charge from the RU.

The RU also publishes the quarterly prosthetic-orthotic newsletter, *Capabilities*, and informational brochures, information packets, and the *Prosthetic-Orthotic Resource Directory*. All these publications are available free of charge.

[4] SHORT RANGE TELEMETRY OF SURFACE MYOELECTRIC SIGNALS

D.F. Lovely
Institute of Biomedical Engineering, University of New Brunswick, Fredericton, NB E3B 5A3

Sponsor: *Natural Science and Engineering Research Council*

PURPOSE—The development of a small battery powered telemetry system for use in the evaluation and training of very young amputees with respect to myoelectrically operated prostheses.

PROGRESS—The Institute of Biomedical Engineering has been involved with the monitoring of myoelectric signals from very young infants for many years. At present this involves the connection of surface mounted electrodes to the recording instrumentation via an umbilical cable.

This setup is far from ideal with young children as quick movements of the subject can easily dislodge the electrodes. A system has been proposed that would employ a small light weight telemetry system to render the umbilical cable superfluous. A small transmitter has been designed and constructed which uses FM modulation to transmit myoelectric information over a distance of several meters. Fabrication of the transmitter has been accomplished in two printed circuit boards measuring 40 by 25 mm. A complementary receiver has also been designed and fabricated.

FUTURE PLANS—Before embarking on clinical trials a packaging system must be developed.

B. Upper Limb: General

[5] NEW CONTROL APPLICATIONS FOR UPPER-LIMB PROSTHESES: DIRECT MUSCLE ATTACHMENT FOR POSITION-SERVO CONTROL

Dudley S. Childress, PhD; Craig W. Heckathorne; Richard F. ff. Weir; Edward C. Grahn; John S. Strysik
Northwestern University, Chicago, Illinois 60611

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A306-2DA)*

PURPOSE—To achieve a significant improvement in the function of electric-powered upper-limb prostheses, we believe it is necessary to develop better control interfaces with inherent sensory feedback. We suggest that small tunnel cineplasties, or other surgical procedures, such as the tendon exteriorization cineplasty developed by Dr. Robert W. Beasley, which externalize the force and excursion of the muscle, can provide this superior control. The muscle would be connected to the prosthetic component through a controller that embodies Dr. David C. Simpson's concept of extended physiologic proprioception (EPP). This control arrangement correlates (in a one-to-one manner) the position, speed, and force of the controlling muscle to the position, speed, and force of the prosthetic component. The physiological sensory feedback inherent in the skin and muscle of the cineplasty would inform the user of the state of the prosthesis in a somewhat subconscious and natural manner.

For persons with long transradial amputations or wrist disarticulations, we envision multiple tunnel cineplasties (small) or exteriorized tendons, each with an EPP controller, providing independent

multifinger control of hand prostheses. At higher levels, such as the short transhumeral or shoulder disarticulation level, small pectoral or deltoid tunnel cineplasties could augment existing control sources to improve control of multifunctional total arm prostheses.

Our work seeks to characterize the control capabilities of persons with existing tunnel cineplasties and to develop concepts for prosthetic fittings using these tunnels.

METHODOLOGY—Fifteen subjects with biceps tunnel cineplasties have agreed to participate in our research. Of these, three participated in the current study. Additionally, one subject participated who has two tendon exteriorizations of forearm muscles.

The subjects performed pursuit tracking of a randomly moving target displayed on an oscilloscope screen. Using movement of the cineplastized muscle to control a follower, they attempted to match the path of the target. A mathematical relationship between the follower's and target's paths provides a measure of control performance. With this measure, we can compare the dynamic control capability of the tunnel cineplasty with other control methods. The pursuit tracking was repeated using glenohumeral flexion and a conventional above elbow control harness and again using the elbow flexion/extension of the subject's intact contralateral arm.

Blind positioning experiments were performed to quantify static positioning capability in comparison to other control methods. Finally, the characteristics of the tunnel cineplasty were recorded for isometric and isotonic muscle contractions.

PROGRESS—All experimental apparatus and procedures have been developed. Tests have been completed on all of the subjects recruited for this initial investigation. We have also developed a prototype EPP electric hand prosthesis for a subject who has exteriorized forearm tendons.

RESULTS—Data analysis for all experiments is yet to be completed. However, preliminary results for pursuit-tracking experiments indicate that the dynamic performance of the muscle tunnel is statistically similar to that of the conventional control harness. Tracking performance with the intact contralateral elbow was superior to the cineplastized muscle and to glenohumeral flexion with a control harness.

The prototype EPP hand prosthesis has been fit to the subject with the exteriorized tendons. Control cables from the tendon tunnels are linked to the hand's mechanism. Contraction of the flexor muscle closes the hand and contraction of the extensor muscle opens it. The length and speed of shortening of the controlling muscles directly control the position and speed of movement of the hand mechanism. In gripping, the isometric force of the muscles proportionally controls the rate at which prehension force is applied. The device requires approximately 6 mm of tendon excursion and a range of 225 to 500 grams-force for operation. We are following up on this fitting to monitor characteristics of the socket, cable interface, control response, and general utilization.

FUTURE PLANS—We plan to build upon the work accomplished in a new project, "Direct Muscle Attachment: Multifunctional Control of Hands and Arms," which will expand the data analysis for all experiments completed to date and to perform additional characterizations tests. In parallel, we are continuing the development of prosthesis designs conceptually and in prototype form to utilize control by direct muscle attachment.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Measurement of the ability of direct muscle attachment to act as a control input for prosthesis controllers, Weir RFff, Childress DS. In: Proceedings of the 7th World Congress of the International Society for Prosthetics and Orthotics, ISPO, 1992, Chicago, IL.

Modification of a bock electric hand for EPP control by exteriorized tendons. Childress DS, Grahn EC, Weir RFff, Heckathorne CH, Uellendahl J. In: Proceedings of the 19th Annual Meeting of the American Academy of Orthotists and Prosthetists, 1993, Las Vegas, NV.

[6] DIRECT MUSCLE ATTACHMENT: MULTIFUNCTIONAL CONTROL OF HANDS AND ARMS

Dudley S. Childress, PhD; Richard F. ff. Weir; Craig W. Heckathorne; Edward C. Grahn; John S. Strysik
Northwestern University, Chicago, IL 60611

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A306-4DC)*

PURPOSE—We believe that better control interfaces with inherent sensory feedback are necessary to achieve significant improvement in the function of electric powered upper-limb prostheses. We have suggested this superior control can be provided through new surgical procedures, such as the tendon exteriorization cineplasty developed by Dr. Robert W. Beasley, or through the development of miniature tunnel cineplasties, which externalize the force and excursion of the muscle. The externalized muscle would be connected, via linkage to an electronic extended physiological proprioceptive (EPP) controller, directly to the prosthetic component. The physiological sensory feedback inherent in the skin and muscle of the cineplasty would inform the user of the state of the prosthesis in a somewhat subconscious and natural manner.

Our goals are to demonstrate the feasibility of using direct muscle attachment to control electric powered prostheses through EPP controllers and to show the superiority of EPP control in producing coordinated movements in multifunctional hand and arm prostheses. The purpose of this phase of the project is to develop the technical components and fitting techniques to utilize direct muscle attachment.

METHODOLOGY—We previously amassed a large body of data that characterizes human performance in the control of tunnel cineplastized muscles. From this data, we concluded that control by tunnel cineplasty is as good as control using glenohumeral flexion with a harness and could therefore provide an alternative or additional control source and maintain the performance advantage of the harness arrangement. Previous work by James Doubler in 1984 showed that position control, as is characteristic of harnessed cable-actuated prostheses, was superior to velocity-control techniques, characteristic of contemporary myoelectric and switch-control systems.

PROGRESS—An engineering model has been developed which represents the interaction between the operator and the position control mechanism for an electronic EPP controller. A subject with exteriorized forearm tendons, for whom we developed a prototype EPP electric hand during the previous funding period, continues to provide us with information on his experiences with the prosthesis.

In an effort to stimulate interest in new surgical techniques for interfacing persons with their prostheses, we sponsored a seminar in Chicago featuring Dr. Beasley and the person with the EPP-controlled electric hand and the exteriorized forearm tendons. The seminar was attended by hand surgeons as well as other health professionals and engineers interested in improving the function of upper-limb prostheses.

RESULTS—Analysis of the subjects' performance with biceps tunnel cineplasties and of position-control systems led to the formulation of a model that represents the interaction between the user and an EPP-controlled mechanism. This model will enable us to evaluate methods to improve the interaction.

We continue to monitor the first clinical fitting (March 1993) of a powered hand prosthesis controlled directly by antagonist muscles (via exteriorized tendons) in a physiological manner. The subject, who had not used the exteriorized tendons for over a decade prior to the fitting, was last seen in June 1994, at which time he demonstrated good control of the prosthesis.

FUTURE PLANS—We expect to redesign the EPP controller based on analyses obtained from our engineering model. The redesigned controller will provide increased stability in the control of the prosthetic component and will be able to be tailored more easily to the user's control characteristics.

We will also be furthering the development of hand prostheses compatible with EPP control by exteriorized tendons and begin development of a prototypical total arm prosthesis with three EPP controlled joints. Two types of hand prostheses are proposed. One will be a third generation version of the high performance Synergetic Hand that will be operable by a single agonist/antagonist pair of exteriorized tendons. The second hand prosthesis will incorporate a third generation powered thumb and fingers configuration. This component will provide separately controlled precision and power grips and will be operated by two pairs of agonist/antagonist muscles with exteriorized forearm tendons. The total arm prosthesis we are proposing is intended for fitting at the shoulder disarticulation level. Two of the EPP control sources will be derived from motion of the clavicle and scapula. The third EPP source is proposed to be a miniature pectoral tunnel cineplasty.

[7] VV59 PROSTHETIC HAND ENHANCEMENTS: COSMETICS, ELECTRONICS, AND NEW LARGER SIZE

Stephen Naumann, PhD, PEng; Ihsan Al-Temen, PEng; Isaac Kurtz, MHSc, PEng; George McMillan; Martin Mifsud, DipE Eng T; John Bishop, EEngT; Greg Bush, BA, Dip O&P, CP(C); Morris Milner, PhD, PEng, CCE
Rehabilitation Engineering Department, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsor: *Variety Village: The Children's Charity*

PURPOSE—The current VASI VV59 hand (for children 5 to 9 years of age) tends to look bulky in the palm area, and we received a number of comments from clients requesting that we address this issue. The mechanical drive dynamic characteristics of the VV59 hand needed to be upgraded to become more responsive to the new proportional control electronics. Clinicians also indicated the need to augment the VASI product line with a hand similar to the VASI VV59, but with longer fingers and thumb to fulfill clients' needs as they grow.

PROGRESS—The Electronics group introduced a new smaller electronics package for the VASI VV59 hand. This allowed us to remodel the shape of the hand cover and achieve a better appearance. A prototype of the new cover was developed and approved by the HMRC Amputee Programme. The tooling for the new cover is underway and scheduled to be completed by the end of 1994.

The need for a hand larger than the VV59 became more apparent for the young users of the VASI products. The design of larger fingers and thumbs for the existing hand's body cover, drive mechanism, and electronics resulted in the new VV711 hand. A set of fingers and thumbs were prototyped and evaluated by the clinical team. The tooling for these components is under way in conjunction with the cover described above.

FUTURE PLANS—The inherent characteristics of the friction drive for the VV59 and VV711 hand make the performance of the hand less responsive when used with the new proportional controls. Other gearing systems and motors will be explored to address this issue.

[8] BIOMECHANICAL STUDY TO IMPROVE GRIP IN CHILDREN'S TERMINAL DEVICES

Yoshio Setoguchi, MD; Julie Shaperman; Maurice LeBlanc; Mark Hoffer, MD; Don McNeal, PhD
Shriner's Hospital; Packard Children's Hospital; Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Clinicians know that young children have difficulty getting a good grip with body-powered terminal devices, and this problem is especially acute in the toddler and pre-school age-

groups. Before attempting new designs or recommending changes in prescription criteria, the investigators are gathering objective measures of children's strength and the mechanical work requirements for operating terminal devices. Results of this study should point to new directions for research and development for the investigators and others. This project is being conducted by the RERC on Technology for Children.

PROGRESS—Two studies have been conducted to study young children's arm and shoulder strength:

1) Using a myometer and methodology developed for a previous study of strength of normal children, we measured the strength of 37 children (20 boys and 17 girls) in shoulder flexion, shoulder abduction, shoulder (girdle) elevation, and shoulder protrusion. All of the children were 3, 4 or 5 years old with unilateral congenital below-elbow limb deficiencies, and all wore prostheses. The results generally supported those from a previous pilot study. A report on the expanded study is currently in preparation.

2) Parents of 23 children, aged 3-5 years, with unilateral congenital below-elbow limb deficiency agreed to participate in a one-year study to find out whether their children's arm and shoulder strength would increase when they increased play time in selected activities. Children's strength was measured when the study started, at 6 months, and at 12 months. Data from the study above showed differences in strength that might be expected at each age without an intervention. Nine of the children in this study increased strength beyond those levels, but 14 others did not. Additional data analysis is underway to identify variables associated with greater than ordinary increases in strength.

Another study was initiated to identify forces generated by muscles used during prehensor operation. Initial sessions were conducted with an adult volunteer. EMGs of twelve muscles were measured using wire and surface electrodes simultaneously during prehensor operation. Manual muscle testing with a myometer is being compared with amplitude of EMG output to identify relative force exerted by each muscle measured. The relationship of the output of wire and surface electrodes is being compared so that surface electrodes only can be used with children in later sessions.

A working group was assembled to discuss findings and suggest priorities and directions for future research on this project. The group included physicians, prosthetists, therapists and parents. The group suggested that efforts be focused on development of a body-powered hand, and features were identified that were considered important. Design specifications have subsequently been developed for a hand to be used by children from 1 to 4 years of age based on features suggested by the working group and on strength measures and efficiency requirements identified in the previous studies.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Mechanical design and analysis of prosthetic prehensors for children. LeBlanc M, Setoguchi Y, Shaperman J. In: Proceedings of the 7th World Congress of ISPO; Chicago, IL: 1992:366.

Mechanical work efficiencies of body-powered prehensors for young children. LeBlanc ML, Setoguchi Y, Shaperman J, Carlson L. JACPOC 1993:27(3):70-5.

Upper limb strength of young limb-deficient children as a factor in using body-powered terminal devices: a pilot study. Shaperman J, Setoguchi Y, LeBlanc M. JACPOC 1993:27(3):89-96.

Work required for operation of body-powered upper-limb prostheses for young limb deficient children. LeBlanc M, Setoguchi Y, Shaperman J, Carlson L. JACPOC 1993:28(1):7-8.

[9] PROSTHETIC ARM DESIGN AND SIMULATION SYSTEM: PADSS

Dudley S. Childress, PhD; Craig W. Heckathorne; Harold Krick, CP; Michael J. Redding; Jack E. Uellendahl, CPO
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The goal of this project has been to assist prosthetists in evaluating different arrangements of prosthetic components for implementing complex arm prostheses. To achieve this goal, we

are developing a graphics-based software tool with which a prosthetist can visualize characteristics of a design under consideration. The practical implication is the potential for reducing the time and effort presently involved in working toward a functionally appropriate prosthesis configuration, especially for persons with high-level and bilateral arm amputations. It is proposed that the current practice of constructing a preparatory prosthesis and altering it through a series of mechanical revisions could be made more efficient if the effect of various component changes and modifications could be analyzed without having to physically implement them.

METHODOLOGY—The prototype program, the Prosthetic Arm Design and Simulation System (PADSS), runs on a color Sun Microsystems SPARCstation 1+. The PADSS incorporates a set of editors with which a prosthetist creates a graphical representation of the client and his/her prosthesis, as well as environmental objects. The representation is constructed from anatomical measurements of the client, the selection and arrangement of prosthetic components, and specifications of the size and placement of environmental objects. The simulated prosthesis is assembled from specific components constructed within the editor and stored in a component library. While assembling the prosthesis, the prosthetist specifies the placement and orientation of each component and the distance between adjacent components (i.e., the segment length). The simulated arm prosthesis can be for any level of amputation and for either the right or left side. Bilateral prostheses can also be simulated.

PROGRESS—The current PADSS version uses the information provided by the prosthetist to generate a stylized four-view (front, right side, left side, and top) display of the human subject and prosthesis. The system then calculates and displays the functional workspace, a volume of space within which the prosthetic prehensor can be positioned using only movements of the prosthetic joints and of the joints of the residual limb. Additionally, the workspace can be viewed in cross-section to reveal the inner geometry, which is generally hidden by the exterior surface of the volume.

The PADSS also displays a contact map of all points on the body surface that can be touched by the prehensor. The combination of the functional workspace and the contact map indicates the possible reach away from the body and onto the surface of the body given the characteristics of the specified prosthesis. By varying components and their placement and orientation, the prosthetist can evaluate the effect of different configurations on these reach parameters.

RESULTS—During development, the PADSS program was used in association with clinical fittings performed by the Prosthetic/Orthotic Clinical Service of the Rehabilitation Institute of Chicago. The program was found most applicable to modeling shoulder disarticulation and forequarter prostheses. The PADSS accurately represented the positioning of electric components and body-powered components for which the operating forces and movement ranges were well within the capabilities of the intended user. The program was less accurate in modeling components which exceeded the user's operating capacity for all or some portion of their range. It was also less accurate for modeling the positioning of prostheses when the user's available range of physiological joint motion was restricted by the weight or mass distribution of the prosthesis.

FUTURE PLANS—A second version of the PADSS program has been proposed to address the modeling inaccuracies identified in clinical testing. This version will incorporate additional physiological data and component characteristics that affect the user's ability to operate an assemblage of prosthetic joints and to use proximal physiological joints to position the prosthesis as a total unit.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Clinical fitting of high level bilateral amputees. Uellendahl JE, Heckathorne CW. In: Proceedings of the Seventh World Congress of the International Society for Prosthetics and Orthotics, 1992:465.

Computer-based visualization tool for the design of upper-limb prostheses. Redding MJ, Heckathorne CW, Childress DS. In: Proceedings of the Seventh World Congress of ISPO, 1992:387.

Visualizing spatial and positioning characteristics of upper-limb prostheses. Heckathorne CW, Redding MJ, Childress DS, Uellendahl JE. In: Proceedings of the Seventh World Congress of ISPO, 1992:385.

[10] EPP-TYPE POSITION-SERVO CONTROL OF ELECTRIC ELBOWS FOR CHILDREN

Dudley S. Childress, PhD; Craig W. Heckathorne; Lennart Philipson, PhD; Maud Edman, CPO; Liselotte Hermansson, OT; Sven-Olov Pettersson, CPO
Northwestern University, Chicago, IL 60611; Örebro Medical Center, Örebro, Sweden

Sponsors: *National Institute on Disability and Rehabilitation Research; Department of Veterans Affairs, Rehabilitation Research and Development Unit; Swedish National Board for Industrial and Technical Development; Research Committee of the Örebro County Council*

PURPOSE—The Arm Prosthetics Unit (APU) at the Örebro Medical Center has been providing myoelectrically controlled prehension devices to children with limb deficiencies since 1971. The majority of the approximately 100 children seen at the APU have limb deficiencies below the elbow, and an electric prehension device has proved to be a useful tool. However, for children with above-elbow deficiencies, the usefulness of the prehension device has been limited by the child's ability to actively position the prosthesis without assisting with the contralateral hand and arm. Cable-actuated body-powered elbow units have not been employed with much success due to the high forces (relative to the child's strength) generally needed to lift a forearm and electric hand. Electric elbow units were applied experimentally in the late 1970s, but were not successful because of poor mechanical performance.

PROGRESS—Within the last several years, there have been significant advances in the design and availability of child-size electric elbows. Additionally, the Prosthetics Research Laboratory of Northwestern University had developed a prototype force-actuated position-servo controller compatible with these elbows. Unlike switch and myoelectric controllers, the NUPRL controller provides inherent feedback of position, speed, and force through a mechanical linkage between a controlling physiological joint and the prosthetic joint. The controller was based on Dr. David C. Simpson's concept of extended physiological proprioception (EPP). In addition to the inherent feedback, the implementation of the controller at the above-elbow level allows for independent control of an electric prehension device using myoelectric signals from the biceps and triceps. Applications of the controller in selected adult fittings have been encouraging.

The availability of improved electric elbows and a controller which provided feedback and independent control led to a cooperative project to re-evaluate the application of electric elbows to children at the Örebro APU.

METHODOLOGY—Three children (ages 12, 11, and 5.5) participated in the initial evaluation phase. All had previously been provided with prostheses from the APU and were skilled in the operation of myoelectrically-controlled electric hands (using biceps and triceps signals). The evaluation prostheses included a myoelectrically-controlled hand (identical to what the child had been using) and an EPP-controlled electric elbow (a NY-Hosmer medium-size unit or a VASI 8-12 unit).

RESULTS—Of the three children, only the oldest, a boy, continues to use the experimental prosthesis. The eleven-year-old, a girl, rejected the prosthesis shortly after receiving it. The appearance, with external electric and mechanical cables, was unsatisfactory to her. She also found the sound of the locking mechanism of the elbow (NY-Hosmer unit) too loud and the weight of the prosthesis (1.5 kg) uncomfortable. The youngest child, a boy, used his experimental prosthesis (with a VASI 8-12 elbow) on occasion for several months. He has a transverse deficiency at the elbow disarticulation level and was subsequently fit with a hybrid prosthesis, having a body-powered elbow and myoelectric hand. He has preferred the lighter weight of the hybrid prosthesis and the faster movement of the mechanical elbow.

The initial evaluation indicates that significant improvements are still needed in the design and implementation of electric-powered elbows for children. Neither of the children who rejected their prostheses cited the control method as a source of problem leading to the rejection. Whether or not EPP-type control can be used advantageously by children using electric-powered prostheses remains an open question.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Application of a force-actuated position-servo controller for electric elbows. Heckathorne CW, Uellendahl J, Childress DS. In: Proceedings of the Seventh World Congress of the International Society for Prosthetics and Orthotics, 1992:315.

Cable-actuated position control of children's electric elbows: a joint US-Sweden evaluation. Heckathorne CW, Philipson L. Capabilities 1992:2(2):4-5.

Extended physiological proprioception for children's electrical prostheses. Heckathorne CW, Philipson L, Hermansson L, Childress DS. In: Proceedings of the Seventh World Congress of the International Society for Prosthetics and Orthotics, 1992:317.

[11] ELECTROMECHANICAL PROSTHETIC HANDS AND VISUAL FEEDBACK

Gary Jacques, BASc, PEng; Stephen Naumann, PhD, PEng; Morris Milner, PhD, PEng, CCE; William Cleghorn, PhD, PEng; Greg Bush, BA, CP(C); and Sheila Hubbard, BSc, P&OT
Institute of Biomedical Engineering, Department of Mechanical Engineering, University of Toronto; Rehabilitation Engineering Department, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsor: *Natural Sciences and Engineering Research Council of Canada*

PURPOSE—There are several documented benefits of powered upper extremity prosthetic hands. Powered prostheses users, lacking tactile and proprioceptive feedback in their prosthetic hands, rely heavily on visual cues when aligning and maintaining objects within their grasp. A detailed investigation using a design method called Quality Function Deployment (QFD) was used to identify visual feedback as an important design parameter to benefit the functional performance of the prosthesis. There has been little previous research into this important parameter.

METHODOLOGY—A group of prosthetists and therapists with recognized experience working with children and powered upper limb prostheses was surveyed. The survey identified and rated the importance of the functional characteristics of the grasping function of the prostheses. It also rated satisfaction with the current commercial products based on these identified functional characteristics.

Through QFD methods, engineering group meetings related design parameters that could be addressed to these functional characteristics and found that visual feedback was an important but poorly understood component of the prosthesis function.

RESULTS—An experimental setup was devised to relate what areas of the prosthesis the user could see, to the elemental time required to grasp the object. This was accomplished using a miniature head-mounted CCD camera while the prosthesis user was performing a grasping task developed for the test. The elemental time required to grasp the object was determined using an industrial engineering technique called Methods-Time Measurement. Data were collected for several subjects using a variety of prosthetic hands and is being investigated for correlations.

FUTURE PLANS—Plans involve the creation of a three-dimensional computer model of the prosthetic hand based on the natural hand. Various geometries and opening mechanisms will be investigated. Combining this model with one of the upper torso will allow visual feedback to be predicted for various new or existing prosthetic hand configurations.

The ultimate goal of this research is to identify a geometric configuration for the prosthetic hand that will take advantage of the knowledge gained related to visual feedback to improve the functional performance of powered prosthetic hands.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Application of quality function deployment in rehabilitation engineering. Jacques GE, Ryan S, Naumann S, Milner M, Cleghorn W. IEEE Trans Rehabil Eng. In press.

Function of prosthetic hands. Jacques GE. In: Proceedings of RESNA '94 Annual Conference, 1994, Nashville, TN. Washington, DC: RESNA Press, 1994.

Pilot study of the effects of visual feedback on the grasping function of prosthetic hands. Jacques GE, Bush G, Hubbard S. In: Proceedings of RESNA '94 Annual Conference, 1994, Nashville, TN. Washington, DC: RESNA Press, 1994.

The role of visual feedback in prosthetic grasping function. Jacques GE, Naumann S, Milner M, Cleghorn W. In: Proceedings of the 4th International Conference on Rehabilitation Robotics, 1994.

[12] MYOELECTRIC CONTROL STRATEGIES

P.A. Parker; B. Hudgins; R.N. Scott
Institute of Biomedical Engineering and Electrical, Engineering, University of New Brunswick, PO Box 4400, Fredericton, NB E3B 5A3

Sponsor: *Natural Sciences and Engineering Research Council of Canada; Hugh Steeper Ltd.; Liberty Mutual Research Centre*

PURPOSE—To develop a multifunction myoelectric control system providing five functions or more.

PROGRESS—A new control algorithm is proposed based on the myoelectric signal generated during the initiation of a contraction. This signal shows a deterministic component which is different for different contraction types. A neural network pattern classifier is used for the function selection. A single myoelectric channel gives recognition performance, with little patient training, of up to 85 percent.

FUTURE PLANS—We seek to develop a two myoelectric channel system to increase the recognition performance.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Adaptive multifunction myoelectric control system. Hudgins B, Parker PA, Scott RN. In: Proceedings of the World Congress of ISPO, 1992, Chicago, IL, 208.

Myoelectric control: beyond 3-state. Hudgins B, Hruczkowski T, Parker PA, Scott RN. In: Proceedings of the Canadian Medical and Biological Engineering Conference, 1992, Toronto, 8-9.

New multifunction myoelectric control system. Hudgins B, Parker PA, Scott RN. In: Proceedings of the ACPOC Conference, 1992, St. Louis, MO.

New strategy for prosthetic control. Hudgins B, Parker PA, Scott RN. In: Proceedings of ISEK International Conference, 1992, Florence, Italy 138.

New approach to multifunction control. Hudgins B, Parker PA, Scott RN. Med Life Sci Engin. In press.

New approach to multifunction myoelectric control. Hudgins B, Parker PA, Scott RN. IEEE Trans Biomed Engin. In Press.

[13] IMPROVING PROSTHETIC PREHENSION

Lawrence E. Carlson, DEng
University of Colorado, Boulder, CO 80309

Sponsor: *National Center of Medical and Rehabilitation Research, National Institutes of Health*

PURPOSE—The purpose of this research is to improve both body-powered and externally powered prehensors. Projects include:

Vector Prehensor. We are developing a voluntary opening prehensor with variable grip force that can be easily adjusted to the demands of the task, improving efficiency of grasping and reducing mechanical energy demands.

Variable Mechanical Advantage (VMA) Prehensor. We are also developing a voluntary-closing device with enhanced gripping efficiency (i.e., rapid sizing with minimal cable excursion coupled with large grip force generation).

General Prehension Research. We are seeking improvements to prehension applicable to any type of prehensor, including anthropomorphic fingers with nonlinearly compliant structure and variable hardness finger materials.

Quantification of Prehensor Performance. We explore methods to quantify grasping performance in the laboratory, including the degree of force and torque that can be effectively applied.

RESULTS—A prototype Vector prehensor, patterned after the finger shapes of the TRS Grip II prehensor, has been designed and fabricated. It employs three standard hook elastic bands mounted to a lever that, when rotated through 55 degrees, varies the gripping force from 1 to 15 lb. Field tests on three amputees have been encouraging. The adjusting lever is easy to manipulate and the range of force available is a distinct advantage over prehensors that have essentially fixed grip force.

The basic feature of the VMA prehensor is that it sizes the fingers at a low mechanical advantage to allow them to rapidly adjust with minimal cable

tension. When an object is encountered, a mechanism shifts the prehensor to a high mechanical advantage configuration which generates large gripping force with a small input cable force. Our prototype VMA prehensor develops 22 lbs of grip force with a cable tension input of under 10 lbs, a five-fold increase in mechanical advantage over a conventional VC prehensor (a TRS Grip 11). The prototype also provides a holding assist function: as cable tension is relaxed to 3 lbs, 90 percent of the grip force is maintained. When cable tension is relaxed further, grip is released. Field testing has shown that the VMA function makes handling soft objects difficult. The mechanism provides only 1/8 in of compression of an object which is inadequate in some situations. The prototype was therefore fitted with a button to lock out the VMA mechanism so that the device can be used as a conventional VC prehensor when desired.

We have acquired various materials for the skin and filler material for nonlinearly compliant finger structures in our general prehension research. Initial fabrication of several combinations has identified likely candidates which may enhance grip performance.

Under our program to quantify prehensor performance, we have designed, built, and calibrated systems to measure the torque and linear force that prehensors can apply to various test objects. Preliminary tests have been performed on three types of prehensor shapes. The data suggest that hand-shaped prehensors are more effective than either hooks or grips for applying torques and linear forces.

FUTURE PLANS—A prototype vectorprehensor incorporating split hook fingers is under development. A custom designed polyurethane band will provide the grip force and allow for a substantially more compact design. A second generation prototype with grip-type fingers will also use these custom hands. Field testing indicates that adjustability of the shift point between the sizing and gripping modes may be valuable on the VMA prehensor. Incorporation of this feature into a third prototype is under consideration. A child's body powered VC hand will be retrofitted with an electrically powered locking mechanism to allow locking and unlocking with minimal energy input.

B. Upper Limb: Above-Elbow

[14] TRIPHASIC PATTERNS IN ABOVE-ELBOW AMPUTEES

Matthijs P. Smits, MS
Liberty Mutual Research Center, 71 Frankland Road, Hopkinton, MA 01748

Sponsor: *Liberty Mutual Insurance Company*

PURPOSE—The research goal is to investigate the difference in muscle control between traumatic and congenital above-elbow amputees.

PROGRESS—In normally limbed humans, voluntary fast elbow movements produce triphasic myoelectric activity patterns in the biceps and triceps muscles. Triphasic patterns have, for the most part, been found to be preprogrammed and generated by the central nervous system. This central preprogramming suggests that phasic patterns might still be observed after amputation, even though the mechanical function of the remnant muscles is lost.

Five normally limbed and ten unilateral above-elbow amputees were asked to perform identical, fast, short elbow flexion and extension movements simultaneously with both arms (using imagined movements, where appropriate) to allow comparison of the muscle patterns from both arms. Of the ten amputee subjects, seven had lost an arm traumatically, and thus had previously possessed normal motor control of the amputated arm. The other three were congenitally limb-deficient. Each had been fitted with four Boston Elbow electrode ampli-

fiers, one placed over the biceps and one over the triceps of each arm.

In the normally limbed subjects, arm dominance was found to cause only small differences in muscle patterns and was not considered an important influence on the data acquired from the amputees. All traumatic amputee subjects showed bi- or triphasic patterns in both arms during elbow flexion. However, the timing and duration of the individual bursts differed between the sound and amputated arms. These differences were inconsistent among subjects and movement types. In addition, only three of the seven traumatic amputees showed phasic patterns in the remnant muscles during elbow extension. The other four produced co-contractions, the cause of which is yet unclear. The congenitally limb-deficient subjects had never possessed a lower arm, so phasic patterns were neither anticipated nor found during elbow flexion or extension. Only the cause of amputation showed a clear relationship with the measured patterns. Other parameters, such as the number of years since amputation (subject range: 0.5 to 46 years), the length of the remnant limb (subject range: 7 cm to elbow length), the use of myoelectric prostheses (subject range: never to always), or phantom sensations (subject range: never to always) did not show clear correlation with the measured muscle activities.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Myoelectric activity during voluntary elbow movements in above-elbow amputees. Smits MP. J Electromyography Kinesiology. In press.

[15] THE LIBERTY MYOSELECTOR: AN ADAPTABLE SCHEME TO SELECT MULTIPLE FUNCTIONS

Matthijs P. Smits, MS
Liberty Mutual Research Center, 71 Frankland Road, Hopkinton, MA 01748

Sponsor: *Liberty Mutual Insurance Company*

PURPOSE—Our research goal is to develop an adaptable scheme for selecting multiple functions in a myoelectrically controlled prosthesis by recognizing distinct muscle contractions.

PROGRESS—Considering the case of above-elbow amputees, a separate function-selection scheme can provide control of additional functions with just one muscle pair. This type of selection scheme involves switching between different control states. In one state, myoelectric control goes to the elbow; in another, to the hand or wrist.

The ideal function-selection scheme would not interfere with normal prosthesis control, would not require the participation of other body parts, and could easily adapt to the capabilities and wishes of the individual amputee. The Liberty MyoSelector has been developed with these criteria in mind.

The concept behind the Liberty MyoSelector is the recognition of a user-selected pattern of myoelectric data, acquired from the amputee's myoelectric control sensors. The MyoSelector switches myoelectric control from one prosthetic joint to another only when the myoelectric data "matches" a predefined pattern. This pattern is programmed into the MyoSelector during training, when the amputee provides sample contractions (e.g., short co-contractions or fast flexions) that teach the MyoSelector what it should recognize.

Physically, the Liberty MyoSelector consists of a tiny microcontroller, which is programmed to continuously record a short window of preprocessed myoelectric activity, as produced in myoelectric prostheses. Tests run on above-elbow amputees have generated encouraging results of more than an 80 percent average of correct recognition without user training. In most tests, the user attempted a short, fast, jerk-type (imagined) elbow flexion contraction. After as few as ten of these training contractions, some amputees were able to control the MyoSclector with no errors. Their training time was approximately one minute.

The test results indicate that the Liberty MyoSelector has the potential for practical use. In addition, several prosthetists and amputees have expressed interest in the device. A Boston Elbow with a prototype MyoSelector is currently under development.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

The Liberty MyoSelector: an adaptable scheme to select multiple functions. Smits MP, Williams TW. In: Proceedings of the 7th World Congress of ISPO, Chicago, 1992:307.

Patent: Method and apparatus for switching degrees of freedom in a prosthetic limb, US Patent Serial no. 07/896,058.

[16] THE NEW BOSTON ELBOW: INCREASED CAPABILITIES

T. Walley Williams, III, MA; Matthijs P. Smits, MS; Albert M. Mahoney
Liberty Mutual Research Center, 71 Frankland Road, Hopkinton, MA 01748

Sponsor: *Liberty Mutual Insurance Company*

PURPOSE—Our team is working to enhance the functionality, performance and reliability of the current Boston Elbow.

PROGRESS—In 1992, the Boston Elbow system was analyzed to see where improved technology could be applied to upgrade capabilities. This effort has now culminated in a substantially better mechanism and control system. The improved elements are organized as follows:

Motor-Drive Train. A three-phase brushless motor increases peak torque to better than 9.0 ft-lb (12.7 Nm) with improved efficiency. Elimination of brushes has substantially reduced electromagnetic interference and should improve reliability and reduce maintenance.

Modularity. A new quick disconnect coupling allows the user to readily remove the drive train and/or adjust humeral rotation friction. Circuit boards are available for quick service under a cover on the prefabricated forearm where the user can also exchange batteries if needed.

Control Board. Available on the control board are several processors that generate control signals for both the elbow and the other devices that are to be used, such as terminal devices (TDs) and wrist rotators. There are two myo-processor channels, two variable resistance channels, two switch control channels, and a variable voltage processor. Any two channels can be connected to two inputs labeled Up and Down which control the elbow direction and speed, derived from the difference in the inputs. Force-sensing resistors and linear potentiometers can be connected, so that the elbow and other prosthetic functions can be controlled by touch pads, by proportional positional servo transducers and/or by a cable-operated force transducer that permits a variant of Extended Physiological Proprioception (EPP) control as suggested by Simpson, Childress, Doubler, Carlson, and others. Extra control lines pass around the elbow and can be accessed through plugs on the control or selector boards.

Selector-Device Driver Board. Whenever possible the elbow system is set up so that TD and elbow control are independent. If that is not the case, the third board is equipped with a logic module that can select almost any imaginable way to control several functions with one or more pairs of control signals, including signal rise recognition and automatic reversion to default functions. The selector board can control standard 6V TDs of Bock, Steeper, Centri, and others. Further, it has a battery saver circuit to limit current flow when the TD motor is stalled.

Automatic Elbow Lock. An important feature retained in the new Boston Elbow is the bidirectional reverse-locking clutch. The clutch is transparent to the user. It simply disengages whenever power is applied to the motor. It will even disengage under a substantial load, which is a unique feature of this elbow. With the clutch engaged, a 50 ft-lb (71 Nm) load can be sustained.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Boston Elbow II: increased capabilities. Williams TW, Mahoney AM, Smits MP. In: Proceedings of the International Symposium on Myoelectric Control, 1993, Fredericton, NB: University of New Brunswick.

Boston Elbow: a cybernetic approach. Smits MP. In: Proceedings of the 12th Congress of the International Ergonomics Association, 1994, Toronto, ON.

[17] THE MYOARRAY: A DIAGNOSTIC TOOL TO TEST AND TRAIN AMPUTEES TO USE MYOELECTRIC PROSTHESES

Peter R. Teare; Matthijs P. Smits, MS; William J. Hanson, MS
Liberty Mutual Research Center, 71 Frankland Road, Hopkinton, MA 01748

Sponsor: *Liberty Mutual Insurance Company*

PURPOSE—The goal of this research is to develop a diagnostic tool to test and train amputees to use myoelectric prostheses.

PROGRESS—To fit a patient with a myoelectric prosthetic device, a prosthetist or therapist tests the patient to determine the best position on the muscle to place the electrodes. Generally, the optimal position is the one where the myoelectric signal is strongest. Typically, a prosthetist attempts to determine the optimal position of the electrode through trial and error, asking the patient to contract the muscle each time the electrode is placed in a different position. The resulting signals are often inconsistent because each contraction is different and muscle fatigue may occur. The MyoArray not only solves this problem, it also facilitates training by providing feedback while the amputee is performing controlled muscle contractions.

The MyoArray has been developed to provide an easy-to-use, portable diagnostic system for quickly measuring myoelectric signals from several positions at once, over a wide muscle area. The device consists of an array of electrodes positioned over the muscle. The electrodes are spaced the same distance apart as Boston Elbow electrodes and are wired to form electrode pairs. When the subject contracts the muscle, the MyoArray continuously reads the myoelectric signals from all electrode pairs simultaneously. It processes these signals to display the filtered or unfiltered (averaged) contraction levels of each of the electrode pairs on a computer screen or a matrix of LEDs. Several display options are available to provide instant feedback: from all the electrode pairs simultaneously, from only the electrode pair that shows the strongest signal, or from any other combination of measured signals. Several prosthetists have expressed interest in the device because of the greater likelihood of locating the optimal electrode sites and improved training. In addition, time and money will be saved while testing, fitting, and training amputees to use myoelectric prostheses.

FUTURE PLANS—Further tests and improvements are needed. However, the MyoArray is planned to be available before 1995.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

The Liberty myoarray: a diagnostic tool to test and train amputees to use myoelectric prostheses. Hanson WJ, Smits MP, Teare PR. In: Proceedings of the International Symposium on Myoelectric Control. Fredericton, NB: University of New Brunswick, 1993.

[18] DEVELOPMENT OF A PROSTHESIS FOR ELBOW DISARTICULATION AMPUTEES

E. Biden
Institute of Biomedical Engineering, University of New Brunswick, Fredericton, NB E3B 5A3

Sponsor: *New Brunswick Medical Research Fund, Whitaker Foundation*

PURPOSE—We seek to develop and evaluate a prosthetic elbow for elbow disarticulation which will allow for a naturally proportioned and functional artificial arm.

METHODOLOGY—The design of the linkage uses a novel optimization system for designing the linkage. Analysis of the link stresses and the basic design are done using conventional computer-aided

design techniques. The completed elbow is being tested in prostheses in the field.

PROGRESS—During 1992, we have tested a new version of the elbow which includes a wrap spring clutch locking system. The first prototype proved to be too sensitive to accidental activation. This has been improved upon in the current design which is just moving into clinical trials. During 1993, the focus was to improve on a prototype which had as its main limitations, a rather bulky appearance when fully extended and the tendency to unlock inadvertently in response to very small pulls on the control cable. The locking problem has been solved by introducing a dead zone at the beginning of the elbow lock/unlock cycle. The cosmetic problem has been less tractable.

FUTURE PLANS—Efforts will be made to move the locking mechanism into the forearm to further shrink the size of the elbow.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Prosthetic elbow of elbow disarticulation prostheses. Biden E, Hughes F, Olive MB, et al. Association of the Children's Prosthetic and Orthotic Clinics Conference, 1993, St. Petersburg, FL.

Development of an elbow prosthesis. Biden E. Whitaker Foundation Biomedical Engineering Research Conference, 1994 Snowbird, UT.

B. Upper Limb: Below-Elbow

[19] EMG PATTERN RECOGNITION

Tom Chau, BASc; Stephen Naumann, PhD, PEng; Hans Kunov, PhD, PEng; Isaac Kurtz, MHSc, PEng
The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8; Institute of Biomedical Engineering, University of Toronto, Toronto, ON M5G 1L4

Sponsor: *The Ontario Rehabilitation Technology Consortium, funded by Ontario Ministry of Health*

PURPOSE—The purpose of the present research is to investigate techniques of reliably classifying processed electromyographic (EMG) signals for myoelectric control of upper extremity prostheses. In particular, the objectives are 1) to classify EMG signal transients from two muscle sites, while minimizing the error probability, and 2) to maintain robust performance under the conditions of prosthetic loading, changing residual limb position and varying forces of contraction, and finally to achieve control over three or more prosthetic functions.

PROGRESS—The chosen parametcrization of the EMG signal is the variance statistic because it is an important information parameter and can be easily estimated. The experimental population consists of long below-elbow amputees. The wrist flexors and extensors are the favored electrode sites. The classification schemes explored are some of the so-called "model-free approaches to pattern recognition." These include artificial neural networks and fuzzy methods.

A classifier tool box has been built in C++ for real-time testing on a 486-PC running under Microsoft Windows. This tool box serves as an operating environment for the different classifiers and allows real-time acquisition from two muscle sites of a subject's limb. Data from two amputee subjects have been collected under the conditions of limb loading, muscle fatigue, limb motion, and varying forces of contraction. Trends in collected data have been identified and have guided the creation of a simulated data set.

To date, three separate classifier modules have been customized and incorporated into the classification tool box. A probabilistic neural network and a fuzzy c-means clusterer are the two model-free modules in operation. A statistical classifier based on the k-nearest neighbor algorithm has also been realized to act as a performance benchmark.

Currently, we are implementing a classifier based on the standard multi-layer neural network, trained by back-propagation. Simultaneously, a fuzzy associative memory has been created for the application and will be linked to the tool box. A hybrid approach combining both neural and fuzzy techniques is under design.

RESULTS—Preliminary results based on simulations are very promising. After training, discrimination of up to six categories (wrist flexion, wrist extension, pronation, supination, digit flexion, and rest) is possible with the probabilistic neural network and the fuzzy classifier. Robustness is demonstrated under conditions of fatigue, changing limb position, and moderate loading. Response times are also acceptable.

FUTURE PLANS—Completion of the tool box is anticipated shortly. Six amputee subjects will be involved in clinically testing the classifiers in real-time. We hope to further improve upon the accuracy and response time of previous methods with the hybrid approach.

RECENT PUBLICATIONS RESULTING FROM THIS WORK

EMG pattern recognition using a probabilistic neural network. Chau T, Naumann S, Kunov H. Proceedings of the Canadian Medical and Biological Engineering Conference, Vancouver, BC, 1994. In press.

Feedback of triceps surae EMG in gait of children with cerebral palsy: a controlled study. Colborne GR, Wright FV, Naumann S. Arch Phys Med Rehabil 1994:75:40-5.

C. Lower Limb: General

[20] CLINICAL AND LABORATORY STUDY OF AMPUTATION SURGERY AND REHABILITATION

Ernest M. Burgess, MD
Prosthetics Research Study, Seattle, WA 98122

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A092-7RA)*

PURPOSE—Prosthetics Research Study (PRS) continued ongoing programs of clinical and laboratory research into amputation surgery; immediate post-surgical amputee management; lower limb prosthetic development, including the automated fabrication of prostheses and other mobility aids; a basic and clinical study of wound healing as it related to amputation surgery and postsurgical management; engineering investigation into the mechanical properties of soft tissues and the response of living soft tissues to application of force; and technology transfer of automated fabrication methods into the clinical services of the VA medical care system.

PROGRESS—Preliminary design and engineering analyses of the prosthesis force transducer have been completed. The design incorporates piezoelectric quartz crystals as force-sensing elements to obtain force information at three discrete locations within the transducer. Given these data (9 forces), the complete set of forces and moments (Fx, Fy, Fz, Mx, My, Mz) at the socket due to ground reaction forces can be obtained. The device as designed will be less than 1 cm thick, 7 cm in diameter, and will weigh approximately 800 g. To date, the analog electronics have been purchased as well as the crystals and other raw materials.

In conjunction with the PRS diabetic footwear study, we have undertaken a study of three dimensional foot morphology. We have obtained digital images of over 100 feet using a Cyberware™ laser scanner, and over 50 pairs of images from an Amfit™ contact scanner. The laser-scanned images provide full 3-D shape information over the entire foot (dorsal and plantar aspects), while the contact scans provide only plantar surface information. Custom software has been written and the

DVA/ShapeMaker™ software has been modified to facilitate quantitative comparison of these scans. To date only preliminary analysis of the data has been undertaken, but shows great promise as a tool for understanding foot morphology, as well as designing and fabricating custom insoles and footwear.

We have developed a compact, self-contained gait activity monitor (GAM) which records the number of steps taken by a patient over a 2-week period. The GAM does not require patient intervention and has a sealed, water-proof case which prevents tampering. It provides the clinician with an objective, reliable measure of functional outcome for evaluation of new prosthetic devices and medical treatments. We have built four prototype units and collected data from three subjects for up to 1 week. We are currently refining the mechanical sensor and designing software for data analysis.

To study the response of skin to mechanical stress, we designed and built an automated mechanical stimulator capable of applying precise, repetitive forces in both the normal and shear directions. The stimulator was applied *in vivo* to the skin of pigs with gradually increasing amplitude over a specified number of days. At the end of the trial period, tissue samples were taken and studied using standard histological procedures. Preliminary experiments suggest there is a change in the structure of collagen fibers in response to the mechanical stress.

An optical silhouette scanner has been designed and constructed for measuring both diurnal and long-term volume changes in a residual limb. This device utilizes a rotating charge coupled device (CCD) camera and light source to obtain a series of 2-D silhouettes around the residual limb. The silhouettes are then reconstructed into a 3-D computer image of the residual limb from which volume measurements can be made. The device is currently under preliminary testing.

Studies were completed where it was found that gamma irradiation of blood transfusions inhibited their ability to sensitize to minor (non-major histocompatibility) transplantation antigens as part of a project to modify blood so as to prevent sensitization yet maintain the ability to induce tolerance for foreign transplant antigens.

The Automated Fabrication of Mobility Aids (AFMA) system makes it possible to produce a limb at reduced price in a shortened time. Rectification techniques permit a consistent socket fit. The data are easily filed with reproducibility of the limb and any needed adjustments easily, quickly, and inexpensively made. These techniques now include a PRS AK socket design unique in its characteristics in that it incorporates the advantages of both the classical quadrilateral socket, the narrow ML(Long) socket, and the advantages of a flexible/external frame socket. This technique together with the development of the VA/DAV/PRS Knee has allowed us to complete the lower limb prosthetic system as planned.

Training courses were developed and begun for the technology transfer of AFMA into the VA Medical Centers. Three centers were established on the west coast, two remote sites where AFMA limbs are now designed and fit and one central fabrication site where they fabricate the AFMA sockets. *See also* J Rehabil Res Dev 1994:31(4).

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Automated fabrication of mobility aids (AFMA): below-knee CASD/CAM testing and evaluation program results. Houston VL, Burgess EM, Childress DS, et al. J Rehabil Res Dev 1992:29(4):78-124.

Effect of FK506 and donor specific transfusion (DST) on skin and composite tissue allograft (CTA) survival in the rat. Kuroki H, Bean MA, Ikuta Y, Burgess EM. In: Transactions of the 38th Annual Meeting of the Orthopaedic Research Society, 1992, Washington DC, 1992:17(1):176.

Interface shear stresses during ambulation with a below-knee prosthetic limb. Sanders JE, Daly CH, Burgess EM. J Rehabil Res Dev 1992:29(4):1-8.

Partial calcanectomy for the treatment of large ulcerations of the heel, and calcaneal osteomyelitis: an amputation of the back of the foot. Smith DG, Stuck RM, Ketner L, Sage RM, Pinzur MS. J Bone Joint Surg 1992:74A(4):571-6.

Special considerations: fitting and training the bilateral lower limb amputee. Smith DG, Burgess EM, Zettl JH. In: Bowker JH, Michael JW, eds. Atlas of limb prosthetics: Surgical, prosthetic and rehabilitation principles. 2nd ed. St. Louis, MO: Mosby Yearbook, 1992:599-622.

All-terrain foot. Mathews D, Burgess E, Boone D. J Prosthet Orthot 1993:5(1):29-44.

Clinical measurement of normal and shear stresses on a trans-tibial stump: characteristics of wave-form shapes during walking. Sanders JE, Daly CH, Burgess EM. Prosthet Orthot Int 1993:17(1):38-48.

Effect of KF 506 and donor-specific blood transfusion on the rat composite tissue limb allograft and the mechanism of long-term graft survival. Kuroki H, Bean MA, Ikuta Y, Akiyama M, Burgess EM. Transplant Proc 1993:25(1):658-61.

Physical fitness: a guide for individuals with lower limb loss. Burgess EM, Rappoport A. Baltimore, MD: Rehabilitation Research and Development Service, Department of Veterans Affairs, 1993.

[21] APPLICATION OF ULTRASOUND AND COMPUTER TECHNIQUES TO LOWER LIMB PROSTHETIC SOCKET DESIGN

Ping He, PhD; Kefu Xue, PhD; Paul Murka, CPO
Department of Biomedical and Human Factors Engineering; Department of Electrical Engineering, Wright State University, Dayton, OH 45435; Fidelity Orthopedic, Inc., Dayton, OH 45402.

Sponsor: *National Institute on Disability and Rehabilitation Research (Field Initiated Research, CFDA 84.133G), U.S. Department of Education Washington, DC 20202*

PURPOSE—In lower limb prosthetic socket design, lack of information about the internal structure of the limb often contributes to the difficulties for achieving the desired weight-bearing characteristics of the prosthesis. The purpose of this project is to develop a new computer-aided socket design system which uses ultrasound imaging techniques to acquire the information about the internal structure as well as the external shape of the limb. By incorporating this information into a computer-aided design software, the new system will enable a prosthetist to design a socket more scientifically and consistently.

The overall project is a three-year research and development project that involves designing and constructing a new system for data acquisition and prosthetic socket design, as well as evaluating the performance of the system through clinical trial. In addition to bringing immediate benefit to the lives of amputees through faster and better socket design and fit, the system can also be used in a long term investigation for optimal socket design and to the advancement of the lower limb prosthetic technology.

METHODOLOGY—The ultrasound data acquisition apparatus includes a water tank measuring 19 inches in diameter and 30 inches tall; a patient seating device composed of a linear actuator and a specially designed chair; an ultrasound transducer and its driving mechanism; an ultrasound scanner and a 80486-based PC. The mechanical part of the apparatus has been constructed by the Machine Shop at Wright State University and works as expected.

Several algorithms for image reconstruction were implemented and tested. Specific effort has been made to develop a procedure for automatic system calibration which we found has a great effect on the quality of the images. Effort has also been made to increase the speed of image reconstruction, enhance the quality of image, and improve the accuracy of edge detection and boundary interpolation.

The system has been tested by scanning a healthy volunteer's leg. The reconstructed ultrasound images were compared with X-ray CT images and MRI images scanned at the same levels. The results indicate that ultrasound image can indeed show clearly the distribution of leg bones and major soft tissues within the limb.

The prosthetic CAD software is a modified version of CANFIT-PLUS developed by VORUM Research Corp. (Vancouver, Canada). Engineers at VORUM have developed an interface for importing the ultrasound image data and modified the display routine so that it can display a gray-scale ultrasound image showing a 2-D distribution of the bones and soft tissues within the limb.

PROGRESS—The overall project is divided into eight specific tasks: 1) design an ultrasound data acquisition apparatus; 2) construct the apparatus; 3) optimize the shape measurement and image display; 4) modify/develop prosthetic CAD software; 5) test the overall functioning of the system and evaluate system against design specifications; 6) train prosthetists; 7) evaluate system performance against application expectation through clinical trial; and 8) summarize the project, and plan for dissemination.

The project was started in September 1992 and the first five tasks have been almost completed.

FUTURE PLANS—The hardware and software still need minor modifications and improvement. We plan to start the clinical trial this summer. The overall project is expected to be completed by the summer of 1995.

[22] COMPUTERIZED METHODS IN PROSTHETICS AND ORTHOTICS

Dudley S. Childress, PhD; J. Jhoun
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Measurement of normal interface contact stresses that occur between the socket and residual limb can be obtained with pressure transducers. The conditions needed when using diaphragm pressure transducers to measure such stresses have been examined and evaluated.

METHODOLOGY—Vertical point loads were applied to circular metal disks in contact with disks of silicone and Pelite™. Diaphragm pressure transducers were placed in a metal surface below the test material. Samples were tested in both a lubricated and unlubricated state, and results are compared with a calibration method earlier developed in this laboratory. Additionally, a gross simulation of limb prosthetic socket mechanics is physically modeled by a solid cylinder made of silicone which is indented at one end. The model allows comparison of actual and analytical solutions of loading.

PROGRESS—Bench studies on the synthetic materials silicone and Pelite are complete.

RESULTS—Lubrication of the contact surface of the silicone disc samples yields results which correlate well with those of another method (cup calibration method) applied to silicone. When Pelite is used, no correlation is found between the two methods. Three major factors are found to affect readings of the sensors: 1) surface condition of the body which is transduced, 2) calibration of the sensor, and 3) compatibility of the interface between the loaded material and the sensor. These factors require attention when using diaphragm pressure transducers to measure contact stresses at an interface.

[23] FUNCTIONAL BIOMECHANICAL CHARACTERIZATION AND FUNCTIONAL DESIGN SPECIFICATION: LOWER-EXTREMITY PROSTHETICS

Dudley S. Childress, PhD; K. Mesplay; V. Sanchez
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Control of lower-limb musculature during walking is studied through representation by mathematical models. One approach toward understanding behavior of the supporting limb during walking requires testing of hypotheses regarding control of the stance limb. The hypothesis that the normal stance leg acts largely as a mechanical impedance during walking is of interest as this particular concept of control is useful in describing function of nonpowered prosthetic legs. Another approach toward modeling is aimed at understanding the limits of control imposed by loss of the lower-limb musculature. Models of walking allow study of the behavior of the swing leg that lacks active muscle control of the ankle joint, knee joint, and hip joint. The hip disarticulation amputee is chosen as a model of this latter case.

PROGRESS—Models of both swing-phase and stance-phase performance of the leg have been developed. Gathering of walking data from a subject with a hip disarticulation is complete. Data has also been collected of stance-leg behavior from four able-bodied subjects.

RESULTS—The lower limb behaves as a mechanical impedance during freely selected human walking. Stiffness relationships are observed for the ankle and knee of the stance limb which support the hypothesis that the lower limb acts as a mechanical

impedance during human gait. Simulation studies in which stiffness relationships are prescribed for whole leg behavior predict reaction forces similar to those observed experimentally. The ankle joint and the knee joint working together are shown to be important in the determination of leg stiffness.

Computer models of walking on a passive leg (as with a hip disarticulation) have been developed and are running. These models show many attributes of regular human walking. The results are part of a PhD dissertation and are now being analyzed.

[24] DYNAMIC RESPONSE PROSTHETIC FEET AND THEIR ROLE IN HUMAN AMBULATION

Dudley S. Childress, PhD; Eric H. Knox
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The primary objective is to understand the role of dynamic response prosthetic feet in trans-tibial prosthetic gait and to determine how the mechanical characteristics of footwear affect this role. This understanding will allow prosthetists to prescribe prosthetic feet more objectively, more accurately, and with greater cost effectiveness. Additionally, this knowledge may indicate ways to improve foot design.

METHODOLOGY—A specially designed foot-loading apparatus consisting of a steel support frame, prosthetic foot mounting jig, and wooden loading beam was used to perform the characterization studies. Prosthetic feet and foot/shoe combinations were mounted upside down to a strain gage instrumented pylon where they contacted a strain gage instrumented plate on the bottom surface of the loading beam through a ball bearing interface. The beam was fixed and allowed to rotate at one end about an axis through the support structure, and weights attached at the opposite end allowed application of physiological loads to the foot. The instrumentation provided a measure of the foot deflection, the total force on the foot, and the center of pressure. Quasi-static load versus deflection tests were performed to investigate the stiffness and hysteresis properties of the feet and shoes. Dynamic characterization tests were performed concurrently with the quasi-static studies and were based on the sudden release of load on the foot which then oscillated about a new equilibrium point. The data were used to calculate the damped natural frequency, the damping ratio which is generally used to determine the relative amount of damping within a foot, and the efficiency of energy return.

PROGRESS—Significant effort has been put into biomechanical characterization of many types of prosthetic feet and several footwear types. The testing has focused on measuring static and dynamic parameters of the feet and shoes outside of the amputee/prosthesis environment. A substantial amount of information has been gathered from the characterization tests, and has been instrumental in the formulation of our hypotheses of foot function. Initial walking trials on two trans-tibial amputees have been performed.

RESULTS—The results of the quasi-static characterization studies include a force versus deflection graph, and a center of pressure versus force graph for each foot or foot/shoe combination at three different foot/ground orientations: heel contact, heel off, and opposite heel contact. The results on prosthetic feet show a large spread of flexibility characteristics, with all of the dynamic response feet having a larger total deflection than the conventional SACH foot, and consequently storing more energy. The results of the force-deflection characteristics of different foot/shoe combinations in the heel off orientation appear to indicate that shoes generally make the foot/shoe combination stiffer than the foot alone. However, the center of pressure versus force characteristics show that shoes shift the center of pressure posteriorly, and we think this shift, which is effectively an alignment alteration, is responsible for the apparent increase in stiffness.

The dynamic characterization results also show a spread of the calculated parameters between the different feet. Overall, the results indicate that the feet are largely undamped and can be thought of primarily as springs. Dynamic testing of shoes in the heel off orientation indicates an increase in damping and energy losses.

FUTURE PLANS—We plan to continue our mechanical characterization of prosthetic feet and foot/shoe combinations for the heel contact and opposite-heel contact orientations. We also plan to continue our walking studies using two experienced trans-tibial amputees. Hypothesis testing will focus on the role that the increased flexibility and energy characteristics of dynamic response feet have in walking.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Influence of shoes on forefoot mechanics of prosthetic feet. Childress DS, Sandifer A, Knox EH. In: Proceedings of the 9th Scientific Meeting of the Japanese Society of Prosthetics and Orthotics, Kobe, Japan, 1993.

[25] DUNDEE LIMB FITTING CENTRE LOWER LIMB AMPUTEE SURVEY

Colin Peter Urquhart Stewart, MD; Mr Amar Singh Jain
Dundee Limb Fitting Centre, Dundee, DD5 1AG, UK

Sponsor: *None listed*

PURPOSE—The lower limb amputee database has been in existence since 1965 when the Dundee Limb Fitting Centre opened. The purpose of it is to provide details of the patients admitted to the Centre, enabling population profile, rehabilitation outcomes and survival details of the lower limb amputees in Tayside to be studied.

METHODOLOGY—All primary and secondary lower limb patients admitted for post operative care are included in the study. A detailed data sheet is completed during their stay. The date of death is also obtained from those former patients and entered into the data enabling life tables (SPSS) to be calculated.

RESULTS—During 1992 and 1993, 177 patients were admitted. In both years 66 percent were at transtibial level and 30 percent at transfemoral level, maintaining a high transtibial level of amputation; 84 percent in 1992 and 90.1 percent in 1993 were vascular related amputations, with the remainder being for neoplasm and trauma. Prosthetic fitting was achieved in 75–79 percent with over 85 percent either going home or to a nursing home placement. Only 1 patient died in the Unit during this time.

An increasing number of patients, over 66 percent, have been supplied with a wheelchair. Thirty percent of patients had a prosthesis only and 45 percent of patients had both wheelchair and prosthesis. This increase in wheelchair prescription we believe is due to an increase in frailty of the patient population. It is interesting, however, that the age of the patients during 1993 decreased from 70 years in 1992 to 66.6 years. During this period there was also an increase in the number of patients undergoing vascular salvage (64 percent). We believe this increase is indicative that vascular disease is occurring earlier necessitating the need for vascular surgery at an earlier stage, unfortunately leading to amputation at a similarly earlier stage.

The overall survival of the patients has, however, risen. The survival remains depressingly poor when compared with the normal population but the average survival of the patients during the full study period (1965–1992) was some 50 months. It is interesting that during the 80s the survival was longer than in the 70s, and this trend is continuing into the 90s. Those with transtibial amputation survived longer than those with transfemoral and similarly those who had had vascular disease were surviving longer than those who had diabetes mellitus related vascular disease. Interestingly, those who had a vascular procedure survived an average of 85 months, while those who had not survived an average of 56 months ($P>0.001$).

IMPLICATIONS—The primary lower limb amputee is surviving longer. Vascular procedures are increasingly being offered prior to amputation but depressingly frequently failing to avoid the lower limb amputation. Despite this the overall survival of the patients is lengthening especially for those who had vascular surgery. This has implications on the rehabilitation of the patients since with the survival lengthening it is even more essential to ensure that comprehensive detailed care is taken of the patient to ensure that as low a level of amputation as possible is achieved, the prosthetic fitting is of the highest quality and their lifestyle is interfered with as little as possible.

There are further implications on the prosthetic service who will need to ensure that the care of the patient is of a highest standard so that this lengthening survival of the patient is presented with the highest quality of life possible.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Dundee revisited: 25 years of a total amputee service. Stewart CPU, Jain AS. Prosthet Orthot Int 1993:17:14-20.

Lower limb amputee survival. Stewart CPU, Jain AS, Ogston SA. Prosthet Orthot Int 1993:16:11-8.

C. Lower Limb: Above-Knee

[26] COMPUTER-AIDED SOCKET DESIGN AND COMPUTER-AIDED MANUFACTURING FOR ABOVE-KNEE PROSTHETICS

Vern L. Houston, PhD, CPO; Carl P. Mason, MSBE; Edward J. Lorenze, MD; Kenneth P. La Blanc, BA, CPO; Mary Anne Garbarini, MA, PT; Hans Richard Lehneis, PhD, CPO

New York University Medical Center, New York, NY; VA Medical Center, New York, NY 10001

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A514-RA)*

PURPOSE—The objectives of this project are 1) to develop an optical digitizer for rapid, accurate, and consistent characterization of the spatial geometry and surface topography of lower limb amputees' residual and contralateral limbs for prosthetics computer-aided design and computer-aided manufacture (CAD/CAM) system input, 2) to develop a five degree of freedom, computer numerically controlled (CNC), milling machine for use in lower limb prosthetics CAM, and 3) to develop and clinically test quantitative CAD design algorithms for ischial containment (IC) and quadrilateral (QUAD) prosthetic sockets.

METHODOLOGY—To achieve these goals, the following protocol was established. A prototype lower limb prosthetics optical laser digitizer is to be designed and constructed. Control, data acquisition, and image processing and display software is to be developed, and comprehensive laboratory and clinical testing of the digitizer conducted. To enable accurate carving of the complex contours required in lower limb prostheses, especially at the brims of sockets for above-knee (AK) amputees, a five degree of freedom, CNC milling machine for prosthetics CAM shall be designed, and a prototype constructed. Quantitative CAD design algorithms for IC and QUAD AK prosthetic sockets based on optical digitizer measurement data shall be developed and tested.

PROGRESS—Since the project began in April 1991, specifications for and a design of an optical laser digitizer were developed, and an initial prototype was manufactured for the DVA by Cyberware Laboratory. Control, data acquisition, and image processing and display software has also been developed by the NY DVAMC researchers. Laboratory testing of the digitizer prototype revealed several faults and design deficits. Problems in the

digitizer control circuitry, and in the master scan head laser illumination intensity and optical component alignment were diagnosed, and corrected. Clinical tests of the digitizer with 14 AK amputees, 12 below-knee amputees, and 10 normal (nonamputee) test subjects have been conducted.

In addition, as part of the clinical trials, a study was performed quantitatively demonstrating the differences in accuracy and consistency obtained between optical digitization techniques, unmodified CASD/CAM plaster wrap casting techniques, and conventional prosthetics modified plaster wrap casting techniques for characterization of the spatial geometry and surface topography of BK and AK amputees' residual limbs. Also, to enable accurate carving of the complex contours required in lower limb prosthetic socket designs, especially at the brims of AK sockets, specifications for and a design of a five degree of freedom, CNC, prosthetics CAM, milling machine were developed, and a prototype constructed.

To derive CAD algorithms for AK IC and QUAD sockets, based on residual limb optical digitizer measurement data, CASD sockets and prostheses were designed, manufactured, and fit on the project's 14 AK amputee test subjects. The physiological, anatomical, biomechanical, and prosthetics characteristics of the test subjects were measured and compiled in the project computerized database. Statistical distributions and correlations were calculated to identify categories of patients and common prosthetics characteristics of patients that were easily fit with the respective CASD IC and QUAD designs, and those that were difficult to fit and required a significant amount of modification and redesign before achieving successful fits. The results were used to formulate statistical mean values for the CASD IC and QUAD socket design template modification region values.

FUTURE PLANS—Further development and enhancement of the optical digitizer to improve its performance and expand its range of applicability is planned. Refinement and enhancement of the CASD socket design templates for optical digitizer measurement data shall also be performed. Extension of the digitizer to characterization of lower limb orthotics patients' limb segments' spatial geometry and surface topography for orthotics CAD/CAM input, together with development of lower limb orthotics CAD design templates is also planned.

[27] FEMORAL DISPLACEMENT IN ABOVE-KNEE SOCKETS

Dudley S. Childress, PhD; Steven R. Borowski
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The purpose of the present work is to complete development of ultrasonic transducers that we hope will enable us to estimate the location of bony structures of the body with respect to prosthetic/orthotic structures being used by subjects. As an initial starting point we are interested in using the transducers to try to track the movement of the femur with respect to an above-knee amputee's prosthesis socket during walking and under specific loading conditions.

METHODOLOGY—At present we are developing the circuitry and hardware for the ultrasonic transducers and testing the transducer systems under controlled conditions. So far this has consisted of using breadboarded electronic circuits with an ultrasonic transducer to make measurements of the location of objects in water baths. We have been trying to increase the signal-to-noise ratio of the transducer and to develop a reasonably simple and effective transducer that can provide adequate accuracy for the application. The sampling frequency of the pulse generator for the transducer is presently 30 Hz.

RESULTS—We have an operational prototype but are not currently satisfied with the signal-to-noise ratio of the ultrasonic system. Trials in which the distance to objects in a water bath are determined have been successful, but the system may be too direction sensitive for use on the body when at-

tached to prosthetic/orthotic systems. Work is continuing. The instrumentation project is part of a master's degree project.

FUTURE PLANS—Our goal for the near future is to use the system to observe the movement to the femur in ischial containment sockets. Our long-range goal is to develop a general-purpose transducer system that can be applied in the evaluation of a broad range of prosthetic/orthotic systems.

[28] MODIFICATION OF THE VAN NES PROSTHESIS

Melissa C. Carson, BScE; Stephen Naumann, PhD; Morris Milner, PhD; William L. Cleghorn, PhD
Rehabilitation Engineering Department, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8; Institute of Biomedical Engineering, Department of Mechanical Engineering, University of Toronto, Toronto, ON M5G 1L4 Canada

Sponsors: *The Natural Sciences and Engineering Research Council of Canada; The Easter Seal Research Institute*

PURPOSE—Previous studies of people who have undergone Van Nes rotation-osteotomy have shown varying degrees of achievable gait efficiency, functional characteristics, and range of motion at the prosthesis knee joint. The overall goal of this study is to improve these functional capabilities for a person using a Van Nes prosthesis. This is accomplished by redesigning the prosthetic knee joint in order to maximize its range of motion through better harnessing of the range of rotated ankle joint motion. As well, the modified design could enhance clinical quality and standards of fit.

PROGRESS—The study group includes people who have had a surgical procedure known as the Van Nes or rotation-osteotomy to treat proximal femoral focal deficiency (PFFD). PFFD is a condition present at birth where the thigh is very short. This can be managed by providing a prosthesis similar to an above-knee prosthesis and immobilizing the knee joint which is close to the hip. However, a procedure was developed by Van Nes in 1950 where the knee joint was again immobilized and the ankle and foot were surgically rotated 180° and located at the same level as the good knee. Thus, the ankle then bends in the same direction as the good knee, and it can control the motion of the prosthesis knee which fits around it like a brace and is strapped to the upper part of the leg, and on the lower part has an artificial foot.

Prosthetic knee joint designs have not generally harnessed affected ankle joint range of motion, which in many studies has not even been measured independent of the prosthesis. In this research, rotated ankle joint active motion is measured in three dimensions with no load and then with applied moments in order to simulate gait while wearing the prosthesis. The empirical data is then transferred to a computer analysis software which allows for superposition of the prosthesis components. Using this tool the prosthesis mechanical knee joint design and position relative to the anatomy can be varied in order to determine the optimal design characteristics. As each person post-rotation-osteotomy can have very different joint function, a parametric design will be developed dependent on certain joint characteristics of the individual. This design will be tested and tried with new volunteers.

FUTURE PLANS—It is anticipated that these design improvements will contribute to the overall performance benefits of this still somewhat controversial surgical procedure, which offers a functional alternative to PFFD management by knee arthrodesis or by Syme's amputation (at the ankle). Additionally, there is a potential to broaden the scope of people who might otherwise not be suitable for a rotation-osteotomy due to a low level of ankle joint motion. For these to become a reality, a more clinically practical measuring tool would need to be developed to apply the parametric design in the clinical setting.

[29] PEDIATRIC ABOVE-KNEE ENDOSKELETAL RUNNING PROSTHESIS

Alan R. Morris, MASc; Stephen Naumann, PhD, PEng
Human Movement Research Programme, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsors: *Variety Ability Systems Inc.; Ontario Rehabilitation Technology Consortium funded by the Ontario Ministry of Health*

PURPOSE—The purpose of this research project is to develop a running prosthesis that will enable smooth and efficient gait for children between the ages of 5 and 12 with an above-knee amputation.

PROGRESS—Two primary areas of work have been undertaken: 1) the development of a three-dimensional computer simulation of able-bodied and prosthetic gait, and 2) the design and development of a multi-component above-knee prosthesis to be used in running and other intense physical activities. Completed during an engineering master's thesis, computerized gait simulation was developed on Dynamic Analysis and Design Software (DADS) mechanical engineering software, using a three-dimensional forward dynamic method integrating acquired able-bodied gait data with a biomechanical model of the lower body.

METHODOLOGY—Following successful simulation of able-bodied movement, the biomechanical model was modified to approximate prosthetic gait. Various components were specified as a result of earlier analytical work, such as polycentric knee linkage (stability); knee damping (stability/velocity control); and a shank-shock absorber (support control).

RESULTS—Computer simulation of able-bodied and above-knee amputee gait has been successfully completed for both walking and running, where simulation of able-bodied gait yielded biomechanical gait characteristics comparable to experimental data. Simulation of the prototype prosthetic gait demonstrated an improvement in the body's center-of-mass trajectory and control of knee flexion during the swing phase of gait. These results have demonstrated sufficient promise to begin practical design and manufacture of a light and rugged prototype.

FUTURE PLANS—Evaluation of prosthesis performance will be achieved through subjective testing and quantitative gait analyses.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Design of an above-knee amputee running prosthesis through gait modelling. Morris AR, Naumann S, Cleghorn WL. In: Proceedings of the Eighth Annual East Coast Gait Laboratory Conference, 1993:59-60.

Gait simulation and the design of a paediatric above-knee endoskeletal running prosthesis. Morris AR, Naumann S, Gleghorn WL. In: Proceedings of the 17th Annual RESNA Conference, 1994. Washington, DC: RESNA Press. In press.

C. Lower Limb: Below-Knee

[30] EFFICIENCY OF DYNAMIC ELASTIC RESPONSE FEET

Sanford Anzel, MD; Jacquelin Perry, MD; Edmond Ayyappa, MS, CPO; Leslie Torburn, MS, PT; Christopher M. Powers, MS, PT
VA Medical Center, STAMP Program, Long Beach, CA 90822; Pathokinesiology Service, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A517-RA)*

PURPOSE—The objectives of this study were to 1) compare the efficiency of four dynamic elastic response (DER) prosthetic foot designs to that of the SACH foot; 2) to define the gait mechanics

induced by each foot, and 3) to evaluate the relative effectiveness of these prosthetic feet for the dysvascular and traumatic amputees.

METHODOLOGY—A total of 17 below-knee amputees (10 traumatic and 7 dysvascular) underwent comprehensive gait analysis and energy cost testing. Each subject was tested with five different prosthetic foot components (SACH, Flex-Foot, Carbon Copy II, Seattle-Lite, and Quantum). Subjects wore each of the five feet for one month prior to testing and were blind as to the particular foot being worn to prevent subjective bias.

Electromyographic activity of six hip and knee muscles combined with kinematic, kinetic, and temporal characteristics of gait were collected during level free and fast walking, as well as ascending and descending ramps and stairs. Ground reaction forces during the stance phase of level walking were also obtained for both the amputated and sound limbs. In addition, the energy expenditure of walking as determined by oxygen consumption during a 20 minute self-selected pace walk was analyzed.

PROGRESS—To date, data processing for all 17 subjects has been completed. Currently, data analysis continues as does the preparation of manuscripts to be submitted for publication. Three published papers have been generated as a result of this study.

RESULTS—Energy cost analysis revealed no significant differences in energy expenditure between the five feet tested. This indicates that prosthetic foot design does not contribute to energy conservation in this population. There was a significant increase in oxygen consumption in the dysvascular group compared to the traumatic group which demonstrates the limitations of physical conditioning associated with peripheral vascular disease. Both groups had significantly higher oxygen consumption compared to normal values.

A significant reduction in the vertical ground reaction force on the sound side, combined with a significant increase in ankle dorsiflexion on the amputated limb was found with the Flex-Foot compared to the other feet tested. These results indicate that by nature of its large arc of motion, the Flex-Foot reduced the need to use a heel rise for tibial progression. The subsequent minimization of the rise in the body center of gravity resulted in a lower vertical loading force on the sound limb which implies a reduction in joint reaction forces.

Preliminary EMG analysis supports previous findings that below-knee amputees demonstrate prolonged activity of the hip and knee extensors during level walking. This is consistent with the increased metabolic cost of ambulation in this population.

Stride characteristics during stair ambulation did not indicate any significant differences between feet that would be considered advantageous for this task. In depth analysis of the Seattle-Lite foot during stair ambulation revealed that the limited dorsiflexion range of this foot compromised the rocker motion at the ankle which was compensated for by a forward trunk lean. This forward lean resulted in prolonged activity of the semimembranosis and the biceps femoris long head.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Below-knee amputee gait in stair ambulation: a comparison of stride characteristics using five different prosthetic feet. Torburn L, Sweiger G, Perry J, Powers CM. Clin Orthop. In press.

The effects of prosthetic foot design on sound limb loading in adults with below-knee amputations. Powers CM, Torburn L, Perry J, Ayyappa E. Arch Phys Med Rehabil. In press.

[31] PROSTHETIC DESIGN FOR DYSVASCULAR BELOW-KNEE AMPUTEES

Sanford H. Anzel, MD; Jacquelin Perry, MD; Edmond Ayyappa, MS, CPO; Catherine Fontaine, MS, PT; JoAnne K. Gronley, MA, PT; Sreesha Rao, MS; Ernest L. Bontrager, MS
VA Medical Center, Long Beach, CA 90322; Pathokinesiology Service, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A735-RA)*

PURPOSE—Despite prosthetic design progress, able traumatic amputees still exert 40 percent more energy due to increased muscular control. The amputees, disabled by diabetes and dysvascular disease, have gait velocity only 40 to 60 percent of normal. Recent gait studies target knee instability from a cushion heel/rigid ankle prosthetic foot as the source of excessive extensor muscle action.

The overall goal of this study is a new prosthetic foot design for the dysvascular amputee which facilitates knee stability and preserves energy. To achieve this, we needed first to define accurately the extensor muscle strength in the residual and contralateral limbs of the dysvascular BK amputee and correlate these values with his or her walking ability. Then it was necessary to define by quantified gait analysis the normal and prosthetic kinetics and kinematics of tibial progression. Finally, we needed to relate the weight acceptance (heel rocker) biomechanics of rigid and mobile prosthetic feet to the dysvascular amputee's gait.

PROGRESS—Fragility of the early dysvascular amputees has led to many cancellations. Despite a 70 percent no-show rate, 15 BK amputees underwent quantified strength and stride testing as well as moton analysis of the amputee's residual and sound limbs to provide preliminary information on the weight acceptance mechanics of the prosthetic limb. To accommodate the loss of the distal limb in the amputee a new normative standard for measuring knee extension strength was determined on 10 normal adults by comparing measurements at the proximal and distal tibia.

RESULTS—*Muscle Strength.* Among the dysvascular amputees, lower limb strength averaged 52 percent of normal. Quadriceps strength measurements showed that for both groups proximal knee extension torque was significantly less than that obtained at the distal tibia ($p<0.001$).

Stepwise regression analysis to identify the functional significance of muscle strength revealed that the hip abduction strength/residual limb and the proximal knee extension strength/sound limb were significant predictors of gait velocity in the dysvascular amputee. Velocity = 23.4 + 0.40 X (sound side knee extension as %N) + 0.49 X (residual limb hip abduction as %N). For free walking velocity, these factors explain 68 percent of the variability. Residual limb hip abduction strength also was a significant predictor of cadence, and sound limb knee extension strength was a significant predictor of stride length.

Heel Rocker Mechanics. Transfer of body weight onto the forward limb at the onset of stance includes a heel rocker effect to preserve progression over the supporting foot. For normal subjects the tibia continually rotated forward on the heel to near vertical alignment (+0.7°, range −4 to +6) until a stable flat-foot posture was attained (10.4 percent GC) before the end of the weight acceptance (WA) period (14 percent GC). The parabolic velocity curves of the shank had a mean peak of 189 deg/sec at 7 percent GC. In contrast, the foot of the dysvascular BK amputee was still in an unstable "heel-only" posture at the end of the prolonged WA period (19 percent GC) and tibial alignment had not reached a vertical position in most subjects (−3°, range −14 to +10). Shank velocity curves showed curtailed peak values (100°/sec), delayed timing (9 percent GC) and irregular patterns. Shank velocity was independent of walking velocity ($r^2 = 0.19$) and the four amputees with near normal velocities (>80 percent N) did not demonstrate improved shank progression parameters. Neither quadriceps strength (26 to 99 percent N) nor the rate at which the foot approached the floor predicts shank velocity related to shank progression. This appears to leave the mechanics of the cushion heel as a determining factor in the way the tibia advances.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Efficiency of dynamic elastic response feet. Perry J, Shanfield S. J Rehabil Res Dev 1993:1:137-43.

Below-knee amputee gait in stair ambulation: a comparison of stride characteristics using five different prosthetic feet.Torburn L, Schweiger GP, Perry J, Powers CM. Clin Orthop Rel Res 1994:303:185-92.

Influence of prosthetic foot design on sound limb loading in adults with unilateral below-knee amputations. Powers CM, Torburn L, Perry J, Ayyappa E. Arch Phys Med Rehabil 1994. In press.

[32] GAIT INITIATION IN BELOW-KNEE AMPUTEES: ANALYSIS OF SAFE FUNCTION

Harry B. Skinner, MD, PhD; Stephen A. Rossi, BSME; William Doyle, MS
Department of Veterans Affairs Medical Center, San Francisco, CA 94121

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A613-RA)*

PURPOSE—The objective of this research is to investigate the transient movement phenomena associated with gait initiation in below-knee (BK) amputees. The neuromuscular coordination necessary for balance maintenance and postural control is compromised in the amputee. Feedback channels including calf muscle spindle activity and ankle joint proprioceptive signals are lost. Since functional (daily living) activities require frequent transitions from stance to ambulation, amputees need to develop skills to safely negotiate the involved weight transfer and postural imbalances. This study investigates the strategies the BK amputee uses to compensate for musculoskeletal asymmetry and provides insight into the potential for gait training or prosthetic mechanical design to improve patient function.

PROGRESS—The study of the forces involved in gait initiation has shown that walking is precipitated by a forward lateral push of the center of gravity by the swing limb in preparation for an assisted fall by the stance foot. Amputees perform this process asymmetrically, mostly in their tendency to weight the intact limb as much and as long as possible. Alignment does not seem to be a critical parameter in the force characteristics of the gait initiation period, especially for those whose gait pattern has long been established. These results do seem to indicate that the majority of effort should be placed at the early stages of gait training during which the asymmetries are established and walking patterns are set.

METHODOLOGY—The subjects for this study consisted of 7 male unilateral BK amputees. Each was fitted with a prosthesis that permitted positive and negative adjustments of the following alignment parameters: foot flexion, foot version, and leg length. For a given run, the subject initiated gait with one foot on each of two side-by-side Kistler force plates. A trial consisted of six such runs, three with the left limb leading and three with the right limb leading. Trials were conducted with the prosthesis aligned to the neutral position and for each of the six prosthetic adjustments. Analysis of the force plate data involved the generation of time and weight normalized ground reaction force plots and the reduction of these plots to the magnitude and timing of key events in the initiation cycle. It was these quantities that were analyzed in a series of two factor ANOVA's with repeated measures in order to identify differences produced by leading limb, and alignment changes.

RESULTS—The shift in weight toward the lead limb prior to lift-off can possibly be explained by a natural fall toward the limb whose stance muscles are being relaxed or by a preparatory postural adjustment that assists in keeping the center of pressure between the two feet. The double-peaked pattern of the stance phase of initiation is consistent with the fact that steady-state gait is achieved very soon after initiation. This study is the first to compare the gait initiation force profiles of both amputated and nonamputated limbs. Interestingly, intact limbs consistently bore more weight, regard-

less of the choice of leading limb. Higher forces were found even during the single support stance phase of gait initiation; the muscles of the intact limb most likely facilitated greater downward accelcrations and larger push-off forces. The timings also demonstrated slower loading and unloading of amputated stance limbs, and faster unloading of amputated lead limbs. This could be a tendency to avoid use of the prosthetic limb, or a natural consequence of decre ased sensory feed-back. The lack of a statistically significant effect of the alignment changes on the force parameters implies that the effects of minor prosthetic adjustments are imperceptible from generalized gait parameters. This result suggests that the timings of initiation events are invariant and possibly attributable to central motor programming.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Initiation of gait in below-knee amputees: the characterization and comparison of force profiles. Rossi SA, Doyle, W, Skinner HB. Gait & Posture 1994:2(1):58.

[33] NEW CAD/CAM METHODS TO ENHANCE PROSTHESIS DESIGN

Dudley S. Childress, PhD; Joshua Rovick; John Steege
Northwestern University, Chicago, IL 60611

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A521-2DA)*

PURPOSE—This program consisted of two projects: 1) the implementation of the finite element method to the fitting of BK sockets and 2) the dynamic rectification and alternative fabrication of sockets. The aim of the first project was to develop capabilities to analyze and design socket shapes from fundamental principals of mechanics. Our approach was to create a finite element (FEA) model of the limb/prosthesis interface based upon experimental measurements. The goal of the second project was to focus on the computer-aided manufacturing of sockets (CAM), with the intent of making CAM more efficient, more versatile, and less costly. The approach was to examine various industrial tools and processes for their possible application to prosthetics CAM. The traditional industrial process examined was the machining process known as computer numerically controlled (CNC) milling. In contrast to CNC, a number of new processes have recently been developed which are typically referred to as rapid prototyping. Two kinds of rapid prototyping processes were also investigated for CAM production of sockets.

RESULTS—The implementation of the finite element method to the fitting of BK sockets involved several steps.

Experimental Measurements. Pressure measurements were made in experimental trials with amputees to examine pressure as a function of socket alignment and type. There were clear trends in the data for individual subjects. However, when the hundreds of experimental trials were lumped together for five amputees, relationships were not so clear. An abstract summarizing surface pressure data as a function of differing socket designs and load states was developed and published.

Tissue Modeling. Software was written which digitally gathered, sorted, and processed load/deflection data from several sites on a residual limb. Data was taken from three subjects and examined in terms of preconditioning, stress-relaxation, strain rate, and nonlinearity. Based upon a combined indentor and finite element studies, the range of modulus values for tissue were determined to be 13 to 90 kPa.

Generic FEA Modeling. A generic FEA model of the BK limb and socket was created based on standard geometric shapes which approximated anthropometric data. This generic model was used for parametric analyses of differing socket shapes and materials and also was compared to models derived from exact CT data. The results of the finite element analyses indicated that the exact and generic finite element models are fairly accurate predictors

of normal interface stresses for the unrectified socket, with both experimental and predicted pressures ranging from 0 to 80 kPa.

Automation of the Method. We developed software to apply bone and tissue edge information (derived from CT scans) to a pre-existing FEA mesh. Software that automated the assignment and interpolation of experimentally determined tissue properties across the surface of the finite element model was also developed. Using this procedure, a model-making session (excluding the scan itself) utilizing 85 levels of CT data now takes only a few hours.

FEA Design of Sockets. A computer model was generated from CT scans. Using FEA, a uniform stress pattern of 10 KPa was applied to the surface of the model. The computer then solved for the shape that the limb must be in order for this stress pattern to occur. By importing this rectified shape into CAM, a check socket was produced that fitted the subject well, as evaluated by prosthetists with our team. A problem we identified during the first attempt to make a socket by FEA methods was the need for a very precise representation of the limb when an attempt is made to design a socket that has almost no surface pressure gradients.

The dynamic rectification and alternative fabrication of sockets holds great promise.

CNC Machining of Models. After developing a computer data file for a socket shape, it is possible for this shape to be carved on a milling machine in a manner similar to the purpose-built prosthetics carving machines that are used with socket CAD/CAM systems. CNC milling presents the possibility of directly machining sockets from blocks of materials. Our investigations of direct socket machining were carried out using wood as the material; however, any machinable material could be substituted.

Rapid Prototyping of Sockets. Rapid prototyping is a term which covers a group of processes which are designed to directly and automatically convert computer-based numerical descriptions of parts into physical parts. We used two fast prototyping approaches (a half dozen or more systems exist) for the production of prosthetic sockets. One socket was created by Stereolithography with the assistance of Baxter Healthcare Corporation's Advanced Engineering Group. The 12-inch long PTB socket took 48 hours of continuous fabrication time. The other method used was Laminated Object Manufacturing (LOM). A 7.5-inch long PTB socket took 26 hours to produce.

Feasibility Study for a Prosthetics Fabricator. The idea of extrusion-based socket construction in which a socket can be built up in layer form from material extruded in liquid or semisolid form was conceived and tested. A simple device which allowed extrusion of thermoplastics was purchased and interfaced to the CNC machine. Results were very encouraging and a merit review proposal was drafted and funded by the DVA to support full-scale development.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Computer-aided manufacturing in prosthetics: various possibilities using industrial equipment. Rovick JS, et al. In: Proceedings of the 7th World Congress of the International Society for Prosthetics and Orthotics, Chicago, IL, 1992:22.

Design of prosthetics sockets using finite element analysis. Steege JW, Silver-Thorn MB, Childress DS. Proceedings of the 7th World Congress of the International Society for Prosthetics and Orthotics, Chicago, IL, 1992:273.

Measurements of below-knee residual limb/prosthetic socket interface pressures. Silver-Thorn MB, Steege JW, Childress DS. Proceedings of the 7th World Congress of the International Society for Prosthetics and Orthotics, Chicago, IL, 1992:280.

Sensitivity of below-knee residual limb/prosthetic socket interface pressures to variations in socket design. Silver-Thorn MB, Childress DS. In: Proceedings of the 7th World Congress of the International Society for Prosthetics and Orthotics, Chicago, IL, 1992:148.

Use of a generic, geometric finite element model of the below-knee limb and prosthetic socket to predict interface pressures. Silver-Thorn MB, Childress DS. In: Proceedings of the 7th World Congress of the International Society for Prosthetics and Orthotics, Chicago, IL, 1992:272.

[34] PRACTICAL APPLICATIONS OF NEW CAD AND CAE TECHNIQUES TO SOCKET DESIGN

Dudley S. Childress, PhD; John Steege
Northwestern University, Chicago, IL 60611

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A521-3DC)*

PURPOSE—We propose to implement the finite element (FE) technique into the design of sockets in a practical way. To accomplish this, we feel that a rational pressure rectification science must be created, the model must be quick to use and accurate, and the process must rely on available and affordable technology.

The proposal is categorized into three interrelated tasks. The first two sections of the work plan are intended to continue to build a more meaningful scientific base for the application of FE design of sockets. The third section addresses the development of a noncomputerized tomography (CT) scan-based methodology for the determination of a limb's structure. Our original models were built from CT scan data, primarily because this data could readily be obtained; however, from the beginning we have been aware of the practical need to obtain this data in other ways.

Results of this proposal should complete the foundation upon which a first generation FE-based prosthetics design system, fully capable of directly interfacing with existing CAD/CAM systems and relying on existing, affordable technology, can be built.

METHODOLOGY—The work centers on three areas: 1) continued refinements in the application of the finite element analysis technique to the design of below-knee (BK) prosthetic sockets based upon static (single load case) models of the prosthesis/residual limb, 2) development of computer design guidelines based upon the prosthesis/limb mechanics during gait (dynamic loading), and 3) incorporation of a new technique for determining complete BK limb geometry which does not rely on CT scans.

PROGRESS—Quasi-static FE models of BK gait have been created and analyzed. These analyses use load data taken from the literature and applied to our CT-based FE models.

Investigation into the use of geometry data obtained via an ultrasonic digitizer has taken place with encouraging results. The data obtained from these scans includes both bone and tissue boundaries and seems well suited for finite element model generation.

RESULTS—Initial results from the FE analyses have indicated that maximum pressure at the socket tissue interface for these models occurs during the 45-60 percent point of the gait cycle. However, the pressure pattern and magnitudes predicted are very uniform and consistent throughout the entire stance portion of the gait cycle. Also noted was distinct deformation of bone in the model. Whether this approximates reality or is a result of modeling insufficiencies will be investigated.

We have been able to incorporate ultrasonic scan data of a human limb into our procedure for creating FE models. This process proved to be fast and simple. We created a model spanning 18 centimeters across the knee joint and composed of 10 layers. The ease at which we were able to do this and the existing quality of the scan data strongly suggests that ultrasonic digitizing equipment is the most likely source of data for an FE design system.

[35] COMPARISON OF CAD/CAM AND CONVENTIONAL TECHNIQUES FOR THE FABRICATION OF TRANS-TIBIAL SOCKETS WITH SUPRACONDYLAR SUSPENSION

Edward D. Lemaire, MSc; Paulo Bexiga, CPO(SA); Thomas John, BSc, MBBS, FRCPC; Guy Martel, MHk, CPO(C)
The Rehabilitation Centre, Ottawa, ON, Canada K1H 8M2

Sponsor: *Labatt's Relay Research Fund, Institute for Rehabilitation Research and Development; Ottawa, ON; Rehabilitation Technology Consortium, Toronto, ON*

PURPOSE—This study will develop a method to quantitatively transfer manual modification techniques to a general CAD/CAM overlay. This overlay will be used to produce and compare CAD/CAM supracondylar suspension sockets with conventionally produced sockets using clinical evaluation, gait analysis, and client satisfaction ratings.

METHODOLOGY—A software program will be written to compare original and modified residual limb shapes. By entering a series of pre- and post-modification shapes, common modification areas will be averaged to produce a generalized rectification pattern suitable for use with a CAD/CAM system. Upon completion of the pattern generation phase of this study the standard rectification pattern will be used for all CAD/CAM produced sockets.

Twelve subjects with trans-tibial (TT) amputations will be recruited for definition of a standard rectification pattern. Four prosthetists will cast and manually modify the positive molds of three patients each. A total of 26 subjects with trans-tibial amputations will be required for the validation phase of this project. Each of the 26 subjects will be fit with a conventional and a CAD/CAM produced socket. A questionnaire will be used to record the subject's personal data. Each subject will be assessed by a prosthetist, complete a satisfaction questionnaire, and undergo a quantitative gait assessment.

If no differences are found between gait results for the two fabrication methods, or if the results for the CAD/CAM produced leg are clinically different but closer to gait results for normals, it will be assumed that the CAD/CAM socket fabrication procedure is superior.

RESULTS—A computer software package (CADVIEW) has been written for Microsoft Windows 3.1 to take output from existing CAD/CAM systems and graphically display a series of socket shapes. Using a standard MS Windows graphical interface, the shape can be rotated in 3-D, enlarged, moved, and scaled to a higher resolution (i.e., to produce a photo realistic image). Since a multiple document interface was used, a clinician can load as many shapes onto the screen as permitted by the computer hardware (multiple socket files, 3-D solid, 3-D wireframe, 3-D composite, 3-D comparison, 2-D comparison, 2-D cross section, 2-D profile). User interface features include a status bar, tool bar, new icons, window color control, and the ability to print the contents of individual windows. A multiview print feature is presently under development.

Regarding graphical and statistical socket comparison, two shapes can be loaded into memory, mathematically aligned to a common axis, and used to calculate the root mean square difference. Graphical features include a 3-D color-graded display, 2-D overlay display, on-screen measurement in 2-D and 3-D, socket statistics, and program setup menus. A function has been completed to determine the peak points (i.e., areas of maximum change); however, work is still in progress to determine and display the boundary areas around these peak points.

FUTURE PLANS—Programming of the manual modification contour identification section is in progress. Preliminary tests of clinician specific modification patterns should start in the fall of 1994.

[36] A COMPARISON OF VAN NES ROTATIONPLASTY AND SYME'S AMPUTATION

Elizabeth Sheil, MASc; Ben Alman, MD; Shiela Hubbard, DipPT, OT, BSc; Patricia Longmuir, MSc; S. Naumann, PhD, PEng; J. Ian Krajbich, MD, FRCSC
Human Movement Research Programme, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsor: *None listed.*

PURPOSE—This was a retrospective study which compared Van Nes rotationplasty (VNR) and Syme's amputation (SA) with knee fusion in the treatment of Proximal Femoral Focal Deficiency (PFFD). Specifically, we compared gross motor function, body image, oxygen utilization while ambulating between selected subjects who have undergone these two treatments and gait laboratory study of selected subjects.

PROGRESS—Sixteen (9-VNR, 7-SA) subjects were evaluated for gross motor function and body image through a questionnaire. Thirteen of the subjects (7-VNR, 6-SA) underwent the metabolic energy cost of ambulation evaluation. Four of these (2-VNR, 2-SA) underwent the biomechanical gait analysis. This pilot study is now complete. Results indicated that there was no difference in gross motor function or perceived body image. Metabolic energy cost of ambulation results showed that the subjects with the Van Nes rotationplasty had a significantly more efficient gait than the subjects with the Syme's amputation ($p<0.05$). Biomechanical gait analysis indicated beneficial differences of the Van Nes rotationplasty over the Syme's amputation.

FUTURE PLANS—Preparations for submitting a proposal for funding to do a complete study are underway.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Biomechanical work in walking and jogging. Colborne GR, Naumann S, Sheil E. In: Proceedings of the 12th Congress of the International Ergonomics Association: Rehabilitation Ergonomics, 1994. In press.

II. Biomechanics

A. Bone and Joint Studies

[37] MAINTENANCE AND ADAPTATION OF BONE TISSUE: THE IMPORTANCE OF MECHANICAL STIMULI

Chris R. Jacobs, PhD; Gary S. Beaupré, PhD; Dennis R. Carter, PhD
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—A relationship between mechanical stimuli and bone adaptation was suggested more than 100 years ago. Several mathematical theories for bone adaptation have been developed in recent years. Our research group has developed a comprehensive theory for bone adaptation that can be used to simulate bone changes during development, growth, adaptation, and aging. Because of its importance to locomotion and total joint replacement, we have focused on the proximal femur to assess the accuracy of our theoretical models and computational simulations.

RESULTS—We have achieved a computer simulation showing the predicted distribution of bone density that bears a strong similarity to the actual distribution. By adopting ideas from other engineering disciplines (continuum damage mechanics) we have modified our bone-remodeling theory, making it possible to predict the anisotropy of the bone material, as well as the density distribution.

The anisotropic extension of our bone-remodeling theory represents a significant advance in our ability to simulate bone adaptation in response to changes in loading or the presence of prosthetic implants. These kinds of simulations should make it possible to improve implant design leading to longer lasting prosthetic joint replacements.

[38] DETERMINATION OF BONE AND JOINT LOADS FROM BONE DENSITY DISTRIBUTIONS

Kenneth J. Fischer, MS; Marc E. Levenston, MS; Chris R. Jacobs, PhD; Dennis R. Carter, PhD; Dianna D. Cody, PhD
VA Medical Center, Palo Alto, CA 94304; Henry Ford Hospital, Detroit, MI 48202

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—Adverse changes in bone density and structure following total joint replacement lead to loosening and eventual failure of the implants. Computer simulations of bone remodeling have been developed to guide the development of implant designs to reduce adverse changes in the bone. Since the loading conditions greatly affect the simulations, accurate estimates of the loads are essential.

Our research group developed a theory and approach to bone remodeling simulations that has been shown to reproduce natural bone density distributions. Simulations have reproduced the natu-

ral bone densities of the metaearpal, the proximal femur, and the acetabulum. The theory states that the local bone tissue will change its density, according to the loads, to achieve a specifie level of mechanieal stimulus, the attractor stress stimulus. In a mature bone, nearly all bone tissue should be at the same mechanical stress stimulus, with little net change in density.

Because the structure of a bone is influenced by the loading conditions, its geometry and internal density distribution must eontain information about its loading eonditions. By adjusting the loads on a bone model to achieve a constant (attraetor) stress stimulus, we should be able to determine appropriate and accurate loads for the bone.

METHODOLOGY—To test that hypothesis, we developed a computer model employing a finite element mesh with the external geometry of the bone and mapped the density distribution into that model. Numerous plausible loads are seleeted, based on our knowledge of anatomy and joint kinematics, and the eomplete normalized stress distribution is caleulated for eaeh. Final seleeted loads will be a combination of these normalized loads.

Within a nonlinear optimization proeedure, the loeal stress stimulus is ealculated and eompared to the attractor stress stimulus. Each load magnitude is iteratively updated until the global stress stimulus error is minimized. Important loads have a large magnitude, whereas incorrect or unimportant loads have negligible magnitude. These estimated loads are evaluated by using them in a bone remodeling simulation. Aceurate loads should reproduce the aetual bone density distribution in the remodeling simulation.

PROGRESS—This load determination method has undergone several stages of testing. Initial tests used an idealized bone-end model and showed that, under the most ideal eonditions, the proeedure is very accurate. The load determination method was also tested with an existing model on the more complex geometry of the proximal femur, whieh has multiple loading sites.

[39] UPRIGHT POSTURE: HOW LIMB BIOMECHANICS LIMITS THE ABILITY TO STAND

Arthur Kuo, PhD; Christopher Runge, MS
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—The ability to maintain balance while standing upright is eompromised in some individuals, such as vestibular-deficient patients (those with inner ear problems), the elderly, and those suffering from nervous system disorders. Among the elderly alone, one-third to one-half of the population aged 65 years and older are at some point harmed by falling. Many of these falls result in serious injury, and for eases in whieh a hip is broken, the mortality rate is nearly one-half. The goal of this projeet is to develop diagnostie and rehabilitation tools based on understanding how the eentral nervous system (CNS) interaets with the museuloskeletal system to eontrol standing.

METHODOLOGY—We would like to understand the roles played by the CNS and by the biomeehanies of the body during posture control. The study is complieated by the faet that the most reliable method for measuring commands sent by the CNS to the museles is eleetromyography, whieh is limited in elinieal praetiee in how reliably it ean reeord from speeifie museles. Most motor-control studies therefore must rely heavily on external measurements of the aetual movements, using eameras, force-sensing platforms, and other sensors. Beeause these deviees provide only a subset of the information needed to eompletely eharacterize a movement, some of our efforts have focused on ways to best use this measurement data to represent the behavior. Only with a good representation of the movement can we proeeed to study thoroughly how the movement is controlled by the CNS.

Fundamental to the study of balance phenomena is the difficulty in differentiating between events due to the body biomechanics and those due to intentional CNS control. The biomechanics of the body constrain what types of movement can occur. We hypothesize that biomechanical modeling can be used to gain insight into central nervous control since the CNS cannot do more than what the biomechanics will allow.

An engineering model of the human body, including important properties and parameters of the skeleton and muscles, computes inputs for the muscles and simulates the resulting movement. Control systems analysis techniques operate on this model to characterize the constraints on possible motions. These biomechanical constraints reduce the possible ways in which the CNS can maintain balance.

PROGRESS—The computer model has shown that control of balance is subject to a large number of biomechanical constraints on movement. The CNS must operate within these constraints to successfully maintain posture. Experiments have shown that changes in CNS control strategies when recovering from a balance disturbance are often due to the effects of these constraints. Understanding how the CNS maintains body balance by controlling the musculoskeletal system, whose properties constrain what type of control will be effective, is critical to the continued development of rehabilitation of persons encountering balance deficits.

[40] THE STRENGTH OF HUMAN CORTICAL BONE WITH SIMULATED METASTATIC LESIONS

Harry B. Skinner, MD, PhD; Stephen A. Rossi, BSME; Joyce H. Keyak, BSME
Department of Veterans Affairs Medical Center, San Francisco, CA 94121

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A741-RA)*

PURPOSE—The objective of this study is to establish a technique for predicting the strength of bones with metastatic tumors. The underlying hypothesis of this study is that the risk of fracture is related to the strength of bone with its defect, and that this strength is a function of three-dimensional geometry and the distribution of mechanical properties. This study will take advantage of CT scan data to generate three dimensional patient specific finite element models, models which would predict stress distributions in the bone surrounding the defect and identify regions at high risk of failure.

METHODOLOGY—The proposed research contains both an experimental and a theoretical component. The experiment requires 15 matched pairs of human femoral shafts to be subjected to four point bending. One of each pair will be left intact, and its failure load will represent whole bone strength; the other will have a spherical defect (6, 12, or 18 mm in diameter), and its failure load will represent the strength of a bone with a simulated metastatic tumor. CT scans will be taken of all the bones prior to mechanical testing and will be used for the generation of finite element models.

The theoretical component of this research involves the generation of the models and calculating failure loads based on model predictions. A cylindrical model will be generated by using the CT scan data solely to ascertain periosteal and endosteal diameters; other model parameters are set to values used in the models from the literature. A second model will utilize CT data to generate geometries more representative of the true bone geometry; once again other model parameters will be from the literature. A third model will use the CT scan data both to characterize the geometry and allow variation in material properties.

This material property variation will be loosely based on values found in the literature, the important concept being that modulus and strength will vary with the square of CT derived densities. All three of these models will predict strengths that are to be correlated to the failure strengths of the experimental bones, and thus test our overall hypothesis that the use of CT data can improve the prediction of bone strength.

PROGRESS—There are a great number of factors that go into the finite element modeling of bone, a material whose properties are inhomogeneous, anisotropic, asymmetric, and generally variable. Our research is designed to evaluate how the inclusion of CT data in the modeling process improves our ability to predict bone strength by accounting for some of the sources of variability. To date, we have refined the finite element modeling method and developed the experimental testing protocol. It is envisioned that the use of our model will improve failure load predictions, eventually enabling surgeons to make informed decision about the need to provide surgical fixation of bones with metastatic lesions.

[41] BIOMECHANICS OF CERVICAL DIAGNOSTIC MANEUVERS: A PILOT STUDY

M. Ram Gudavalli, PhD; John Triano, MA, DC; Avinash Patwardhan, PhD; Marion McGregor, DC, MSc; Robert Havey, BS;
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141; National College of Chiropractic, Lombard, IL 60148; Loyola University Medical Center, Maywood, IL

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B91-214AP)*

PURPOSE—Specific objectives of this research were to 1) conduct *ex vivo* experiments on cadaveric spine specimens to determine the vertebral displacements and the stretches of the representative neck tissues (intertransverse ligament, anterior longitudinal ligament, and vertebral artery at C1-C2 level) during the vertebral artery provocation (VAP) test designed to challenge these structures in extreme extension and rotation; and 2) develop a computer model of C1-C2 motion segment that can be used to estimate the vertebral displacements, the stretches of the ligaments and the vertebral artery, and loads on the ligaments during the simulated VAP test. The long-term goal of the project is to quantify and describe the biomechanical events that occur during orthopedic diagnostic testing conducted on neck pain patients. This information is useful in identifying the tissues that are challenged during the diagnostic maneuvers and provide useful information for validating the underlying hypotheses of these diagnostic procedures.

METHODOLOGY—The *ex vivo* experiments were conducted on five, fresh human cadaveric cervical spine specimens consisting of the head and C0-C4 to measure the vertebral displacements, ligament stretches, ligament loads, and vertebral artery stretch at the C1-C2 joint level. These measurements were based on an optoelectronic three-dimensional motion-analysis system (WATSMART), a miniature Hall-effect stretch transducer, and differential variable reluctance transducers (DVRT stretch transducers). The stretch transducers were used to measure the stretches of the anterior longitudinal ligament (ALL), capsular ligament (CL), and the vertebral artery under simulated VAP test which involves the loading of the head and the cervical spine in combined motions of extension and rotation. The computer model idealizing the ligamentous structures at the C1-C2 joint level was developed by incorporating the geometry and the material properties of the cervical spine to predict the biomechanical response under loading conditions of extension and rotation similar to the VAP diagnostic test.

RESULTS—The results indicate that C1-C2 joint mean displacements were 10.9 degrees in extension and 33.3 degrees in rotation. The mean ligament stretches were 2.83 mm for the ALL and 2.87 mm for the CL, and the mean stretch for the vertebral artery was 0.9 mm. The model predictions correlated well with experimental values for the displacements and ligament stretches, whereas they did not correlate well with the vertebral artery stretches. The inability of the model to predict the vertebral artery stretch may be attributed to the following two reasons: 1) the artery does not contain blood during the *ex vivo* experiments, thus losing its true elasticity, and 2) the artery does not rigidly attach to

C1 or C2 vertebrae. Future studies may consider perfusion of the artery during the *ex vivo* experiment to simulate *in vivo* elasticity of the artery.

FUTURE PLANS—This pilot study demonstrates that the vertebral displacements and the ligament stretches can be studied under the diagnostic maneuvers as proposed in the pilot study. The computer model development can be extended to include several vertebrae and the connecting ligaments, discs and the facet joints. Future studies would be to develop similar protocols to investigate other diagnostic maneuvers commonly used in the case of neck-pain patients. A manuscript for a scientific journal and abstracts for scientific meetings will be prepared.

[42] OPTIMUM IMPLANT STIFFNESS FOR LUMBAR FUSION: A PILOT STUDY

Tae-Hong Lim, PhD; Avinash G. Patwardhan, PhD; Michael Zindrick, MD
Department Orthopaedic Surgery, Medical College of Wisconsin, Milwaukee, WI 53226; Rehabilitation R & D Center (151L), VA Hines Hospital, Hines, IL 60141; Hinsdale Hospital, Hinsdale, IL 60522

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #A91-278AP)*

PURPOSE—The purpose of this study is to investigate the effects of spinal instrumentation on the biomechanical properties of the intervertebral disc adjacent to the stabilized segment. The hypothesis to be tested in this pilot study is that spinal fusion with rigid instrumentation causes significant changes in the biomechanical properties of the intervertebral disc adjacent to the fused segment.

The specific objectives are 1) to develop an *in vivo* canine model to investigate biomechanical effects of spinal instrumentation, 2) to investigate the load-displacement behavior of the intact and stabilized canine lumbar spines to quantify the changes in rigidity due to a rigid fixation, 3) to investigate whether the viscoelastic properties of the disc above an instrumented segment differ significantly from the corresponding disc from a nonoperated control group, and 4) to investigate whether the intervertebral disc above the stabilized segments shows visual signs of degenerative changes.

If such changes exist, efforts will be made to correlate the biomechanical changes with grades of disc degeneration. The results of this study will be valuable in determining whether the viscoelastic properties of the discs are sensitive to the altered mechanical environment following fusion with rigid instrumentation, and in identifying a subset of biomechanical measurements that are most appropriate for future studies of disc degeneration. The long-term goal of our research is to estimate the optimum initial rigidity of a surgical construct to minimize adverse effects on adjacent segments while ensuring solid biologic fusion in normal anatomic alignment.

METHODOLOGY—The animal model was developed using a total of 10 adult male purpose-bred mongrel dogs (weight: 25-30 kg). Five control dogs (age 2 years) were euthanized at the beginning of the study and their lumbar spines were harvested for biomechanical studies. In five experimental dogs (age 1.5 years), posterior spinal fusion was performed using Isola transpedicular system (with one transverse connector) spanning three disc spaces (L5-sacrum). At the end of 30 weeks, the animals were euthanized and their lumbar spines were harvested. Static load-displacement data were obtained from each lumbar specimen to quantify the rigidities of the intact (control) and stabilized lumbar spine specimens (L5-sacrum). Viscoelastic properties of the L4-5 disc (the level adjacent to the fusion mass) were quantified in terms of the creep and cyclic load-displacement responses using an Instron materials testing machine. Data obtained from the biomechanical tests will be analyzed using multivariate analysis of variance to identify statistically significant differences between the control and experimental groups.

PROGRESS—Five control dogs were sacrificed and the lumbar spines were harvested for biomechanical tests to obtain the baseline data. All five lumbar spine specimens from the control group have undergone biomechanical tests for obtaining the static load-displacement, creep and cyclic load-displacement data. Spinal fusion surgery with Isola instrumentation system was performed on five experimental dogs according to the proposed protocol. After completion of the 6-month follow-up period, the animals were sacrificed. Mechanical testing on the harvested spine specimens has been completed on three specimens from the experimental group.

FUTURE PLANS—All biomechanical tests and subsequent data analysis are expected to be completed by September 1994. If the hypothesis to be tested in the pilot study is accepted, a comprehensive study will be designed with multiple experimental groups including fusion with bone graft alone, fusion with a currently used stiff implant, and fusion with surgical constructs of lesser rigidities.

[43] CORRELATION OF STREAMING POTENTIALS WITH STAGES OF BONE REPAIR/REMODELING

George Van B. Cochran, MD; Bok Y. Lee, MD; Mark Otter, PhD
VA Medical Center, Castle Point, NY 12511; Helen Hayes Hospital, West Haverstraw, NY 10993

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A16O-4RA)*

PURPOSE—While bone repair/remodeling is thought to be influenced by mechanical forces, the transducing signal that controls bone cell activity remains undefined. Circumstantial evidence points to mechanically induced fluid flow in bone with concomitant production of streaming potential (SP), also known as stress-generated potentials, as a possible control mechanism. *In vivo* studies of SPs in normal bone have been few, and nothing is known of their occurrence or characteristics during reparative or resorptive processes. Although various mechanical and/or electrical systems are being developed or are in clinical use in attempts to affect bone healing as well as osteoporosis, the relationship of SPs to these treatment modalities remains unclear. This project aims to define how SPs relate to specific stages and types of bone healing and remodeling, as a step toward determining their clinical significance.

PROGRESS—The investigators previously developed a model for studying the magnitude and frequency dependence of SPs in living canine tibia using a regime of bending deformation (0.1-40 Hz) applied by a specially designed servohydraulic loading system. The SPs are measured by an improved design of Ag-AgCl electrodes. Using this system, all experimental work on the current project has been completed, with measurements obtained on all canines scheduled for the three experimental models. A paper on the drill hole model has been tentatively accepted for publication; analysis of data from the osteotomy and disuse models is still in progress.

METHODOLOGY—Using the techniques described, SPs were measured *in vivo* and *in vitro* on three different models in canine tibia.
Drill Hole Model. SP measurements during servohydraulic loading at 2, 4, and 12 weeks during the healing process of 4 mm drill holes in canine tibia.
Osteotomy Model. SP measurements on bone and callus during programmed servohydraulic loading during healing at 6 and 12 weeks following creation of 8mm gap osteotomy in the tibia, stabilized with an external fixator. SPs are correlated with callus stiffness and histology.
Disuse Atrophy Model. After section of patella and achilles tendons followed 6-week immobilization in one hindlimb, SPs were measured as a function of the increased porosity of cortical bone, in comparison with the contralateral limb exposed to continued weightbearing.

RESULTS—*Drill Hole Model.* SP magnitudes, normalized to periosteal strain, were smaller for drill holes at 2 and 4 weeks postsurgery relative to either remodeling ($P<0.05$ at 10HZ) or normal intact

($P<0.001$ at 10 Hz) controls both *in vivo* and *in vitro*. SPs of 12-week drill holes were similar to SPs of remodeling controls and tended to be smaller than SPs of normal intact controls. Mean SP normalized to bone impedance was approximately the same for all sites, suggesting that the smaller SPs during healing and remodeling relate to lower bone impedance and/or greater porosity. SP as a function of bending frequency for normal sites was similar to that observed previously, while it was more variable for drill holes and remodeling controls, probably due to variations in bone microstructure. Observed differences in SP magnitude and frequency response to loading associated with stages of healing indicate that endogenous electric fields do indeed respond to the structural changes and are therefore capable of providing feedback information to the repair and remodeling process.

Osteotomy and Disuse Models. SPs have been shown to be present at 6 and 12 weeks at the healing site of 8 mm gap osteotomies with magnitude varying with callus strain. Also, there appear to be changes in SPs associated with disuse atrophy. Analyses of data from these experiments is still in progress.

FUTURE PLANS—Results of this project are being utilized in a new project series aimed at identifying biochemical and other factors which may modulate SPs in healing and remodeling bone.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Comparison of streaming potentials in healing, remodeling and intact cortical bone. MacGinitie LA, Seiz KG, Wu DD, Bieber WA, Otter MW Cochran GVB. Orthop Transact 1992:16(2):544-5.

[44] A STUDY TO INVESTIGATE THE BENEFITS OF PHYSIOTHERAPY AND EXTERNAL SUPPORTS ON THE ACL DEFICIENT KNEE

Sheila Fairgrieve; Jeremy Linskell; George Kerr
Dundee Limb Fitting Centre, Dundee DD5 1AG Scotland

Sponsors: *Sport Aiding Medical Research for Children (SPARKS)*

PURPOSE—Rupture of the anterior cruciate ligament (ACL) is relatively common, yet its management is controversial. There is mounting evidence that a reflex arc exists between the mechanoreceptors in the ACL and the hamstring muscle group, thus suggesting a proprioceptive role. It has been advocated that rehabilitation should emphasize proprioceptive training, but the efficacy of these regimes have not been evaluated. Functional braces are often prescribed, yet earlier work would indicate that they offer little mechanical support. Despite this, patients will report that their knees 'give way' less often. It is hypothesized that 1) proporioceptive training will result in improved knee performance, and 2) braces improve stability by enhancing proprioceptive feedback.

METHODOLOGY—Over the two years of the project, ACL deficient patients will be allocated to one of two groups. The first group will progress through a conventional muscle strengthening program. The second group will in addition, follow a specific proprioceptive training program. Tests will be performed pre-treatment and after three months of treatment, to measure function, laxity and proprioception.

PROGRESS—Three jigs have been developed, for the assessment of proprioception, using modifications previously reported techniques. Each of the proprioception assessment jigs has been tested on a population of normal subjects, and normal ranges have been obtained for each. Knee laxity and brace function will be assessed using the Knee Signature System (KSS).

FUTURE PLANS—The hypothesized role of knee braces as proprioceptive reinforcers, rather than as mechanical supports, has important implications for their prescription. Once the proprioceptive tests have been validated on a population of ACL deficient subjects, it is intended to apply them to a wide range of pathological conditions of the knee.

[45] SKELETAL MUSCLE CHARACTERISTICS DURING SUBMAXIMAL ACTIVATION

P.A.J.B.M. Huijing; G.C. Baan; M.E.T. Willems; B.R. Roszek; J.F. Boudet
Vrije Universiteit, Faculty of Human Movements Sciences, Dept. of Functional Anatomy, 1081 BT Amsterdam, The Netherlands

PURPOSE—The purpose of this project was to make a link between results of experiments studying muscle properties under maximal activation and *in vivo* properties of muscles that are rarely characterized by maximal activation. For that purpose several conditions of submaximal activation will be imposed for a systematic analysis.

METHODOLOGY—In addition to variables of muscle geometry (i.e., fiber length, aponeurosis length and fiber and aponeurosis angles), the number of sarcomeres in series within fibers and the filament length parameters were determined. In an initial study, submaximal activity was induced by simultaneous stimulation of the nerve by two sets of electrodes: one for 100 Hz supramaximal current and one for 600 Hz optimal effect current. The 600 Hz stimulation causes derecruitment of active motor units, in sequence according to the size principle, during the tetanic contraction.

RESULTS—Length-force characteristics of submaximally active rat medial gastrocnemius muscle differ from that of the maximally active muscle: with fewer motor units active the optimum length (i.e. the length at which maximal active force was generated) was found to occur at higher muscle lengths. The degree of this shift of optimum length was dependent on the decrease of force exerted. For the full length range of possible optimum lengths no changes of variables of muscle geometry were shown. In contrast at lower muscle length muscle geometry for submaximally active muscles differed from that of maximally active muscles. The findings were interpreted as an indication for the existence of inhomogeneities of sarcomere lengths of different fibers, which most probably is organized at the motor unit level: the bigger motor units would tend to exert their optimum force at lower muscle length and smaller motor units at higher muscle lengths. It was hypothesised that changes of firing rates of motor units may play a role as well in this experiment.

IMPLICATIONS—Length-force and force velocity properties of submaximally active muscle are likely to be very much dependent on the degree of activation. This will allow the central nervous system an extra dimension of control in the execution of movements. For functional electrostimulation (FES) this finding will have important implications as well.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Stimulation level-dependent length-force and architectural characteristics of rat gastrocnemius muscle. Huijing PAJBM, Baan GC. J Electromyogr Kinesiol 1992:2:112-20.

[46] SKELETAL MUSCLE REACTION TO GROWTH AND IMMOBILIZATION

P.A.J.B.M. Huijing; R.H. Rozendal; J.W. Heslinga; M.E.T. Willems
Vrije Universiteit, Faculty of Human Movement Sciences, Dept. of Functional Anatomy, 1081 BT Amsterdam, The Netherlands

Sponsor: *Netherlands Organization for Research, Foundation for Biological Sciences.*

PURPOSE—This project studied the reaction of skeletal muscle to immobilization at short length in relation to muscle architecture.

METHODOLOGY—Effects were studied for 4- and 6-week periods of growth and immobilization. Experimental effects were considered for immobi-

lized as well as contralateral muscles, which were compared to control muscles. In addition to variables of muscle geometry (i.e., fiber length, aponeurosis length and fiber and aponeurosis angles), the number of sarcomeres in series within fibers and filament length parameters were considered.

RESULTS—Growth effects were similar for contralateral medial gastrocnemius muscles (GM). In immobilized rats considerable differences were encountered between GM muscles from both the immobilized right legs and free left legs. Muscles from both sides differed in physiological cross sectional area, but not in number of sarcomeres from control muscles. Despite different degrees of atrophy for contralateral muscles, fiber and aponeurosis angles did not differ, nor did myofilament length parameters. Indications were found for changes in the inhomogeneity of sarcomere length of different fibers, particularly in muscles from the contralateral (non-immobilized leg). In soleus muscles growth as well as immobilization caused changes of number of sarcomeres in series within fibers. Immobilization induced atrophy was not higher in SOL than in GM.

IMPLICATIONS—A major adaptation to immobilization is shifting muscle optimum length to the immobilized length. The major effect of short length immobilization is atrophy. Depending on the degree of pennation of the muscle this will lead to a varying degree of muscle shortening: in highly pennate muscle this shortening will be much greater than in less pennate muscle. To obtain the shift of muscle optimum length in very pennate muscle this shift due to atrophy is sufficient. In contrast, in less pennate muscle adaptation of number of sarcomeres is necessary as well. This decrease of number of sarcomeres affects muscle length range of active force exertion.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Effects of growth of rat semimembranosus muscle. Willems MET, Huijing PAJBM. Anat Rec 1992:233:25-31.

Effects of short length immobilization of medial gastrocnemius muscle of growing young adult rats. Heslinga JW, Huijing PAJBM. Eur J Morph 1992:30:257-73.

Muscle fibre (hyper)trophy and atrophy in relation to fibre angles. Huijing PAJBM, Heslinga JW. J Biomech 1992:25:695.

Unilateral immobilization affects contralateral rat gastrocmenius muscle architecture. Heslinga JW, Rozendal RH, Huijing PAJBM. Acta Anat 1992:143:213-35.

Muscle length-force characteristics in relation to muscle architecture: a bilateral study of unilaterally immobilized rats. Heslinga JW, Huijing PAJBM. Eur J Appl Physiol 1993:66:289-98.

[47] QUANTITATIVE FUNCTIONAL ANATOMY OF THE UPPER EXTREMITY

R.H. Rozendal; H.E.J. Veeger; L.H.V. van der Woude; F.C.T. van der Helm; K.N. An
Vrije Universiteit, Faculty of Human Movement Sciences, Dept. of Functional Anatomy, 1081 BT Amsterdam, The Netherlands; Department of Measurement and Control, Delft University of Technology, 2600 AA Delft, The Netherlands; Orthopedic Biomechanics Lab, Mayo Clinic, Rochester, MN 55905

Sponsor: *Netherlands Organization for Research; Foundation of Biophysics*

PURPOSE—Quantitative data on the musculoskeletal system of shoulder and arm are needed with a view to: 1) analysis of movements of shoulder girdle and arm, based on arm movement registration in activities such as wheelchair driving; 2) analysis of movements of shoulder girdle and arm in activities of daily living (ADL) and vocational activities; 3) analysis in the mechanics of shoulder luxation syndromes; 4) analysis of the outcome of arthrodesis of the shoulder; and 5) aiding interpretation of in vivo human palpation data.

PROGRESS—A dynamic model of the human shoulder has been developed at the Delft University of Technology. The model is being used to describe the dynamics of the shoulder girdle and arm in activities such as wheelchair propulsion or ADL. Activities are analyzed in terms of muscle strains.

The model will be extended with information on muscle dynamics and anatomical data on elbow muscles. This information was acquired during a stay of Veeger with Dr. An of the Mayo Clinic, Rochester MN.

FUTURE PLANS—We plan to use the model in orthopaedic pathology, rehabilitation (wheelchair propulsion and ADL) and ergonomics.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Geometry parameters for musculoskeletal modelling of the shoulder mechanism. Van der Helm FCT, Veeger HEJ, Pronk GM, Van der Woude LHV, Rozendal RH. J Biomech 1992:25:129-44.

Analysis of the kinematic and dynamic behavior of the shoulder mechanism. Van der Helm FCT. J Biomech 1994:27:527-50.

Finite element musculoskeletal of the shoulder mechanism. Van der Helm FCT. J Biomech 1994:27:551-69.

[48] KINEMATIC AND DYNAMIC ANALYSIS OF THE SHOULDER MECHANISM

F.C.T. van der Helm; J.H. de Groot; L.A. Rozendaal; S. Stroeve; B. Kaptein; G. Brouwn
Man-Machine Systems Group, Dept. of Mechanical Engineering, Delft University of Technology, 2628 CD Delft, The Netherlands

Sponsor: *None listed*

PURPOSE—The goal of the research team is to gain insight in the functioning of the shoulder mechanism (i.e. muscles, ligaments, bones, etc.) in order to improve the diagnosis, treatment and prevention of shoulder complaints. Specific clinical applications are the development of a glenohumeral endoprosthesis, treatment of habitual subluxation. Ergonomic applications focus on manual wheelchair propulsion and steelmill bricklayers.

A biomechanical model of the shoulder has been developed, for forward and inverse dynamic simulations. Forward simulations are useful for investigating neuromuscular strategy and stability, as well as parameter sensitivity. Inverse simulations include muscle dynamics, and have been used to analyze the wheelchair propulsion stroke.

RESULTS—Preliminary results indicate a good agreement in temporal patterns between muscle activation and EMG. The shoulder is analyzed with a number of techniques. The contribution of proprioceptive feedback for the stability of the glenohumeral joint is investigated. The stability is tested with perturbations and subsequent muscle reflexes, recorded with EMG. 2-D X-ray has been used to test velocity effects on the scapulohumeral rhythm. 3-D reconstructions have been made from 2-D X-rays, using the motion constraints of the scapula. Neural networks are used to simulate the learning and adaptive behaviour for motor tasks. Magnetic Resonance Imaging is used to obtain morphological parameters for the shoulder model on living subjects.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Analysis of the kinematic and dynamic behavior of the shoulder mechanism. Van der Helm FCT. J Biomech 1994:27(5):527-50.

Finite element musculoskeletal model of the shoulder mechanism. Van der Helm FCT. J Biomech 1994:27(5):503-27.

Interaction between the joints in the shoulder mechanism: the function of the costoclavicular, conoid and trapezoid ligaments. Pronk GM, Van der Helm FCT, Rozendaal LA. Proc Instn Mech Eng 1994:207, 219-29.

Loading of shoulder girdle muscles in consequence of a glenohumeral arthrodesis. Van der Helm FCT, Pronk GM. Clin Biomech 1994:9:139-48.

Control of shoulder muscles during goal directed movements, an inverse dynamic analysis. Happee R, Van der Helm FCT. J Biomech. In press.

Three-dimensional recording and description of motions of the shoulder mechanism. Van der Helm FCT, Pronk GM. J Biomech Eng. In press.

B. Human Locomotion and Gait Training

[49] A COMPARATIVE STUDY OF STABILOGRAM-DIFFUSION ANALYSIS AND TRADITIONAL POSTUROGRAPHIC ANALYSES

James J. Collins, PhD; Carlo J. DeLuca, PhD; Lewis A. Lipsitz, MD; Adam Burrows, MD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Harvard Medical School, Cambridge, MA 02115

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA)*

PURPOSE—In this study, we compared the ability of stabilogram-diffusion analysis to identify age-related changes in postural control with that of more traditional posturographic techniques.

METHODOLOGY—We examined 25 healthy young subjects (aged 19-30) and 25 healthy elderly subjects (aged 71-80, recruited with the assistance of the Claude D. Pepper Geriatric Research and Training Center) under quiet-standing conditions. The respective center-of-pressure (COP) trajectories were examined as one-dimensional and two-dimensional random walks, according to stabilogram-diffusion analysis. We also considered five commonly-used COP parameters, total sway path length, maximum anteroposterior (AP) displacement, maximum mediolateral displacement, root-mean-square displacement, and radial area. Resultant values for these parameters were calculated from the COP time series for each of the above elderly and young subjects. Standard statistical analyses were used to compare the results for the two populations.

PROGRESS—This study clearly demonstrated that stabilogram-diffusion analysis provides the ability to discriminate among different age groups, whereas traditional analytical techniques, in general, do not.

A paper based, in part, on this study was presented at the 46th Annual Scientific Meeting of the Gerontological Society of America in New Orleans, LA.

RESULTS—We found that only one of the five traditional COP parameters, maximum AP displacement, was significantly different between the two age groups. This is in sharp contrast to the results for the stabilogram-diffusion parameters that were calculated from the same COP time series: statistically significant differences between the young and elderly subjects were found for 14 of the possible 18 parameters. Moreover, and perhaps more importantly, it is unclear how the above traditional measures can be related to the operational characteristics of the neuromuscular mechanisms involved in balance control (beyond the general statement that increased maximum AP displacements are probably indications of increased postural instability). As discussed elsewhere, stabilogram-diffusion parameters can be directly related to the steady-state behavior of the open-loop and closed-loop postural control mechanisms.

[50] BICYCLE ERGOMETRY TO IMPROVE AMBULATION IN HEMIPLEGIC STROKE PATIENTS

David A. Brown, PhD; Charles G. Burgar, MD
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B763-RA)*

No report was received for this issue.

[51] INITIATION OF HUMAN WALKING

Ray J. Morin, BS; James J. Collins, PhD; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA)*

PURPOSE—There has been considerable research related to human locomotion over the past several decades. Little of this research has focused on gait initiation. Gait initiation is the transition period between upright 'quasi-static' posture and actual movement. A limited number of previous studies have attempted to characterize gait initiation using invariant parameters. Invariant parameters are parameters that do not change with varying experimental conditions (e.g., changes in progression speed). Such parameters may be indicative of pattern-generating control mechanisms in the central nervous system. The objective of this preliminary study was to determine whether the initiation of walking can be characterized by a set of invariant biomechanical parameters and to examine how the nature of these parameters changes as a function of age.

METHODOLOGY—We examined five healthy young females (aged 22-26) and five healthy elderly females (aged 66-73). Subjects initiated walking under three different speed conditions ('slow,' 'normal,' 'fast') from a force platform, which measured the displacement of the center of pressure under their feet. Simultaneously, an ELITE motion analysis system recorded the movements of each subject's right lower limb.

PROGRESS—We found that the percent times in the step cycle to maximum ankle dorsiflexion and maximum displacements of the center of pressure, respectively, were invariant across all speeds for both the young and elderly subjects. We also found that the relative times of foot-contact events (toe-off and heelstrike) were invariant in the elderly, but variant in the young.

RESULTS—These findings suggest 1) a number of biomechanical parameters, regardless of age, display invariances during gait initiation, and 2) the elderly may rely more on pattern-generating mechanisms for gait initiation, rather than relying on the 'fine tuning' effects of various feedback mechanisms.

[52] COMPUTATIONAL POSTUROGRAPHY: IN NUMERO EXPERIMENTS ON POSTURAL CONTROL

James J. Collins, PhD; Carlo J. DeLuca, PhD; Ann Pavlik, BS; David Albert, MS
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA); the National Science Foundation*

PURPOSE—In our earlier posturographic investigations, we proposed that open-loop and closed-loop neuromuscular control mechanisms are involved in the regulation of undisturbed, upright stance. The objective of this study was to develop a software package that could be used to conduct *in numero* experiments to test the above open-loop/closed-loop hypothesis and to explore the functional roles of related neural and biomechanical factors.

METHODOLOGY—The computer model we developed can take the form of a single-link or multi-link inverted pendulum. The joints of each pendulum are constrained by spring-dashpot systems and noisy force actuators. The software package permits the user to set interactively each parameter affecting the modelled system. The computer model is also enabled to explore the effects of various control systems, such as: 1) a proportional, derivative, accelerative feedback con-

troller, 2) a variable-gain feedback controller, 3) a sampled data system, and 4) an ON/OFF feedback controller with an error dead zone. The output of the system consists of the time-varying position of the system's center of mass and center of pressure.

PROGRESS—The software package will eventually be used to examine the effects of the following factors on quiet-standing postural stability: 1) muscle stiffness, 2) feedback gain, 3) feedback thresholds, 4)feedback time delays, 5) muscle force fluctuations, and 6) body-segment inertial properties.

[53] THE INTEGRATION OF VISUAL INPUT INTO THE AGED POSTURAL CONTROL SYSTEM

James J. Collins, PhD; Carlo J. DeLuca, PhD; Lewis A. Lipsitz, MD; Adam Burrows, MD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Harvard Medical School, Cambridge, MA 02115

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA)*

PURPOSE—In this study, we utilized stabilogram-diffusion analysis to examine how visual input is integrated into the aged postural control system.

METHODOLOGY—We examined 25 healthy elderly subjects (aged 71-80, recruited with the assistance of the Claude D. Pepper Geriatric Research and Training Center) under quiet-standing conditions. All subjects were tested under eyes-open and eyes-closed conditions. The respective center-of-pressure (COP) trajectories were parameterized according to stabilogram-diffusion analysis.

RESULTS—As with the healthy young subjects (aged 19-30) discussed in a separate report, we found that visual input is integrated into the aged postural control system in one of two different ways: either it significantly modifies the open-loop control mechanisms, or it significantly alters the closed-loop control mechanisms. However, whereas the young subjects were roughly evenly divided between these two schemes, the majority of the elderly individuals (18 of 25) utilized the former scheme during quiet standing. It thus appears that fewer elderly individuals utilize the latter scheme (i.e., modification of closed-loop postural control mechanisms, during undisturbed stance). This result may be related to the general finding that aged individuals often lose the ability to modify the gain of their reflex-based feedback systems. Such a change could predispose an individual to an increased risk for falling. This issue will be considered in a future posturographic study.

[54] AGE-RELATED CHANGES TO OPEN-LOOP AND CLOSED-LOOP POSTURAL CONTROL MECHANISMS

James J. Collins, PhD; Carlo J. DeLuca, PhD; Lewis A. Lipsitz, MD; Adam Burrows, MD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Harvard Medical School, Cambridge, MA 02115

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA)*

PURPOSE—Older adults often exhibit problems in posture and balance. These disorders predispose the elderly to falls, which are the most common cause of trauma and the largest single cause of accidental deaths among the aged. There is a pressing need to investigate and understand age-related disturbances to postural control mechanisms. In this study, we evaluated the ability of stabilogram-diffusion analysis to identify and yield insights into age-related changes in postural control.

METHODOLOGY—We examined 25 healthy young subjects (aged 19-30) and 25 healthy elderly subjects (aged 71-80, recruited with the assistance of the Claude D. Pepper Geriatric Research and Training Center) under quiet-standing conditions. The respective center-of-pressure (COP) trajectories were parameterized according to stabilogram-diffusion analysis.

RESULTS—Using this approach, we found that the overall stochastic activity of the open-loop postural control mechanisms increases in the elderly. Moreover, we showed that the steady-state behavior of the open-loop control schemes is more positively correlated and therefore perhaps more unstable in the aged. On the other hand, we found that the steady-state behavior of the closed-loop postural feedback mechanisms is more negatively correlated and therefore perhaps more tightly regulated in the aged. Finally, we found that the temporal and spatial characteristics of the interaction of the open-loop and closed-loop control mechanisms change as a function of age. In the elderly, for example, open-loop control schemes are utilized for longer time intervals during undisturbed stance.

This study demonstrated that stabilogram-diffusion analysis can be used to distinguish the COP trajectories of healthy young subjects from those of healthy elderly individuals. This work also showed that the aging process results in changes in the functional behavior of the open-loop and closed-loop postural control mechanisms and that these changes can be characterized quantitatively during periods of undisturbed stance.

A paper based, in part, on this study was presented at the 46th Annual Scientific Meeting of the Gerontological Society of America, November, 1994, in New Orleans, LA.

[55] THE EFFECTS OF VISUAL INPUT ON OPEN-LOOP AND CLOSED-LOOP POSTURAL CONTROL MECHANISMS

James J. Collins, PhD; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA); Liberty Mutual Insurance Company*

PURPOSE—In an earlier posturographic investigation, we proposed that open-loop and closed-loop control mechanisms are involved in the regulation of undisturbed, upright stance. In this study, stabilogram-diffusion analysis was used to examine how visual input affects the operational characteristics of these control mechanisms.

METHODOLOGY—We examined 25 healthy male subjects (aged 19-30) under quiet-standing conditions. The subjects were tested under eyes-open and eyes-closed conditions. The center-of-pressure (COP) trajectories were analyzed as one-dimensional and two-dimensional random walks, according to stabilogram-diffusion analysis. Stabilogram-diffusion analysis leads to the extraction of repeatable COP parameters that can be directly related to the resultant steady-state behavior and functional interaction of the neuromuscular mechanisms underlying the maintenance of erect posture.

RESULTS—Using this techniquc, it was found that visual input affects the performancc of the postural control system in one of two different ways: either it significantly modifies the steady-state behavior of the open-loop postural control mechanisms, or it significantly alters the characteristics of the other closed-loop feedback mechanisms that are involved in balance control. The experimental population was roughly evenly divided between these two schemes. For the first group (13 of 25 subjects), visual input principally caused a decrease in the stochastic activity of the open-loop control mechanisms. For the second group (12 of 25 subjects), visual input caused an increase in the stochastic activity and uncorrelated behavior of the closed-loop control mechanisms.

On the basis of these results, it is hypothesized that visual input, in both schemes, serves to decrease the stiffness of the musculoskeletal system. Using stabilogram-diffusion analysis, it was also found

that the two groups of subjects behaved similarly under eyes-closed conditions. This result suggests that the open-loop postural control mechanisms and reflex-based feedback systems, respectively, of healthy, young individuals are organized in functionally equivalent ways.

[56] RANDOM WALKING DURING QUIET STANDING

James J. Collins, PhD; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *National Science Foundation, Washington, DC 20550; Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA)*

PROGRESS—In an earlier investigation, we hypothesized that the fluctuations of the center of pressure (COP) under a subject's feet during quiet standing are chaotic. Chaos can be defined as the occurrence of highly irregular or apparently random behavior in a deterministic nonlinear system. Using analytical and surrogate-data techniques from dynamical systems theory, we found, however, that COP trajectories were indistinguishable from correlated noise sequences that were generated from the original time series. We thus concluded that it was inappropriate to consider postural sway as the output of a chaotic process. In this study, we therefore tested the alternative hypothesis that the fluctuations of the COP during undisturbed stance can be modelled as a system of correlated random walks.

METHODOLOGY—We examined 10 healthy young subjects, 5 males and 5 females, under eyes-open, quiet standing conditions. An instrumented force platform was used to collect the COP trajectories under each subject's feet during multiple 90 sec trials. Surrogate random-walk data sets were generated by randomly shuffling the increments in the original time series. This shuffling process preserved the amplitude frequency distribution of the original time series, but destroyed any temporal correlations in the data. Scaling exponents, which quantify the correlations in the increments making up a time series, were then computed for both the original COP time series and the surrogate data sets.

PROGRESS—The results of this study thus support the hypothesis that the fluctuations of the COP during quiet standing can be modelled as a system of correlated random walks.

RESULTS—We found that there were statistically significant differences between the scaling-exponent computations for the original and surrogate data sets. For the original COP time series, there were two scaling regions, a short-term region and a long-term region, in the processed-data plots. The scaling exponent computations revealed that over the short-term region (less than 1.0 sec time intervals), the COP behaves as a positively correlated random walk, whereas, over the long-term region (greater than 1.0 sec time intervals), it behaves as a negatively correlated random walk. For the surrogate data sets, on the other hand, there was only a single scaling region in the respective processed-data plots. The computed scaling exponents for this region were those expected for an uncorrelated random walk.

[57] INTEGRATED ASSESSMENT OF FACTORS AFFECTING FUNCTIONAL CAPACITY FOR LOCOMOTION

Walter N. Tapp, PhD; Angeles Flores, MD; Thomas W. Findley, MD, PhD; Douglas L. Cordero; Wanda L. Boda, PhD; Sue Ann Sisto, PT, MS
VA Medical Center, East Orange, NJ 07019

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B614-RA)*

PURPOSE—Gait, stability of walking, and the energy required to sustain walking are important factors that affect functional capacity for walking with lower-limb prosthetics. While investigations of each of these factors provide important information regarding the prescription, use, and effectiveness of lower-limb prosthetics, there is a need for methods that will integrate information from different approaches into a coherent framework and provide testable predictions. We have developed a mathematical model of walking that combines anatomical and structural information to produce predictions about an individual's gait and energy consumption during working.

METHODOLOGY—We tested the locomotion of above-knee and below-knee amputees, as well as controls walking on a treadmill and over the ground. Subjects were videotaped wearing passive reflective markers, and these data were digitized and subjected to gait analysis. Subjects also walked on a treadmill test that enabled us to determine the energy cost of submaximal and maximal activity. In order to simulate a change in the prosthetic, we added a 1-pound weight just above the ankle on the prosthetic limb.

PROGRESS—We developed a mathematical model of walking that enables us to compute predictions for the gait parameters and to measure the mechanical energy cost of walking for a given person wearing a particular prosthetic device. Predictions of gait parameters can be directly compared with experimentally measured gait parameters, and mechanical energy loss can be compared with mechanical energy loss.

RESULTS—The mathematical model provides good quantitative agreement with experimental gait data from both amputees and normals. In some cases, predictions from the model agree with experimental gait data to a startling degree: we found less than 2 percent difference between model prediction and experimental data. We also found that the addition of 1 pound to the ankle of the prosthetic enabled amputees to walk faster and tended to normalize gait parameters without affecting oxygen consumption during walking. In contrast, attaching 1 pound to the ankle of nonamputees reduced their speed, distorted their gait mechanics, and decreased their maximal treadmill performance. The differences in gait parameters and walking speed in normals and in amputees due to the addition of weight at the ankle were predicted by the current mathematical model.

FUTURE PLANS—Further work is needed to clarify the relationship between the mechanical energy computed by the model and the metabolic energy measured experimentally. We believe that, with further development, this mathematical model of walking could eventually provide a tool that is clinically useful for helping to understand how different prosthetic components and designs affect an amputee's gait, stability, and energy expenditure during walking.

[58] RESTORATION OF GAIT FOR THE STROKE PATIENT

Robert L. Ruff, MD, Ph.D; Janis L. Jacobs, MS, MA; Avram Scheiner, PhD
Motion Study Laboratory, VA Medical Center, Cleveland, OH 44106

Sponsor: *VA Rehabilitation Research and Development Service (Project #B679-RA)*

PURPOSE—We are testing a new technology, a multi-channel, implanted Functional Neuromuscular Stimulation (FNS) system for stroke rehabilitation. We are comparing conventional physical therapy treatment with FNS treatment using implanted electrodes.

METHODOLOGY—Six chronic (6 months or more post stroke) stroke subjects will be studied, each subject serving as his own control. A single case study design will be used, specifically a multiple treatment ABCBCD design. Phase A is a baseline period of no treatment. Phase B is conventional neurorehabilitation for motor retraining; Phase C, FNS exercise/FNS gait training; Phase D, provision of totally implanted FNS orthotic system (optional, according to subject request and results of previous treatments), and monitoring of carry-over effects post FNS treatment for those subjects not receiving the implanted FNS orthotic device.

Outcome measures are classified into three tiers of physical function of increasing difficulty. The first tier is voluntary movement at a single joint with the body in a static position. The second tier is voluntary motor control during walking. The third tier is functional capability at home and work. EMG, kinematic data, kinetic data, gait description data, manual muscle test, coordination, balance, and functional capability data will be collected.

RESULTS—Four subjects have been admitted into the study. Of those, two subjects have completed conventional physical therapy treatment and have had five intramuscular electrodes implanted. Preliminary analysis indicates that following conventional physical therapy, Subject 1 demonstrated improved walking speed; and Subject 2 demonstrated improved voluntary function in several muscle groups in the involved lower extremity, in additional to resolved stance phase knee hyperextension. Following one month of FNS intervention using implanted electrodes, Subject 2 demonstrated improved stance knee control, improved stance weight shift, and improved swing phase limb flexion.

Results of this study have the potential to provide clinically applicable information to give us a better understanding of 1) the efficacy of FNS exercise/gait training as compared with conventional neurorehabilitation techniques and as compared with no treatment, 2) the suitability of an array of FNS stimulator subject command controls for use during rehabilitation procedures and home use, and 3) the preliminary predictive criteria on the suitability of stroke patients for the implanted FNS orthotic system.

[59] COMPUTER-AIDED MOVEMENT ANALYSIS IN A REHABILITATION CONTEXT

Jeremy Linskell; Sheila Fairgrieve; David Condie; David Rowley
Dundee Limb Fitting Centre, Dundee DD5 1AG Scotland

Sponsors: *EEC Social Fund, AIM Programme*

PURPOSE—The purpose of this project is to develop standardized protocols for the clinical application of gait analysis in a number of patient categories. It is intended that by the end of the project, the protocols which are developed will be in routine clinical use at a number of gait analysis laboratories across Europe. The reason for the development of standardized methods of data col-

lection, analysis, and presentation is to allow for the pooling of data to improve the understanding and significance of results, leading to the application of knowledge-based systems in the analysis and interpretation of data for improved diagnosis and prescription.

PROGRESS—The project interaction has already lead to a close collaboration between the centers involved, with existing experience and knowledge being pooled. Out of this collaboration, various clinical centers have joined into pathology oriented clusters, with each of these clusters developing and evaluating its protocols under the supervision of a cluster leader.

This center is responsible for the cluster investigating degenerative diseases of the knee joint. A basic test protocol has been established and the testing of patients is well underway. An interface is in development to allow the clinical test data to be written to a central database. The patient's gait is being analyzed as a series of discretely defined parameters extracted from the gait data variables, which can then be analyzed in conjunction with the clinical data using descriptive statistics. Each center in the cluster is also producing an age-matched normal database. Apart from being responsible for the knee cluster, this center is also involved in a number of other patient clusters. One of these is the surgical management of spastic diplegic children and the other is the management of stroke patients with chronic gait disorders.

[60] THE EFFECTS OF HEAD INJURY ON OPEN-LOOP AND CLOSED-LOOP POSTURAL CONTROL MECHANISMS

James J. Collins, PhD; Carlo J. DeLuca, PhD; Casey Kerrigan, MD; Ann Pavlik, BS
NeuroMuscular Research Center, Boston University, Boston, MA 02215; Spaulding Rehabilitation Hospital, Boston, MA 02114

Sponsor: *The Liberty Mutual Insurance Company*

PURPOSE—Head injuries are often the result of accidents that occur during a variety of daily activities, such as descending stairs or driving a motor vehicle. These injuries can lead to a series of long-term movement and balance problems. It is surprising, therefore, that only a small number of posturographic investigations have reported on means for evaluating the severity of and dysfunction due to head injury. The objective of this preliminary study was to use stabilogram-diffusion analysis to gain an increased understanding of the functional neuromuscular changes that result from head injuries.

METHODOLOGY—We examined 10 patients with head injuries. The patients were recruited from the Spaulding Rehabilitation Hospital in Boston, MA. Each patient's postural stability was evaluated by using a force platform to measure the movements of the center of pressure (COP) under their feet. The patients were tested under eyes-open and eyes-closed conditions for multiple 30-s trials. The COP trajectories were parameterized according to stabilogram-diffusion. The parameters obtained for each of the patients were compared with those from age-matched healthy individuals.

RESULT—Preliminary analyses indicated that the operational characteristics of the open-loop postural control mechanisms were significantly different for the patients and healthy individuals. For example, the stochastic activity of the open-loop control mechanisms was higher in the head-injured patients. In addition, it appears that the patients utilize the open-loop control schemes for longer periods of time and over larger areas of the base of support during periods of undisturbed stance.

[61] FEIGNING POSTURAL INSTABILITY

James J. Collins, PhD; Carlo J. DeLuca, PhD; Casey Kerrigan, MD; Ann Pavlik, BS
NeuroMuscular Research Center, Boston University, Boston, MA 02215; Spaulding Rehabilitation Hospital, Boston, MA 02114

Sponsor: *The Liberty Mutual Insurance Company*

PURPOSE—Posturographic methodologies could eventually form the foundation of a treatment and evaluation program for head-injured patients. In such a program, posturographic tests and stabilogram-diffusion analysis could be utilized, for example, to determine objectively when an injured individual has recovered sufficiently to reenter the work force. If the aforementioned techniques are to be useful for such a task, however, then they must be capable of identifying fraudulent behavior. It is unclear, for instance, whether or not healthy individuals could 'trick' conventional balance tests into classifying them as patients with balance disorders. Thus, the objective of this preliminary study was to determine whether or not stabilogram-diffusion analysis can discriminate between head-injured patients (with balance disorders) and healthy individuals who are mimicking postural instability.

METHODOLOGY—We examined 10 patients with head injuries. The patients were recruited from the Spaulding Rehabilitation Hospital in Boston, MA. Each patient's postural stability was evaluated by using a force platform to measure the movements of the center of pressure (COP) under their feet. The patients were tested under eyes-open conditions for multiple 30-s trials. We also examined 10 healthy individuals. The healthy individuals were tested using the protocol described above, except they were also instructed to mimic a balance problem during the experiments. All COP trajectories were parameterized according to stabilogram-diffusion.

RESULTS—Preliminary analyses indicated that there were significant differences between the two populations in terms of the long-term dynamics of the stabilogram-diffusion plots. In particular, the subjects feigning postural instability always exhibited at least one distinct periodic oscillation in their plots, whereas the head-injured patients did not. This finding suggests that the COP trajectories of feigning subjects have significant power at a least one frequency, whereas those of head-injured patients have a broad-band power spectrum without any significant peaks at the lower frequencies. This result was confirmed through a preliminary analysis of the power spectra of the two populations.

[62] POSTURAL CONTROL ADAPTABILITY DURING PROLONGED SPACEFLIGHT

James J. Collins, PhD; Carlo J. DeLuca, PhD; Ann Pavlik, BS; Serge H. Roy, ScD; Mark Emley, MS
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *NASA through the MIT Man-Vehicle Laboratory and the NeuroMuscular Research Center, Boston University, Boston, MA 02215*

PURPOSE—The objective of this study was to examine how the sensorimotor systems underlying balance control adapt to prolonged periods in microgravity. This project was a component of the NASA shuttle program involving the Spacelab Life Science (SLS-02) mission.

METHODOLOGY—The shuttle astronauts were tested at the Johnson Space Center in Houston, TX. Postural stability was evaluated by using a portable force platform to measure the movements of the center of pressure (COP) under the feet of each of the astronauts. All astronauts were tested under eyes-open conditions for multiple 30-s trials. Each astronaut was tested on four different pre-flight occasions and four different post-flight occasions. Pre-flight COP trajectories were examined as one-dimensional and two-dimensional random walks,

according to stabilogram-diffusion analysis. (The post-flight data will be processed and analyzed in similar fashion at a later date.)

RESULTS—Preliminary analyses of the pre-flight posturographic data revealed that the astronauts performed consistently on the different testing days. In addition, we found that their stabilogram diffusion results were similar qualitatively and quantitatively to those obtained from healthy young subjects who were recruited from the Boston University community.

[63] THE DEVELOPMENT OF A DIRECT ULTRASOUND RANGING SYSTEM FOR THE QUANTIFICATION OF AMBULATION

Dudley S. Childress, PhD; Joseph N. Licameli
Northwestern University, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Most gait analysis devices are not suitable for use in a clinical setting because of their complexity and high cost. We are developing a direct ultrasound ranging system (DURS) for trials with quantitative evaluation of ambulation in a simple way. The DURS operates by emitting an ultrasound and infrared pulse simultaneously from a transmitting unit at a sampling frequency of 22 Hz. The receiver unit then measures the time difference between the arrivals of the light and sound pulses. By calibrating for the speed of sound, this time difference is then converted into a measurement of the distance between the transmitting and receiving units. Distance samples are stored in a computer and processed through a differentiation algorithm to obtain an estimate of the forward velocity profile of the body during ambulation. From this velocity profile, additional gait parameters such as gait speed, cadence, stride length, step time, and other variables can be determined.

PROGRESS—We have completed the development of the first DURS prototype. This prototype interfaces with a personal computer through the parallel port, and the calibration for the speed of sound is accomplished manually through the hardware. In addition, the software was written to implement a three-point differentiator followed by a three-point time averager to convert the distance samples obtained from the device into velocity samples. The time averager was implemented to smooth the velocity data as the process of differentiation tends to enhance discontinuities and sharp edges.

With this first prototype, velocity measurements were taken on the ambulation of subjects with normal gait. These velocity profiles were then compared with velocity profiles obtained from the CODA 3 system in our Human Mechanics Measurement Laboratory to test the accuracy of the DURS.

RESULTS—The velocity profile obtained from the DURS and the CODA 3 system are very similar. Both devices accurately measure the periodic fluctuation in the velocity of the body trunk during normal gait. In addition the gait speed determined from the DURS is consistently within 5 percent of the gait speed determined from the CODA 3 system. These preliminary results suggest that the DURS can be utilized to accurately quantify ambulation.

FUTURE PLANS—To further test the accuracy of the DURS in quantifying ambulation, we will calculate additional gait parameters such as cadence, stride length, and step time from the DURS data and compare them with similar calculations performed on the data obtained from the CODA 3 system. Additionally, improvements will be made on the DURS software to facilitate the calculations of the aforementioned gait parameters, and to improve the presentation of the obtained results. The system is to be interfaced with a lap-top computer so that it is portable.

[64] ASSESSMENT OF VARIABILITY IN HUMAN WALKING

E. Biden
Institute of Biomedical Engineering, University of New Brunswick, Fredericton, NB E3B 5A3

Sponsor: Natural Sciences and Engineering Research Council of Canada

PURPOSE—We seek to develop statistical models to assess the variability inherent in normal human gait and to apply those models to assess gait disorders.

METHODOLOGY—Bootstrap models allow assessment of variability in data without making prior assumptions about the distribution of the data. In the work now in progress, data for normal individuals is processed to establish means, variances and the relationships between standard deviations and percentiles. These models may then be used to classify other data. Such classification is done by establishing how far an individual is from the mean and then assessing the percentile in which they fall based on the bootstrap model.

PROGRESS—During 1992, more computationally efficient bootstrap models have been developed for use in this project. These models allow analysis of raw and modelled data without having to assess directly the covariance structure of the models. In 1993, this project continued the investigation of the variability inherent in normal human movement. We have further developed methods which allow the variability to be expressed as percentile of normal.

RESULTS—In 1992 we have applied the technique to assess the gait of children who were born prematurely and to other data which relates to the gait of people with total joint replacement. During the past year we have modified the basic bootstrap algorithm to compute the variability based on time slices rather than using the covariance structure of fitted curves. This simplifies modelling, particulary for data such as force, where polynomials and fourier series have difficulty when trying to model data around footstrike and toe off. The modified technique allows working directly with the data and is substantially faster (by a factor of 3 to 4, depending on the problem) than the previous computational technique.

FUTURE PLANS—This work will be applied to look at gait in individuals with total knee replacements.

[65] HARD-WIRED CENTRAL PATTERN GENERATORS FOR QUADRUPEDAL LOCOMOTION

James J. Collins, PhD; Sally A. Richmond, MS
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *The Patricia Roberts Harris Fellowship*

PURPOSE—Legged animals typically employ multiple gaits, that is, phase-locked patterns of limb movements, for terrestrial locomotion. Animal locomotion is generated and controlled, in part, by a central pattern generator (CPG), which is an intraspinal network of neurons capable of producing rhythmic output. It is commonly assumed that each animal gait requires a separate CPG. In this study, we designed a series of computer experiments to test two hypotheses: 1) a hard-wired CPG can produce multiple phase-locked oscillation patterns that correspond to natural animal gaits, and 2) the production of multiple phase-locked oscillation patterns by a hard-wired CPG is a model-independent phenomenon.

METHODOLOGY—We modelled a quadrupedal locomotor CPG as a system of four coupled

nonlinear oscillators. Through numerical experimentation, we demonstrated that this model could produce multiple phase-locked oscillation patterns that correspond to three common quadrupedal gaits: the walk, trot, and bound. Transitions between the different gaits were generated by varying the network's driving signal and/or by altering internal oscillator parameters. The above *in numero* results were obtained without changing the relative strengths or the polarities of the system's synaptic interconnections (i.e., the network maintained an invariant coupling architecture).

RESULTS—This work thus clearly established the plausibility of utilizing a single, hard-wired CPG for quadrupedal locomotion. We also showed that the ability of the hard-wired CPG to produce and switch between multiple gait patterns was a model-independent phenomenon (i.e., it did not depend upon the detailed dynamics of the component oscillators and/or the nature of the inter-oscillator coupling). Three different neuronal oscillator models, the Stein neuronal model, the van der Pol oscillator, and the FitzHugh-Nagumo model, and two different coupling schemes were incorporated into the network without impeding its ability to produce the three quadrupedal gaits and the aforementioned gait transitions.

Papers based, in part, on this study were presented at the Dynamics of Animal Locomotion Workshop in 1993 in Waterloo, Canada, and the Graduate Student Science Research Day '93 in Boston, MA.

[66] THE EFFECTS OF NOISE ON A LOCOMOTOR CENTRAL PATTERN GENERATOR MODEL

Sally A. Richmond, MS; James J. Collins, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *The Patricia Roberts Harris Fellowship*

PURPOSE—Noise is ubiquitous in physiological systems. Currently, there is growing interest in understanding how the presence of noise affects the functioning of various neurophysiological control systems. The objective of this study was to examine the effects of noise on the dynamics of a locomotorcentral pattern generator (CPG) model.

METHODOLOGY—We modelled a quadrupedal locomotor CPG as a system of four coupled nonlinear oscillators. In a series of computer experiments, we added noise separately to the CPG oscillator signals, the CPG driving signal, and the inter-oscillator coupling terms. We incorporated three different types of noise: 1) white, additive noise, 2) white, multiplicative noise, and 3) correlated noise.

RESULTS—Low levels of noise (for all three cases) could be added directly to the oscillator signals without significantly altering the gait-controlling signals produced by the CPG network. Similarly, moderate and high levels of noise could be added to the network's driving signals and coupling terms, respectively, without affecting the system's output. In addition, we found that noise did not prove useful in promoting transitions between the different quadrupedal animal gaits. For example, noise did not significantly alter the gait transition times, nor did it catalyze previously unobtainable gait transitions, such as the bound-to-walk and bound-to-trot transitions. In summary, this study demonstrated that noise has little effect on the dynamics of our proposed quadrupedal locomotor CPG model.

Papers based, in part, on this study were presented at the Dynamics of Animal Locomotion Workshop in Waterloo, Canada, and the Graduate Student Science Research Day '93 in Boston, MA.

[67] A GROUP-THEORETIC APPROACH TO RINGS OF COUPLED BIOLOGICAL OSCILLATORS

James J. Collins, PhD; Ian N. Stewart, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; Nonlinear Systems Laboratory, Mathematics Institute, University of Warwick, Coventry, UK

Sponsor: *Nonlinear Systems Laboratory, Mathematics Institute, University of Warwick, Coventry, UK*

PURPOSE—Rhythmic oscillations proliferate in physiological systems and processes. They are involved in such diverse applications as: digestion, circulation, sleeping, mastication, locomotion and ventilation. Considerable interest has been shown in understanding how these oscillations are generated and controlled. The proposition that the associated neural and/or muscular mechanisms can be modelled as systems of coupled oscillators has been postulated by many. The objective of this study was to develop a general approach for studying symmetric rings of coupled biological oscillators.

METHODOLOGY—We approached the above problem from the perspective of group theory, which is a branch of mathematics that was invented specifically to deal with symmetries. Our resulting methodology was based on the finding that symmetric ring networks of coupled nonlinear oscillators possess generic patterns of phase-locked oscillations. Transitions between different patterns of activity were modelled as symmetry-breaking bifurcations. Importantly, the analysis associated with this approach is independent of the mathematical details of the oscillators' intrinsic dynamics and the nature of the coupling between the oscillators.

RESULTS—This methodology thus provides a framework for distinguishing dynamic behavior which is universal from that which depends upon further structure. General theories about general models can serve as useful starting points for investigations in mathematical biology. Often it is not readily apparent what type or form of model should be used to approximate a particular physiological system. As described above, the presence of symmetry in a system imposes strong restrictions on its dynamics and thereby simplifies the theoretical analysis. One is thus enabled, in certain situations, to obtain robust principles for simple networks.

A manuscript based on this work has been accepted for publication in Biological Cybernetics.

[68] COORDINATION OF MUSCLES IN GAIT

R.H. Rozendal; G.J. van Ingen Schenau; M.F. Bobbert; H.E.J. Veeger.
Vrije Universiteit, Faculty of Human Movement Sciences, Dept. of Functional Anatomy, 1081 BT Amsterdam, The Netherlands

Sponsor: *Netherlands Organization for Research; Foundation of Biophysics.*

PURPOSE—The coordination of lower limb muscles has been studied in explosive movements of the lower limb. Rules for coordination of biarticular leg muscles were formulated and tested in movements and in simulation studies. Recently the work has been extended to arm functioning. Neuronal network modelling is used for studying the learning aspects of coordination.

METHODOLOGY—Inverse dynamic modelling of running and walking in combination with simulation of various forms of jumping is used. For modelling, data are acquired with high speed film and from 1991 studies using VICON system, force platform and EMG. For simulation a SPACAR package is used.

PROGRESS—Biarticular muscles play a unique role in transporting rotational energy from proximal to distal segments when a person jumps up. The muscles contribute to the mechanical goal of the movement, maximizing effective power at takeoff. They compensate for the diminishing contribution to translation of the body's cen-

ter of gravity by extension (rotation) of lower limb segments.

Timing of the activation of these muscles, as well as the fact that they co-contract with their antagonists, is important. In bicycling it appears essential that such co-contractions are instrumental in producing thrust, as well as direction of movement, in the extending limb.

These concepts were validated in human walking and running by experimenting and modelling. In gait, biarticular hamstring and rectus femoris muscles are active in early stance. They co-contract with monarticular hip and knee extensors, and tune hip and knee movements while the leg is shortening and lengthening (knee flexion in early stance), regulating the level of potential energy.

Simulation proved most of the above mentioned concepts. A sensitivity analysis, concentrating on length of moment-arms of bi-articular muscles was conducted. In simulations of jumps, disturbances are not corrected by changes in stimulation patterns but by mechanical properties of muscles. Various starting positions result with one stimulation program in nearly optimal performance. From the study of running it appeared that bi-articular muscles distribute net moments in ballistic leg extensions. Optimal coordination is regulated with the aim of efficiency of expenditure of mechanical energy by mono-articular and bi-articular muscles. Arm movements are studied in which direction of force application and movement is not identical.

FUTURE PLANS—Learning of the optimal simulation pattern will be analysed by conducting simulations of mechanical nature and simulations of neural networks. Wheelchair propulsion will be analysed.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Control of an external force in leg extensions in humans. Jacobs R, Van Ingen Schenau GJ. J Physiol 1992:457:611-26.

Intermuscular coordination in a sprint push-off. Jacobs R, Van Ingen Schenau GJ. J Biomech 1992:25:953-65.

SPACAR, a software subroutine package for simulation of the behavior of biomechanical systems. Van Soest AJ, Schwab AL, Bobbert MF, Van Ingen Schenau GJ. J Biomech 1992:25:1219-21.

Influence of the bi-articularity of the gastrocnemius muscle on vertical jumping achievement. Van Soest AJ, Schwab AL, Bobbert MF, Van Ingen Schenau GJ. J Biomech 1993:26(1)1-8.

C. Other

[69] THE EFFECTS OF HEAD POSITIONING ON PRESSURE GENERATION IN THE PHARYNX DURING NORMAL SWALLOWING: A PILOT STUDY

Marilyn S. Berman, PhD; Inge H. Thomas, PhD
VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #C91-22lAP)*

PURPOSE—We seek to determine the relationship of head positions to bolus forces in order to establish some theoretical basis for the clinical effectiveness of various head positions for specific types of dysphagia. Toward that end, we compare forces generated in the pharynx and applied to the bolus during normal swallows with various clinically used altered head positions, compare these data to previously obtained data on normals without altered head positions, and use these comparisons to establish a normative data base regarding forces on the bolus for later studies evaluating dysphagic patients.

PROGRESS—The Manofluorographic Laboratory has been established and is used for patient evaluation as well as for research. The protocol for its use is in place. All 15 subjects have been run and data collected. Preliminary data analysis is complete. Thorough review of relevant literature has been accomplished.

The prototype instrumentation used to obtain force measurements in this investigation adds a new quantitative dimension to the traditional evaluation and treatment of dysphagia. After completing this study and the follow-up study on dysphagic patients, the swallowing clinician will have a more accurate basis for selecting particular head positions for specific types of dysphagia.

METHODOLOGY—Fifteen subjects, between the ages of 20 and 65 and with no history of swallowing problems, were used. Simultaneous recording of manometry and fluoroscopy (manofluorography). Each subject was seated and a four-sensor solid-state pressure catheter was positioned. Four 10 cc swallows were accomplished in each of four head positions (turning, tilting, forward, and back). Radiation times were limited to 2 minutes to avoid overexposure. Six bolus forces were determined for each swallow in addition to transit times and bolus velocities. These data will be analyzed by a Repeated Measures Analysis of Variance. Results will be compared to previously obtained with upright head positioning.

RESULTS—Preliminary results reveal the noteworthy phenomenon of aspiration in three of the normal subjects. Two extra subjects were included to allow for subject attrition if the procedure was not completed within the radiation time limits. This event did not occur. Subject attrition did occur, however, due to repeated unforeseen equipment failures. Immediate future plans are to complete the data analysis and prepare the results for publication. A proposal to study the effects of head positioning on pressure generation in the pharynx during the swallowing of dysphagics is nearing completion. The data to be obtained in the project is expected to contribute substantially to our knowledge regarding the use of head positions as a clinical tool in dysphagia management.

[70] DEVELOPMENT OF A LOW-DIMENSIONAL REPRESENTATION OF LIFTING DYNAMICS: A PILOT STUDY

Ted Morris; John Trimble
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B91-28AP)*

PURPOSE—Of the over 400,000 low back pain compensation claims filed each year in the United States, approximately 50 percent are lift-related. Previous studies have not clearly revealed the general rules that may govern musculoskeletal dynamics during lifting which could be used to better teach people how to lift and avoid injury. Since balance must be maintained while exerting forces required for the lift, we hypothesized that a robust, low-dimensional relationship exists between lower extremity joint torques (lumbosacral, hip, knee, and ankle) and the postural alignment of COG and COP and that it is invariant across sex, weight, height, lifting style, and the weight lifted.

METHODOLOGY—We used a WATSMART system to record body segmental motion, ground reaction vector and forces on the handles of a loaded box. Each subject performed a free-style lift using five different weights (13 to 50 lb) presented in random order with the subject blinded from knowing the weight to be lifted. Each lifting task was repeated for 30 sec. At the end of each lift, the weights were returned to their initial position and the subject returned to upright posture. An inverse dynamics model was used to predict the reaction torques at the lumbosacral, hip, knee and ankle joints. The axial compression force through the lumbosacral disc was also computed. The handle reaction forces were used to parse each lift cycle, account for the total external force acting on the subject, and validate the model.

RESULTS—We have tested 10 females and 11 males with no history of low back pain. Three females and five males were highly trained lifters. All subjects were within 21 to 36 years of age. Since the data for one subject was incorrectly recorded, another sub-

ject was rccruited to complete the experimental protocol.

Inverse dynamic analysis and human motion analysis software was written to compute COG, COP, GRF, and L5S1 disc compression force, joint torques and relative angle. Data from scveral subjects were selected and analyzed to validate the proposed biomechanical model. Results indicated that the model accounted for 90 percent of the variance of force measurements.

PROGRESS—Several MatLab analysis routines were written for regression analysis and preliminary analyses of variance. A local area network was installed to directly and efficiently transfer data from the motion analysis system to the Macintosh for storage, analysis, and retrieval.

Visual and statistical MANOVAs have been completed on the first 13 subjects. We are in the process of analyzing the remaining subjects and repeating the analysis for the complete subject set.

FUTURE PLANS—We believe that the results support our original hypothesis. Several new studies could be formulated based on testing the robustness of this relationship by controlling other task variables beyond the weight lifted: regulating lifting frequency, offsetting the personís base of support relative to the location of the load, and size and weight distribution of load.

The proposed relationships can be used as a framework to deduce biomechanical models that predict causality of injury. Accordingly, in order to link our current model to possible injury modalities, we would like to pursue future studies which attempt to relate the primary actuators and other skeletal structures used to control thc trunk and legs to our relationships identified in our research.

We believe the most clinically relevant study could be accomplished by extending the current study to include subjects with diagnosed low back injuries. An equal number of this subject population could be tested and analyzed within one year. Completing this study has the potential to have an immediate clinical impact on currcnt preventative treatment regimes.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

How many bits of data are needed to understand lifting dynamics? Morris T, Trimble J. In: Proceedings of the Second North American Congress on Biomechanics, Chicago, IL, 1992.

[71] CONTRALATERAL VS. IPSILATERAL CANE USE

Jacqueline J. Wertsch, MD; Gerald F. Harris, PhD; Hongsheng Zhu, PhD; Joe Nerry, BS; Khomeshwari Arcot, MS
Zablocki VA Medical Center, Milwaukee, WI 53295; Marquette University, Milwaukee, WI 53233; Medical College of Wisconsin, Milwaukee, WI 53226

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A624-RA)*

PURPOSE—The objective of this project was to determine the effect of using a cane in the ipsilateral (IP) versus contralateral (C) hand on plantar pressures. Plantar pressure-time data were recorded with a portable data-acquisition system during contra/ipsilateral cane use. Statistical analysis of pressure patterns was performed to determine the effect of cane use.

METHODOLOGY—A portable insole sensor system was used to measure plantar pressures at fourteen sites on the soles of both feet during extended rccording periods. Interlink prcssure sensors were used because of low cost, simple circuitry, and flexibility. Sensor locations were clinically determined by recording subject walking patterns on an APEX foot imprinter during multiple trials. To compensate for nonlinearity and temperature drift, all sensors were dynamically calibrated at 36°C to generate piecewise linear lookup tables for translation of voltage to pressure data. A standard J-canc with an adjustable height was used. All tcsts werc conducted on a 32 m concrcte walkway. Each subject wore a pair of PW Minor extra-depth shoes with insoles instrumented with pressurc sensors. Each subject was fitted with the cane such that the

handle was at the level of the greater trochanter of the femur according to standards used in physical therapy. The unpaired t-test ($p=0.05$) was used to statistically analyze the trial-to-trial variation and compare pressure distribution patterns during cane gait and normal walking.

PROGRESS—IP- and C-cane use has been successfully studied. The information on plantar pressure distribution during cane gait is useful for establishing valid criteria for prescribing canes, for training patients in cane use, and for assessing the nature and degree of walking assistance needed by disabled subjects.

RESULTS—The feasibility of the original concept to determine the effect of using a cane in the IP and C hands on plantar pressures has been demonstrated. The effects of ipsilateral and contralateral cane use have been tested through clinical trials. Thirty subjects have been studied during both IP- and C-cane usage. Pressure-time integals, contact durations, and peak pressures for each sensor were analyzed. Analysis of the data (over 2400 total steps) indicates that C-cane use results in an average pressure decrease of 21.5 percent when compared to unassisted gait. With IP-cane use, subjects unloaded an average of 17.0 percent while also increasing average pressure (9.1 percent) in the uninvolved foot, which was not seen in C-cane use. Thus, C-cane use appears to provide unloading of the foot with no increase in loading on the uninvolved foot. Loading patterns over the plantar surface of the foot were also affected by cane usage. C-cane use resulted in the greatest unloading on the lateral side of the foot (35 percent), while both IP- and C-cane use minimally unloaded the medial side of the foot (14 percent).

FUTURE PLANS—The results of the study may help physicians to assess insensate feet with assistive devices. Further study should include the use of an instrumented cane in order to provide controlled loads during ambulation. Veterans that may benefit from future study include a large number of patients who are at high risk of development of foot pressure sores.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Quantitative analysis of cane cadence with a portable microprocessor-based system. Schulman RA, Wertsch JJ, Zhu H, Jacobsen S. Arch Phys Med Rehabil 1992:72:971.

Portable insole pressure system. Wertsch JJ, Webster JG, Tompkins WJ. J Rehabil Res Dev 1992:29(l):13-8.

III. Functional Assessment

[72] THE EFFECTS OF SENSORY-NEURAL DEFICITS ON BALANCE AND POSTURE IN INDIVIDUALS WITH MULTIPLE SCLEROSIS: A PILOT STUDY

William De l'Aune, PhD; Richard T. Jackson, PhD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B91-253AP)*

PURPOSE—We are investigating the occurrence and extent of sensory deficits in early multiple sclerosis, especially those affecting posture and balance. We wish to develop and enhance testing procedures that are used to diagnose and assess the degree of these deficits. Our purpose is both to better detect the subtle abnormalities that lead to the initial diagnosis and to have better criteria to accurately judge the results of rehabilitation programs.

METHODOLOGY—We have tested an initial group of 27 subjects with mild multiple sclerosis (MS). For the testing of balance and posture control, we have used the NeuroCom Equitest dynamic posturography system with two adaptations we devised. In addition to the standard motor and sensory tests, we measure the energy use in each test in joules/kg and we retest the subject in sensory tests 4-6 with his head extended 55°. Besides posturography, we also employ a device that measures the subjective visual vertical and horizontal. Subjects are asked to align a light bar to vertical and horizontal with their head erect and tilted 45° laterally to the right and left.

In the posturography motor tests of MS patients, the latency and adaptation scores tended to be abnormal. Only one subject produced normal scores in both latency and adaptation tests. Twenty of the patients tested had at least one abnormally long latency in the backward or forward translations of the forceplate. Most patients had more than two abnormal latencies. This result was very similar to work by two other groups using different techniques. We also found that 22 of the 25 patients tested had at least two abnormal scores in the "toes up and toes down" adaptation tests.

PROGRESS—We have shown that we can enhance the sensitivity of posturography tests both by the simple maneuver of 55° head extension and by the calculation of energy use per body weight during the tests. We have also shown that tests of visual alignment can prove valuable in establishing degrees of abnormality. We are presently using these procedures to assay the effects of strength training on equilibrium in the elderly.

RESULTS—Compared to age and sex-matched normal volunteers, the MS patients produced larger errors in their estimations of vertical and horizontal. Nine of our MS subjects made abnormal estimations when their head was erect. However, when the head was tilted 45° to the right or left, 24 of the 27 were abnormal. Tilting the head in the roll plane makes the test more difficult and more sensitive to abnormalities of integration. It is not clear how the visual, vestibular, and somatosensory data is coordinated to make the visual judgment. Apparently, demyelinating lesions (such as in MS) affect the coordination. Neither the motor posturography tests nor the light alignment abnormalities are specific for lesions of MS. Both tests probably involve the same common pathways for balance. Although patients with early MS and patients with purely vestibular disorders often have similar complaints, they have quite different profiles of abnormality on dynamic posturogoraphy and tests of visual vertical and horizontal.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Abnormalities in posturography and estimations of visual vertical and horizontal light bar alignment in multiple sclerosis. Jackson RT, Epstein CM, De l'Aune WR, Park K. In: Abstracts of the 17th meeting of the Association for Research in Otolaryngology, 1994:110.

Abnormalities in posturography and estimations of visual vertical and horizontal in multiple sclerosis. Jackson RT, Epstein CM, De l'Aune WR. Am J Otol. In press.

[73] DEVELOPMENT OF A PREDICTIVE MODEL OF DRIVING PERFORMANCE IN STROKE PATIENTS

Janet P. Szlyk, PhD; Claire E. Pizzimenti, OD
VA Medical Center, Chicago, IL 60612

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C754-RA)*

PURPOSE—The overall aim of our studies is to determine the visual and cognitive factors predictive of automobile driving performance in patients who have suffered cerebral vascular accidents (CVAs) affecting primarily the occipital cortex and resulting in hemianopsia, or hemifield loss.

METHODOLOGY—We are currently collecting data from stroke patients over the age of 65, and from an age-similar control group. These data include the results of visual tests including contrast sensitivity, visual fields, color vision, and visual acuity. In addition, we are collecting information from a battery of neuropsychological tests including subtests from the Wechsler Adult Intelligence Scale-Revised, the Wechsler Memory Scale-Revised, and tests of visual form discrimination. The neuropsychological tests are designed to establish the level of cognitive deficit as a result of the stroke. The subjects' driving abilities are evaluated through the use of an interactive driving simulator and an on-road test. The stroke patients also undergo a neurological screening.

PROGRESS—To date, we have tested a large group of older control subjects, a group of CVA patients (approximately equivalent numbers of left and right visual field loss), and a sample of younger control subjects (age range, 21 to 64 years).

RESULTS—Differences in driving performance indexes on the simulator have been found between the patients and the older control subjects. The stroke patients are having more incidents where they cross over the boundaries of the driving lanes, more accidents, delayed response times to stop signs, more abrupt braking patterns, and are driving at slower speeds compared to the older control subjects. Differences in on-road driving performance have been found between the patients and the older control subjects as well. The stroke patients have lower overall scores, and have lower scores on sub-areas on the road tests such as intersection observance, backing-up, attention, lane observance, and merging. The stroke patients also tend to drive at slower speeds on the road test.

We are finding some strong relationships between vision and driving performance. Better visual acuity appears to be correlated with higher speeds, shorter braking response times, and fewer lane boundary crossings, when these indexes are tested on the driving simulator, and better contrast sensitivity has shown to be related to higher speeds, fewer lane boundary crossings, and fewer simulator accidents. Better visual acuity also appears to be positively correlated with higher overall scores on the road test, and specific subindexes on the road test, including maintaining proper lane position while merging and maintaining appropriate speed. Likewise, higher contrast sensitivity also seems to be positively correlated with higher scores on specific subindexes on the road test, including maintaining proper lane position, while driving straight ahead, and while making a right or left turn, and driving at appropriate speeds.

Higher cognitive abilities are also showing a relationship to driving performance on the simulator and on the road test. Lower scores on the test of visual form discrimination have been found to be significantly related to higher slopes of the braking

response curve. This may reflect a tendency for those who have difficulty discriminating a sign to brake more abruptly. The overall score on the road test has been shown to be related to digit span subtest scores (a test of visual attention) and the judgment-of-line-orientation scores (a test of visual perception).

FUTURE PLANS—A subgroup of the stroke patients has been identified with more horizontal eye scanning movements than the control group, reflecting an attempt to expand their perceptual/visual field space in order to compensate for visual field losses. Future research will be aimed at identifying characteristics indicative of these compensation strategies in the stroke patients.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Assessment of driving performance in patients with retinitis pigmentosa. Szlyk JP, Alexander KR, Severing K, Fishman GA. Arch Ophthalmol 1992:110:1709-13.

Evaluating the driving skills of patients with homonymous hemianopsia using an interactive simulator. Szlyk JP, Brigell M. Invest Ophthalmol Vis Sci 1992:33(Suppl).

Functional visual fields: differentiation of perceptual and sensory losses. Jones LF, Szlyk JP, Seiple WH, Fishman GA. Invest Ophthalmol Vis Sci 1992:33(Suppl).

Effects of age and hemianopic visual field loss on driving. Szlyk JP, Brigell M, Seiple WH. Optom Vis Sci 1993:70(12):1031-7.

Evaluation of driving performance in patients with juvenile macular dystrophies. Szlyk JP, Fishman GA, Severing K, Alexander KR, Viana M. Arch Ophthalmol 1993:111:207-12.

The relative effects of aging and compromised vision on driving performance. Szlyk JP, Seiple WH. Invest Ophthalmol Vis Sci 1994:35(Suppl).

[74] FUNCTIONAL ANALYSIS OF FEEDING AND INTERACTION DISORDERS WITH YOUNG CHILDREN WHO ARE PROFOUNDLY DISABLED

David P. Wacker, PhD; Wendy K. Berg, MA
University of Iowa, Iowa City, IA 52242-1011

Sponsor: *United States Department of Education, National Institute on Disability and Rehabilitation Research, Washington, DC 20202*

PURPOSE—The major purpose of this three-year project is to teach young children with profound and multiple disabilities who engage in challenging behavior to interact with their care providers in more positive ways on functional (feeding) and social (play) tasks.

METHODOLOGY—All children receive an assessment of reinforcer preferences coupled with a brief functional analysis of challenging behavior. Following these assessments, care providers are taught to interact with the children in ways that are more reinforcing to the children. Intervention begins with tasks that are relatively easy and then involves more demanding tasks that take several months to train.

Collateral changes in both child and care provider behavior are probed, as well as the long-term durability of the overall effects of treatment.

PROGRESS—To date, 30 children have been referred for participation from an inpatient unit (infants and toddlers with bronchopulmonary dysplasia who are ventilator dependent and toddlers with severe feeding disorders), a day care center (toddlers and preschool children with profound, multiple disabilities), and a local school district (preschoolers with profound disabilities). Assessment and treatment procedures have been completed for a total of 10 children and are in progress for 15 children (5 children discontinued prior to completion due to family circumstances).

RESULTS—Our preliminary results indicate that our assessments have been successful in identifying the environmental function of inappropriate behavior. Innovative treatments have been developed and implemented based on the functional analyses. These treatments have resulted in increases in appropriate communicative and social behavior and decreases in inappropriate behavior. Specifically, for the 10 children who have completed treatment, appropriate social behavior has increased by an average of 43 percent, and inappropriate behavior has decreased by an average of 75 percent. The procedures have been applied to children with a wide range of disabilities (mild to severe developmental delays) and topographies of aberrant behavior (noncompliance/off-task behaviors to life-threat-

ening self-injury). The assessment and treatment procedures appear to have utility across a wide range of children, settings, and behavior problems.

FUTURE PLANS—During the final year of the project, an additional 15 children will participate. The assessment and treatment procedures described above will be implemented with these children, and changes in inappropriate and social behavior will be measured. In addition, we plan to evaluate the extent to which our treatments generalize across settings (e.g., home and school), people (e.g., parents and teachers), and materials (e.g., toys and academic tasks).

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Functional analysis of separate topographies of aberrant behavior. Derby KM, Wacker DP, Peck S, et al. J Appl Behav Anal 1994:27.

IV. Functional Electrical Stimulation

A. General

[75] SELECTIVE NEURAL-MUSCULAR STIMULATION USING MAGNETIC FIELDS AND IMPLANTABLE COILS

Kent R. Davey, PhD; David A. Ross, MSEE
Georgia Institute of Technology, Atlanta, GA 30332-0250; Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B682-RA)*

PURPOSE—This research is related to the VA's spinal cord injury research priority and mission to provide services to spinal cord injured veterans. The purpose was to research and develop an alternative to functional electrical stimulation (FES). FES produces chemical half-cell reactions in the fluids surrounding a stimulation site that over time have been known to cause electrode corrosion and nerve necrosis. Magnetic stimulation does not rely on half-cell reactions, and thus causes no chemical imbalance in the fluids surrounding nerve tissue. The goal of the project was an implantable magnetic stimulation device that would selectively stimulate peripheral nerve fibers. The criteria for success were 1) the implanted device must reliably stimulate a peripheral nerve, 2) the implantable device must stimulate only the selected nerve, and 3) the power required to stimulate a nerve magnetically must be comparable to that required to stimulate a nerve electrically.

METHODOLOGY—The strategy was to achieve the above goals via the research and development of a magnetic core that maximized both the magnitude and the spatial gradient of the E-field produced by a 1khz oscillating B-field in the core. To maximize the magnitude of the E-field at the nerve site, an occlusion was placed in the center of the core with an opening just large enough to contain the nerve fiber. This was intended to channel electrical current to the site and increase the E-field gradient at the site.

PROGRESS—The project is complete. A small magnetic toroid core wound with 11 turns of 26-gauge wire was placed around the sciatic nerve of an African bullfrog. The nerve was cut close to the hip, and the loosened end of the distal segment threaded through the central orifice. Enervation was witnessed visually by muscle movement. When the power level rose above 10 milliwatts of average power, stimulation began.

RESULTS—The methods described above proved successful. Two cores were tested on African Bullfrogs as described above. One was comprised of orthinol with dimensions of 4 cm OD, 2.4 cm ID, 1.1 cm height, with a 0.3175 mm orifice occlusion. The other was a vanadium permendur toroid with a 1.9 cm OD, 1.27 cm ID, 0.635 cm height, with a 1.9 mm orifice occlusion. Both magnetic cores were capable of stimulating the nerve, as witnessed by muscle movement. Proper choice of core material was a key factor. The core had to sustain B-fields as high as 0.5 to 1 tesla without saturating. The vanadium permendur core performed best.

FUTURE PLANS—The results suggest a promising alternative to conventional FES. Peripheral nerves were effectively stimulated with low threshold excitation levels. However, several questions remain to be researched: 1) since use of a totally enclosed toroid is impractical, would a toroid folded around the nerve perform as well? 2) how will nerves handle the mechanical load of a toroidal core in close

proximity to it? 3) two toroids with anti-parallel flux patterns were used to produce hyperpolarizing potentials on the outboard regions of a nerve bundle with a polarizing potential in the central region. Can such multiple units be employed to preferentially stimulate smaller nerve fibers to the exclusion of larger ones in the same bundle?

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Towards functional magnetic stimulation (FMS) theory and experiment. Davey K, Ross D. IEEE Trans Biomed Eng. In press.

[76] REHABILITATION OF THE COLON AFTER SPINAL CORD INJURY: A PILOT STUDY

Lisa Riedy, PhD; Keith Bruninga, MD; James S. Walter, PhD; Ali Keshavarzian, MD; Jeremy Fields, PhD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B92-511AP)*

PURPOSE—The purpose of this research is to develop a new method of treatment for spinal cord injured (SCI) patients suffering from gastrointestinal (GI) problems. This is important because the colon is the site of the most frequently documented GI problems for chronic SCI patients. Current methods of managing bowel disorders in SCI patients include drug therapy and manual evacuation techniques. These techniques require either considerable time to induce defecation or are limited by a lack of control which may result in damage to the anal sphincter. Therefore, we believe alternative rehabilitation approaches, such as neuroprosthetics, are important to consider for control of bowel evacuation.

METHODOLOGY—SCI (T-1) male cats will be used to study the effects of sacral anterior root, sacral spinal cord, direct colon, and anal sphincter stimulation on bowel responses. Previously, we developed a suture style electrode for direct stimulation of the bladder wall. This type of electrode was evaluated in this study for managing colon function. This electrode consisted of 316LVM stainless steel wire which was stripped to an exposed length of 8 cm. The end was inserted into a 21-gauge needle which allowed the electrode to be sutured circumferentially around the colon wall. Stimulating parameters that induced affective defecation included a 6 ms pulse, a repetition rate of 40 pps, and a current sweep from 1-35 mA.

PROGRESS—In this study, we have begun to evaluate an animal (cat) model of colon function and activity before and after SCI. Preliminary studies indicated that direct stimulation around the colon wall with a suture type electrode provided selective activation and defecation in the two SCI animals studied. In addition, we have observed successful defecatory responses with sacral nerve stimulation in one of these animals.

RESULTS—The most significant preliminary finding was that direct colon stimulation alone may promote defecation and colon pressure changes similar to those observed in a spontaneously active animal. Sacral nerve stimulation alone appears to produce increased abdominal pressure but less colon activity.

FUTURE PLANS—Measurements of transit times, gastrocolic reflexes, as well as colon and abdominal pressures will be used to define colon function. Transit times and segmental movements will be monitored with a videotaped fluoroscopy of the movements of radio-opaque makers injected into the ileum through an implanted tube. Gastrocolic responses will be monitored by observing the effects of eating on segmental transit times.

We plan to continue evaluating the various stimulation tactics (intermittent, high-energy stimulation, and continuous low energy) in order to optimize their effects on increasing colonic motility. In addition, we plan to determine if a combined stimulation approach may be the most effective treatment of colonic dysfunctions such as impaction.

[77] HIGH CHARGE DENSITY, BIPOLAR ELECTRODES FOR CHRONIC FNS

James S. Walter, PhD; Lisa Riedy, PhD; Paul Zaszczurynski; Stuart Cogan, PhD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141;
EIC Laboratories, Norwood, MA 02062.

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B658-2RA)*

PURPOSE—The purpose of this research includes: characterizing *in vivo* environments and developing stimulating waveforms to minimize electrode corrosion; evaluating high strength lead materials for percutaneous and intramuscular electrodes; developing improved *in vitro* environments for evaluating electrodes; and using activated iridium oxide (AIROF) coatings for electrodes.

METHODOLOGY—Methods will include *in vitro* and *in vivo* studies. *In vitro* studies will be conducted with a three electrode arrangement in a variable impedance bath constructed of an island made of a glass plate located above our electrolyte solution. Eight-ply gauze is placed on the plate, the reference (Pt) and test electrodes are placed on top of the gauze, and covered with additional gauze. The impedance of the bath varies with the number of gauze sheets used. Studies will evaluate the effects of pulse protocols, potential transients, buffers, and protein on the corrosion response. Titanium and 316LVM will be the principal substrates evaluated. *In vivo* studies will be conducted in SCI cats. Studies consist of performing a laminectomy over T-7, implanting two Pt counter electrodes and approximately 20 test electrodes, and inserting a chronic bladder catheter. Both anodic and cathodic-first pulsing will be evaluated. The corrosion response of electrodes pulsed under different stimulating conditions will be evaluated.

PROGRESS—Previously, we developed an *in vitro* bath consisting of 29 mM bicarbonate, 3 mM phosphate, and 137 mM NaCl purged with 5 percent CO_2/6 percent O_2 to a final pH of 7.4 for *in vitro* analysis. This bath mimics the interstitial fluid environment in the absence of protein and collagen. In this study, we have begun to investigate the effects of protein on the corrosion response and electrical transients of 316LVM electrodes stimulated *in vitro* by incorporating physiological levels (0.4 g/L Albumin) into our standard *in vitro* bath. Preliminary observations using the AIROF coatings are that the coating adhere well to the metal substrate and that increased charge injection limits are possible compared to noncoated substrates. Additional observations indicate that the impedance of the *in vivo* electrode environment plays an important role in the corrosion response of implanted electrodes.

RESULTS—Preliminary data indicated no effect on the corrosion response or electrical transients of electrodes stimulated in the presence of protein. Further studies are underway using ten times the protein levels present *in vivo* to confirm this finding.

Initial *in vitro* monophasic, capacitively-coupled, pulsing studies with charge injections ranging from 40 to 240 $\mu C/cm^2$ were imposed on AIROF coated 316LVM electrodes. The responses of pulsed electrodes can best be described in terms of electrical transients (Emax, Eacc and Ipp). Emax(A) of the electrode at the end of the current pulse was 0.29V at 40 $\mu C/cm^2$ and increased to 0.52 V at 240 $\mu C/cm^2$. This is considered a small transient and not expected to produce corrosion. In contrast, stimulation of the uncoated 316LVM electrode with anodic-first pulsing showed very large values of Emax(A) 1.2-2.5 V at 40 $\mu C/cm^2$. These electrodes showed corrosion responses after only 24 hrs of pulsing. Emax(C) for cathodic pulsing remained small throughout 96 hours of pulsing. SEM evaluation of the electrode revealed no breaks in the AIROF coating.

FUTURE PLANS—We plan to conduct detailed *in vitro* and *in vivo* evaluations of high charge capacity coatings of Ir (AIROF) as a means of achieving bipolar charge injection capacities exceeding those presently available with uncoated alloys.

[78] IMPLANTABLE ELECTRODES USING IRIDIUM OXIDE FILM TECHNOLOGY

James S. Walter, PhD; Lisa Riedy, PhD; Stuart Cogan, PhD; Meegan McCaffrey; Paul Zaszczurynski
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141;
EIC Laboratories, Norwood, MA 02062.

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B658-RA)*

PURPOSE—The purpose of this research is to improve implantable electrodes for neuroprosthetic applications. This is important because functional neuromuscular stimulation (FNS) is widely used in the treatment of many neurological disorders including bladder dysfunction, respiratory pacing, and limb paralysis. Despite this widespread use, applications of FNS are limited by electrode malfunctions, such as corrosion and breakage.

PROGRESS—In this study, we investigated the relationship of charge injection and electrical transients on the corrosion response of 316LVM and MP35N electrodes. Additional studies with 316LVM electrodes evaluated the effect of time constants (TC) of either capacitor or coil coupled discharge circuits on the corrosion response. All electrodes were evaluated *in vitro* using an electrolyte solution, representative of interstitial fluid, consisting of 29 mM bicarbonate, 3 mM phosphate, and 137 mM NaCl purged with 5 percent CO_2/6 percent O_2 to a final pH of 7.4.

METHODOLOGY—Monophasic, anodic and cathodic-first current pulses were applied in a 3-electrode test cell comprised of the test electrode, a large surface area Pt counter electrode, and a saturated calomel reference electrode. The stimulation protocol consisted of 100 μsec pulses at a repetition rate of 60 pps and was conducted until electrode dissolution was apparent or for not more than 240 hours. The charge injection densities used, 20, 40, and 80 μC/cm2, corresponding to currents of 3.8, 7.5, and 15 mA. The corrosion responses were monitored over time using light microscopy and confirmed with scanning electron microscopy.

RESULTS—The most significant finding was that 316LVM electrodes withstood pulsing with considerably less corrosion resulting than the MP35N electrodes for both monophasic pulsing protocols and for all charge injection densities tested. For both alloys the corrosion responses were greatest with anodic-first pulsing compared to cathodic-first pulsing. In addition, as the charge injection densities decreased, the rate of corrosion also decreased over time. Of the electrical transient components examined, the access voltage (Eacc) was most affected by corrosion.

In order to evaluate the effect of TCs on the observed corrosion responses, three capacitor coupled circuits with TCs of 0.77, 6.2, and 28.1 ms and one coil coupled circuit with a TC of 0.17 ms were evaluated. Corrosion was only observed for electrodes stimulated with the longest TC (28.1 ms). This result is not surprising since the 28.1 ms TC is almost the same as the interpulse period (25 ms).

FUTURE PLANS—We plan to determine if the present charge injection capabilities can be exceeded by coating the electrodes with anodized iridium oxide films. In addition, the corrosion responses observed *in vitro* will be correlated to those observed *in vivo*.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Reduced corrosion of pulsed 316LVM stainless steel electrodes by short-time constant discharge circuits. Riedy L, Walter JS, Cogan S, et al. In: Proceedings of the 14th Annual Conference IEEE Engineering, Medicine and Biology Society, 1992:14:2374-6.

Comparison of electrical transients and corrosion responses of pulsed 316LVM stainless steel and MP35N electrodes. Riedy L, Walter JS. In: Proceedings of the 15th Annual Conference IEEE Engineering, Medicine and Biology Society, 1993, San Diego, CA, 1499.

Comparison of 316LVM and MP35N alloys as charge injection electrodes. Cogan SF, Jones GS, Hills D, Walter JS, Riedy L. J Biomed Mat 1994:28:233.

Comparison of electrical transients and corrosion responses of pulsed MP35N and 316LVM stainless steel electrodes. Riedy L, Walter JS. Am Biomed Eng. In press.

[79] MANAGEMENT OF CENTRAL VENTILATORY INSUFFICIENCY THROUGH ABDOMINAL AND THORACIC STIMULATION: A PILOT STUDY

Robert B. Dunn, PhD; James S. Walter, PhD; John M. Walsh, MD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141;
Loyola Medical Center, Department of Medicine, Maywood, IL 60153

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B91-235AP)*

PURPOSE—Electrical activation of the diaphragm via phrenic nerve stimulation has successfully maintained resting levels of alveolar ventilation in spinal cord injured and selected hypoventilating patients. Although technical improvements have provided for long-term care, the lack of coordinated contractions of accessory muscles has severely limited the usefulness of this technique. Normally, chest wall enlargement acts synergistically with the diaphragm to inflate the lungs. With diaphragm stimulation alone the chest wall collapses. This overburdens the diaphragm and contributes to fatigue. Electrical activation of the chest wall inspiratory muscles would assist the diaphragm and increase the efficiency of diaphragm pacing. Electrical activation of expiratory muscles would provide further enhancement and demonstrate the feasibility of inducing an electrically generated cough. The goals of the present study are to develop techniques that could be applied in the clinical setting to coordinate diaphragm pacing with accessory muscle stimulation.

METHODOLOGY—In acute dogs following anesthesia, suture style intramuscular electrodes were inserted in each hemidiaphragm close to the entry of the phrenic nerves. Accessory muscle stimulation was obtained from intramuscular implantation of stainless wire electrodes with a small hooked end inserted through a 27-gauge needle. The needle containing the electrode was pulsed through the skin and into the superficial muscle.

PROGRESS—To date we have made significant progress at stimulating accessory respiratory muscles via intramuscular electrodes. We had little if any success with subcutaneous electrodes no matter the location. Bilateral stimulation of electrodes in the chest wall rostral to the 9th intercostal space consistently produced chest expansion. Electrodes placed in the lateral or sternolateral regions next to rib margins were the most effective. Electrodes placed in the caudal intercostal spaces produced little change or collapsed the chest wall. Intramuscular electrodes in the rectus abdominis and external obliques when stimulated consistently increased intra-abdominal pressure and supported expiration. These results demonstrate the effectiveness of intramuscular electrodes in stimulating accessory respiratory muscles to assist electrically generated diaphragm contractions.

FUTURE PLANS—We plan to determine the extent to which electrically stimulated accessory muscles will support and enhance ventilatory efficiency during diaphragm stimulation. Finally, we will also study the possibility that electrically activated cooperative actions of accessory and diaphragmatic contractions would generate a cough, thereby introducing a naturally induced clearing mechanism for the airways.

[80] ELECTRICAL ACTIVATION OF THE DIAPHRAGM FOR VENTILATORY ASSIST

J. Thomas Mortimer, PhD; Brian D. Schmit
Case Western Reserve University, Cleveland, OH 44106-4912

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B634-2RA)*

PURPOSE—The purpose of this research is to develop a diaphragm pacer that will be the primary treatment method for ventilation of patients with respiratory paralysis and intact phrenic nerves. In order to reduce time for surgery and recovery from surgery, we are developing electrodes for diaphragm activation that can be implanted with the aid of a laparoscope. The electrodes, implant devices, and implant technologies have been developed and tested for function and safety.

METHODOLOGY—Four Dacron free hemispherical electrodes were implanted in each of four dogs using laparoscopy. One additional dog was implanted with two electrodes. At 2-week intervals the dogs were anesthetized, hyperventilated to apnea, and tested for ventilatory function. Recruitment curves were recorded for each electrode and the tidal volume to stimulation frequency relations were measured to determine muscle conditioning. Tidal volume was obtained by software integrating a flow measurement from a Fleisch pneumotachometer.

Electrode implant was done under laparoscopy. Electrode placement was tested by temporarily attaching the electrode to the muscle using suction and acquiring recruitment curves. Recruitment curves were obtained by applying test pulses and measuring abdominal pressure. Recruitment curves for 6-10 test locations were compared to get the best implant location for each hemidiaphragm.

PROGRESS—We have completed the testing of one type of epimysial electrode and are now testing two new electrode designs. Electrodes using a stimulating surface within a recessed well were adequate for producing full-time ventilation in four dogs. The electrode design was improved using a protruding hemispherical stimulating surface to assure electrode contact during implant. Dacron reinforced and Dacron free hemispherical electrodes were tested in dogs using recruitment curve measurements to assure placement near the phrenic nerve motor point. The Dacron free electrodes did not have adequate strength to hold a staple and 50 percent of them were dislodged from the diaphragm. Tests of Dacron reinforced hemispherical electrodes are still underway. We are revisiting the use of intramuscular electrodes because of their highly desirable tissue reaction properties. We have developed a device that would greatly facilitate implantation of the intramuscular stimulating electrode and we are in the process of evaluating it.

RESULTS—Testing of the Dacron free hemispherical electrodes resulted in 10 electrode failures in eighteen implanted electrodes. The mode of failure was dislodgment of the electrodes from the muscle surface due to tearing of the electrode itself. The staples used to implant the electrode remained in place.

We have received approval from the FDA for our application to implant intramuscular electrodes in the diaphragm of human subjects system to evaluate the feasibility of our respiratory assist device.

FUTURE PLANS—In the next year we plan to complete tests of Dacron reinforced epimysial electrodes for diaphragm pacing. We will also conclude a study on stimulus parameters for reducing fatigue. We expect to complete the evaluation of the intramuscular stimulating system. Upon completion of these tests we will choose the most promising technology and commence human studies. We expect to have completed an automated clinical testing system.

[81] EVALUATION AND OPTIMIZATION OF FES TECHNIQUES FOR EXERCISE

Roger M. Glaser, PhD; Thomas Mathews, MD; Stephen F. Figoni, PhD; Mary M. Rodgers, PT, PhD; Agaram G. Suryaprasad, MD; Satyendra C. Gupta, MD; Pouran D. Faghri, MD; Janet A. Ponichtera-Mulcare, PhD; Steven R. Collins; William P. Couch

VA Medical Center, Dayton, OH 45428; Institute for Rehabilitation Research and Medicine, Wright State University School of Medicine, Dayton, OH 45435; Rehabilitation Institute of Ohio, Miami Valley Hospital, Dayton, OH 45409.

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B433-2RA)*

PURPOSE—The purpose of this continuation program is to provide effective functional electrical stimulation (FES) exercise techniques for improving health, physical fitness, and rehabilitation outcome of patients with spinal cord injury (SCI). Objectives are to continue evaluation of acute and chronic physiologic responses (muscular, aerobic metabolic, and cardiopulmonary) to existing FES exercise modes including knee extension (KE), leg cycle ergometry (LCE) and combined FES-LCE + voluntary arm-crank ergometry (HYBRID), as well as to determine biomechanical characteristics of these therapies to assess potential benefits and risks to SCI patients. Additionally, we seek to modify the design of existing FES exercise devices to optimize muscular, aerobic metabolic, and cardiopulmonary responses to the various FES exercise modes, while maintaining patient safety. Finally, we are working to design more progressive FES exercise training protocols to optimize adaptations of the muscles utilized and the cardiopulmonary system.

METHODOLOGY—Groups of SCI subjects are administered a series of exercise stress tests to determine the initial performance (i.e., strength and endurance) of their paralyzed lower-limb muscles for FES, and their arm muscles, as well as to determine their peak metabolic and cardiopulmonary responses. Subjects are then assigned to participate in a series of 12-week exercise training programs using the various FES exercise modes and protocols. They are again exercise stress tested after each training program to determine changes in fitness. Modifications to the FES instrumentation design are tested to optimize the physiologic responses and enhance training effects. The biomechanics of each exercise mode are studied to determine the appropriateness of the limb movements and to minimize orthopedic risks.

PROGRESS—KinCom isokinetic dynamometer testing indicated that increasing maximal current from 150 mA to 300 mA during FES-induced contractions can substantially improve performance in most cases. This can expand the population who could successfully participate in FES exercise programs.

RESULTS—For KE exercise, there were significant increases (+68 percent) in the maximal load (6.8 vs. 11.3 kg) and number of repetitions achieved at given load resistances (68 vs. 113 reps). However, some subjects experienced co-contractions of the quadriceps and hamstring muscles which hindered performance gains. For LCE exercise, the power output (PO) was increased from 8.7 W to 19.4 W (+124 percent). There were also significant increases in peak oxygen uptake (VO_2: +34 percent), pulmonary ventilation (V_E: +44 percent), heart rate (HR: +24 percent), cardiac output (Q: +33 percent) and blood lactate concentration (+81 percent). Improved response magnitudes were also obtained when the calf muscles were co-contracted with the hamstring muscles. This elicited significant increases in VO_2 (+14 percent), V_E (+12 percent), HR (+8 percent), stroke volume (SV: +15 percent), and Q (+18 percent). Both LCE modifications resulted in greater muscle mass being incorporated which will most likely translate into more effective training results.

We found that 12-16 weeks (i.e., 36 sessions) of FES-LCE exercise training by 18 SCI subjects resulted in significant increases in peak PO (+45 percent), VO_2 (+23 percent), V_E (+27 percent), HR (+11 percent), and Q (+13 percent) for this activity. Furthermore, FES-LCE training appears to

elicit favorable changes in resting and submaximal exercise cardiovascular responses. Quadriplegic subjects tended to have higher and more stabilized resting HR and blood pressure (BP), which helped to alleviate their chronic hypotension. In contrast, paraplegic subjects tended to have lower and more innocuous resting BP following training. For both groups, submaximal exercise HR and BP significantly decreased and SV and Q significantly increased indicating improvements in both peripheral and central circulatory fitness.

FUTURE PLANS—Various biomechanical aspects of our mathematical model for FES-LCE exercise are being tested to further to enhance training effectiveness. HYBRID exercise will be used to determine the extent to which cardiopulmonary system reserve is depleted when using the optimized FES-LCE system. More progressive training protocols which involve exercise for shorter durations but at a higher resistive load will be employed to determine if physiologic adaptations can be accelerated. Our results thus far suggest that SCI patients should derive benefits from FES exercise including increased levels of physical fitness, reduced incidence of secondary medical complications, and improved rehabilitation outcome.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Functional electrical stimulation cycle ergometer exercise: training effects on cardiorespiratory responses of spinal cord injured subjects at rest and during submaximal exercise. Faghri PD, Glaser RM, Figoni SF. Arch Phys Med Rehabil 1992:73:1085-93.

Metabolic and hemodynamic responses to concurrent voluntary arm crank and electrical stimulation leg cycle exercise in quadriplegics. Hooker SP, Figoni SF, Rodgers MM, Glaser RM, Mathews T, Suryaprasad AG, Gupta SC. J Rehabil Res Dev 1992:29:1-11.

Physiologic effects of electrical stimulation leg cycle exercise training in spinal cord injured persons. Hooker SP, Figoni SF, Rodgers MM, Glaser RM, Mathews T, Suryaprasad AG, Gupta SC. Arch Phys Med Rehabil 1992:73:470-6.

Arm and leg exercise stress testing in a person with quadriparesis. Figoni SF, Glaser RM. Clin Kinesiol 1993:47:25-36.

Improving the efficacy of electrical stimulation-induced leg cycle ergometry: an analysis based on a dynamic musculoskeletal model. Schutte LM, Rodgers MM, Zajac FE, Glaser RM. IEEE Trans Rehabil Eng 1993:1:109-25.

Tibial bone density loss in spinal cord injured patients: effects of FES exercise. Hangartner TN, Rodgers MM, Glaser RM, Barre PS. J Rehabil Res Dev. In press.

B. Upper Limb Applications

[82] FUNCTIONAL NEUROMUSCULAR SYSTEMS FOR UPPER EXTREMITY CONTROL

Patrick E. Crago, PhD; P. Hunter Peckham, PhD; Michael W. Keith, MD; Kevin L. Kilgore, PhD
Cleveland VA Medical Center, Cleveland, OH 44106

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B011-5RA)*

PURPOSE—The objective of this project is to deploy and quantitatively evaluate implantable functional neuromuscular stimulation systems to restore hand grasp and release in C5 and C6 quadriplegic patients.

METHODOLOGY—Multichannel implantable stimulator systems are surgically implanted in C5 and C6 quadriplegic patients to provide controlled grasp and release. An implant stimulator is placed in a subcutaneous pocket overlying the pectoralis major muscle. Seven epimysial electrodes are placed on muscles of the hand to provide motor function, and an eighth is placed in the supraclavicular area to provide sensory feedback. Augmentative surgical procedures also may be performed, including tendon

transfers of voluntary and paralyzed muscles. Post-surgery, subjects are casted for 3-4 weeks and then undergo a period of muscle conditioning using electrical stimulation. Subsequently, during a 3-week inpatient rehabilitation stay, grasp patterns and control parameters are customized, subjects are trained to use the neuroprosthesis, and their functional ability with and without the device is evaluated. They are then discharged with the neuroprosthesis.

An extensive set of quantitative assessment tools have been developed to evaluate the function provided by the neuroprosthesis, analyze potential deficiencies in system properties, and determine potential improvements. These assessments include 1) Static Recruitment Characteristics, which are the input/output properties of each electrode as a function of stimulus level; 2) Input/Output Properties of Hand Grasp, which are the overall relationships between the subject's command and the force and position of the digits; 3) Specific Task Analysis, which combines simultaneous command/control and task performance assessment; 4) Grasp-Release Test (GRT), which measures the performance of the hand itself for manipulation of various objects; 5) Activities of Daily Living (ADL) Test, which compares subject performance with and without the neuroprosthesis in at least six activities; 6) Automated Usage Logging, which refers to automatic record keeping within the neuroprosthesis about the subject's use of the device; and 7) Telephone Interview, which is used to determine the subject's usage patterns in the home environment.

PROGRESS—Nine subjects have received implant stimulators (six males, three females; four C5 subjects, five C6 subjects). Seven subjects have completed the training and functional evaluations (GRT, ADL Test, Telephone Interview) using the device. Also, Automated Usage Logging is being performed regularly with seven subjects, and the data are being stored for later automated analysis. For the assessment of the Input/Output Properties of Hand Grasp, we have developed a new sensor and new software to characterize those properties. Seven subjects have been assessed using the new system (four were tested at least twice). The Specific Task Analysis was converted to run on a modern computer without the need for a motion analysis system by incorporating gravity sensors into the instrumented objects. Six subjects have performed the Specific Task Analysis tests.

RESULTS—Five subjects use the neuroprosthesis regularly for functional tasks and exercise. A sixth subject who also used it for function and exercise died due to unrelated causes. A seventh subject primarily uses it for exercise. All seven of these subjects have demonstrated the ability to use the neuroprosthesis to perform tasks and activities more independently. The last two subjects recently joined the study and have not progressed to the stage of using the device functionally, although they use it for exercise. The Input/Output Properties assessments have indicated that object size and wrist position have a large effect on grasp opening and force production. These tests also identified nonlinearities in the input/output curves, which were used to revise the grasp patterns. The Specific Task Analysis data have been used to identify which parts of a typical functional task consume the most time, indicating where system improvements are needed.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Motor prostheses for restoration of upper extremity function. Peckham PH, Keith MW. In: Stein RB, Peckham PH, Popovic DB, eds. Neural prostheses: replacing motor function after disease or disability. New York: Oxford University Press, 1992:162-87.

Neural prostheses: clinical applications of functional electrical stimulation in spinal cord injury. Peckham PH, Creasey GH. Paraplegia 1992:30:96-101.

Opportunities and challenges for the clinical utilization of functional electrical stimulation. Peckham PH. Assist Technol 1992:4:46-8.

Analysis of the reliability of percutaneous intramuscular electrodes in upper extremity FNS applications. Memberg WD, Peckham PH, Thrope GB, Keith MW, Kicher TP. IEEE Trans Rehab Eng 1993:1:126-32.

Restoration of functional grasp-release in tetraplegia with implantable neuromuscular stimulation and tendon transfer. Peckham PH, Keith MW, Stroh KC, Kilgore KL, Hart RL. Electrophysiol Kinesiology 1993:5:269-74.

C. Lower Limb Applications

[83] FES-AIDED PARAPLEGIC GAIT USING A CONTROLLED-BRAKE ORTHOSIS

William K. Durfee, PhD; Allen Wiegner, PhD
University of Minnesota, Minneapolis, MN 55455; VA Medical Center, West Roxbury, MA 02132

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B579-RA)*

PURPOSE—Restoration of gait to paraplegics using functional electrical stimulation is a challenging problem. One difficulty is controlling the FES system for stability and smooth gait. It is possible to improve walking function using surface stimulation by adding a mechanical orthosis in combination with the FES. Based on preliminary work of our group, we have developed such a hybrid system for functional FES-aided gait. The orthosis contains controllable friction brakes at the joints. The purpose of the brakes is to shift the burden of controlling a gait trajectory from having to control the stimulated muscles and spastic reflexes to controlling the brake, a well-behaved mechanical element. To evaluate brake designs and performance, we are testing and comparing the ability of SCI paraplegics to achieve FES-aided gait both with and without the orthosis. The assessment includes kinematic, dynamic, and metabolic variables.

PROGRESS—Pilot studies based on stimulation of able-bodied subjects to control the knee joint demonstrated the utility of the controlled-brake approach. By combining fine control of the brake with gross control of muscle stimulation, performance on position tracking tasks was greatly improved over both open and closed-loop control schemes which used stimulation alone.

We have designed and constructed a wearable orthosis which can apply controlled braking loads to the knee and hips. The orthosis structure is fabricated from machined aluminum and chromoly tubing. Braking loads are applied by magnetic particle brakes coupled to the joints through an Evoloid gear transmission. Joint position and torque are measured by sensors. The entire system is controlled by a PC connected to the brace by a long umbilical cable.

The orthosis has been tested in a single, T-6 complete paraplegic subject at the West Roxbury VA Medical Center. Results have demonstrated improved distance and joint trajectory control when compared to FES gait without the brace.

FUTURE PLANS—Under continuing VA funding, we are evaluating the system on additional SCI subjects, developing a second generation orthosis that incorporates small DC motors at the hips to aid in hip flexion, and starting the process of developing product design versions of the brace. The clinical trials will take place at the West Roxbury VA Medical Center in Boston, MA, and at the VA Medical Center in Minneapolis, MN.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Design of a controlled-brake orthosis for regulating FES-aided gait. Durfee W, Goldfarb M. In: Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1992.

Control of standing and gait using electrical stimulation: influence of muscle model complexity on control strategy. Durfee W. Prog Brain Res 1993:97:369-81.

Design of a wearable orthosis for applying controlled dissipative loads to the lower limbs. Durfee W, Goldfarb M. In: Proceedings of the Winter Annual Meeting of the American Society of Mechanical Engineers, 1993.

Preliminary evaluation of a controlled-brake orthosis for regulating FES-aided gait. Durfee W, Goldfarb M, Wiegner A. Walsh N. In: Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1993.

Verification of musculoskeletal models for FES applications. Durfee W. In: Proceedings of the IFAC Symposium on Modeling and Control in Biomedical Systems, 1994.

Controlled-brake orthosis for FES-aided gait (PhD thesis). Goldfarb M. Department of Mechanical Engineering, Massachusetts Institute of Technology, 1994.

[84] DEVELOPMENT OF AN ON-LINE CORRECTION CAPABILITY FOR FNS LOCOMOTION: COMPUTER SIMULATION OF PARAPLEGIC GAIT THROUGH MULTIPLE GAIT CYCLES

Howard J. Chizeck, ScD; Avram Scheiner, PhD; Donald C. Ferencz
Department of Systems, Control, and Industrial Engineering, Case Western Reserve University, Cleveland, OH 44106; VA Medical Center, Gait Laboratory, Cleveland, OH 44106

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B683-RA)*

PURPOSE—The goal of this computer study is to develop a computer simulation of human gait for multiple gait cycles. Simulation of multiple gait cycles will allow for determination dynamic forces and torques developed during gait that result from disturbances in the previous cycle and allow development and testing of control systems that can correct for transients and time varying system parameters. In addition, because system design will require examining steady state conditions, simulations of multiple gait cycles are required to confirm system stability. The ultimate purpose of this simulation is to test different control parameters and controller designs before they are implemented in lower extremity FES systems with human subjects.

METHODOLOGY—A method for formulating and driving a 23 degree of freedom android model computer simulation through multiple gait cycles has been developed. Computational problems associated with changing constraints during transitions between phases of gait are avoided by modeling foot-to-floor contact as an external force. Net joint torques, computed from kinematic data by inverse dynamics and transformed into sine functions, are used to drive limb motion. The problem of model instability is overcome by emulating the effects of stiffness at the joints by using proportional-derivative controllers. These simulations have been implemented on a SPARC workstation utilizing ADAMS software.

PROGRESS—Continuous gait has been simulated up to 100 gait cycles.

RESULTS—Model stability was achieved with the addition of stiffness at the joints. This local control scheme, consisting of independent linear controllers at each joint, generally showed adequate position control for the multi-link android. Torque levels at all joints were substantially above normal range but within possible physiological levels. The contribution of the open loop torques to total joint torques were generally small during stance phase but were significant during swing phase (especially during after heel strike and toe off where the highest peaks occurred). This suggests stiffness regulation is most important during weight bearing. Joint kinematics and foot contact forces generally followed a normal gait pattern producing a forward displacement of approximately 1 m/s at a walking frequency of 0.5 Hz. The most significant deviation from a normal walking pattern was excessive hip abduction during stance phase causing a waddling (medial lateral sway) motion.

FUTURE PLANS—Future studies will account for muscle activation and force properties and examine how net torque and stiffness might be obtained with various controllers that activate individual muscles. We will examine the effects of variation of joint stiffness, which will arise from a combination of the inherent muscle properties and the properties of the controller, on tracking error and model stability. These simulations will be used to obtain quantitative information about the use of adaptive predictive control of muscle torque and joint angle trajectories and rule based modification of stimulation patterns in controller design.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Simulation of normal and FES induced gait using a 23 degree-of-freedom model. Scheiner A, Ferencz DC, Chizeck HJ. In: Proceedings of the 15th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1993, San Diego, CA.

Effect of joint stiffness on simulation of the complete gait cycle. Scheiner A, Ferencz DC, Chizeck HJ. In: Proceedings of the 16th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1994, Baltimore, MD.

Simulation of the complete gait cycle using a 23 degree-of-freedom model. Scheiner A, Ferencz DC, Chizeck HJ. In: Proceedings of the 13th Southern Biomedical Engineering Conference, 1994, Washington, DC.

[85] DEVELOPMENT OF AN ON-LINE CORRECTION CAPABILITY FOR FNS LOCOMOTION: MATHEMATICAL MODELS FOR MUSCLE CONTROL

Howard J. Chizeck, ScD; Seokjoo Chang; Donald C. Ferencz
Department of Systems, Control, and Industrial Engineering, Case Western Reserve University, Cleveland, OH 44106; Cleveland VA Medical Center, Gait Laboratory, Cleveland, OH 44106

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B683-RA)*

PURPOSE—The purpose of this research is to develop mathematical models for closed-loop control of electrically stimulated muscle in paraplegics. These models, when incorporated into high level control systems for FNS locomotion, will provide more accurate joint position and muscle torque trajectories, by compensating for the varying response of electrically stimulated muscle due to changing position, velocity, and stimulation parameters.

METHODOLOGY—We have developed a mathematical model of electrically stimulated quadriceps muscle in paraplegics under both isometric and non-isometric conditions. Experiments were performed measuring output torque (for the isometric case) and joint angle (for the non-isometric, inertial load case). In the case of non-isometric (free swinging) experiments, a separate load model was first identified to determine the muscle force based upon joint position and velocity. A recursive algorithm (sequential nonlinear least squares) was used to estimate the parameters of a nonlinear, coupled model of muscle force, incorporating terms for activation, length, and velocity dynamics. The model identification was performed under varying both stimulus pulsewidth (PW) and stimulus period (SP).

PROGRESS—We have begun work on developing a model-based predictive control strategy for electrically stimulated muscle, based upon the model described above. Here several schemes of adaptive predictive control are being evaluated. These controllers use the estimated model of muscle output force from stimulation input to derive a control law which determines the input based upon output measurements.

RESULTS—With the recursive estimation method described above, we have shown that muscle output torque can predicted for time horizons up to 0.5 seconds with a fractional error (sum of error magnitude divided by total output) of less than 20 percent. This is sufficient to be incorporated in adaptive controller designs for movement control of electrically stimulated muscle. Computer simulation studies using this identification algorithm with several adaptive predictive control strategies have shown stable muscle responses to the derived inputs.

FUTURE PLANS—We plan to implement the adaptive predictive controllers (based upon the identified muscle models) in experimental trials to control both muscle torque and non-isometric joint angle. These controllers will eventually be incorporated into high level control schemes for control of functional movements in paraplegics (such as stair ascent and descent) to provide more consistent, repeatable, and energy-efficient movements.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Characterization of paraplegic disturbance response during FNS standing. Moynahan M, Chizeck HJ. IEEE Trans Rehab Eng 1992:1(1):43-8.

Nonlinear joint angle control for artificially stimulated muscle. Veltink PH, Chizeck HJ, Crago PE, El-Bialy A. IEEE Trans Biomed Eng 1992:39:368-80.

Improved models for the lower leg in paraplegics. Scheiner A, Stein RB, Ferencz DC, Chizeck HJ. In: Proceedings of the 15th Annual Conference of the IEEE Engineering in Medicine and Biology Society, 1993, San Diego, CA, 1151-2.

Identification of electrically stimulated quadriceps in paraplegic subjects during load transitions. Chang S, Chizeck HJ, Stein RB, Scheiner A, Ferencz DC. In: Proceedings of the American Control Conference, 1994, Baltimore, MD.

Feedback control of the knee joint under a varying load on supine paraplegic subjects. Willemin DE, Chizeck HJ. IEEE Trans Biomed Eng. In press.

[86] DEVELOPMENT OF AN ON-LINE CORRECTION CAPABILITY FOR FNS LOCOMOTION: A FUZZY LOGIC RULE BASE FOR GAIT PHASE DETECTION AND CORRECTION

Howard J. Chizeck, ScD; Sau Kuen Ng, BS; Margaret Skelly, BS
Department of Systems, Control, and Industrial Engineering, Case Western Reserve University, Cleveland, OH 44106; Cleveland VA Medical Center, Gait Laboratory, Cleveland, OH 44106

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B683-RA)*

PURPOSE—The purpose of this research is to develop and evaluate a controller for improved functional neuromuscular stimulation (FNS) locomotion in complete paraplegic subjects. The goal of this improvement is to make possible the use of FNS systems outside of the laboratory by compensating automatically for perturbations such as changing surfaces, disturbances, and internal changes (such as muscle fatigue). By reducing the time currently required by technical staff to maintain the FNS system, the practicality and clinical acceptance of these systems will be greatly enhanced.

METHODOLOGY—The method of correcting FNS gait developed in this work is in two parts: first, a fuzzy logic rule base has been developed which determines the phase of gait of a paraplegic subject walking with FNS using sensor measurements. Secondly, these observed sensor measurements, along with the detected gait phase, are used to determine a quality of gait and provide adjustments to the electrical stimulation pattern to improve the locomotion.

PROGRESS—During the past two years, a system of fuzzy logic rules to evaluate the phase of gait has been developed. The rules for detection of events is developed from pairing of clinical observations and sensor measurements (hip, knee, and ankle goniometers), using a modification of rule identification schemes. These identified rules were then used to estimate phase of gait on the same and different walks from the same subjects.

During this report period, work has also begun on detecting various gait anomalies via sensor measurements. Using solid-state accelerometers mounted on the paraplegic's rolling walker, the angle of inclination has been estimated. This will provide a method of modifying gait patterns when one external variable (i.e., slope) changes. Work has also begun on detecting a deficit of FNS gait (toe drag during the swing phase) using the estimated phase of gait and sensor measurements of foot contact force.

RESULTS—Errors in gait phase estimates were computed as the difference between predicted and actual gait phase (as determined by clinical observation). With this system, all phases of gait were predicted in all subjects and walks, with a small but varying time delay in the prediction of each phase; the accuracy of the prediction appears to be related to the quality of FNS walking. In addition, statistical comparisons showed that, in nearly all cases, the fuzzy logic rules for gait detection performed better than traditional non-fuzzy (lookup table) rules.

FUTURE PLANS—Within the next year, we plan to implement and begin experimental evaluation of on-line stimulation adjustment rules. To measure the capability of this rule-based system to improve FNS gait, statistical analysis will be done on the original gait data and on the corrected gait data to provide a measure of the effectiveness of on-line sensor-driven stimulation control.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Adaptive and nonlinear control methods for neural prostheses. Chizeck HC. In: Stein R, Peckham PH, Popovic DB, eds. Neural prostheses: replacing motor function after disease or disability. New York: Oxford Press, 1992:298-328.

Fuzzy logic gait event detector for fes paraplegic gait. Ng SK, Chizeck HJ. In: Proceedings of the 15th Annual Conference of the IEEE Engineering in Medicine and Biology Socicty, 1993, San Diego, CA, 1238-9.

Fuzzy vs. non-fuzzy rule base for gait event detection. Ng SK, Chizeck HJ. In: Proceedings of the 16th Annual Conference of the IEEE Engineering in Medicine and Biology Society, 1994. In press.

[87] DEVELOPMENT OF AN ON-LINE CORRECTION CAPABILITY FOR FNS LOCOMOTION: STATE ESTIMATION OF ELECTRICALLY STIMULATED MUSCLE USING THE EMG SURFACE RESPONSE

Howard J. Chizeck; Abbas Erfanian; Reza M. Hashemi
Department of Systems, Control, and Industrial Engineering, Case Western Reserve University, Cleveland, OH 44106; Department of Electrical Engineering, Tarbiat-Modarres University, Tehran, Iran; VA Medical Center, Gait Laboratory, Cleveland, OH 44106

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B683-RA); Tarbiat-Modarres University, Tehran, Iran*

PURPOSE—The closed-loop control of FNS locomotion systems provides some advantages over the open-loop control. In general, feedback control can increase the linearity of input-output behavior, improve repeatability by decreasing the system sensitivity to internal parameter variation, as well as external disturbance and electrode movement. However, the development of closed-loop control of FNS requires real-time feedback information about the muscle states. Unfortunately, the use of sensors have some limitations, especially for real-time applications. This research will investigate the feasibility of the EMG signal of electrically stimulated muscle as a feedback information in the closed-loop control of FNS locomotion.

There are several objectives of this study. The first is to develop and verify a predictive model related electrical stimulation and the Evoked EMG. Such a model should enable investigators to predict the force in various conditions of operation (i.e., isometric, and non-isometric, fatigued, and non-fatigued). The second objective is to characterize the relationship between the EMG signals and joint angle. The next objective is to characterize the changes in the dynamics of muscle contraction and muscle excitation during prolonged electrical stimulation. Thc fourth objective is to investigate the mechanisms of muscle fatigue during prolonged electrical stimulation using the EMG signal.

PROGRESS—Up to now, we have shown that the EMG-based model of electrically stimulated muscle can successfully predict the muscle output torque for long time horizons in isometric conditions. Once the model is identified for some patterns, then the generality of the model is verified by predicting outputs for different patterns.

RESULTS—Moreover, the results suggest that both the peak amplitude and power spectrum of the EMG signal can be used to determine knee joint angle during isometric stimulation. In addition, changes in the characteristics of the evoked EMG occur during sustained stimulation. The resting membrane potential changes with fatigue. Other related changes are prolongation and enlargement of the positive after-potential of the pulse response, a decrease of the peak amplitude of the evoked EMG, and a shift in time of the peak amplitude of the pulse response.

The major finding of the fatigue analysis is that there exists an almost linear relationship between contraction fatigue and excitation fatigue, and that there does not appear to bc a distinct separation between these two during maximal stimulation. Moreover, an autoregressive model of joint torque was identified and analyzed during sustained stimulation. It was found that the corresponding z-plane poles move toward the unit circle in a path that indicates decreasing stability, decreasing damping

and decreasing natural frequency of a corresponding continuous time model.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

EMG signal of electrically stimulated muscle as an indication of joint-torque, and joint angle. Erfanian A, Hashemi RM, Badie K, and Hatamlui H. In: Proceedings of the 5th Iranian Conference on Biomedical Engineering, 1992.

Characterization of changes in the dynamics of muscle contraction during prolonged electrical stimulation. Erfanian A, Chizeck HJ, Hashemi RM. In: Proceedings of the 16th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1994, Baltimore, MD.

Evoked EMG in electrically stimulated muscle and mechanisms of fatigue. Erfanian A, Chizeck HJ, Hashemi RM. In: Proceedings of the 16th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1994, Baltimore, MD.

Relationship between joint angle and evoked EMG in electrically stimulated muscle. Erfanian A, Chizeck HJ, Hashemi RM. In: Proceedings of the 16th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1994, Baltimore, MD.

[88] RESTORATION OF STANDING PIVOT TRANSFER FOR QUADRIPLEGIC PATIENTS USING A TOTALLY IMPLANTED FNS SYSTEM

Ernest B. Marsolais, MD, PhD; Paul C. Miller, MEd
VA Medical Center, Cleveland, OH 44106-1702

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B743-RA)*

PURPOSE—The purpose of this project is to investigate the use and effectiveness of an implanted eight channel functional neuromuscular stimulation (FNS) system to enable quadriplegic individuals to perform standing pivot transfers. Development of this system will result in increased ease of daily routines for the user and the caregiver.

METHODOLOGY—Closed helix electrodes fitted with removable percutaneous leads have been implanted in C6-7 incomplete quadriplegics. There is an interconnector at the proximal end of each electrode that allows the electrode to be connected to either a percutaneous lead or to the implantable stimulator. Eight electrodes are implanted in each individual, four bilaterally, in the quadriceps, erector spinae, and in two of the following: posterior adductor, hamstring, and gluteus maximus. The subjects are started immediately on a program of electrically induced exercises for the purpose of building muscle strength and endurance. When sufficient levels of strength and endurance are achieved, functional stimulation patterns are developed and standing activities are attempted. Each subject participates in three training/exercise sessions per week. The ability to stand and perform a pivot transfer is learned in these one-on-one training sessions. When the pivot transfers can be performed repeatedly and competently, the percutaneous leads are removed and the internal stimulator is implanted.

PROGRESS—One of the three subjects has received the implanted stimulator. The other two subjects are progressing towards receiving the implanted stimulator. Some of the differences in the amount of time required to progress through the training period are the differences in incompleteness of the subjects, differences in the initial muscle strength, and the fact that the subject that has received the implanted system, participated as an inpatient and thus was able to participate on a daily basis.

RESULTS—Three subjects have begun participation in this project. All three subjects are able to stand and two of the three are able to perform a pivot transfer with minimal standby assistance. An alternate controller was also developed so that users with limited dexterity can optimally and easily use the system.

FUTURE PLANS—The plans of this project are to implant at least four more quadriplegic individuals in this coming year. We also intend to increase the accuracy and the ease of the current implantation process with the development of an arthroscopic

implantation technique that will enable the surgeon to view the nerve and the placement of the electrode.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

FNS augmentation of transfers for quadriplegic patient using a totally implanted stimulator. Marsolais EB, Scheiner A, Miller PC, Kobetic R, Jacobs J. In: Proceedings of the 39th Annual American Paraplegia Society Conference, 1993, Las Vegas, NV.

Implanted FES standing and transfer system for quadriplegia. Marsolais EB. In: Proceedings of the 39th Annual Meeting of the Orthopaedic Research Society, 1993, San Francisco, CA.

FES standing and transfer system for paraplegia. Marsolais EB. J Am Paraplegia Soc 1993:15(2)145.

Implanted FES standing and transfer system for quadriplegia. Marsolais EB. J Am Paraplegia Soc 1994:16(2):95.

Functional electrical stimulation for transfers in the neurologically impaired. Marsolais EB, Kobetic R, Miller PC, Scheiner A, Jacobs JL. In: Proceedings of the American Academy of Orthopaedic Surgeons Annual Meeting, 1994, New Orleans, LA.

[89] FUNCTIONAL PARAPLEGIC WALKING WITH ELECTRICAL STIMULATION

Ernest B. Marsolais, MD, PhD; Rudi Kobetic, MS
VA Medical Center, Cleveland, OH 44106-1702

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B681-RA)*

PURPOSE—The purpose of this research is to develop a practical functional electrical stimulation system for walking in paraplegia. This includes development of surgical techniques to implant electrodes and stimulator, external controller hardware and software for RF-powering and control of the implant, software to setup stimulation patterns for exercises, stepping, walking and stair climbing, and muscle conditioning and gait training protocols.

METHODOLOGY—Percutaneous double helix intramuscular electrodes are implanted in paraplegic volunteers in major muscles controlling trunk, hips, knees, and ankles. Soft tissue endoscopic techniques are being developed for implantation of intramuscular and nerve cuff electrodes under direct vision and to clip them at the motor point to improve reliability and precision of the placement. Nerve cuff electrodes will be implemented for muscles that respond poorly with intramuscular electrodes. Subfascial electrodes have been used for superficial muscles of the back and posterior thigh. The muscles are conditioned with electrical exercises and programmed for movements. Available clinical muscle and gait evaluation techniques were adapted to paraplegics. When sufficient functions are achieved, kinematic, kinetic, and metabolic energy evaluations are performed.

PROGRESS—All subjects implanted with intramuscular electrodes regained enough muscle strength and fatigue resistance to stand and make steps. Electrical stimulation did not cause excessive tibial compartment pressure to cause compartment syndrome. Evaluation of paraplegic gait with video-based motion analysis system showed asymmetry between left and right step length. When compared to normal, most temporal and spatial parameters exhibited much larger standard deviation than normal walking at similar speed. Major deviation from normal kinematics were observed in movements of hip, pelvis, and trunk.

RESULTS—The accuracy of electrode implantation can be increased by using modified arthroscope to guide insertion. The movement of the electrode remains to be a problem. Double helix electrode survival was 62 percent for 5 years. The survival rate for 1 year was increased by 6 percent when the helix was encapsulated in silastic tubing. Major cause of electrode failure included 6 percent due to inability to place the electrode during surgery and 12 percent during the first 6 weeks post implantation due to changes in muscle response to stimulation. Seventy percent of subfascial electrodes used for stimulation of posterior thigh and back muscles survived for one year.

FUTURE PLANS—We will further develop endoscopic technique to improve electrode implantation and fixation at the motor point. Guidelines will be implemented for modifying stimulation patterns of electrically driven functions in a user friendly software for use by clinicians. A major effort will be made to integrate electrically driven movements into activities of daily living. With miniaturization of the external controller and a RF-driven implant this system could be worn all day and used practically by individuals with paraplegia for exercising, standing, walking, and climbing stairs.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Augmentation of the accuracy of percutaneous electrode implantation by using a modified arthroscope to guide insertion. Doyle J, Scheiner A, Marsolais EB. Arthroscopy 1992:8(2):162-5.

Effect of functional neuromuscular stimulation on anterior tibial compartment pressure. Doyle J, Kobetic R, Marsolais EB. Clin Orthop 1992:284:181-8.

Hip and trunk stability in paraplegic electrically augmented gait. Marsolais EB, Mansour JM. IEEE Trans Biomed Eng 1992:11(4): 64-7.

Endoscopic electrode implantation for enhanced stimulation of hamstring branches of the sciatic nerve. Osman SG, Marsolais EB. J Am Paraplegia Soc 1993:16(2)101.

[90] RESTORATION OF MUSCLE ACTIVITY THROUGH FES AND ASSOCIATED TECHNOLOGY: THE RAFT PROJECT, A CONCERTED ACTION

Antonio Pedotti
Centro di Bioingegneria, Fondazione Pro Juventute Don Gnocchi IRCCS, Politecnico di Milano, Milano, Italy

Sponsor: *Commission of the European Communities*

PURPOSE—The concerted action, "Restoration of muscle activity through FES and associated technology," (RAFT), has been approved by the European Community in the frame of the ongoing program BIOMED II aimed at promoting medical research in the European Community.

This 3-year project started January 1, 1993, with the objective of stimulating research into reactivating paralyzed or poorly controlled muscle function in order to permit patients with a wide range of disabling conditions to perform activities of daily living more effectively. This will in turn lead to an increase in their independence and reduce the financial burden of the support upon the various European national social security arrangements. RAFT builds on the work completed under the MORE program by using the valuable network of centers which are already collaborating effectively in the areas of FES and paraplegic ambulation, as evidenced by the 6 workshops and numerous personnel interchange visits made under this program, together with the publication of the book, *Restoration of walking for paraplegics*. The three main objectives have been identified as major research topics.

METHODOLOGY—The nerves going to the muscles are made of a mixed population of fibres, including motor and sensitive pathways. Given this organization, the stimulation of a nerve trunk does not allow good selectivity in terms of reaching the right muscle and obtaining a reliable modulation of force by recruiting the different motor units. Special investigations on animals and stimulation modality are required for that. In order to obtain an acceptable movement, it is also important to adapt the control strategies to the individual patient. This goal can be obtained a priori by considering the type and level of the lesion, the anthropometric, physiological and anatomical characteristics of each patient in conjunction with the results of specific tests for spasticity, paresis, etc. From the dynamic point of view the optimal adaptation can be reached by quantitative analysis of performance and by using simulation techniques in order to choose the best rules for muscle recruitment.

The selection of patients and the definition of a proper training before and after the implantation is key to attaining good results. Since the SCI patient cannot feel sensations of muscular fatigue and since the composition of fibers (fast and slow) is very

often modified in these patients, it is important to detect the fatigue in order to avoid the muscle damage by FES.

It is important to provide a multidisciplinary evaluation during the concerted action of all the clinical and research achievements. This is to be made mostly from the clinical trials, organized within the European clinical network in the different SCI centres.

PROGRESS—In order to reach the objectives of the concerted action, 44 centers from most of the European countries will collaborate. The Project Leader will be aided by a Project Management Group (PMG) whose composition is reflecting the major topics and the research activity going on in several European countries: P. Rabischong (Montpellier, France), T. Sinkjr (Aalborg, Denmark), J. Stallard (Oswestry, Great Britain), H. Boom (Enschede, Holland), T. Brandt (Munchen, Germany), G. Anogianakis (Thessaloniki, Greece).

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Restoration of walking for paraplegics: recent advancements and trends. Pedotti A, Ferrarin M, eds. Commission of the European Community COMAC BME. Milano, Amsterdam: Edizioni Pro Juventute, IOS Press, 1992.

[91] BIOMECHANICAL ANALYSIS OF PARAPLEGIC WALKING WITH ORTHOSES AND FES

Maurizio Ferrarin, PhD; Marco Rabuffetti, Dr Eng; Giuseppe Abello, Dr Eng; Antonio Pedotti
Centro di Bioingegneria, Fnd. Pro Juventute IRCCS, Politecnico di Milano, Milano, Italy

Sponsor: *Italian Ministry for University and Scientific Research; Italian National Research Council; European Community*

PURPOSE—This project seeks to develop and apply a biomechanical evaluation protocol to analyze the locomotor pattern of paraplegic patients walking with pure mechanical orthoses and with hybrid systems (orthoses + FES). The aim is to obtain a tool for optimizing the external walking device to each patient considering both the mechanical adjustment and the electrical stimulation pattern.

METHODOLOGY—A multifactorial gait analysis system has been adopted to collect simultaneously all significant data about assisted walking. It consists of an ELITE system for kinematic analysis, a force platform for ground reaction force detection, an 8-channel electromyograph to record myoelectric activity of supralesional muscles, and a personal computer with suitable software to store, process and graphically represent all collected data.

A devoted kinematic acquisition protocol in terms of particular marker displacement with technical reference points (used to calibrate and reconstruct anatomical landmarks covered during movement) has been developed and implemented. A set of interesting variables has been individuated ranging from general spatio-temporal gait parameters to time course of upper and lower limb joint angles, center of gravity displacements, joint torque and power, GRF impulses. Taking into account the complexity of considered movement and the severity of locomotor disability, we had to minimize the number of trials and the acquisition times, at some expense to data consistency and significance. Gait analysis is performed both with and without FES assistance, in order to quantify the improvement on walking pattern produced by electrical stimulation.

RESULTS—Preliminary acquisitions have been performed on paraplegics walking with ORLAU-Hip Guidance Orthosis (HGO) in order to validate the procedure. It was optimized and applied to paraplegics walking with LSU-RGO (Reciprocating Gait Orthosis) without FES. Preliminary results from data comparison show interesting differences in locomotor strategy strictly correlated with the different mechanisms involved in the two orthoses. Furthermore some differences in patients using the same orthosis have been pointed out, revealing the presence of different possible strategies in their use.

FUTURE PLANS—Acquisitions on patients using RGO with and without FES will be performed both

at the end of the training period and after 6 months of functional use of the orthosis. After data analysis a set of trial with modified stimulation patterns are planned, in order to find the optimal one for each patient.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

3-D analysis and modelling for evaluation and adaptation of assisted walking. Ferrarin M, Palmieri R. In: Restoration of walking for paraplegics: recent advancements and trends. Pedotti A, Ferrarin M, eds. Commission of the European Community COMAC BME. Milano, Amsterdam: Edizioni Pro Juventute, IOS Press, 1992:143-8.

Biomechanical assessment of paraplegic locomotion with hip guidance orthosis (HGO). Ferrarin M, Pedotti A, Boccardi S, Palmieri R. Clin Rehabil 1993;7(4):303-8.

Gait analysis in paraplegics walking with RGO orthosis. Ferrarin M, Rabuffetti M, Pedotti A, Lusvardi M, In: Book of abstract of biomechanics XIV. ISB Congress; 1993 July 4-8; Parigi:402-3.

[92] ESTIMATION OF ELECTRICAL STIMULUS: TORQUE RELATIONSHIP IN QUADRICEPS MUSCLE FOR FES APPLICATION ON PARAPLEGIC PATIENTS

Maurizio Ferrarin, PhD; Alberto Campisi, DrEng; Antonio Pedotti
Centro di Bioingegneria, Fondazione Pro Juventute Don Gnocchi IRCCS, Politecnico di Milano, Milano, Italy

Sponsor: *Italian Ministry for University and Scientific Research, Italian National Research Council*

PURPOSE—This study aims to determine the relationship between the electrical stimulus parameters applied to the quadriceps muscle through surface electrodes and torque at knee joint generated by stimulated muscles. The final goal is to develop a general tool for the optimization of stimulation patterns in walking restoration for paraplegics through the use of functional electrical stimulation (FES).

METHODOLOGY—A mathematical model of knee joint, considering its muscular and skeletal components, has been developed using a nonlinear second order equation. The unknown parameters (visco-elastic properties) have been estimated from kinematic data (captured with an ELITE system) acquired during passive pendular motion of the leg and using optimization procedure. Using these estimated parameters and the kinematic data acquired during knee movement due to transcutaneous electrical stimulation of the quadriceps, the net torque generated by stimulated muscles has been computed. Repeating this procedure with different stimulation parameters (frequency, impulse duration and modulation) a nonlinear relationship between torques and these parameters has been estimated. The stimulating device is an 8-channel programmable system linked to a personal computer on which all controlling software has been implemented. Validation will be performed in two ways: comparison with similar data from the literature and from trials with voluntary muscle contraction on healthy subjects.

RESULTS—To date experiments on four healthy subjects have been performed in order to test both the experimental and the analytical procedure. The elastic property of muscles seems to be better described by a complex function than a linear one, the latter being better for muscle viscosity. Classical torque-stimulus frequency relationship with threshold and saturation behaviour has been obtained. Preliminary trials on two paraplegic patients showed the applicability of all the procedures on pathological subjects.

FUTURE PLANS—When the procedure validation is completed, a set of trials on paraplegic patients will be performed. Using estimated parameters, a closed loop system to control knee movement will be implemented using a goniometer to detect joint angle displacement. The final goal is to use the same approach for all muscles stimulated by a future multichannel implanted system, and to combine these models with a comprehensive simulation model of human walking, in order to have a general tool for stimulation pattern optimization and control strategy development.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Kinematic analysis and modelling for control optimization of FES for paraplegics. Pedotti A, Ferrarin M. In: Salmons S, ed. Proceedings of the International Symposium on Therapeutic Stimulation; Liverpool, UK 1992:18.

A modelling approach to stimulation pattern optimization. Ferrarin M. In: Restoration of walking for paraplegics: recent advancements and trends. Pedotti A, Ferrarin M, eds. Commission of the European Community COMAC BME. Milano, Amsterdam: Edizioni Pro Juventute, IOS Press, 1992:207-13.

Evaluation of the muscle torque at the knee joint resulting from electrical stimulation by using kinematic analysis. Ferrarin M, Baglioni P, Campisi A, et al. In: Muscular Components in Functional Electrical Stimulation. Edwards J, ed. Proceedings of EEC BIOMED RAFT Concerted Action; Salford, 1993 June 25-26; Salford, UK:University College Salford Publications, 1994:26-35.

[93] NOVEL FES SYSTEM IMPROVING LOCOMOTION ABILITIES IN SCI SUBJECTS BY ENHANCED VOLUNTARY CONTROL BASED ON SENSORY INTEGRATION AND EXTENDED SENSORY PERCEPTION

Alojz Kralj, DSc Prof; Tadej Bajd, DSc, Prim; Rajko Turk, MD; Rajmond Šavrin, MD
Faculty of Electrical and Computer Engineering, University of Ljubljana, Slovenia; Republic of Slovenia
Rehabilitation Institute, Ljubljana, Slovenia

Sponsor: *National Institute on Disability and Rehabilitation Research, Field Initiated Research Award No. H 133 GOO 151*

PURPOSE—Our study investigates the significance of upgrading the existing four-channel minimal walking pattern by additional stimulation channels delivered to ankle plantar flexors, hip extensors and hip abductors.

METHODOLOGY—We devised a method of eight-channel functional electrical stimulation (FES) for enhancing patients' voluntary control over their walking patterns with the help of a smart yet rather simple control module attached to the handle of the crutch. The FES design is based on optimization of bending moments along the long lower extremity bones.

This device was tested in dynamic walking patterns, including unstable states, where the subject is gravity and inertia driven in the direction of walking, on 94 SCI patients (so far the largest analysed FES-treated group of SCI persons).

RESULTS—The four-channel stimulator was intended for either unilateral or bilateral application to incomplete or complete SCI patients. Our eight-channel stimulator retains that purpose while improving function. It contains not only stimulation capabilities but patient monitoring evaluation and sensory restoration functions as well. It enables execution of sensory electrocutaneous feedback implement through sensory integration as "warning" in case of a hazardous gait situation or "reward" in case of a successfully accomplished step.

IMPLICATIONS—The implementation was upgraded during the course of (and as a result of) the trials. A wireless link has been provided between the crutch control module and the FES orthosis attached to the paraplegic subject to improve cosmesis and avoid failure due to wire breakage. The concept utilized in the original model for ultrasound distance-velocity gait measurement is retained in this system, but with continued study and development of more capable miniaturized components other approaches will doubtless become feasible.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Bending moments in lower extremity bones for two standing postures. Munih M, Kralj A, Bajd T. J Biomed Eng 1992:14:293-301.

FES gait restoration and balance control in spinal cord-injured patients. Kralj AR, Bajd T, Munih M, Turk R. Prog Brain Res 1993:97:387-96.

Unstable states in four-point walking, Bajd T, Kralj A, Zefran M. J Biomed Eng 1993:15:159-62.

Significance of FES assisted plantar flexion during walking of incomplete sci subjects. Bajd T, Kralj A, Karcnik T, Savrin R, Obreza P. Gait & Posture 1994:2:5-10.

V. Geriatrics

[94] OPTOKINETIC TESTING FOR DIAGNOSIS AND REHABILITATION OF BALANCE DISORDERS

Cynthia G. Fowler; Robert H.I. Blanks; Carol A. Zizz
VA Medical Center, Long Beach, CA 90822

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C691-RA)*

PURPOSE—The purposes of this project are to develop 1) age-related norms for monocular and binocular optokinetic nystagmus (OKN) and postural sway, 2) OKN and sway profiles on patients with unilateral vestibular lesions, and 3) OKN and sway profiles on patients during compensation from unilateral vestibular nerve section. This research should provide a clinical protocol and related computer hardware and software to improve the diagnosis and rehabilitation of vestibular disorders.

METHODOLOGY—Studies are examining the use of monocular and binocular OKN testing in the diagnosis and treatment of vestibular and balance disorders. All studies are being performed on normal subjects and patients with well-defined VIIIth nerve lesions.

After an audiologic evaluation, horizontal optokinetic motion stimuli (randomized bar pattern, projected on a circular screen produced by a multi-axis shadow projection system) are presented. There are two test conditions, binocular and monocular (right and left eyes). OKN is recorded at stimulus velocities 10-100°/s in 10° increments to the right and to the left (randomized presentation). There is a 30 s period in stationary stimuli, a 30 s period of moving stimuli, and a 30 s period of darkness. In the balance protocol, these stimuli are presented while the subject stands on a balance platform that measures anterior-posterior and lateral sway.

PROGRESS—Over 70 normal subjects ages 8 to 70 years have completed the optokinetic protocol. All subjects have similar response patterns, producing OKN at speeds consistent with stimulus velocities up to 50-60°/s. There is no significant regression with subject age or gender. There is, however, a rightward preponderance, with higher gain for rightward stimuli.

RESULTS—Six subjects with acoustic neuromas presented an abnormal response pattern. Before surgery to remove the neuroma, OKN was asymmetrical; gain was low when the stimulus moved away from the side of the compensated lesion as compared to normal values when the stimulus moved ipsilaterally (e.g., the contralateral gain was approximately 0.6 compared to 0.9 for ipsilateral gain at 60°/s). During the acute postoperative period (<30 days), the ipsilateral and contralateral gain of horizontal OKN was low and symmetrical. During the intermediate period of postoperative recovery (30-60 days), the OKN became asymmetrical with an improvement in ipsilateral gain. Finally, during the chronic phase of recovery (>2 months), three of the six neuroma subjects revealed OKN gain that was symmetrical and within normal limits. Monocular OKN produced similar pre- and postoperative effects. These data suggest that monocular and binocular optokinetic testing can be used to monitor the vestibular compensation of subjects following vestibular nerve section.

In the postural sway protocol, normal subjects and those with pre- and postoperative acoustic neuromas are being evaluated on a balance platform with eyes open and closed, and in the presence of optokinetic stimuli from 10-100°/s. In normals, sway is enhanced with eyes closed, and there is some movement in the rightward sway with rightward optokinetic stimuli. Well-compensated neuroma subjects exhibit responses similar to those in the normal

group, although with slightly more sway in conditions with eyes closed. One poorly compensated subject had significant postural sway in the direction of the lesion when optokinetic stimuli were also moving in that direction.

FUTURE PLANS—Data collection continues to evaluate a shortened optokinetic protocol for use in a wider range of subjects, including those on ototoxic medications. Data collection continues on the balance platform to define balance strategies in normal aging subjects and to monitor compensation in subjects recovering from vestibular lesions.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Abstract: Changes in horizontal optokinetic nystagmus (HOKN) following hemilabyrinthectomy. Blanks RHI, Fowler CG, Zizz CA, et al. In: Proceedings of the Society for Neuroscience, 1992, Anaheim, CA.

Abstract: Normal adaptation functions of optokinetic nystagmus. Fowler CG, Zizz CA, Blanks RHI. In: Proceedings of the American Academy of Audiology Convention, 1992, Nashville, TN.

Monocular and binocular testing to improve the diagnostic value of horizontal optokinetic nystagmus. Fowler CG, Zizz CA, Blanks RHI. Am J Audiology 1993:3:44-7.

Abstract: Age-related differences in binocular and monocular optokinetic nystagmus. Fowler CG, Zizz CA, Blanks RHI. In: Proceedings of the American Speech-Language-Hearing Association, 1993, Anaheim, CA.

[95] UPPER BODY MOTION ANALYSIS FOR AMELIORATION OF FALLS IN THE ELDERLY

Eric Sabelman, PhD; Carol H. Winograd, MD
Palo Alto VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E601-RA)*

No report was received for this issue.

[96] INFLUENCES ON LONG BONES: DEVELOPMENT, GROWTH, AND AGING

M.C.H. van der Meulen, PhD; E.R. Morey-Holton, PhD; Dennis R. Carter, PhD; B. Mikic, MS; D.M. Kingsley, PhD
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—To enhance our understanding of factors involved in skeletal development, growth and aging, we are examining genetic regulation and hormonal effects in addition to mechanical loading. In our studies we are using theoretical and experimental approaches in conjunction with animal models to identify structural, geometric, and material changes to the skeleton.

PROGRESS—In a collaborative study with NASA Ames Research Center we are using experimental and computer models to study the effects of disuse on the skeleton. We believe these studies will help to understand changes resulting from spinal cord injury. Decreased loading will be achieved by hindlimb suspension and possibly spaceflight (depending on tissue availability). The first set of experiments show that hindlimb suspension significantly decreases the femur's torsional strength, primarily by altering the geometry of the bone.

Osteoporosis is a severe health problem in the United States affecting 40 percent of postmenopausal women and a smaller, but significant, percentage of elderly men. Postmenopausal women experience a reduction in circulating estrogen levels. Estrogen replacement therapy is the most established drug treatment to date for osteoporosis; however, only a modest decrease in the rate of

bone loss is achieved. In addition, only women are candidates for estrogen therapy, and many women are not eligible for a variety of health reasons. Currently a variety of natural and synthetic potential chemical treatments are being researched. We will be examining several models and how the bone strength is affected by the treatment. Experimental testing and computer models are two approaches that can be used to assess the efficacy of treatment.

One area that shows promise for the treatment of skeletal diseases involves the use of growth factors. Growth factors are chemical compounds that affect the growth and development of a variety of skeletal tissues. One class of growth factors found naturally in the body is the bone morphogenic proteins (BMPs). These proteins are known to play a critical role in early skeletal development when bones and joints are first formed in utero. However, the role of the BMPs during adulthood is not well understood. We are investigating the effects of one member of the BMP family (BMP-5) on long bone development and adaptation in a mouse model. These types of studies may suggest the use of growth-factor therapy for the treatment of osteoporosis in humans.

[97] EFFECTS OF EXPECTATION, REWARD, AND ACTIVITY ON SUBTYPES OF SCHIZOPHRENIA

Morris Bell, PhD; Paul Lysaker, PhD
VA Medical Center, West Haven, CT 06516

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #D515-2RA)*

PURPOSE—This research investigates the benefits of productive activity in the rehabilitation of patients with diagnoses of schizophrenia, seeking answers to six key questions: Does pay act as a reward for schizophrenic patients in a work program leading to greater productivity? Does greater expectation for productive activity lead to more productivity? Does greater productivity lead to better rehabilitation and clinical outcomes? Does greater expectation increase the likelihood of relapse and rehospitalization? Are subtypes of schizophrenia based on psychological and neurobehavioral measures useful predictors of rehabilitation outcome? What are the enduring effects of a time-limited work therapy intervention?

METHODOLOGY—One hundred fifty patients with DSM-III-R diagnoses of schizophrenia have been recruited, stratified by prior work function and negative symptoms, and randomly assigned to one of three levels of expectation for work: 20 hours (high expectation, N = 60), 10 hours (low expectation, N = 60), or no hours (self-regulation control condition, N = 30) of work required per week. All subjects were offered a work placement at the medical center with duties similar to those of regular employees. Subjects attended weekly groups where support is provided, level of expectation is reinforced, and weekly information on productivity and clinical status are obtained. Research staff evaluated work performance through on-site monitoring and supervisor interview. Half the subjects received weekly pay at $3.40 per hour for 6 months, and half were offered work without remuneration. Clinical status, productivity, and other measures were evaluated at baseline and re-evaluated at 6 and 12 months.

PROGRESS—The study randomized 150 subjects, conducted over 520 group meetings, more than 2,300 weekly individual symptom evaluations and over 950 biweekly work evaluations, and supervised subjects working in excess of 26,000 hours. Staff developed a comprehensive manual of group procedures developed and achieved good to excellent reliabilities on measures used. We have completed 96 percent of 5-month follow-up interviews, 93 percent of 1-year follow-ups, and 94 percent of 3-year follow-ups.

RESULTS—Subjects who received pay were more likely to begin and sustain productive activity. Paid subjects worked more hours than unpaid subjects both during the intervention and the following 6

months. Compared to unpaid subjects, paid subjects demonstrated a decrease in total symptom severity and in positive and emotional discomfort symptoms. Forty-two percent of paid subjects in had at least a 20 percent improvement in emotional discomfort, as well as a significantly lower rate of rehospitalization during the intervention and the following 6 months.

Subjects in the high expectation group worked more 20-hour work weeks than other subjects. However, over the course of the 6-month work program, subjects in the high expectation condition did not work more hours or weeks than other subjects.

Findings indicate that subjects had the greatest impairments in social skills, although these deficits improve over time. Concurrent symptomatology predicts work performance accounting for more than 27 percent of the variance on some measures. Neuropsychological deficits were associated with impairments in work performance.

We have examined methods of subtyping schizophrenia using premorbid history, negative symptoms, and insight level. We found that insight predicted poorer work performance and that negative symptoms predicted poorer performance also, but not decreased levels of participation. We have replicated factor analyses suggesting that symptomatology of schizophrenia can be described using 5 components: positive, negative, cognitive disorder, hostility, and emotional discomfort.

IMPLICATIONS—Findings indicate that pay increases participation in work activity and greater work activity is associated with greater clinical improvements including symptom improvement and fewer relapses. We will shortly assess whether clinical benefits are detectable at three year follow-up.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Positive and negative syndrome scale and brief psychiatric rating scale: reliability and predictive validity. Bell MD, Milstein RM, Goulet JB, Lysaker PH, Cicchetti D. J Nerv Ment Dis 1992:180:723-8.

Pay as an incentive in work participation by patients with severe mental illness. Bell MD, Milstein RM, Lysaker PH. Hosp Community Psychiatry 1993:44:684-6.

Work capacity in schizophrenia. Lysaker PH, Bell MD, Milstein RM, Goulet JG. Hosp Community Psychiatry 1993:44:278-80.

Relationship of positive and negative symptoms to cocaine abuse in schizophrenia. Lysaker PH, Bell MD, Milstein RM, Goulet JL. J Nerv Ment Dis 1994:182:109-12.

Cognitive component of schizophrenia: factorial and concurrent validity. Bell MD, Lysaker PH, Milstein RM, Goulet JG. Psychiatr Res. In press.

Five factor model of schizophrenia. Bell MD, Lysaker PH, Milstein RM, Goulet JG. Psychiatr Res. In press.

Insight and cognitive impairment. Lysaker PH, Bell MD. J Nerv Ment Dis. In press.

Insight and treatment compliance in schizophrenia. Lysaker PH, Bell MD, Milstein RM, Goulet JG, Bryson GJ. Psychiatry. In press.

[98] AGE-RELATED CHANGES IN THE TRICEPS SURAE STRETCH REFLEX AND POSTURAL CONTROL

Steven L. Wolf, PhD, PT, FAPTA; Richard L. Segal, PhD, PT
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E723-RA)*

PURPOSE—This study examines the latency and magnitude of the triceps surae (TS) stretch reflex (SR) across the age continuum and seeks to confirm reports from previous literature that the latency is prolonged and the magnitude of response is reduced as a function of aging. These assessments are a necessary precursor to developing training techniques to improve timing and size of stretch reflex responses to postural perturbations in older individuals. This project specifically seeks to ascertain the relationship between reflex responses and aging in the presence of controlled postural perturbations. Ultimately the goal of this research is to develop instrumentation that will train appropriate reflex responses to sudden postural movements in older individuals and, in the process, reduce the incidence and sequelae of falls.

METHODOLOGY—All data are collected from the release of a platform held in place by an electromag-

net. This release results in a toes-up displacement (range, 10°, approximate velocity, 94°/sec). All subjects are supported by wearing a harness suspended from overhead beams. To eliminate possible fatigue, the number of drops was reduced from the original 250 to 50. Sessions still take from 1-2 hours.

PROGRESS—Thus far 46 of our projected 60 subjects have been evaluated. Before testing these subjects, major modifications on equipment had to be undertaken since our original torque motor could not support the weight of most subjects. Computer programs to analyze the timing and magnitude of muscle responses were written before testing our first subjects. Appropriate procedures to confirm the reliability of data acquisition have also been developed and tested.

RESULTS—Thus far data have been gathered from 46 of our projected 60 (10 subjects per each decade of life; range, 20-90) subjects. Plotting these data in terms of muscle responses to a toes-up perturbation reveals a reduced magnitude of TS muscle reflex response over the age spectrum with a slightly longer latency. In addition, the response from the anterior leg muscles, necessary to correct the toes-up perturbation, shows only a slight increase when corrected for age during the earlier phase of the response (75-100 msec) and a delayed response thereafter (150-225 msec). Final interpretation of these data must await quantitative analysis once all age cells have been filled with a minimum of 10 subjects each.

FUTURE PLANS—We plan to complete our data collection for this phase of the project by October 1994 and to continue in our study to improve SR responses to postural perturbation in older, nonfalling, individuals.

[99] A KNOWLEDGE-BASED SYSTEM FOR SELECTING ELOPEMENT CONTROL DEVICES

Franklin Coombs, MS; Bettye Rose Connell, PhD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E596-2R)*

PURPOSE—This study was designed to develop an expert system to aid administrators and health facilities designers in selecting elopement control devices. Investigators obtained and incorporated data from gerontological experts, facility design experts, and manufacturers on factors contributing to elopement opportunities and extant alarm system performance.

METHODOLOGY—We examined 15 VA and 14 private nursing homes. Sites were selected to represent a variety of nursing home designs representing different situations in which administrators might wish to install alarm systems to control elopement. The descriptions incorporated building layouts, staffing patterns, admission and retention practices, and profiles of individuals at risk of elopement.

These data were then used to identify critical issues in selecting interventions as well as expert opinion on appropriate and effective interventions for specific situations. This information was solicited through administrator responses to case studies and through an expert meeting.

Six elopement control device manufacturers were contacted to obtain specifications of available devices, and request recommendations for elopement control devices to meet the requirements of two prototypical nursing home descriptions used in the expert meeting. Information from those manufacturers was reviewed by electrical and electronic engineers to compare the specifications of the devices, and determine whether the manufacturer-recommended devices met those requirements.

Exsys Professional, an advanced expert system shell development program, was used to structure the expert system. The pilot version was evaluated at the expert meeting. Modifications were then made to incorporate changes in domain expertise, to correct discrepancies, and to add additional functional capabilities.

PROGRESS—The final expert system achieved the goals of this project. Input from the experts, as well as administrators and staff involved in the project, indicated that three facets of the expert system (i.e., description of at-risk patient behaviors, staff availability to monitor at-risk patients, and range of interventions) need to be expanded beyond the scope originally intended. This will be addressed in future research.

RESULTS—There were a number of coincidental findings. Nursing home administrators indicated that there was little information available about elopement control interventions of any kind. Although innovative solutions have been implemented by several VA NHCUs in an effort to prevent elopement, the effectiveness of these interventions could not be evaluated in the present study.

These results have been widely disseminated. Presentations were made at three professional conferences on architecturally based opportunities for elopement and elopement control. A booklet on selecting alarm systems that meet site-specific needs was developed and disseminated to practitioners. A second booklet on secure outdoor spaces is planned. Study results have also been disseminated through continuing education courses for administrators and geriatric nurses. Finally, the results have been applied, in consultation with Loma Linda NHCU staff, in planning renovations to a nursing home unit to accommodate a psychogeriatric program. Results of this collaboration were presented at VA's 1993 National Training Program on the care of the mentally ill in nursing homes, and at meetings for national gerontological nursing and Alzheimer's Association continuing education.

FUTURE PLANS—Proposals are planned that build on this study, including an evaluation of the effectiveness of different interventions (funded), and the effect of facility design on job stress in nursing homes with mixed populations of demented and nondemented individuals (in preparation).

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Alarm system technology in elopement prevention. Sanford J, Fazenbaker S, Connell BR. Tech Disabil 1992:2(1):22-33.

[100] ENVIRONMENTAL AND BEHAVIORAL FACTORS IN FALLS AMONG THE ELDERLY

John Templer, PhD; Bettye Rose Connell, PhD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E539-R)*

PURPOSE—This project's purpose was to study the role of environmental and behavioral factors, as well as personal factors, in falls and near-falls among elderly people. The specific aims were to identify and describe the role of salient environmental and behavioral factors in fall and near-fall events among elderly nursing home residents; compare the relative accuracy of primary data on fall events with postincident self-report data and secondary data; and assess the acceptability of the data collection methodology from the participants' perspective.

METHODOLOGY—Residents at the Atlanta Center with a history of falls were invited to participate. Motion-activated video technology was used to record all activities in participants' rooms over a 2-month period. Following a fall or near-fall, participants were interviewed to reconstruct the event from their perspective. An exit interview with each participant was used to determine participants' attitudes toward the video methodology. Health-related and functional information was obtained using standard clinical procedures.

RESULTS—Twenty-eight individuals participated in seven data collection cycles. Fall or near-fall incidents were observed for 16 participants. There were 47 incidents recorded; 35 were near-falls and 12 were falls. One fall resulted in a serious injury (fractured femur). During postincident interviews, residents

offered simple explanations for incidents that they recalled. Many near-falls were not recalled.

The observational data for each incident were coded to characterize the individual's sequence of body movements, positional changes and interactions with the environment. This procedure was applied to the individual's movements immediately prior to an incident, the incident itself, and recovery from the incident.

A panel of neurologists, orthopedists, physical therapists, gerontological nurses, geriatricians, biomedical engineers, and architectural researchers, knowledgeable about falls in older people, reviewed the case histories of participants and the observational data on incidents. Expert opinion and consensus were used to describe incidents in detail and to identify precipitating factors.

PROGRESS—Three major patterns of causation were identified: multitasking, excessive environmental demands, and inappropriate transfer techniques and use of assistive devices. Multitasking incidents reflected difficulties with walking and engaging in another activity at the same time. Incidents involving excessive environmental demands reflected an absence of environmental features to compensate for functional losses (e.g., lack of handholds in open space, changes in lighting levels), and use of inappropriate items as assistive devices (e.g., unlocked wheelchairs, rocking chairs). Incidents involving inappropriate transfer techniques and use of assistive devices included inappropriate independent and assisted transfers and ambulations.

The expert panel also identified potential interventions to reduce or delay the occurrence of incidents similar to those observed. These include modifying inappropriate behaviors, environmental changes, and staff training. The experts also identified needed research in the area of falls in older people.

FUTURE PLANS—An intervention agenda based on the experts' input will be formulated, linking risk factors and interventions. This agenda will be developed and submitted for publication. The expert panel's suggested research agenda will also be developed as a publishable article. Finally, observational components of the study methodology are being replicated at the Durham VA ECRC to assist staff in developing and evaluating interventions for frequent fallers.

[101] EVALUATION OF INTERVENTIONS TO PREVENT ELOPEMENT AMONG NURSING HOME PATIENTS

Bettye Rose Connell, PhD; Jon A. Sanford, MArch
Atlanta VA Medical Center, Decatur GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E759-RA)*

PURPOSE—This 2-year study evaluates the effectiveness and appropriateness of widely used interventions to control elopement among dementia patients in long-term care. The interventions studied are electronic alarm systems and secure outdoor spaces. We shall examine the difference in the average time that elapses between elopement incidents and staff detection, with and without alarm system use; whether alarm system use reduces the frequency of subjects' elopement incidents; whether the availability of a secure outdoor space reduces the frequency of subjects' elopement incidents; whether the availability of a secure outdoor space reduces the amount of time subjects spend near exit doors; whether alarm system use negatively impacts mood and behavior among residents at risk of elopement; and whether alarm system use and subject access to secure outdoor spaces reduce staff job stress ratings.

METHODOLOGY—This project employs a single subject (multiple baseline across sites) design. Video-based observations will be used to monitor and evaluate the effectiveness of technological and environmental interventions. Researchers will evaluate interventions for their effect on frequency of elopement incidents, the time required for staff detection and response to elopement incidents, resident mood and behavior, and staff stress. At least three

individuals considered by staff to be at risk of elopement will be selected at each of the three VA NHCUs participating in the study.

Multiple baseline methodology will be used to collect baseline data, followed by staggered implementation of the interventions at all three sites. The first intervention will be a wall-mounted alarm system. The second will be a secure outdoor space adjacent to the unit. Intervention 2 will not be implemented until after the frequency of target behaviors has stabilized following Intervention 1. Data on the frequency of actual and attempted elopements, and the duration of elopement incidents prior to staff detection, will be collected during baseline and during each phase.

During the baseline period video observation will continue from 6AM until 8PM to obtain information on which to base a postintervention time sampling plan. Video tapes will be viewed and coded to identify target behavior incidents. Interrater reliability for incident identification will be established by having an independent observer repeat the tape screening for 25 percent of the tapes. Agreement level will be computed by dividing the number of agreements by the number of agreements plus disagreements. Tape reviewers will be trained until their agreement percentage reaches 90. To prevent reliability decay, a random sample of each reviewer's incident identification will be checked at weekly intervals during the study. Cohen's kappa will be used to determine interrater reliability for the coding of target behaviors. After coding by the primary coder, an independent coder will recode target behavior occurrences for 25 percent of the incidents identified by initial tape review. Training for coders will continue until a Cohen's kappa of at least 0.70 is obtained. Random sample of coder classifications of target behaviors will be checked for the duration of the study.

Unintended negative effects of the interventions will be evaluated by staff ratings of subjects' mood and behavior, using an instrument similar to Section E of the Minimum Data Set (administered weekly by primary care staff). Staff stress will be evaluated with the Maslach Burnout Inventory, administered during the baseline period, at the end of Intervention 1, and at the end of the Intervention 2.

PROGRESS—The study was begun in April 1994; beyond initial steps, no results are in hand at the time of this writing.

[102] DESIGN OF NEW TOILET PROTOTYPES FOR ELDERLY AND DISABLED VETERANS

Jon A. Sanford, MArch; Pascal Malassigne, MID
Atlanta VA Medical Center, Decatur, GA 30033; Clement J. Zablocki VA Medical Center, Milwaukee, WI 53295

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E666-RA)*

PURPOSE—This 2-year study to design and test new toilet prototypes is one in a series of projects that are concerned with the ability of older and disabled people to carry out routine daily activities independently and safely. Difficulty in toileting independently is common among nonambulatory individuals who have problems transferring between their wheelchairs and a toilet as well as with older people with gait and mobility problems who experience difficulty raising and lowering themselves on and off a toilet. In response to the problems, this study will develop and evaluate two new prototypes and four retrofit designs to be used with existing toilets that are intended to foster safe and independent toileting among nonambulatory older and disabled individuals who can transfer independently. Each of these designs will be fitted with grab bars in order to ensure independent and safe transfer and toileting among older and disabled veterans. The study will result in research-based information that can be used in the future development of new products that will better fit the needs of the target populations.

METHODOLOGY—The safety and responsiveness of the toilet prototypes will be based on expert assessment of subjects' performance simulating toileting activities and feedback from the partici-

pants of perceived independence and safety. Participants will be videotaped using each of the designs, as well as a control design. Each will be evaluated in terms of its safety and responsiveness to the participants' functional capabilities.

The methods and procedures developed for our previous and ongoing studies have been adapted for this study. These include 1) an analysis of previous research and anthropometric data in order to develop criteria for new toilets designs (e.g., data collected on physiological and functional abilities of users, data on toilet fixture design, manufacturing processes, and toilet room configurations), 2) development of design alternatives and construction of full-scale toilet prototypes based on the design criteria, 3) testing of subjects simulating toileting activities and solicitation of subject ratings of perceived safety and independence of each of the toilet and grab bar configurations, 4) expert analysis of videotapes of each subject simulating toileting activities, and 5) analysis of pre- and posttrial questionnaires in order to rate and validate the function of the prototypes, redesign and modification of prototypes as necessary based on the analysis, and preparation of design recommendations and guidelines.

PROGRESS—The prototype and retrofit designs have been designed, constructed, and pretested. Modifications have been made to the designs as indicated by the pretests and testing has begun. Ten participants have been tested; seven are male and three are female. Testing has taken place on one prototype (straddle toilet) and two retrofits (wide insert with recessed handles and insert with side handles). The passive assistance with angled seat prototype as well as the narrow insert with recessed handles and insert with vertical handles has not yet been tested.

FUTURE PLANS—Testing will continue in Milwaukee until 1994. At that time, the test unit and the toilet prototypes and retrofit designs will be returned to Decatur to complete the testing. The data will be analyzed and recommendations regarding potential modifications will be made.

[103] APPLICABILITY OF ACCESSIBILITY CODES TO MEET THE NEEDS OF ELDERLY PEOPLE

Jon A. Sanford, MArch; Ron Mace, FAIA
Atlanta VA Medical Center, Decatur, GA 30033; Center for Accessible Housing, North Carolina State U, Raleigh, NC 27695-8613

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E629-RC)*

PURPOSE—This study examined several key design characteristics impacting the safety and independence of elderly people in toileting. In addition, toilet configurations based on accessibility standards for toileting were compared to designs intended to assist older people.

METHODOLOGY—Participants were recruited from staff and outpatients at the Atlanta VA Medical Center, residents of three private nursing homes and three senior centers in the Atlanta area, and residents at the Atlanta, C.J. Zablocki, and Audie L. Murphy VA NHCUs. In all, 116 individuals were tested; 66 were ambulatory and 50 used wheelchairs.

The project used a task performance and analysis methodology in a repeated measures design. A transportable mockup of a toilet room was constructed, with accommodations for two toilet seat heights and four grab bar configurations at two heights, as well as for two cameras for videotaping the trials. The walls of the testing unit were marked with a grid to indicate where the grab bars were grasped in the trials.

The protocol included a pretrial interview and eight test trials. The pretrial information included demographic, cognitive, and medical/physical information, as well as personal characteristics. The trials consisted of asking participants to approach and get on the toilet, stay seated a few seconds, and get off.

Each trial was videotaped from the side and from overhead. This was repeated for each configuration at both heights.

After each trial, participants evaluated their performances. The posttrial interviews included questions related to safety, ease of use, and helpfulness of the grab bars. After all eight trials, participants were asked to rank the configurations for safety, ease of use, and personal preference.

The video data were scored using scalar rating categories of safety and independence. The coding system included issues such as location of body when undertaking a task, location of hand(s) on the grab bar(s), and location of body in relation to the toilet.

PROGRESS—The project was completed in October 1993.

RESULTS—This study provides evidence to support anecdotal data that accessibility standards do not meet the needs of older individuals. These data clearly indicated that non-compliant grab bars are at least as effective for ambulatory and, in some cases, more useful for nonambulatory older adults. Moreover, dual side bars flanking the toilet are most effective when the toilet is not located next to a side wall, eliminating the need for traditional three- or five-foot wide toilet stalls with walls within reaching distance of either side of a toilet.

These findings are particularly important in the design of such facilities as nursing homes and senior centers, where the law mandates one thing but where individual needs mandate something different. It is even possible that the use of code-compliant configurations might increase dependence, whereas alternative, noncompliant configurations might promote independence. These results also provide much needed criteria for the design of new grab bar configurations to enhance the safety and independence of older people in toileting. Of particular interest are side bars that incorporate a diagonal element, side bars located at multiple heights, and side bars that facilitate pulling oneself out of a wheelchair and across the toilet seat.

FUTURE PLANS—This study was concerned only with independent transfer. Many older individuals require person-assisted transfers regardless of the grab bar configuration. Although pivoting dual side grab bars, such as those examined here, would appear to offer increased flexibility, choice, and space in which to accomplish a person-assisted transfer, further research is planned to determine the optimum configurations for these types of transfers.

[104] BALANCE TRAINING IN ELDERLY FALLERS AND NONFALLERS

Carol E. Coogler, ScD, PT; Steven L. Wolf, PhD, PT
Emory U School of Medicine, Atlanta, GA 30322

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E542-RS)*

PURPOSE—We seek to determine whether balance biofeedback training has led to improvements in balance scores as measured by dynamic posturography, and whether this form of training produces changes in incidence of falls in the faller group different from the nonfaller group.

To this end, we are investigating whether documented histories of falls in older adults can be detected by a dynamic posturography evaluation, and we are comparing the results of traditional sensory and motor balance testing results to the results obtained from dynamic posturography evaluation. We also want to assess the effectiveness of a balance training device that utilizes visual biofeedback for postural control, determine the effectiveness of the balance training in decreasing the number of falls in older adults, and to assess the long-term effects of balance

training on the postural control characteristics tested.

METHODOLOGY—From four different independent living centers in Atlanta we recruited 86 subjects between the ages of 65 and 99 who met the criteria and consented to participate in the project. Each subject was assessed, signed an informed consent, classified as a faller or nonfaller, and randomly assigned to the treatment or nontreatment group. Each was evaluated three different times: pretest, posttest, and 4-month follow-up. Those subjects assigned to the treatment group received eight, 1-hour balance training sessions during a 1-month interval, while the subjects assigned to the nontreatment group only kept a record of their falls but received no treatment.

PROGRESS—Only six of the subjects did not complete all of the testing, due to falls, stroke, and death. The data has been entered in the computer and analysis is being completed at this writing.

[105] EFFECTS OF STRENGTH CHANGES FOR OLDER ADULTS

L. Jerome Brandon, PhD; Beth Sharon, MS; Lisa Boyette, MEd
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E721-RA)*

PURPOSE—Muscle strength is generally recognized as a major component of successful performance in almost every physical activity, including activities of daily living. A decline in strength associated with the resorption of bone and the diminishing integrity of muscle and connective tissue is a common characteristic of aging that threatens the independence of elderly persons. Therefore, this 2-year study was designed to evaluate the effects of resistive strength training and flexibility exercises on muscle strength, muscle morphology, and functional ability in older adults.

This research will provide insights on the benefits of resistive strength training and flexibility exercises which should assist in establishing guidelines for a more active and independent senior existence.

METHODOLOGY—This study is designed to evaluate the impact on muscular fitness of a 4-month resistive strength training and flexibility exercise intervention. Between 45-50 elderly participants will train 3 days a week for 1 hour daily. A control group of 45-50 individuals will receive the same treatment as the experimental group, except for the training intervention. A repeated measured experimental design, where both the experimental and control groups receive pre- and post training assessments for muscle strength, endurance, flexibility, balance, and functional ability, will be employed in this study. Morphological changes within the muscle will be assessed with Magnetic Resonance Imaging and selected anthropometric measurements. Balance will be measured by a Neurocom Equitest Dynamic Posturography machine. Selected functional ability tests will also be employed.

PROGRESS—We have completed data on 37 experimental subjects and 26 control subjects. The final groups will begin during this summer and we expect to complete data collection during the fall.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Effects of strength training on muscle fitness development in older females. Abstract. Sharon BF, Boyette L, Anderson KA, Brandon LJ. J Aging Phys Activity 1993:1(1):109-10.

Effects of strength training on elderly females. Abstract. Sharon BF, Boyette L, Anderson KA, Brandon LJ. Med Sci Sports 1994:26(5):S214.

[106] RESTRAINT OF AMBULATORY NURSING HOME RESIDENTS WITH COGNITIVE IMPAIRMENTS

Dale C. Strasser, MD; Catherine H. Hennessy, DrPH
Atlanta VA Medical Center, Decatur, GA 30033; Centers for Disease Control and Prevention, Atlanta, GA 30307

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E722-RA)*

PURPOSE—The purpose of this 2-year study is to investigate the behaviors and environmental factors that result in the use of physical or chemical restraints on ambulatory, cognitively impaired nursing home residents. The frequency of restraint use is being observed systematically to estimate the impact of federal legislation mandating restraint reduction and the changing nursing home environment. Influences on staff decision-making regarding restraint are also being investigated.

METHODOLOGY—We have gathered data from video monitoring and direct observation to determine the prevalence and correlates of physical restraint use. A coding scheme to identify restraint status, ambulation status, the presence of staff, and agitated behavior has been developed. This coding scheme is being applied to randomly sample footage of videotapes taken in the research site in 1988, 1990, and 1993/1994, and to direct observations made in the nursing home in 1994. The use of these time periods permits an assessment of restraint use before, during, and after the enactment of federal restraint reduction guidelines. Analysis of the data has focused on determining the proportion of residents restrained, staff-to-resident ratios, and time trends in restraint during these three study periods, and between two different floors of the facility (one serving more cognitively impaired residents). Chemical restraint use will be assessed through a review of patient medication records, including standing orders and PRN use of psychotropic medications. Additional information on patient characteristics, including functional status and medical conditions, is being collected from the 1993 Minimum Data Set (MDS) record for each resident. Focus groups with nursing home staff and administrators have also been conducted to obtain in-depth qualitative information on institutional environment, regulatory, financial, and other factors influencing decisions to restrain. An additional study to model restraint decisions based on staff responses to hypothetical case vignettes is being developed.

RESULTS—The videotape analysis indicated that more residents were restrained on the unit serving the more cognitively impaired residents (48 percent vs. 11 percent). On the unit with higher restraint use, wheelchair use tripled between 1988 and 1993, and the number of Geri-chairs also increased significantly over this time period. The percentage of residents restrained (including Geri-chair use) decreased from 1988 (48 percent) to 1990 (32 percent), but increased in 1993 (65 percent). The 1994 participant observations corroborated the prevalence of restraints established from the 1993 videotapes. These data and other descriptive information on the residents suggest that care management in this facility, including patterns of restraint use, reflects the needs of a population that is aging in place. Results from the focus groups confirm staff awareness of and strategies for dealing with the needs of an older, more impaired nursing home population than in previous years. Major concerns among the nursing staff related to the perceived need for restraint use included fall risk, positioning, time constraints, and insufficient staff-to-resident ratios. Nursing home administrators' comments emphasized the regulatory, fiscal, and staffing requirements that constrain quality of care and place limits on resident autonomy.

FUTURE PLANS—The project has been extended to March 1995. Tasks to be accomplished during the extension include the completion of data analysis and dissemination of the results. In addition to the publication listed below, dissemination to date has included a presentation of preliminary findings at

the 1993 Gerontological Society of America (GSA) meeting. A symposium to present project findings has also been accepted for the 1994 GSA meeting, and an invited article is in preparation for Nursing Home Medicine.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Restraints in long-term care. Archea C, McNeeley E, Martino-Saltzman D, et al. Phys Occup Ther Geriatr 1993:11(3):3-23.

[107] EFFECTS OF AGE AND RESISTANCE TRAINING ON SKELETAL MUSCLE

Jane F. Hopp, PhD, PT; Margaret F. Baumann, MD
Department of Physical Therapy and Section of Geriatric Medicine, Department of Medicine, University of Illinois at Chicago, Chicago, IL 60612; VA Medical Center, Chicago, IL 60612.

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E724-RA)*

PURPOSE—The specific aim of this project is to determine the effects of race and age on skeletal muscle contractile performance and anaerobic metabolism during isokinetic resistance exercise. This work will result in the development of strengthening programs that will improve skeletal muscle force generating capacity and the physical capacity of old persons.

METHODOLOGY—Healthy Caucasian and African American men, 20 to 35 years of age (adult) and 69 years of age and older (old), participate in this study. Forces produced by the subjects' right quadriceps femoris muscles are measured using an electromechanical dynamometer during a single bout of maximal isokinetic resistance exercise and during 12 weeks of resistance training. Needle biopsies of the subjects' right vastus lateralis muscles are performed prior to and following the exercise bout and prior to and following 12 weeks of training. Anaerobic substrate and metabolite concentrations are determined in mixed and single fast- and slow-twitch muscle fiber preparations.

PROGRESS—Investigation of quadriceps femoris muscle group force production and anaerobic metabolism in adult Caucasian and African American men and old Caucasian men during a bout of 35 maximal isokinetic concentric contractions performed at an angular velocity of 3.14 rad/sec have been conducted. Biochemical analyses to determine anaerobic substrate and metabolite contents in mixed and single fast- and slow-twitch muscle fiber preparations from pre- and post-training biopsy samples have also been performed.

RESULTS—Preliminary results suggest that the percent decline in quadriceps femoris muscle peak torque during a maximal isokinetic exercise bout is similar in adult Caucasian and African American men. Anaerobic glycolysis in the vastus lateralis muscle during the bout is also similar in adult Caucasian and African American men. Phosphagen utilization in the vastus lateralis muscle during the bout is, however, greater in adult African American men compared to adult Caucasian men. During the bout, there is a greater utilization of intramuscular phosphagens in vastus lateralis fast-twitch fibers compared to vastus lateralis slow-twitch fibers in both adult Caucasian and African American men. The finding that adult African American men have a slightly higher percent of fast-twitch fibers and a slightly lower percent of slow-twitch fibers in the vastus lateralis muscle than adult Caucasian men may explain, in part, the racial difference in intramuscular phosphagen utilization during the bout.

Quadriceps femoris muscle peak torque decline during a maximal isokinetic exercise bout is greater in adult Caucasian men compared to old Caucasian men. Anaerobic glycolysis in the vastus lateralis muscle during the bout is, however, similar in adult

and old Caucasian men. Phosphagen utilization in the vastus lateralis muscle during the bout is also greater in old Caucasian men compared to adult Caucasian men. In old Caucasian men, the cross-sectional area of vastus lateralis fast-twitch fibers is decreased compared to the cross-sectional area of vastus lateralis fast-twitch fibers in adult Caucasian men. Based on these preliminary findings, the ability of the vastus lateralis muscle to generate energy anaerobically during a bout of maximal work does not decrease with age in men. Thus, an impaired anaerobic energy supply in the vastus lateralis muscle does not appear to contribute to the age-related decline in quadriceps femoris force production. The age-related decline in quadriceps femoris force production may be due, in part, to a decline in the size of aging fast-twitch fibers.

FUTURE PLANS—Investigation of the effects of 12 weeks of resistance training on quadriceps femoris muscle force production and on anaerobic metabolism in mixed and single fast- and slow-twitch fiber preparations obtained from vastus lateralis muscle of adult and old men prior to and following training will be conducted.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Effects of age and resistance training on skeletal muscle: a review. Hopp JF. Phys Ther 1993:73(6):361-73.

[108] QUANTITATIVE POSTUROGRAPHY: AGE-RELATED CHANGES IN POSTURAL STABILITY

James J. Collins, PhD; Carlo J. DeLuca, PhD; Joseph F. Jabre, MD
VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E720-2RA)*

PURPOSE—The goals of this posturographic study are 1) to gain a better understanding of how the natural aging process affects the neuromuscular mechanisms involved in balance control, 2) to demonstrate that elderly fallers can be distinguished from healthy elderly individuals, and 3) to begin developing an objective, noninvasive technique to identify elderly individuals who are at risk of losing their balance and falling.

METHODOLOGY—In the pilot study, we developed a technique, stabilogram-diffusion analysis, for examining quiet-standing center-of-pressure (COP) trajectories. This approach was applied to populations of 25 healthy young subjects (aged 19-30) and 25 healthy elderly subjects (aged 71-80). These analyses, revealed that when the COP trajectories obtained during quiet standing are interpreted over short-term time intervals (throughout the duration of the COP time series), open-loop control schemes are utilized by the central nervous system, whereas, when interpreted over long-term time intervals, closed-loop control mechanisms are called into play to regulate upright stance. This approach led to the extraction of repeatable COP parameters that could be directly related to the resultant steady-state behavior and functional interaction of the neuromuscular mechanisms underlying balance control.

These investigations also showed that visual input is integrated into the postural control system in one of two different ways: either it significantly modifies the open-loop postural control mechanisms, or it significantly alters the other closed-loop postural control mechanisms. In addition, the pilot study clearly demonstrated that stabilogram-diffusion analysis can be utilized to distinguish the COP trajectories of healthy young subjects from those of healthy elderly subjects. Similarly, this work showed that the aging process results in changes in the functional organization of the open-loop and closed-loop control systems involved in postural control and that these changes can be characterized quantitatively during periods of undisturbed stance.

In this proposed full study, we plan to expand the above posturographic investigation of healthy individuals to the full range of ages and to examine aged individuals who have documented histories of postural instability and falling. Specifically, we will examine the postural stability of 125 healthy sub-

jeets. This population will be broken down into five age groups of 25 subjeets eaeh. The age groups to be studied are: 31-40, 41-50, 51-60, 61-70 and 81-90. We will also examine 50 elderly patients with doeumented histories of postural instability and failing. This latter population will be divided into two groups of 25 patients eaeh: elderly fallers with vestibular disorders, and elderly fallers with peripheral neuropathies.

These studies will be direeted toward aehieving the six speeifie objeetives. We seek 1) to develop a simple, elinieal teehnique for quantitatively evaluating an individual's postural stability, 2) to evaluate the ability of stabilogram-diffusion analysis to diseriminate between healthy elderly individuals and aged patients with doeumented histories of postural instability and falling, 3) to gain an inereased understanding of how the aging proeess affeets the funetioning and the interaetion of the open-loop and elosed-loop eontrol sehemes involved in postural eontrol 4) to establish a normative posturographie database for different age groups, 5) to gain an inereased understanding of the age-related effeets visual input has on the steady-state behavior of the open-loop and elosed-loop postural eontrol meehanisms, and 6) to begin developing a multivariate statistieal teehnique that ean be used to identify and diagnose elderly individuals who are at risk for falling and to evaluate quantitatively the progress of rehabilitation therapies applied to sueh individuals.

IMPLICATIONS—The information derived from these studies eould eventually be utilized for the diagnosis of postural and movement disorders and for the rational design of effeetive rehabilitation therapies. It is hoped that this work will reduee the frequency, morbidity, and eost of falling in the aged and thereby improve the general quality of life for elderly veterans.

[109] EFFECT OF CHAIR DESIGN ON CHAIR RISE PERFORMANCE IN DISABLED OLD ADULTS

Neil B. Alexander; Daniel J. Koester; Albert B. Schultz.
Geriatrics Center, University of Michigan, Ann Arbor, MI 48019-0010; GRECC, VA Medical Center, Ann Arbor, MI 48195

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E760-RA)*

PURPOSE—Diffieulty in rising from a ehair is a signifieant problem for many older veterans. The purpose of this researeh is to investigate, biomeehanieally, why many older persons have diffieulty with important ehair mobility tasks. By using these measurements, we hope to understand how aspeets of ehair rise performanee and ehair design influenee sueeessful rises from a ehair.

In subjeets who differ by age and by funetional disability, our objeetives are to understand how performanee biomeehanies are influeneed by eertain ehair design parameters and joint motion strategies and by available strength, joint range of motion, and balanee eapabilities.

METHODOLOGY—Using an optoeleetronie eamera system and seat and foot foree plates, we will measure body segment kinematies and external support reaetions that young (aged 20-35) and old (aged 60 and over) adult subjeets use to rise from an adjustable laboratory ehair. We will then utilize a biomeehanieal model to provide the peak joint torque strengths used. Finally, we will examine the relationships among 1) age, 2) disability level, 3) available strength, joint range of motion, and balaneing ability, 4) sueeess in rising during the chair task and the ehair design parameters assoeiated with the task, and 5) the joint ranges of motion and torque strengths used when they sueeeed.

PROGRESS—Young and old adults performed ten ehair rise tasks designed to present an inereasing level of rise diffieulty, based on varying seat height, handle use, foot support, and rise speed. All young and old adults were able to rise when the seat was raised to a position simulating a bar stool, with or without use of handles and when the seat was lowered to standard height, whether the handles

were at the side or in the front. The old were unsuccessful in rising when they had to slow their rise speed and when they had to rise while standing on a reduced support surface (a beam). Pending biomechanical analyses of the joint torques and joint ranges of motion required to perform these rises will provide insight into why some old adults did not succeed in rising.

RESULTS—In our pilot study, we videotaped young (n = 22) and older adults living independently in a retirement center (O, n = 29) as they rose from a laboratory chair designed to vary seat height, backrest recline/seat tilt, and seat compressibility. Task performance timing and body motion were acquired by digitization of the video record. Subjects also reported on rise difficulty and seating comfort using a 5-point scale. We were thus able to quantitatively assess the rise challenge that common chair design parameters presented to frail, yet independent older adults. Decreased seat height, increased backrest recline/seat tilt, and increased seat compressibility required longer rise times and greater body motion. While increased seat height apparently alleviated some rise difficulty, increased height was also rated as less comfortable.

FUTURE PLANS—We will reexamine the effects of chair design parameters in a more technically involved protocol as specified above. The implications of these studies thus far are that chair design parameters can affect rise performance in older adults. Moreover, chair adjustments, such as in height, may assist egress from the seat, but possibly at the expense of decreasing seating comfort.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Chair design affects how older adults rise from a chair. Alexander NB, Koester DJ. J Am Geriatr Soc 1993:41:SA16.

[110] EFFECTS OF MUSCLE STRENGTH ON BALANCE DURING MOVEMENT IN THE ELDERLY

M. Melissa Gross, PhD; Carol H. Winograd
VA Medical Center, Ann Arbor, MI 48105

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E642-RA)*

PURPOSE—Falls are a serious problem in the elderly. Approximately one-third of those above age 65 fall each year, and many of these falls result in serious injury, even death. Much research effort has gone into identifying the causes of falls in the elderly. Although these studies have determined the significant factors that correlate with falls, they do not provide an understanding of how each risk factor contributes to postural instability and falling. Specifically, the role of decreased muscle strength in falls has not been examined. For example, it is not yet known which muscles are most important to maintain balance, and how strong they should be to perform activities of daily living with a low risk for falling.

Our approach in the proposed study is to understand how muscle strength contributes to balance during movement and risk for falling in the elderly. We have chosen to focus on balance during movement, rather than during standing, since most falls occur during movement. We hypothesize that decreased muscle strength in the elderly limits their ability to maintain balance during movement, and thus contributes significantly to their risk for falling. We expect that improved understanding of the effects of muscle strength on balance during movement will aid in the design of muscle-strengthening programs to decrease fall risk in the elderly.

METHODOLOGY—Thirty-nine residents (mean age 83.4 yrs.) of a local retirement center participated in the study. Subjects were screened for functional ability and medical status, and were assigned to intervention or control groups. The intervention group exercised 3 times per week for 12 weeks in a progressive-resistance, strength-training program under the guidance of a personal trainer. The control subjects participated in a low intensity

stretch and range of motion exercise program 3 times per week for 12 weeks. Intervention and control subjects were subsequently crossed over into the other group for an additional 12 weeks of participation.

Each subject underwent 6 sessions of biomechanical testing: just before, midway, and just after their participation in the intervention and control programs. Subjects were asked to rise from a chair in a variety of conditions that challenged the strength and balance demands of the task (e.g., with or without use of hands) and to perform standing balance tasks (e.g., one and two-legged stance).

PROGRESS—Data analysis is underway. All but the most frail of the exercise subjects were able to markedly increase their exercise effort (i.e., repetitions × resistance level) over the 12-week course of training sessions. Preliminary results showed that some intervention and control subjects were able to complete more chair rise tasks than they had prior to the intervention period. Even after only 6 weeks of strength training, exercise subjects showed quantitative changes in chair-rise performance. For example, subjects participating in the exercise intervention were able to rise from a chair significantly faster than the control subjects.

IMPLICATIONS—With this study, we expect to find if a muscle strength training program can significantly affect the ability to perform a variety of chair rise and balance tasks in a group of elderly individuals with varying levels of disability. Not only will we determine whether functional capacity increases, but also how performance of the tasks changes quantitatively as a function of the exercise training program. We expect that such information will lead to further development of intervention programs to maintain mobility and decrease fall risk in elderly individuals.

[111] DO CHANGES IN STRENGTH IMPROVE BALANCE AND FUNCTION IN ELDERLY MEN AND WOMEN?

Gary Kochersberger, MD; Stephanie Studenski, MD, MPH; Pamela Duncan, PhD, PT; Julie Chandler, MS, PT; Margaret Schenckman, PhD, PT
Extended Care Rehabilitation Center, Durham VA Medical Center, Durham, NC 27705

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E661-RA)*

PURPOSE—Physical frailty becomes more prevalent as age increases. Some portion of frailty appears to be due to disuse or deconditioning and may be reversible. While there is strong evidence that one aspect of frailty, strength, can be improved in older persons, it is less clear that overall improvements in function result. Thus, the focus of this study is not on the ability to increase strength, but on the ability of increased strength to reverse functional loss.

The large majority of frail elders reside in the community. For reasons of access, however, most intervention studies have focused on well community dwellers or frail persons in congregate settings. This study was designed to bring the intervention directly into the homes of frail elders in order to target the most relevant population. The study combines the use of a strengthening exercise program based on principles of exercise physiology, a highly relevant population and the use of state-of-the-art measures of physical performance and balance to answer the key question of whether increasing strength results in improved physical performance and balance in frail community dwelling elderly.

METHODOLOGY—Following signing an informed consent and examination by a physician, subjects undergo a test battery that involves measurements of lower extremity strength, endurance and balance. Subjects are randomly assigned to a control or an intervention group. Those in the intervention group immediately begin a 10-week, in-home supervised exercise program of progressive resistance exercise using body weight and Theraband, incorporating concentric and eccentric contractions at functional

velocities. Those in the control group are followed via letters and phone calls during the 10 weeks, with subjects in both groups returning to the VA for a post-test at the end of the 10 weeks. Subjects in the control group are then offered the exercise intervention. Outcome measures are designed to assess change in strength, postural sway, balance, physical performance, confidence in mobility, and physical function.

PROGRESS—Wc have met our goal of enrolling 100 subjects (50 men, 50 women) in this study. Twelve subjects have dropped out of the study due to medical reasons. By June, 96 subjects had completed the program, and the final 4 subjects were scheduled for their post-test. Data entry has occurred on a rolling basis. Preliminary data analysis has begun.

RESULTS—The main hypotheses have not been tested. Results thus far are from preliminary analyses only. In a subset of 57 subjects therc was a 16 percent gain in the summary isokinetic strength index (ankle dorsiflexion, knee extension) in the intervention group versus a 1 percent increase in strength in the control group. In a subset of 61 subjects, following the exercise intervention, significant increases in strength were found in right quadricep peak torque at 60°/scc and isometrically. These strength gains were found to occur independently of age, depression, and physical performance.

FUTURE PLANS—Four abstracts have been submitted to Gerontological Society of America's 47th Annual Meeting with acceptance pending. One abstract has been submitted to the Society of Biomechanics' Annual Meeting with acceptance pending. A paper is currently being written on Postural Sway and its Relationship to Physical Impairment and Function. Data analyses of the primary hypotheses will occur once all subjects have completed the intervention. A number of secondary papers arc planned.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Developing an index of ankle strength. Duncan PW, Chandler JM, Samsa G, Rose D, Studenski SA. Gerontologist. Program Abstracts 46th Annual Scientific Meeting, Gerontological Society of America 1993:33(Special 1):140.

Postural sway and its relationship to physical impairment and function. Rose DK, Duncan PW, Hughes, MA, et al. Gerontologist. Program Abstracts 46th Annual Scientific Meeting, Gerontological Society of America 1993:33(Special 1):146.

[112] SYNCHRONIZED ELECTRICAL STIMULATION THERAPY IN ELDERLY INCONTINENT MEN: A PILOT STUDY

Pat D. O'Donnell, MD
Cincinnati VA Medical Center, Cincinnati, OH 44199

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #E91-356 AP)*

PURPOSE—Urge incontinence related to detrusor hyperreflexia is the most common cause of one of the most debilitating problems affecting older veterans; it is also one of the major causes for confinement of older veterans to chronic care facilities. The purpose of this project is to determine the efficacy of electrical stimulation on urinary incontinence in older men.

METHODOLOGY—The type of electrical stimulation is noncontinuous delivered prior to the onset of an involuntary detrusor contraction, with the stimulation being activated by a prototype electronic monitoring device. Electronic signals from the external anal sphincter were recorded telemetrically to determine the pattern of electromyographic activity that occurs prior to the onset of the contraction. The analysis of the signal has been processed for determination of waveform characteristics and a prototype detection circuit has been developed bascd on these electromyographic wave characteristics. When the pattern of electromyographic activity that precedes a contraction is detected by the prototype detection circuit, an electrical stimulation is deliv-

ered to the external anal sphincter: this results in reflex inhibition of the bladder that prevents the involuntary detrusor contraction and hence the urinary incontinence.

The design of the study involves baseline monitoring of incontinence severity based on frequency of incontinence episodes and volume of involuntary urine loss. The control group has a delay without treatment with incontinence severity outcome measures performed after the delay interval. The experimental group has baseline measures of incontinence severity following electrical stimulation and incontinence severity outcome measures following therapy.

The efficacy of the synchronized electrical stimulation treatment will be determined by a comparison of the incontinence severity measures among the control group which has a delay in therapy and the experimental group which has immediate therapy. Following the incontinence severity measures in the delay group, that group will undergo synchronized electrical stimulation treatment with outcome measures following therapy. The outcome measures in each group will be compared as well as pretreatment and posttreatment continence severity.

PROGRESS—This synchronized electrical stimulation device has the potential to specifically treat detrusor hyperreflexia and result in continence for chronic-care incontinent older men. Incontinence in older chronic-care men due to detrusor hyperreflexia represents one of the most difficult management problems in this group of patients.

[113] MANIPULATING JOINT COMPLIANCES AND GROUND-REACTION FORCES TO PREDICT FALLING POTENTIAL: A PILOT STUDY

Charles J. Robinson; Mark Redfern; Gyan Agarwal
Highland Drive VA Medical Center, Pittsburgh, PA 15206; University of Pittsburgh; Pittsburgh, PA; University of Illinois at Chicago, Chicago, IL

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #E91-355AP)*

PURPOSE—The objective is to develop a novel device to measure postural stability and, by extension, the potential for an individual to fall. This device consists of a sliding plate where the friction between the plate and its guide rails can be set between zero and infinity. Thus, the plate is either completely fixed, or completely slippery (electric banana peel) or somewhere in between. The plate's movement can be controlled, so that it can also be translated in a manner similar to other postural support platforms. We also can correlate measures from this platform with other measures taken with the ankle and knee joint compliance test fixtures that were recently transferred to our lab from the Hines VA Rehabilitation Research and Development Center.

METHODOLOGY—Once version 2 is available, the subjects will be asked to stand quietly on the plate. In unpredictable fashion, the slip friction of the plate will be varied, so that the horizontal component of the anterior-posterior ground reaction force vector will initiate movement when this force exceeds the friction and static friction (stiction) forces. We also will test the subject's ability to compensate (with eyes open and with eyes closed).

PROGRESS—Version 1 of the device has been built with VA funds and tested. This version uses precision, recirculating ball bearing slides to support the platform, a 4 horsepower torque motor to stabilize or move it, and a custom, programmable controller to adjust the closed loop feedback parameters depending on the slipperiness desired. The design worked well to minimize dynamic friction, but it proved to have excessive resistance to initial movement (stiction). Thus, using funds from the University of Pittsburgh, Version 2 has been designed and should be available mid-summer 1994. This version uses air bearings and a linear motor, and incorporates load cells into the four corners of the platform.

With the pilot funding, we have constructed a safety cage from commercially available Uni-Strut

framing so that when subjects stand on the plate, they are in a safety harness to prevent actual falls. We have secured a widely used piece of clinical equipment, the NeuroCom, to carry out some perturbation experiments, and to compare those results with findings from our test device.

[114] BEHAVIORAL TREATMENT OF URINARY INCONTINENCE

J. Gary Linn, PhD; Hazel L. Best; Kristen M. Holzapfel, MA
Alvin C. York VA Medical Center, Murfreesboro, TN 37130

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E725-RA)*

PURPOSE—This study is attempting to validate prompted voiding as a technique for treating urinary incontinence among male patients on a Department of Veterans Affairs intermediate care unit. We are also identifying the characteristics of male intermediate care patients who are successful in a program of prompted voiding training and rehabilitiation, and assessing the implications of participation in such a program for patient mental health status.

METHODOLOGY—During the 21-day interventions, assistants checked each patient every hour for wetness or dryness. They then prompted the patient and toileted him only if he responded affirmatively to the prompt. Social approval was delivered for dry checks and for requests for toileting assistance. Mild social disapproval has been delivered for wet checks. The proposed elements of prompted voiding have been followed. These elements include 1) contacting the patient on an hourly basis, 2) asking him if he is wet or dry, 3) physically checking of the patient and providing feedback on the accuracy of his response, 4) delivering social approval if dry, and corrective feedback if wet, 5) prompting the patient to request toileting assistance, 6) providing toileting assistance if requested, 7) redelivering social approval for appropriate toileting (minimum of one minute of pleasant social interaction), and 8) offering water, making sure call light is within reach, and telling the patient when he can expect the next visit.

PROGRESS—This project has completed baseline data collection, the prompted voiding intervention, post intervention assessments and a three-month follow-up measurement on two treatment groups. Baseline, post intervention, and follow-up information was also gathered on control subjects. Seventy-eight patients were recruited for the study (with an attrition of three) and necessary urological assessments were made. Nursing staff on the intermediate care ward were trained in the prompted voiding procedure and data gathering. Pre- and post-intervention measures of the Dementia Rating Scale (DRS); Independent Toileting Assessment (ITA); Hamilton Anxiety Scale (HAS); and the Hamilton Depression Rating Scale (HDRS) were taken. Seven-day baseline incontinence procedures for experimental and control subjects were also successfully implemented.

RESULTS—Our results show that the percentage of checks that all experimental patients were assessed wet declined from an average of 42 percent during the baseline to 17 percent during treatment conditions (Chi-square sig. at 0.05). The average number of requests for toileting assistance of experimental patients increased from an average of 0.38 per day per patient to a treatment average of 2.3 (Chi-square sig. at 0.05). Control group patients did not show such significant changes on either measure: Baseline average wet $=35.4$ percent, treatment period average wet $=39.2$; baseline requests $=0.44$ per day per patient, treatment period requests $=0.40$ per day per patient. Furthermore, there was a 36 percent increase in correct toileting (Chi-square sig. at 0.05) between baseline and treatment for the experimental group. Correct toileting was defined as voiding in a bedpan, urinal, or toilet.

The control group did not show such substantial change with a 3 percent decrease in correct toileting. The variables most predictive of improvement by wet patients at the end of the prompted voiding treatment were 1) whether or not the patients responded to a prompt for toileting on the first day of treatment, 2) staff assessment of the patient's ability to function, 3) level of cognition as

measured by the DRS, 4) normal bladder capacity, and 5) age. For the treatment group there were significant declines in depression (as measured by the CESD) between baseline and post-intervention measures, but no significant changes in the level of cognition (as measured by the DRS).

In summary, there is significant evidence that male VA intermediate care patients become more continent and are more likely to engage in correct toileting as a result of participation in a prompted voiding program. Furthermore, significant declines in depressive symptoms were observed for the trainees from pre- to post-treatment. Presentations based on these results and were made at the annual meetings of the Western Social Science Association and of the Disability Studies Association, both in 1994.

FUTURE PLANS—During the remainder of this project we will continue with data analyses for presentation and publication. We are particularly interested in the continuity in gains in correct toileting and overall urinary continence made by our subjects. This will be captured by our three-month follow-up data. Furthermore, we will be revising the presentations which will be made for the WSSA and Disability Studies meetings and submitting them for publication. Finally, we plan to do a pilot study on night-time urinary incontinence. This is an area which apparently was not influenced by this program of prompted voiding and is the next logical step for our Rehabilitation Research Program on urinary incontinence.

[115] EFFECTS OF AGING ON THE BONE TISSUE OF THE FEMORAL NECK ON MEN AND WOMEN

Roy D. Bloebaum, PhD
Bone and Joint Research Laboratory, VA Medical Center, Salt Lake City, UT 84148; Division of Orthopedic Surgery, University of Utah School of Medicine, Salt Lake City, UT 84132

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—Femoral neck fracture is a complex problem which includes reduced bone strength due to osteoporosis, altered bone mineral, and changes in the gross morphology of the femur. The frequency of femoral neck failure is expected to increase as the veteran population continues to age. The cost of long-term care and surgical intervention has been estimated to cost the US and VA health care system 16 billion dollars a year by the year 2000.

The purpose of this research is to determine how aging changes effect the bone tissue of the femoral neck in males and females. The goals also include investigations using advanced imaging technology to measure porosity (osteoporosis), mineral changes at the microscopic level in both the cortical and cancellous bone, and gross anatomical changes of the femoral neck. This data will be used to determine the differences in the aging process between males and females, and help to understand why females have a higher incidence of femoral neck failure when compared to males.

PROGRESS—To date, the majority of the research has been focused on male donors and work is in progress to investigate female aging changes. Males were studied first in order to hopefully determine the influences of post menopausal changes in women.

RESULTS—Results to date have shown that clinical imaging techniques cannot consistently identify aging changes when comparing our results using advanced electron microscopy techniques. The scanning electron microscopy techniques have shown that the cortical thickness reduces by 10-27 percent, depending on the region of the femoral neck with aging. Our data also showed an increase in mineralization of the interstitial bone while a reduction in mineral levels was occurring in the osteons with aging.

FUTURE PLANS—This research should lead to the development of better clinical models for researching and treating osteoporosis and measuring the

effects of various therapies on bone metabolic diseases.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Age related hypermineralization of the femoral neck and possible fracture implications. Boyce TM, Bloebaum RD. Trans Orthopaed Res Soc 1992:17(2):420.

Comparison of human and canine external femoral morphologies in the context of total hip replacement. Bloebaum RD, Ota DT, Skedros JG, Mantas JP. J Biomed Mater Res 1993:27:1149-59.

Cortical aging differences and fracture implications for the human femoral neck. Boyce TM, Bloebaum RD. Bone 1993:14:769-78.

Influence of mineral content and composition on grayievels in backscattered electron images of bone. Skedros JG, Bloebaum RD, Bachus KN, Boyce TM, Constantz B. J Biomed Mater Res 1993:27(l):57-64.

Aging changes in osteon mineralization in the human femoral neck. Crofts RD, Boyce TM, Bloebaum RD. Bone 1994:15(2):147-52.

[116] SWALLOWING DYSFUNCTION IN ELDERLY HEAD AND NECK CANCER PATIENTS

William B. Ershler, MD
William S. Middleton Memorial Veterans Hospital, Madison, WI 53705

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E726-GA)*

No report was received for this issue.

[117] SWALLOWING PHYSIOLOGY RELATED TO NORMAL AGING

JoAnne Robbins, PhD; Ross Levine, MD; Jennifer L. Wood, MS; Ellen Roecker, PhD; Erich Luschei, PhD
Wm. S. Middleton VA Hospital, Madison, WI 53705; University of Wisconsin Medical School, Madison, WI 53792; Department Speech Pathology, University of Iowa at Iowa City, Iowa City, IA

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E727-GA)*

PURPOSE—The major finding among the few studies of swallowing in different age groups is that older people swallow more slowly. Increased duration is found to occur before the more automatic pharyngeal stage of the swallow. While the contribution of the tongue to initiate the swallow and influence other parts of the sequence is recognized, little is known about the effects of aging on lingual performance during swallowing. Since research indicates differential movement patterns of specific regions of the tongue during a swallowing event, the present study was designed to compare isometric and swallowing pressures generated at discrete points across the tongue surface in healthy young and old subjects. The hypotheses that 1) maximal lingual pressures would decline with age, 2) the percent of maximal lingual pressure used in swallowing would not change with age, and 3) periventricular white matter lesions would be associated with decreased pressures generated by specific regions of the tongue (tip, blade, and/or dorsum) during a swallowing event, were tested.

METHODOLOGY—*Subjects.* Data were collected from two groups of healthy men stratified by age. Mean ages for the two groups were 75 years and 25 years with age ranges between 65-68 and 22-33, respectively.

Pressure. The Iowa Oral Performance Instrument (IOPI) was used to measure lingual pressures at the tip, blade, and dorsum. Pressures were recorded at each site during two tasks: 1) maximal isometric gestures, and 2) saliva swallowing. Three trials were attempted per placement site.

Kinematics. Prior to videofluoroscopic recordings of liquid and semi-solid swallows, radiopaque pellets were fixed to the tongue tip, blade, and dorsum for later point-place tracking with our customized soft-

ware Speech/Swallowing Interactive Image Processing Program which facilitates movement analysis of soft tissue structures and provides a reliable source of measurement for temporospatial parameters.
Brain Imaging. MRI scans (t2-weighted) were obtained on a 1.5 tesla General Electric Signa scanner.

PROGRESS—Data collection is complete. The pressure and MRI data have been analyzed and are reported herein. Videofluoroscopic swallowing recordings are currently being analyzed.

RESULTS—This work confirmed our hypothesis that maximal lingual pressures decline with age. Although only the blade placement site was significantly reduced in the older group, pressures tended to be lower for the older group at the dorsum and tip as well. Increased periventricular white matter lesions were found in older subjects who generated less isometric pressure. While peak swallowing pressures did not decline with age as did maximal isometric pressures, the pressure reserve, which is the difference between maximal isometric and swallowing pressure, also declines with age.

A major implication of this finding is that even though swallowing is a submaximal pressure task, as individuals grow older, they may be working harder to maintain critical pressures for effective swallowing. These findings also indicate that the older individual who is more likely than the young to encounter a condition that may compromise his oromotor function (stroke, degenerative disease, etc.) is at a disadvantage in terms of pressure reserve for adequate spontaneous compensation. Findings indicate the potential benefit of lingual muscle strengthening exercises for older people.

FUTURE PLANS—While the IOPI served the purposes of this project, we are currently developing a pressure-sensitive pseudopalate for obtaining more accurate and reliable sequential lingual pressures during swallowing. Also, the time-intensive kinematic analyses of the videofluoroscopic swallow studies continues.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Oropharyngeal swallowing in normal adults of different ages. Robbins JA, Hamilton JW, Lof GL, Kempster G. Gastroenterology 1992:103:823-9.
Movement analysis of oropharyngeal dysphagia: a computer-assisted approach. Potratz J, Dengel G, Robbins JA, Brooks B. J Med Speech Pathol 1993:1:61-9.
Age effects on lingual pressure generation and implications for swallowing, Wood JL, Robbins JA, Roecker EB, Robin DA, Luschei ES. ASHA 1993:35(10):224-5.

[118] AGE-RELATED CHANGES IN SENSORY-MOTOR PERFORMANCE

Barbara M. Myklebust, PhD
Laboratory of Sensory-Motor Performance, VA Medical Center, Milwaukee, WI 53295

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A390-3RA)*

PURPOSE—Our goal is an integrated understanding of sensory-motor performance changes in aging. Alterations in neural signal processing, strength, joint stiffness, gait, and postural steadiness are compared in healthy elders and elderly fallers, to identify functional differences. Our template of sensorimotor performance also identifies age-related changes in patients with neurologic or orthopedic disease.

We hypothesize that: objective performance measures differ in healthy elders, elderly fallers and young adults; elders are heterogeneous in the type and extent of performance changes; falling is a multifaceted problem, which differs between people; during aging, biomechanical and neurophysiologic changes become risk factors for falls; healthy elders have compensatory mechanisms to cope with deficits; and performance is more impaired in the elder with a number of risk factors than with a single, significantly deviant risk factor.

METHODOLOGY—We evaluate healthy elders and elderly fallers using the neurological exam and objective measures of reflexes, joint compliance,

voluntary movements, SSEPs, standing balance, and gait, and standard questionnaires about activity level, self-perception of steadiness, and falls history.

PROGRESS—Nine deficits of aging are defined as risk factors for falls: impairments in sensation, reflexes, joint compliance, and joint angles in gait, and tandem walking; reduced strength, gait velocity, and reaction times; frontal release signs. We compare the types, prevalence, and magnitude of risk factors in healthy elders with elderly fallers.

RESULTS—We have performed sensory-motor performance measures on 15 fallers and 102 healthy aging subjects 45 years and older (66 are 65-75 years). Longitudinal studies were performed on 32 subjects.

Gait Studies. Cross-sectional and longitudinal analysis of free speed walking of 61 healthy elders (ages 65-87 years) demonstrates: general slowing of kinematic measures with increasing age; increased gait cycle duration and percent stance time, and decreased stride length and velocity; and shorter stride lengths and lower velocites in females than males. Most subjects also demonstrated at least 1 deviation in tandem walking, sensation, SSEP, stretch reflexes, joint compliance, voluntary reaction times or standing sway area and/or velocity.

Postural Steadiness. We characterize postural steadiness with measures of center of presssure with eyes-open (EO) and eyes-closed (EC). Our studies show: significant age-related changes in time- and frequency-based measures; more age-related changes with EC than with EO; differences between EO and EC measures are greater for healthy elders than young adults; many significant measures are non-collinear and non-correlated, suggesting that more than one process causes age-related changes.

Voluntary Movements. Voluntary reaction times and peak velocity of movement were significantly reduced in elders. Some subjects were unable to make fast plantarflexions to a 20 degree target.

SSEPs. In 58 subjects, onset latency of the SSEP was significantly prolonged. Latencies were even more prolonged with vibratory/proprioceptive deficits.

Myotatic Reflexes. Myotatic reflexes of 52 healthy elderly subjects (65-75 years) were tested by a standard neurologic exam and with EMGs. Left/right differences were common. Myotatic reflexes were unremarkable in 38-45 percent of cases, depressed or absent in 41-45 percent, and hyperactive in 13-17 percent. Reciprocal excitation was evoked in 5 cases, and reflex irradiation in 22.

Healthy Aging vs. Elderly Fallers. Common among fallers were cerebellar signs, delayed or absent SSEPs, and decreased reflexes. Voluntary ankle movements were very slow, with significant variability; joint compliance was impaired. Ankle profiles and kinematic parameters of gait were significantly impaired.

FUTURE PLANS—Targeting patients at risk for falls is key to injury prevention. Heterogeneity of sensory-motor performance is a feature of healthy elders. We test relationships among performance deficits which differentiate healthy elders and fallers. Our goal is to identify predictive markers of risk factors for falls to guide therapeutic interventions to minimize falls risk.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Biomechanical analysis of the sit-to-stand motion in elderly subjects. Millington PJ, Myklebust BM, Shambes GM. Arch Phys Med Rehabil 1992:73:609-17.

Characterization of postural steadiness and ankle joint compliance in the elderly. Prieto T, Myklebust J, Myklebust B. IEEE EMBS Magazine 1992:11:25-7.

Clinical trial of strengthening and aerobic exercise to improve gait and balance in elderly male nursing home residents. Sauvage LR, Myklebust BM, Crow-Pan J, et al. Am J Phys Med Rehabil 1992:71:333-42.

Characterization and modeling of postural steadiness in the elderly: a review. Prieto TE, Myklebust JB, Myklebust BM. IEEE Trans Rehab Eng 1993:1:26-34.

Development of the stretch reflex in the newborn: reciprocal excitation and reflex irradiation. Myklebust BM, Gottlieb GL. Child Dev 1993:64:1036-45.

Postural control as a nonlinear dynamical system. Myklebust J, Prieto T, Myklebust B. Scientific and engineering applications of the Macintosh. In press.

[119] ATTENTION IN EARLY DEMENTIA

Lee Willis, PhD; Maurine Behrens, PhD; Loren Meyerink, PhD
Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *Alzheimer's Disease Diagnostic and Treatment Center*

PURPOSE—The purpose of this study was to identify possible differences in attention in Alzheimer's and multi-infarct dementias. The study employed tests that are sensitive to deficits in different forms of attention with the goal of discovering a pattern of test results that may discriminate the two dementia groups in the early stages of the disease processes.

METHODOLOGY—We studied 95 English-speaking elderly subjects, 28 with a diagnosis of dementia of Alzheimer's type (AD), 14 with a diagnosis of multi-infarct dementia (MID), and 53 non-demented controls (NC). All dementia diagnoses were made by a neurologist and were based on information from clinical histories, physical and neurological examinations, laboratory tests, results of neuroimaging procedures, and results on a battery of neuropsychological tests, not including tests used in the present study. Entry criteria included: a score on the Mini-Mental State examination (Folstein) of at least 17 and a score on the Clinical Dementia Rating scale (Hughes) between 0.5 and 2.0. Thus, all AD and MID subjects presented with mild to moderate dementia.

Five tests were used, which contribute to the Attention Quotient of the revised Weschler Memory Scale: Mental Control, Digit Span Forwards and Backwards, Visual Span Forwards and Backwards were presented in the standard order. A battery of five computer-driven tests of visual attention were presented in fixed order to assess 1) orienting to environmental change, 2) selective attention to letters or symbols, 3) selective attention to colors, 4) divided attention with competing stimulus-response demands, and 5) focused attention with a distracting background stimulus. A computer-driven presentation made possible a simple, single-response task with the contrasts between tasks concentrated on different attentional demands.

RESULTS—A MANOVA carried out on results of the five Weschler Memory Scale tests showed highly significant main effects for diagnostic group $F(2, 92) = 25.41$, $\rho < 0.0001$ and for test, $F(4, 368) = 41.07$, $\rho < 0.0001$. There was also a significant group by test interaction, $F(8, 368) = 4.43$, $\rho < 0.0001$. Post hoc analyses showed some between group differences for all tests except Digit Span Backwards. There was a significant difference only between ADs and NCs for Digit Span Forwards. For Mental Control and Visual Span Forwards and Backwards there were significant differences between the normal control group and the two dementia groups, but not between the two dementia groups. The pattern of means showed a consistent ordering, from best to worst performance of NC > MID > AD.

A second MANOVA was carried out on the reaction time measure for the five computer-driven tasks. Again, there were significant main effects for group, $F(2, 92) = 43.11$, $\rho < 0.0001$ and for test, $F(4, 368) = 46.45$, $\rho < 0.0001$, and a significant group by test interaction, $F(8, 368) = 3.18$, $\rho < 0.001$. Post hoc analyses revealed significant differences between normal controls and the two dementia groups on all tests and significant differences between the two dementia groups on the divided attention test. The pattern of means on each of the computer tests showed normal controls to be consistently superior to the two dementia groups. Performance of MIDs was superior to that of ADs on selective attention tasks and inferior to that of ADs on divided attention tasks.

A further MANOVA was carried out on errors of omission (failing to respond), intrusion (responding to the wrong stimulus), and anticipatory responses (responding before a stimulus was present) on the computer-driven tasks. Data from the orienting task were not included in error analysis since errors of intrusion were not possible on this task. Errors were summed for each subject across the

remaining four tasks. The results of the analysis showed significant main effects for group $F(2, 92) = 19.79$, $\rho < 0.0001$ and for test $F(2, 184) = 16.96$, $\rho < 0.0001$. There was no significant group by test interaction. The pattern of means was for normal controls to make the fewest errors and for AD's to make the most errors. Across groups, the greatest number of errors were intrusions and the smallest number were omissions. Results of a correlation analysis on all ten attention tasks showed that only four of a possible 45 first-order correlations were not significant. All four involved Digit Span Backwards.

PROGRESS—These results were reported at the Twentieth Annual INS Meeting, February 5-8, 1992, San Diego, CA, abstracted in J Clin Exp Neuropsychol 1992:14(1):22.

[120] LATER LIFE EFFECTS OF EARLY LIFE DISABILITY: COMPARISONS OF AGE-MATCHED CONTROLS ON INDICATORS OF PHYSICAL, PSYCHOLOGICAL, AND SOCIAL STATUS

Margaret L. Campbell, PhD; Bryan Kemp, PhD; Kenneth Brummel-Smith, MD
Rehabilitation, Research and Training Center (RRTC) on Aging with Disability, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute of Disability and Rehabilitation Research, Office of Special Education and Rehabilitation Services, United States Department of Education, Washington, DC 20202*

PURPOSE—The Later Life Effects of Early Life Disability study (LLE) took place between 1988 and 1993. The major goal of this project was to conduct a systematic cross-sectional study of the physical, psychological, and social status of persons aging with early- and later-life onset of disability, and to make selected comparisons to a group of age-matched controls. Polio and spinal cord injury (SCI) constituted the early-life onset disabilities with stroke representing the mid- to later-life onset of disability.

The study combined the life course perspective of sociology with the bio-psychosocial model of geriatric rehabilitation. Unlike traditional approaches of medical rehabilitation, which emphasize the impairment and functional aspects of disability, the life course perspective focuses on describing the temporal structure of disability and examining the consequences of variations in the timing of disability events for the well-being of survivors as they age.

METHODOLOGY—The two research objectives of the study were to determine if there are differences within subject groups in functional health status due to demographic and disability-related characteristics, and to evaluate to what extent differences reported in health and well-being across sub-samples are due primarily to age, to duration of disability, or to a combination of factors related to both aging and disability.

To qualify, participants had to be 50 years of age or older, and the onset of disability had to be within specific time periods (25 and 20 years for polio and SCI, respectively, and 1 to 6 years for stroke). The final sample consisted of 265 participants: 120 with polio, 25 with SCI, 60 with stroke, and 60 non-disabled controls. With the exception of the SCI sample, used exclusively as a pilot study, all participants were recruited from general newspaper solicitation and disability support groups.

Data collection procedures relied on self-administered medical, life history, and activity questionnaires, standardized psychological measures of mental health status and personality, and four clinical assessments, including: a medical exam conducted by a physician; a functional exam conducted by a physical therapist; a psychological evaluation conducted by a clinical psychologist, and a social history conducted by a medical sociologist. A fifth assessment for bone density testing for osteoporosis was conducted at an outside facility.

RESULTS—The data resulting from these procedures were analyzed at both the descriptive level, using chi-square and correlational statistics, and tests of mean differences, and at the predictive level, using analysis of variance and covariance models. Several focused investigations were also conducted to examine specific hypotheses related to the stress-

buffering effects of social support, the effectiveness of stroke rehabilitation, and the risks of osteoporosis for females from the polio and controls subsamples.

The major conclusions of the LLE are both methodological and substantive. Methodologically, they point to the importance of examining within samples differences in the timing and severity of disability as keys to detecting significant subgroup differences in functional health status at time of measurement; and, substantively, they point to the utility of the life course perspective for contributing to our understanding of who is most at risk for developing the new health problems and functional losses associated with secondary disabilities.

In March, 1993 the LLE culminated in a cross-disability conference of over 300 individuals, including people with disabilities, their family members, and health professionals. Proceedings from this conference, *Aging with a Disability: Lessons Learned from Post Polio and Stroke*, have been published and approximately 500 copies distributed free of charge to polio and stroke support groups across the United States.

[121] EVALUATION OF ADAPTIVE DEVICE USE BY OLDER ADULTS WITH MIXED DISABILITIES

Laura N. Gitlin, PhD; Desiree Y. Burgh, MEd
Department of Occupational Therapy, Center for Collaborative Research, Thomas Jefferson University, Philadelphia, PA 19107

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education*

PURPOSE—The rising number of older adults with chronic disabilities creates a pressing need to develop cost-effective rehabilitation strategies which maximize independence. One strategy is the use of assistive devices. The purpose of this research study is threefold: 1) to determine the individual and situational factors which influence the use of assistive devices in the home; 2) to evaluate the effectiveness of an enriched home-based training program designed to bridge the transition from hospital to home; and 3) to determine the clinical considerations of rehabilitation therapists in selecting, training, and dispensing assistive devices to their elderly patients.

METHODOLOGY—A total of 250 older adults with a primary diagnosis of either a cerebrovascular accident (CVA), lower limb amputation, or an orthopedic deficit were recruited for the study from two free-standing rehabilitation facilities in the area. Subjects were interviewed just prior to discharge from rehabilitation and then in their homes at one, two, three, and six months following hospitalization. Also, subjects received a brief telephone interview at 12 months post-discharge. Major interview domains at each testing occasion included device perceptions, psychological well-being, functional status, frequency of device use, and reasons for use and non-use. Following the predischarge interviews, subjects were randomly assigned to either an experimental group which received up to six home visits from an occupational therapist, or a control group which received no intervention services. The purpose of the intervention was to enhance the ability of subjects to use assistive devices to perform those activities which were important and valued.

PROGRESS—We are currently in the analytic phase of this study with numerous manuscripts in progress or under review which examine the number and types of devices issued to subjects, the relationship between functional status and device prescription, the underlying meaning of assistive device use for subjects with different impairment types, factors which predict assistive device use in the home following rehabilitation and the extent to which a range of devices are used in the home.

RESULTS—Analyses of the 250 baseline (Time 1 interviews) provided a description of the type and range of devices issued to this sample of older persons who represented primarily first-time users of devices. Each impairment group presented distinct characteristics. The orthopedic patients tended to be older, female, Caucasian, and lived alone; amputees

were younger, African-American, and lived with another; CVA patients were Caucasian, female, and also lived with another. Subjects reported having on average one or less devices in the home prior to this hospitalization, although those with an amputation reported an average of two devices and a greater number of prior health conditions. Subjects, regardless of type and level of impairment received an average of 8 devices (range 1-18) during rehabilitation. Devices for mobility, dressing, and bathing were primarily issued although different types of devices were issued for each group reflecting the functional consequences of their underlying medical condition. Analyses also revealed that a disability measure such as the Functional Independence Measure (FIM) may be insufficient as a primary indicator of the number and type of devices offered in rehabilitation especially for orthopedic patients. For the CVA group however, the FIM was a significant predictor for the number of devices issued for seating, feeding, and bathing. Also, cognitive function as measured by the FIM was not significantly related to the number of issued devices for subjects in any group.

Other emerging findings of significance include the importance of psychosocial factors such as morale and positive device perceptions, and expectation to use a device to predict actual use of devices in the home.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Adaptive device use in the home by older adults with mixed disabilities. Gitlin LN, Levine RE, Geiger C. Arch Phys Med Rehabil 1993:74:149-52.

Prescribing adaptive devices to the elderly: principles for treatment in the home. Gitlin LN, Levine RE. Int J Technol Aging 1992:5(1):107-20.

Therapeutic dilemmas in the care of the elderly in rehabilitation. Gitlin LN. Top Geriatr Rehabil 1993:9(1):11-20.

Technology and self-care: what can social science research contribute to an understanding of technology use and aging. Gitlin LN. In: Proceedings of the National Invitational Conference on Research Issues Related to Self-Care and Aging, Sage Publications. In press.

[122] USE OF TECHNOLOGY TO PROMOTE REHABILITATION OF OLDER PERSONS: REDUCING THE BARRIERS TO INDEPENDENCE

Paula Guerette, PhD; Richard Nakai, MS
Research & Training Center on Aging, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—With the recent advances in technology, much can be done to apply technology to minimize the risk of safety mishaps for older adults with disabilities. The purpose of this project was to provide information to professionals and to older consumers regarding ways that technology can be used to prevent accidents. In addition, the project also sought to evaluate one type of technology (medication reminders) and to provide feedback to product manufacturers regarding the applicability of their design features for the older adult population.

METHODOLOGY—A focus group was held to establish the criteria that older adults consider important about medication organizers. Product databases were reviewed and a total of eight medication organizers and reminders of varying sizes, shapes, and features were selected for evaluation. Twenty-eight older adults participated in the product evaluation. Functional measures were recorded for each participant. Each participant evaluated a total of five products in the laboratory, consisting of a series of exercises to test all the product features. Next, each participant evaluated a non-programmable medication organizer and a programmable reminder in the home for a period of two weeks. After this, products were rated along a series of criteria, and in-home experiences with the products were documented.

RESULTS—Information regarding the utility of various product features has been documented. Feedback was provided to each manufacturer in the form of a confidential report of the study findings, as well as recommendations for product modifications. Several manufacturers implemented some of

these modifications. An informational brochure, designed to be available at pharmacy counters, is currently being published. This brochure highlights the range of product features that are available in medication organizers and reminders to address various functional limitations. An article on interface design of programmable reminders has been submitted for publication.

To provide information about ways that technology can be used to improve the safety of older adults, a book, *Safety Begins at Home: A Resource Guide for Professionals, Older Adults & Their Caregivers* has been published. In addition, a three-part safety series has been conducted in an area independent living facility for older adults. Presentations and workshops addressing home and product safety and design have been conducted at professional meetings, including RESNA and ASA, and at area professional schools.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Design features of medication organizers and dispensers: evaluation by older adults. Guerette P, Nakai R. In: Proceedings of RESNA International '92, 1992, Toronto, ON. Washington, DC: RESNA Press, 1992.

Interfaces for "high tech" medication reminders: some guiding principles. Guerette P, Nakai R. In: Proceedings of the 16th RESNA International Conference, 1993, Las Vegas, NV. Washington, DC: RESNA Press, 1993.

[123] THE ROLE OF TRAINING TO ENHANCE UTILIZATION OF IN-HOME SUPPORT: A COMPARISON BETWEEN OLDER HISPANICS AND ANGLOS WITH A DISABILITY

Judith M. Mitchell, PhD
Rehabilitation, Research & Training Center on Aging, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education*

PURPOSE—This 5-year study was recently begun for the purpose of enhancing successful use of in-home supportive services by Hispanic and Anglo disabled older adults, thereby preventing unnecessary institutionalization. This study intends to identify by ethnic group the significant problems associated with in-home supportive services and the preferences that would facilitate that use. Secondly, this study will develop and test training models for both Hispanic and Anglo older adults that will strengthen their use of in-home supportive services. In-home assistance may take the form of housekeeping services, help with personal hygiene, transportation services, or medication management, and typically is needed when older adults face functional limitations or frailty usually resulting from disability.

METHODOLOGY—Data collection and training development will occur in three phases. Phase I of the project will use a field study design to collect information on both the problems and the needs of disabled older adults who now use in-home support services. Data will be collected in the three categories of 1) service delivery preferences, 2) psychological issues and concerns associated with using in-home supportive services, and 3) issues of autonomy/independence and the desired level of family and professional involvement.

In Phase II training programs will be developed to educate older adults on the successful use of in-home support services. These programs will include relevant knowledge about the services, and skills and techniques to utilize services effectively and comfortably. They will address indepth the problems and concerns identified in Phase I.

In Phase III training program effectiveness and outcomes will be tested by assessing satisfaction with training and the application and outcomes of skills and knowledge learned.

PROGRESS—Current progress has been the following: 1) the creation of a sample pool and data base of 1300 older adults from which interview participants will be selected, 2) the creation of a consumer advisory council consisting of Hispanic and Anglo older adults to provide input on all phases of project development, and 3) the preliminary development of a draft of the survey and interviewing instrument to be used for data collection in Phase 1.

[124] POLICY AND FUNDING ALTERNATIVES TO PROMOTE COMMUNITY AND SUPPORTIVE SERVICES FOR OLDER PERSONS WITH A DISABILITY

Fernando M. Torres-Gil, PhD; Linda A. Wray
Rancho Los Amigos Medical Center, University of Southern California, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education*

PURPOSE—Research supports the need for and effectiveness of rehabilitation regardless of age. Nonetheless, legislation limits rehabilitative programs for older persons, health services reimbursement emphasizes acute illnesses rather than chronic conditions, and aging and disability professionals promote separate agendas. Policy makers acknowledge the need to shift from the traditional acute care model of health and work-life model of rehabilitation to flexible health and social service models that address rehabilitative needs across all ages.

This five-year study (1989-1994) examined policies affecting rehabilitation service delivery to older persons, identified service delivery barriers, and recommended policy and financing mechanisms to remove the barriers.

METHODOLOGY—Staff employed two investigative methods: 1) content and legislative analyses of literature, laws, and regulations; and 2) key-informant interviews regarding geriatric rehabilitation with representatives of federal Congressional committees and state aging, health, social service, and rehabilitation agencies.

PROGRESS—Staff examined public programs and regulations, developed a compendium of best practice geriatric rehabilitation models, created a computerized database of relevant research literature, and reported on research findings in journals, books, and at professional meetings.

RESULTS—While more than 80 federal and other public programs offer rehabilitative services, program objectives, definitions of disability, eligibility criteria, and reimbursement schemes vary widely and interact unevenly across programs. Many older persons experience changes in their functional ability and health as they age. Complications associated with the changes may be prevented, improved, or compensated for through rehabilitation. Rehabilitation, however, remains largely associated with younger persons who receive services fostering independent living and a return to work-life. Most geriatric rehabilitation focuses on short-term/medical functional restoration following acute episodes or long-term/non-medical functional maintenance. A broader range of services is constrained by budget deficits, allocation decisions, the categorical nature (e.g., age- or condition-basing) of existing policies, and limited consensus on geriatric rehabilitation definitions and goals as well as the appropriate service mix to achieve those goals.

IMPLICATIONS—Active-life, rather than work-life, must be the central focus of rehabilitation if older people are to receive equal access to rehabilitation programs. Future needs of all persons with disabilities can be met if 1) research continues to support the effectiveness of a range of rehabilitative services across the life course, 2) providers and the public are educated on aging, disability, and rehabilitation issues, and 3) grassroots organizations advocate appropriate and accessible services.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Long-term care policy: a California dilemma. Wray L, Torres-Gil F. In: Larue, Bayley, eds. Long-term care in an aging society: choices and challenges. Buffalo, NY: Prometheus Press, 1992:39-66.

Availability of rehabilitation services for elders: a study of critical policy and financing issues. Wray L, Torres-Gil F. In: Ansello, Eustis, eds. Aging and disabilities: seeking common ground. Amityville, NY: Baywood Publishing, 1992:55-67.

Funding and policies affecting geriatric rehabilitation. Torres-Gil F, Wray L. Clin Geriatr Med 1993:9(4):831-40.

Geriatric rehabilitation: linking aging, health, and disability policy. Sheets DJ, Wray L, Torres-Gil F. Top Geriatr Rehabil 1993:9(2):1-17.

Incorporating independent living outcomes in rehabilitation agencies: older disabled persons as an underserved population. Sheets DJ, Wray LA, De Jong FJ. Phys Occup Ther Geriatr. In Press.

[125] AN ANALYSIS OF POLICY BARRIERS TO ACCESSING TECHNOLOGY SERVICES FOR INDIVIDUALS AGING WITH A DISABILITY

Fred J. De Jong, PhD; Linda A. Wray
Rancho Los Amigos Medical Center, University of Southern California, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education*

PURPOSE—This 5-year study was undertaken in 1994 to investigate policies affecting the availability, affordability, and accessibility of assistive technologies aimed at maintaining community-based living and the employment of middle-aged and elderly individuals with a disability (excluding spinal cord injury and mental illness). A study completed in 1994 by the University of Southern California and Rancho Los Amigos Center on Aging found that few programs provide rehabilitative services such as assistive technologies for middle-aged and older persons; and that aging and disability groups pursue separate political agendas and represent independent public programs competing for limited resources. This study's investigation of assistive technology service delivery will test hypotheses about whether and how the aging and disability systems collaborate and coordinate services.

The study will analyze the extent to which publicly funded assistive technologies are available and appropriate to the changing needs of persons as they age with disabilities, and develop and evaluate recommendations for improving program responsiveness. The study's research agenda parallels that of "An analysis of policy barriers to accessing technology services for individuals aging with a spinal cord injury," conducted by the same investigators.

METHODOLOGY—The study employs three investigative methods: 1) primary data collection, 2) legislative analyses to examine the responsiveness of existing public policies, and 3) demonstration and experiential study reviews on maintaining the independence and employment of individuals aging with a disability. The project's data collection efforts are coordinated with other research projects associated with the Rancho Los Amigos Center on Aging with a Disability and the Center on Aging with a Spinal Cord Injury.

PROGRESS—Our program has 1) established a Consumer-Oriented Research Advisory Committee to advise the projects' data collection efforts, 2) developed a typology of assistive devices, and 3) designed preliminary portions of the survey questionnaire to be fielded in 1995. Project staff also input into a bibliographic database abstracts of project-relevant materials; mailed information about the current project to a preliminary mailing list of 150 key policy makers in the aging, disability, and rehabilitation communities; and collaborated with other academic researchers to develop and participate in a pre-conference program on aging, disability, and rehabilitation issues held in conjunction with the 1994 American Society on Aging annual meeting.

FUTURE PLANS—Research, policy, and dissemination activities include: 1) collecting and analyzing the project survey data; 2) designing the sampling framework and protocol for the follow-up intensive policy-oriented surveys of consumers, employers, vendors, and policy makers; and 3) reporting on the implications of our research in refereed journal articles, professional meetings, and mailings to the project's list of key policy makers.

[126] AN ANALYSIS OF POLICY BARRIERS TO ACCESSING TECHNOLOGY SERVICES FOR INDIVIDUALS AGING WITH A SPINAL CORD INJURY

Fred J. De Jong, PhD; Linda A. Wray
Rancho Los Amigos Medical Center, University of Southern California, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education*

PURPOSE—This 5-year study was undertaken in 1994 to investigate policies affecting the availability, affordability, and accessibility of assistive technologies aimed at maintaining community-based living and the employment of middle-aged and elderly individuals with spinal cord injury (SCI). A study completed in 1994 by the University of Southern California and Rancho Los Amigos Center on Aging found that few programs provide rehabilitative services such as assistive technologies for middle-aged and older persons; and that aging and disability groups pursue separate political agendas and represent independent public programs competing for limited resources. This study's investigation of assistive technology service delivery will test hypotheses about whether and how aging and disability systems collaborate and coordinate services.

The study will analyze the extent to which publicly-funded assistive technologies are available and appropriate to the changing needs of persons as they age with SCI, and develop and evaluate recommendations for improving program responsiveness. The study's research agenda parallels that of "An analysis of policy barriers to accessing technology services for individuals aging with a disability," conducted by the same investigators.

METHODOLOGY—The study employs three investigative methods: 1) primary data collection and 2) legislative analyses regarding the responsiveness of existing public policies; and 3) demonstration and experiential study reviews on maintaining the independence and employment of individuals aging with a disability. The project's data collection efforts are coordinated with other research projects associated with the Rancho Los Amigos Center on Aging with SCI and Center on Aging with a Disability.

PROGRESS—The program has 1) established a Consumer-Oriented Research Advisory Committee to advise the project's data collection efforts, 2) developed a typology of assistive devices, and 3) designed preliminary portions of the survey questionnaire to be fielded in 1995. Project staff also input into a bibliographic database abstracts of project-relevant materials; mailed information about the current project to a preliminary mailing list of 150 key policy makers in the aging, disability, and rehabilitation communities; and collaborated with other academic researchers to develop and participate in a pre-conference program on aging, disability, and rehabilitation issues held in conjunction with the 1994 American Society on Aging annual meeting.

FUTURE PLANS—Research, policy, and dissemination activities include 1) collecting and analyzing the project survey data, 2) designing the sampling framework and protocol for the follow-up intensive policy-oriented surveys of consumers, employers, vendors, and policy makers, and 3) reporting on the implications of our research in refereed journal articles, professional meetings, and mailings to the project's list of key policy makers.

[127] POLIO DISABILITY: PERSONAL MEANING, WELL-BEING, AND AGE

Mark Luborsky, PhD; Jessica Scheer, PhD
National Rehabilitation Hospital Research Center, Washington, DC 20010

Sponsor: *The National Institute of Child Health and Human Development*

PURPOSE—We seek to discover how people with life-long physical impairments interpret and experience new losses in later life and to build on those findings to advance cultural theories of disability

experiences. We see a major gap in knowledge about disability concerning the macro level of cultural factors (shared values, beliefs, norms) and the micro level of personal factors (interpretations and experiences). We argue that individual micro level experiences are informed by the macro level cultural frameworks in which people learn to live with disabilities.

METHODOLOGY—Polio was selected as a model for aging with disabilities because its natural course provides three distinct paths of experience: recovery without impairments, life-long residual stable impairments, and life-long stable impairments which unexpectedly convert to progressive impairments. These life paths will comprise the three major contrast groups for study, with six study cells drawn according to contrast group, gender and age (45-62; 63+). A total of 156 subjects (78 in Philadelphia and 78 in Washington) will be interviewed for three 1-1/2-hour sessions in their home.

Subjects will be selected from clinic, support group, and community populations. Methods will include illness/disability narratives, ethnographic discussions, and some standardized tests.

PROGRESS—In conjunction with the PGC staff, staff start-up education and training has been completed. An extensive literature annotation and review on the medical and psychosocial aspects of post-polio sequelae, the psychosocial aspects of physical disability, culture and disabilty, and culture and aging has been completed. Structured interview techniques were developed during a series of six 1-day meetings in Philadelphia and Washington, and during weekly conference calls.

The major task of the first 9 months of the study was to develop and pilot test the in-depth Structured Lifetime Disability Interview protocol. We worked continually to ensure that the questions and probes would produce information relevant to the project goals. Staff members each tested the complete protocol with at least one subject, and revisions were made to the protocol accordingly.

At present, the active recruitment process in the three recruiting sources (local Post-Polio clinics and neurologists, local Post-Polio support groups, and the community-at-large) has begun, and we expect to complete the first five interviews by July.

FUTURE PLANS—Paper abstracts have been accepted by the Society for Disability Studies Annual Meetings and the GINI International Polio Network Meetings in June 1994 and the American Anthropological Association Annual Meetings (November 1994.)

[128] DISCUSSING CPR/DNR CHOICES WITH GERIATRIC INPATIENTS: THE PSYCHOLOGICAL IMPACT ON THE PATIENT

Judith Mitchell, PhD; Kenneth Brummel-Smith, MD; Sally Straneva-Kalpakoff, DO
Rancho Los Amigos Medical Center, University of Southern California, Downey, CA 90242

Sponsor: *Rehabilitation Research and Training Center on Aging*

PURPOSE—A significant number of geriatric patients have strong positive or negative attitudes regarding non-resuscitation following a cardiopulmonary arrest. Many physicians have been reluctant to discuss CPR (cardiopulmonary resuscitation) or DNR (do-not-resuscitate) choices with their older patients because they assume harmful patient consequences such as increased fear and anxiety, depression, and patient concern that hospital care would deteriorate if non-resuscitation was chosen. As a result, when a cardiac arrest occurs, physicians have in the past relied on either themselves or a family member to make life-or-death decisions which are not always in accordance with the wishes of the patient.

This study investigated the psychological impact of discussing CPR and DNR decisions with medically stable geriatric inpatients on a rehabilitation ward and encouraging them to make these decisions for themselves.

METHODOLOGY—A randomized control group design was used, assigning patients to either the physician-initiated discussion of CPR/DNR or a placebo discussion of diet. Patients were assessed for depression, anxiety, death anxiety, hospital

satisfaction, hopelessness and negative self-evaluation at baseline and 24 hours following the discussion.

RESULTS—Cardiopulmonary resuscitation was chosen by 68 percent of subjects in the CPR/DNR discussion group. No adverse psychological effects occurred as a result of the discussion. A discharge interview found that 97 percent of the subjects believed that physicians should routinely discuss CPR preferences with patients, although only one subject had discussed this topic with his physician prior to the OBRA rulings.

IMPLICATIONS—There is no evidence from this study to suggest that discussion of CPR/DNR preferences with patients in clinical settings produces psychologically harmful outcomes. This study supports the importance of discussing CPR/DNR decisions directly with patients and documents patient interest to personally examine this topic with their physician.

[129] CAREGIVER HEALTH

Lee Willis, PhD; Nancy Nielsen-Brown, PAC; Judith Mitchell, PhD
Rancho Los Amigos Medical Center, Downey, CA, 90242

Sponsor: *Rehabilitation Research and Training Center on Aging*

PURPOSE—The elderly disabled are frequently cared for by their elderly spouses. The caregiving role can be physically and emotionally stressful, placing the caregiver at heightened risk of illness and chronic disease. Although there has been an abundance of research focusing on the adverse emotional and social effects of elderly caregiving, there have been few studies of the physical health consequences for this group. The purposes of this study were to investigate with group comparison design the health consequences of caregiving and the relationships between physical health and psychosocial characteristics of caregivers.

METHODOLOGY—Twenty-four primary caregivers and 31 non-caregivers received complete physical examinations, including evaluation of cardiovascular, respiratory, musculoskeletal, sensory, and neurological systems. This produced a continuous scale of morbidity with 110 individual variables, age and gender adjusted when appropriate. Subjects independently completed scales evaluating: personality, social support, locus of control, perceived stress, psychological distress, and problem behaviors by the spouse.

RESULTS—Analysis of results showed no significant differences between groups for age, education, or gender. There were statistically significant differences in morbidity, greater for caregivers: total morbidity score, $\rho<0.001$; standing blood pressure, $\rho<0.01$; sitting blood pressure, $\rho<0.001$. Caregivers reported significantly more psychosocial problems: psychological distress, $\rho<0.05$; inadequate social attachments, $\rho<0.05$; health perceived not to be in their own control, $\rho<0.02$; and more behavioral problems attributed to the spouse, $\rho<0.0001$. When psychosocial and reported spousal problems were entered into step-wise regression equations, a model that predicted 38 percent of the variance associated with total morbidity for non-caregivers included: quantity and severity of daily hassles, the perception that good health is not in one's own control, and inadequate social attachments. The model predicting 69 percent of the variance associated with morbidity for caregivers included: quantity and severity of daily hassles, the perception that health is not in one's own control, and a dependent personality style.

IMPLICATIONS—The results of this study provide evidence for the potentially negative impact on health of providing primary care to a spouse by an elderly individual. The effect is detectable on routine physical examination, not requiring expensive and intrusive procedures. Elevated blood pressure was a particularly salient feature for caregivers. Certain psychological and social characteristics of the caregiver and behavioral problems of the care receiver predicted a substantial amount of measured morbidity.

[130] PSYCHOSOCIAL FACTORS AND HEALTH IN THE ELDERLY

Lee Willis, PhD
Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *Rehabilitation Research and Training Center on Aging*

PURPOSE—The purpose of this investigation is to study the relationships between psychosocial factors and long-term health outcomes in the elderly.

METHODOLOGY—The physical health of 144 initially healthy individuals between 65 and 91 (67 males and 77 females) was evaluated prospectively over an eight year period. Measures of personality (16 Personality Factor scale, Cattell, 1970), social support (Interview Schedule of Social Interaction, Henderson et al., 1980), and locus of control (Multidimensional Health locus of Control Scale, Wallston and Wallston, 1978) were obtained at year one when all participants were free of any disease; by histories, physical, and laboratory examinations. Annually, histories were updated, physical and laboratory examinations were repeated, and each participant's health was coded on a 10-point morbidity scale developed for the longitudinal investigation (Thomas et al., 1986; Willis et al., 1988). Nine subjects died during the course of the study. For statistical analyses, independent measures included: the three demographic factors of gender, marital status, and age; four dimensions of personality; six dimensions of social support; and three dimensions of health locus of control. The principal dependent measure was the morbidity score.

RESULTS—There were no significant relationships between gender or marital status and health outcomes at years four or eight. There were significant relationships between morbidity at year four for age, $\rho < 0.0001$, and certain psychosocial variables: anxiety (16PF-2), $\rho < 0.001$, lack of independence (16PF-4), $\rho < 0.05$, unavailability (ISSI-AVSI), $\rho < 0.05$, and inadequacy (ISSI-ADSI), $\rho < 0.05$, of social interactions. These four psychosocial measures and age were entered into two step-wise regression analyses, with morbidity score as the dependent measure. Morbidity at year four was predicted by age, accounting for 4 percent ($\rho < 0.05$) of the variance and anxiety, accounting for 13 percent of the variance ($\rho < 0.01$). At year 8 these values were to 3 percent for age (NS) and 6.5 percent for anxiety ($\rho < 0.01$).

Significant results ($\rho < 0.01$) of analyses comparing psychosocial measures, obtained when the subjects were healthy, with the development of specific diseases during the eight years of study can be summarized as follows: individuals who were diagnosed with cancer initially reported low levels of both adequate social integration and the presence of confiding relationships; those who developed clinical hypertension initially reported low levels of available and adequate personal attachments, social integration, and confiding relationships; those receiving a diagnosis of heart disease initially reported higher levels of anxiety, less available or adequate social integration and inadequate attachments.

IMPLICATIONS—The results of this study indicate that relatively enduring personality traits and related social habits and practices can have a significant influence on long-term health outcomes, perhaps most detectable in the later years of life.

VI. Head Trauma and Stroke

[131] COMPUTER-ASSISTED TREATMENT OF HEMI-INATTENTION IN R-CVA PATIENTS

Jeffrey S. Webster, PhD; Payandeh Abadee, MD
Department of Veterans Affairs, Long Beach, CA 90822

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B610-RA)*

PURPOSE—A primary risk factor for falls among right hemisphere stroke patients (R-CVA) is hemi-inattention (i.e., neglect, hemispatial neglect to left space). In the present grant, we have developed techniques using a computer to train these subjects to compensate for neglect-related problems during simulated high accident risk activities (i.e., wheelchair propulsion). We investigated if such training will reduce their accident proneness.

METHODOLOGY—Our subjects were wheelchair-bound, R-CVA patients who showed hemi-inattention to left space. With the aid of computer programs, subjects were trained to sit at true vertical, systematically scan into left space, and to fully scan into left hemispace while performing computer simulations of risky activities including propelling a wheelchair through a cluttered runway. Computer simulation has been used so that training could begin even if the subject could not drive a wheelchair at the outset of therapy.

Training was initiated within the first week of the subjects' admission to the rehabilitation service in order to maximize its impact on other rehabilitation activities. At the end of the study, 18 trained R-CVA subjects' performances were compared with a group of 32 R-CVA subjects, matched to the trained group on screening measures, who received inpatient rehabilitation but no computer training. These groups were compared on the frequency of falls during their inpatient stay. In addition, we assessed the generalization of training to other neuropsychological measures, and to a wheelchair obstacle course we developed.

PROGRESS—Our grant began in October 1990 and by August 1993, we had developed all the software, piloted the programs, screened 46 subjects for the study, and completed training with 18 R-CVA patients.

RESULTS—Seventeen of 18 subjects who received at least 15 sessions of training, evidenced improvement on the training tasks. Comparisons of post-training performance on our wheelchair obstacle course were very promising as our subjects made far fewer frontal contacts and sideswipes than the untrained group ($F[1,47] = 7.44$; $p < 0.001$). Overall, approximately 80 percent of the subjects' obstacle course performances following training were no worse than our neurologically normal controls. We also noted that all post-training neuropsychological measures (Rey Figure and Letter Cancellation) showed significant improvements with regard to the amount of information attended to in left space and how far to the left they started the task (e.g., reduction in rightward orienting tendency). Nonetheless, most patients still showed at least mild hemispatial neglect. Examination of Incident Reports revealed that falls were significantly fewer in the trained group than in the untrained group, after training had been initiated, $F(2,94) = 5.46$; $p < 0.01$. Only one of the 17 subjects who demonstrated training effects fell, whereas 17 of the 32 control subjects experienced at least one fall during their inpatient stay. Finally, both OT and PT reports indicated improvement in their patients' attentiveness at post-assessment.

FUTURE PLANS—As of Fall 1993, we began a continuation grant designed to make our training program transferable to rehabilitation personnel. The first phase of the study is to determine if we can replicate results with a projection LCD system with

a computer monitor system. The later would reduce the cost and space requirements of the program. We have trained 10 subjects already. The second phase involves training Occupational Therapists to use the program. In preparation of this phase, we are completing a training manual and revising computer programs to be more user friendly.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Scoring method for logical memory that is sensitive to right hemispheric dysfunction. Webster JS, Godlewski MC, Hanley GL, Sowa MA. J Clin Exp Neuropsychol 1992:14:222-38.

Predictors of falls among right-hemisphere stroke patients in the rehabilitation setting. Rapport LJ, Webster JS, Flemming K, et al. Arch Phys Med Rehabil 1993:74:621-6.

Effect of attentional bias to right space on wheelchair mobility. Webster JS, Rapport LJ, Godlewski MC, Abadee PS. J Clin Exp Neuropsychol 1994:16:129-37.

Hemispatial neglect in simulated wheelchair obstacle course performance. Roades L, Webster JS, Morrill B, Rapport LJ, Lopez M. Clin Neuropsychol. In press.

Spatial attentional factors associated with digit span performance in hemispatial neglect. Rapport LJ, Webster JS, Dutra R. Neuropsychologia. In press.

[132] NEUROACTIVATION SPECT IMAGING FOR ASSESSMENT OF REHABILITATION POTENTIAL FOLLOWING CEREBRAL INFARCTION

Anthony G. Mlcoch, PhD; Earl Barnes, PhD; Thomas Milo, PhD; Mark Boles, MD
Audiology and Speech Pathology Service, Nuclear Medicine Service, Edward Hines Jr. VA Hospital, Hines, IL 60141.

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—The neurophysiology of recovery following cerebral infarction is poorly understood. The purpose of this project is to develop and validate a sensitive single photon emission computer tomographic (SPECT) technique for comparing resting to neuroactivation states in order to reliably detect focal cortical and subcortical regions of altered rCBF and to identify activation patterns associated with the recovery of patients with aphasia secondary to cerebral infarction.

METHODOLOGY—Twenty neurologically normal subjects and 20 patients with aphasia secondary to cerebral infarction that occurred at least one year prior to participation in the project will be recruited. Each will be asked to perform one of four tasks while undergoing as SPECT brain imaging using the radiopharmaceutical 99mTc HMPAO. The tasks are 1) identifying words from a list delivered aloud, 2) listening to a tape-recorded story, 3) naming pictured objects, and 4) orally describing a series of action pictures.

PROGRESS—The project is in the pilot stage. To date, we have entered one normal subject who listened to a recorded story for the activation task. Results are inconclusive. With in the next 4 to 6 months we expect to enter 10 subjects. Hopefully this will enable us to determine whether neuroactivation can be obtained employing the tasks we have chosen and to develop sensitive and reliable techniques for quantifying and identifying cortical and subcortical regions of activation. Once this is established the project will proceed to where we will attempt to detect neuroactivation patterns associated with aphasic patients exhibiting good and poor recovery.

[133] INTEGRATING TRAUMA AND REHABILITATION (ITR)

Gerben DeJong PhD; Byron Hamilton, MD, PhD; Wayne S. Copes, PhD; Howard R. Champion, FRCS, FACS; Deborah L. Wilkerson, MA; Sherri Tepper, ScD.
National Rehabilitation Hospital Research Center, Washington, DC 20010.

Sponsor: *Centers for Disease Control, Medlantic Research Institute, Atlanta, GA 30333*

PURPOSE—This 3-year study has two major purposes. The first is to link 308 patient records of individuals with traumatic brain injury (TBI), spinal cord injury (SCI) and hip fracture (HF) from two national data bases: trauma care and rehabilitation. These records will be used to develop a patient injury and functional profile from time of injury to discharge from medical rehabilitation. The second is to determine characteristics associated with access to rehabilitation, and determine the impact of rehabilitation on functional, behavioral, and psychosocial outcomes. The 110 identified patients with TBI and their significant others will be interviewed and matched to trauma patients who did not receive rehabilitation who will also be interviewed.

METHODOLOGY—The study sample is derived from the Major Trauma Outcome Study (MTOS) national trauma data base, and from the Uniform Data System (UDS), a national rehabilitation data base. Lists of institutions participating in MTOS and UDS were reviewed to identify rehabilitation hospitals likely to have injured patients referred by nearby MTOS facilities. For each candidate UDS institution, data from corresponding MTOS facilities were searched for potential matching patients. UDS and MTOS institutions with significant numbers of potential matches were identified and their participation solicited. UDS sites determined whether the participants had received acute care, and followed up by confirming the patients' identification at the MTOS trauma centers. After agreement between common elements in UDS and MTOS patient records were determined, the records were linked in an injury through rehabilitation database for analysis.

A questionnaire was developed to assess the long-term outcomes (injury>2 years) of TBI on individuals who received and did not receive rehabilitation. The questionnaire includes the Functional Impairment Measure (FIM), the Health and Activities Limitation Survey (HALS), the Health and Activity Questionnaire (HAQ), as well as questions on the types of rehabilitation received, the type of health insurance before/after injury, as well as sociodemographic characteristics. Significant others of both groups of patients will also be interviewed in order to ascertain post-injury data, and determine the validity of the patients' responses.

PROGRESS—During the three years of the study, trauma and rehabilitation data bases have been linked and the proposed sample size achieved. Individuals who did receive rehabilitation have been interviewed, as well as their significant others, and matched individuals who did not receive rehabilitation and their significant others are being tracked and interviewed. A manuscript describing the linking process and the demographic, trauma, and rehabilitation characteristics of the sample has recently been completed. Another completed manuscript compares the self-report of function made by individuals with TBI with the observations made by their significant others. A paper investigating factors associated with access to rehabilitation is in progress.

FUTURE PLANS—The funding for this study ended July 31, 1994. Data will continue to be analyzed in order to determine the factors that increase the odds of receiving rehabilitation, and identify the impact of rehabilitation on functional, behavioral, and psychosocial outcomes of individuals with TBI. A manuscript will be written describing the matching process, as will one focusing on methodological issues in TBI, and one looking at the impact of TBI on the significant others.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Linking data sources. Tepper S. Second Conference of the Division of Trauma and Emergency Medical Systems, 1993, Virginia.

Outcomes in traumatic brain injury: Self-report versus report of significant others. Tepper S, DeJong G. J Head Trauma Rehabil. In press.

[134] ORTHOKINETIC ORTHOSES: SYSTEMATIC REPLICATION OF A CLINICAL EFFICACY STUDY OF ORTHOKINETICS TREATMENT FOR A PATIENT WITH UPPER EXTREMITY HEMIPARETIC MOVEMENT DYSFUNCTION IN POST-ACUTE CVA

Renate L. Neeman, PhD, OTR, FAOTA; Mo Neeman, PhD
The Center for Orthokinetics Research and Education, Williamsville, NY 14221

Sponsor: *Orthokinetics Research Foundation, 5 Sedgemoor Court, Williamsville, NY 14221*

PURPOSE—This systematic replication of a previous rehabilitation study investigated the efficacy of orthokinetic orthoses application for partial restoration of voluntary movement to a patient with a nonfunctional hemiparetic left upper extremity, 26 months post right thrombotic cerebral vascular accident (CVA).

METHODOLOGY—The patient, a 49-year-old male with left hemiparesis 26 months post-CVA, was presented for orthokinetics treatment with active range of motion (AROM) of the left elbow extension from 90° to 80°, which could not be further restored to full-range AROM by standard rehabilitation. The patient was given a two-stage treatment by application of orthokinetic orthoses to the paretic upper extremity comprising first a single-subject design pilot study, followed by a clinical rehabilitation course of orthokinetics treatment over 26 weeks in twice-weekly sessions of 1 hour each, based on the positive outcomes of the pilot study.

An experimental orthokinetics treatment, of double-blind single-subject design, was administered to his paretic upper extremity. The application of orthokinetic orthoses was based on the rationale of the neurophysiological mechanism of orthokinetics treatment for muscle imbalance in paretic limbs, which utilizes the active (fully elastic) and inactive (relatively inelastic) fields of the orthokinetic cuff. The active field of each orthokinetic cuff was placed overlying the agonist muscles, the inactive field overlying the antagonists, with resulting activation of the agonist musculature, via selective cutaneous stimulation of low-threshold, slowly adapting mechanoreceptors (e.g., Merkel's disks) by excitation of α-motoneurons and of γ-motoneurons by α-γ coactivation, with reciprocal inhibition of the antagonist musculature.

During orthokinetics treatment, three orthokinetic orthoses (cuffs) were applied, two on the patient's arm and one on his forearm, positioned according to the rationale for activation of elbow extension. The treatments were administered to the patient double-blind. Internal validity (cause-effect relationship) was tested by inclusion in a short-duration pilot study of a single-subject design time-series A1-C1-A2-B1-A3-C2-A4-B2 of nontreatment control phases (A1-A4), placebo treatment phase (C1), sham treatment phase (C2), and orthokinetics treatment phases (B1, B2).

RESULTS—During baseline and placebo treatment phases A1-C1-A2, elbow AROM was 10° (i.e., no remediation by placebo effect occurred); in contrast, during orthokinetics treatment phase B1, elbow AROM increased to 120°, and then regressed to baseline of 10° in nontreatment phase A3; elbow mobility decreased further to AROM = 3° in sham treatment phase C2, (then rose again to baseline of 10° in nontreatment phase A4, and finally increased to AROM = 125° in orthokinetics replication phase B2. These outcomes were consistent with application of the orthokinetics treatment (in phases B1, B2), and with its underlying neurophysiological rationale, supporting the treatment's internal validity. The inferences from orthokinetics treatment outcomes in the single-subject design pilot study were supported by statistical analysis of the time-series, using Bartlett's test of variance homogeneity (showing absence of serial dependency), followed by *t*-test.

The pilot study was followed by a clinical course of orthokinetics treatment for 26 weeks. The left elbow AROM was increased to 145°, and forearm pronation achieved normal limits with active supination return to 0 degrees. Active wrist extension of 15° was achieved from 15 degree flexion to 0°; and 15° extension from 90° to 75° at the proximal interphalangeal joints of the 2nd to 5th fingers. This permitted holding and stabilizing of objects with the paretic hand for manipulation with

the right hand. Additional gains were demonstrated in active left shoulder flexion to 110°, and abduction to 90° with elbow flexed; horizontal abduction with elbow extended, of 0° to 80°, and horizontal adduction 0° to 30° were attained. The patient gradually resumed part-time work in his shop and greenhouse, while wearing the orthokinetic cuffs. His work tolerance increased to 5 hours per day after 26 weeks of treatment. These positive rehabilitation outcomes, in the patient's late post-acute period, were not attributable to spontaneous neural recovery, and hence supported internal validity and clinical efficacy of the orthokinetic orthotics intervention.

FUTURE PLANS—Future plans for the project include further investigations of orthokinetic orthotics treatment for persons with paretic motor dysfunction sequelae of stroke, and traumatic brain injury.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Rehabilitation of a post-stroke patient with upper extremity hemiparetic movement dysfunctions by orthokinetic orthoses. Neeman RL, Neeman M, J Hand Ther 1992:5:147-55.

Efficacy of orthokinetic orthotics for post-stroke upper extremity hemiparetic motor dysfunction. Neeman RL, Neeman M. Int J Rehabil Res 1993:16:302-7.

[135] MUSICAL ATTENTION TRAINING PROGRAM

Jeffrey Jutai, PhD; Peter Rumney, MD; Robert Gates, PhD; Roger Knox, PhD; Vivienne Wit, BMT, MTA
Research Department, Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsor: *Easter Seal Research Institute; Police Association of Ontario*

PURPOSE—The goal of this project is to investigate whether improvements of attention in adolescents with brain injuries, trained through the adjunctive mode of electroacoustic music, are 1) clinically significant, 2) specific to auditory information processing, 3) long lasting, and 4) dissociable from motivational/emotional factors.

PROGRESS—Brain-injured adolescents are randomly assigned to two treatment groups: an experimental group (n = 15) receiving ten weeks of musical attention training, and a control group (n = 15) on a similar schedule working with electronic music technology in an unstructured context. The musical attention training consists of two task modules addressing progressively higher attention levels. The tasks were developed in a 1991 pilot study: "Attention Enhancement for Head Injured Adolescents through Music Therapy with Electroacoustic Instruments."

The first task module involves percussion sound identification and is modelled on similar Attention Process Training activities employing letters, words and numbers developed by Sohlberg and Mateer. The second task module requires that the subject respond to a melodic motive or pair of motives and, in some cases track a musical metre. Software has been developed to be used in administering the tasks and recording data.

Two validated tests administered weekly record baseline and outcome measures of information processing: the Paced Auditory Serial Addition Task and the Continuous Performance Test. A test battery is also given for comparison before and after the treatment period, to distinguish changes in attentional processing from changes in other cognitive domains.

Computer software for data recording was originally developed by Steve Derventzis as a fourth-year engineering thesis project. For this study, the software was rewritten from the original MS-DOS to Windows format, and an additional task administration module was added. A further upgrade has been produced based on knowledge gained from the pilot study. Activities including improvisation and song-playing have been developed for the control group. Twelve subjects have been enrolled in the study to date, and task administration and testing are in progress.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Attention training with brain injured adolescents. Jutai J, Knox R, Gates R, Rumney P. In: Proceedings of the Adjunctive Musical Glenrose Rehabilitation Hospital Annual Rehabilitation Research Conference, 1993.

Assessment in training of cognitive-communication skills following head-injury. Thomas-Stonell N, Johnson P, Jutai J, Schuller R. In: Proceedings of the American Speech, Language and Hearing Association Annual Convention, 1993, Anaheim, CA.

User-determined evaluation of technological advances in assistive devices. Jutai J, Day BWH, Boschen K, Lindsay P, Carpenter S. In: Proceedings of the First North American Regional Conference of Rehabilitation International, 1993, Atlanta, GA.

[136] REDUCING MOTOR DISABILITY IN HEMIPARETIC STROKE BY MANIPULATION OF SENSORY INPUT FROM THE PARETIC UPPER LIMB: A QUANTITATIVE EVALUATION

Jules Dewald, PT, PhD; Joseph Given, PhD
Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *Department of Education, National Institute on Disability and Rehabilitation*

PURPOSE—The disability of the upper limb after a hemiparetic stroke is often perceived as one of the most frustrating experiences stroke survivors endure. There are well defined reasons for the disproportionate impact of cerebral stroke in upper limb function, such as the greater relative area of cortex devoted to upper limb control, coupled with the fact that arm motions play a major role in both activities of daily living and in the workplace. A large number of neurotherapeutic techniques claim that their respective interventions create the best results. However, because of the absence of quantitative measures to evaluate the effect of these therapeutic interventions on limb motor behavior, little progress has been made toward the determination of the optimum intervention protocols for impaired limb motion.

The broad objective of our research is to quantify how sensory input can reduce disturbed muscle synergic relations and/or spasticity and thereby improve function of the impaired limb. Specific objectives of this study are 1) to determine whether the excitation of different tonically active skin afferents increases the disturbances in muscle coactivation patterns observed in stroke, 2) to determine whether reducing the excitation of tonically active skin afferents normalizes abnormal muscle activation patterns in stroke subjects, 3) to establish the optimum sensory stimulation parameters for spasticity reduction in stroke subjects, and 4) to investigate whether the effects of sensory deprivation or stimulation recorded under static conditions (objectives 1 and 2) or sensory stimulation (objective 3) result in significant functional improvement during voluntary arm motions.

PROGRESS—Subject recruitment and testing is underway. It is still too early in the study to draw any conclusions.

[137] THE PREDICTIVE VALUE OF COGNITIVE/BEHAVIORAL MEASURES IN PATIENTS AFTER STROKE IN ASSESSING FUNCTIONAL OUTCOME

Kristi Kirschner, MD; Rebecca Goodman, PhD
Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—The major objective of this study is to examine the efficacy of neurological tests in predicting functional outcome for stroke patients. A battery of neuropsychological tests will be administered to each subject early post-stroke. Functional outcome will be measured at 1, 3, 6, and 12 months post-stroke. Analyses will be done to determine the critical variable or set of variables related to functional outcome.

METHODOLOGY—Previous studies in this area have methodological shortcomings which limit the

utility of their findings. This project was designed to avoid these shortcomings. Some of the major methodological strengths of this study are the following.

Subject Sample. Aphasics were excluded from some previous studies. This study will include aphasics, and the cognitive battery includes tests which can be performed by these patients.

Study Design. This study will be longitudinal instead of cross-sectional.

Statistical Strategy. A common strategy in previous studies was to put all the predictors into one correlational analysis, then simply list the variables which had the strongest correlation with outcome. We would like to do further analyses, where indicated, to get a more precise picture of the role of cognitive abilities in functional independence. A broad range of cognitive domains will be tested, allowing us to determine if there are critical, limiting cognitive factors.

RESULTS—Subject recruitment is underway. It is still too early to draw any conclusions.

[138] IMPROVING VOCATIONAL OUTCOMES OF INDIVIDUALS WHO HAVE SUSTAINED A STROKE

Deborah Crown, MS; Rita McMahon, MS
Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—The overriding goal of Vocational Rehabilitation is to assist individuals with a disability in attaining vocational goals (i.e., return to work) at a level appropriate to their abilities. The vocational functioning and status of individuals who have sustained a stroke is significantly less than individuals with other disabling conditions. It is strongly felt that there currently exists a lack of a focused, succinct assessment to assist the Vocational Rehabilitation professional in providing cost-effective, high quality services to increase successful vocational outcomes.

The broad objective of this project is to develop a good assessment tool for proper diagnosis for Vocational Rehabilitation and improve the probability of positive vocational outcomes for individuals who have sustained a stroke. Specific objectives of this study are to investigate the Functional Assessment Inventory (FAI) and evaluate it for its suitability for application to the stroke population. Based on results of that investigation, we shall identify appropriate areas of the FAI which require modifications to improve the assessment tool for the stroke population.

PROGRESS—Subject recruitment and testing is currently underway.

[139] THE EFFECTIVENESS OF A TELEPHONE SUPPORT GROUP FOR STROKE CAREGIVERS

Robert Hartke, PhD; Rosemarie King, PhD
Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—This study explores the effectiveness of a unique intervention for the stress of caring for a stroke survivor. A total of 136 older, spousal caregivers of stroke survivors will be randomly assigned to a treatment or control group. The control group will receive written material on caregiver stress and assessed upon recruitment and after 6 months. The treatment group will participate

in an 8-week, professionally led educational/support group held mostly by telephone conference calls. They will be assessed upon recruitment, after the group intervention, and at 6 months. It is hypothesized that the treatment group will show less depression, loneliness, burden, increased health behavior, and increased competence.

PROGRESS—Subject recruitment and testing is currently underway.

[140] EFFECTS OF AEROBIC EXERCISE ON YOUNG PERSONS POST-STROKE

Michele Averbuch, PT; Jim Hibler, PT
Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—Forty young stroke survivors will participate in an aerobic fitness program to determine the effects of aerobic exercise on fitness levels, ambulatory speed, and life satisfaction. This program was designed to meet the needs of the young stroke population after they responded to a survey assessing outcomes after discharge from a rehabilitation hospital.

METHODOLOGY—Subjects will participate in a 10-week aerobic walking program after completing a 10-week control period in which they will be instructed to maintain their normal daily routine. A second 10-week control phase will follow the exercise portion to allow each subject to serve as his/her own control. Fitness tests will be performed throughout the control and exercise portions of the program using a treadmill and metabolic cart. The exercise program will occur three times per week and will include a weekly educational component. The goals of this study are to demonstrate improvements in fitness levels, functional ambulatory measures, and quality of life. An emphasis will be placed on promoting independence and facilitating re-entry into the community.

PROGRESS—Subject recruitment and testing is currently underway.

[141] A CONTROLLED STUDY OF THE EFFECTS OF EMG FEEDBACK AND ELECTRICAL STIMULATION ON MOTOR RECOVERY IN ACUTE STROKE PATIENTS

John McGuire, MD
Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—Despite conventional rehabilitation efforts, loss of upper extremity control continues to be one of the main limiting factors determining functional independence in stroke survivors. The restoration of motor control relies on the convergence of at least three types of physiologic information: central representations of motor output encoding the goal of movement, afferent input to provide the means to monitor movement progress, and relevant data from motor memory.

The main objective of this project is to investigate in a controlled manner whether more normal muscle synergistic relations can be encouraged in acute stroke patients by using either EMG feedback, functional electrical stimulation or a combination of these therapeutic interventions.

PROGRESS—Subject recruitment and testing are underway.

[142] COURSE OF RECOVERY OF COGNITIVE-COMMUNICATIVE PROBLEMS IN RIGHT BRAIN DAMAGED INDIVIDUALS

Leora R. Cherney, PhD; Anita S. Halper, MA
Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—The purpose of the present study is to describe the variety of communicative impairments associated with right hemisphere stroke and measure the natural history of changes in communicative effectiveness over time, and to assess whether subgroups of right hemisphere communicatively impaired patients might be identified as a function of underlying deficits in attention, memory, and/or perception or as a function of lesion location.

Historically, it was assumed that only left hemisphere damage resulted in language deficits while right hemisphere damage had no important effect on communication. However, recent evidence suggests that the right hemisphere makes an important contribution to language processing, and it is now widely acknowledged that right hemisphere stroke also results in impairments in communication. Right hemisphere communication impairments are believed to result from underlying deficits in attention, memory, and perception. However, the precise relationship between communication impairment and deficits in these cognitive processes is not well understood. Appropriate rehabilitation interventions cannot be designed until a better understanding of the relationship between communication and these cognitive processes emerges. There also is very little data regarding the course of recovery of cognitive-communicative problems in patients with right hemisphere damage. Increased knowledge about the rate, amount, and patterns of recovery of communication problems in right hemisphere stroke patients is needed to facilitate the selection of more effective rehabilitation interventions.

PROGRESS—To date, ten subjects have been enrolled in the study. It is still too early to draw any conclusions.

[143] CO-MORBIDITIES AND COMPLICATIONS IN STROKE: INCIDENCE, RISK FACTORS, AND EFFECTS ON OUTCOMES

Elliot Roth, MD; Allen Heinemann, PhD
Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—Individuals who sustain a stroke may be as disabled by the consequences of associated medical conditions as by the stroke itself. This study is designed to investigate clearly and systematically the incidence, risk factors, and impact on rehabilitation outcomes of preexisting conditions and medical complications of stroke.

The major goal of this study is to develop a risk assessment technique to enable clinicians to identify stroke patients at risk for medical complications and to determine the effects of medical problems on rehabilitation outcome.

Specifically this project will 1) describe the prevalence of preexisting medical conditions, laboratory abnormalities, and secondary intercurrent medical conditions in individuals with stroke; 2) investigate the predictive accuracy of the occurrence of preexisting conditions and existing illness severity scales for assessing risk of acute complications during rehabilitation; 3) develop and evaluate a complication risk assessment index specific to the rehabilitation setting; and 4) determine the interdependence between preexisting conditions, secondary complications, rehabilitation outcomes, and cost effectiveness of rehabilitation.

PROGRESS—Currently, data collection is underway. It is still too soon to draw any conclusions.

[144] PREVENTION OF THROMBOEMBOLISM IN STROKE REHABILITATION PATIENTS

David Green, MD, PhD
Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—Deep vein thrombosis and pulmonary embolism are important causes of morbidity and mortality in patients who have survived a recent stroke. Following a brief period of hospitalization in an acute care setting, patients with a stroke are transferred to a rehabilitation facility. There, the attention of patients and caregivers is focused on overcoming neurological impairment and the resumption of independent living. However, complicating these efforts is a vulnerability to thromboembolism, which has been shown to affect 60-75 percent of elderly stroke patients. This is a study to compare two methods of thromboprophylaxis (calf compression boots and low molecular weight heparin) to see which is most safe and effective. All patients admitted to the Rehabilitation Institute with the diagnosis of stroke occurring within the previous 28 days, but no sooner than 7 days from the acute event will be screened and considered for the study. The end points will be to determine efficacy as the presence or absence of thrombus, as defined by venous flow studies, venography, positive V/Q scan or pulmonary angiography. Also, to determine the safety by the presence or absence of bleeding, either intracranial (positive CT scan or MRI), or elsewhere (decline in hematocrit of >5 percent, hemoglobin >2g).

PROGRESS—Currently, seven subjects have been enrolled in the study. It is too soon for any conclusions.

[145] COMMUNITY RE-ENTRY AND FUNCTIONAL STATUS OF PEOPLE FOLLOWING BRAIN INJURY REHABILITATION

Mary F. Schmidt, PhD; Allen W. Heinemann, PhD; Lauree Garvin, MA
Midwest Regional Head Injury Center for Rehabilitation; Prevention, Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: Rehabilitation Institute of Chicago, Chicago, IL

PURPOSE—The extent to which people who have sustained brain injury (BI) attain community reintegration is poorly understood. In particular, changes in functional status following traumatic BI have not been fully documented. The objectives of this ongoing study are to describe 1) the life status of patients who had received comprehensive medical rehabilitation, 2) changes in status from before injury to one year after injury, and 3) quality of life and life satisfaction issues.

PROGRESS—Data collection began in June 1992. Head injury centers in each of six different geographic regions (Eastern, Southeastern, Midwest, Ohio Valley, Southwestern, and Rocky Mountain) contributed to the present data. Plans are to continue data collection in the Midwest for at least the next six months. Preliminary reports are being compiled at this time and a final report will be compiled during 1995.

METHODOLOGY—This is a cross-sectional study of adaptation to brain injury. Individuals who differed in time since BI were interviewed using the Regional Head Injury System's Post-Acute Data Set, a collaboratively developed instrument funded by the Rehabilitation Services Administration. The questionnaire takes 30 minutes to complete. The instrument was designed to cover aspects of impairment, disability, and handicap. Sections of the instrument collect demographic, medical and rehabilitation information, current living arrangement, functional status and personal assistance needs, community mobility and activities, occupation and

use of time, social support, leisure activity and quality of life. Functional status is assessed by asking respondents to report whether they alone, someone else, or both they and someone else performed specific activities now and before injury. This information allowed us to assess changes in functioning following BI.

RESULTS—The sample currently consists of 1100 individuals with brain injury. The median length of time since injury is 3 years. Eighty-four percent reported loss of consciousness (LOC) with a median length of LOC of 5 days. Sixty-two percent of the sample is male and 80 percent Caucasian, 9 percent African American. Over half had educations beyond high school. About half had never married, and 15 percent were divorced. Although 70 percent were employed when injured, only 15 percent were working at the time of interview. Respondents indicated that their most frequent daily activity reported is watching television or listening to a radio. One-third to one-half reported decreases in ability to perform activities of daily living such as meal preparation or housework.

Forty-three percent of respondents indicated that they were satisfied with life, while 35 percent reported mixed feelings and 22 percent were dissatisfied. Fifteen percent indicated that brain injury had a severe impact on their life, 36 percent indicated that brain injury changed their lives "a lot," 35 percent reported "some" impact and 13 percent said that their lives had not changed due to brain injury.

IMPLICATIONS—Overall, traumatic brain injury has a major impact on several aspects of life functioning years after injury. Reductions in employment, independent functioning, social participation, and quality of life were noteworthy. The impact of injury on women's functioning appears greater than on men's functioning in several respects: they reported a greater reduction in specific aspects of independent functioning and greater social isolation. Age also appears related to aspects of handicap in that younger respondents had fewer potential social supports available to them. These results reveal the impact of TBI generally and on age and gender-related roles specifically. They suggest that post-acute rehabilitation programs should consider and address rehabilitant role expectations and barriers to service utilization.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Gender and age-related role changes one year after brain injury. Heinemann, AW, Schmidt, MF, Garvin, LJ. Paper presented at the Annual Conference of the American Congress of Rehabilitation Medicine, Denver, CO, 1993.

Community re-entry from the professional perspective. Schmidt, MF, Heinemann, AW, Garvin LJ. Seminar presented at the Traumatic Brain Injury Rehabilitation and Outcomes: Entering the Age of Accountability Conference, sponsored by the Rehabilitation Institute of Chicago and the Rehabilitation Institute of Michigan, Chicago, IL, May 13, 1994.

VII. Independent Living Aids

A. General

[146] RESTORATION OF SIT-TO-STAND FUNCTION IN ELDERLY PATIENTS USING FNS

Janis L. Jacobs, MS, MA; E. Byron Marsolais, MD, PhD
Motion Study Laboratory, VA Medical Center, Cleveland, OH 44106

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E698-RA)*

PURPOSE—The objective of this project is to test the hypothesis that functional neural stimulation (FNS) can restore sit-to-stand transfer capability in the geriatric outpatient. Many geriatric patients would be able to remain at home if they were able to perform the sit-to-stand transfer independently or with minimal assistance. Quantification of the efficacy of rehabilitation techniques will provide needed rationale and justification for treatment procedures.

METHODOLOGY—For baseline purposes five normal elderly subjects were tested; their sit-to-stand transfer was characterized using video records, force plate data, and EMG data. Patients have been divided into two treatment groups: Group 1, conventional physical therapy; and Group 2, surface FNS exercise/coordination training. To date, it has not been possible to locate geriatric subjects who are both unable to stand and who are willing and able to receive implanted electrodes.

PROGRESS—The two treatment groups were provided their respective treatments three times weekly for eight weeks. The FNS treatment was individualized for each subject. The outcome measure was functional capability. Muscle strength and surface EMG data was collected to assist in interpreting a possible mechanism of change in function.

RESULTS—*Normal Elderly.* We have determined the pattern of muscle activity during sit-to-stand for five normal elderly subjects. Five muscles were monitored: gluteus maximus, hamstrings, quadriceps, gastrocnemius/soleus, and anterior tibialis. Muscle on/off times were calculated in reference to each of the following five biomechanical events: initial body movement, seat-off, hands off, acceleration/deceleration change, and final knee extension. ANOVA was used to determine extent of universality of muscle on/off times across these five subjects. A neuromuscular control model for sit-to-stand has been derived from this data.

A sit-to-stand rating scale has been created, validated, and tested for inter-rater reliability ($r = 0.99$). This scale will be used for functional testing of all subjects in the study; in addition, the scale is suitable for clinical use.

Group 1 (conventional rehabilitation). Four subjects have been treated. Preliminary data analysis indicates that three of four subjects improved in the sit-to-stand transfer. A video of functional outcome for each subject was made and will be subjected to analysis according to the sit-to-stand scale which was developed for this study.

Group 2 (surface FNS exercise and coordination training). Five subjects have been treated. Preliminary analysis indicates that three of the five improved in the sit-to-stand transfer. Data will be analyzed as described for group 1.

[147] DEVELOPMENT OF A PORTABLE BIOFEEDBACK CANE: A PILOT STUDY

Jacqueline J. Wertsch, MD; Gerald F. Harris, PhD; Patrick Moran, BS; Khomeshwari Arcot, MS; Hongsheng Zhu, PhD
Zablocki VA Medical Center, Milwaukee, WI 53295; Marquette University, Milwaukee, WI 53233; Medical College of Wisconsin, Milwaukee, WI 53226

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #A91-215AP)*

PURPOSE—The purpose of this project was to develop a system that not only gives audiofeedback to the patient regarding the amount of cane loading in real time but also records cane loading for every step to allow analysis of the consistency of the loading. The feedback cane system simultaneously acquires cane vertical force data and gives an audiofeedback signal to the user while allowing the patient to walk freely.

METHODOLOGY—Two sensors, strain gage and a force sensing resistor (FSR), were used in this study to closely verify load signals while investigating alternative sensor technologies. The strain gage bridge offers a linear response while the FSR is more easily attached and requires less external circuitry. The sensor outputs are amplified to a 0-5 V range as required by the A/D converter. The two sensors are connected to the A/D converter on board a Motorola 68HC11 microprocessor. The converter is capable of collecting data from two channels at over 7000 samples per second. The sampling rate is controlled by the microprocessor using the internal timer to run an interrupt driven sampling routine. The sensors are calibrated using a load cell to produce a look-up table of voltages to forces. A ratio of patient weight (input by the user) is used by the system to set audio feedback. A high frequency audio signal (2 kHz) is used for cane overload and a low frequency audio signal (1 kHz) for cane underload.

PROGRESS—The feasibility of the original concept has been proven. We have developed a portable biofeedback cane which simultaneously acquires cane vertical force data while giving audiofeedback.

RESULTS—The reliability and practicality of the system was demonstrated through pilot clinical trials. Ten normal adult subjects have been evaluated in this study. In order to determine the feasibility of system usage in a typical ambulatory environment two different cane sensors (strain gage and FSR) were also evaluated. Results indicated that audio feedback significantly altered ($p<0.05$) cane peak forces in 9 of 10 subjects. Cane force-time integral was also significantly altered in all 10 subjects as was foot-floor contact duration in 7 of 10 subjects. Because peak pressures, force-time integral, and contact duration are biomechanically important in transferring loads throughout the musculoskeletal structure, control of them through audio feedback may prove significant in the rehabilitation setting. These results also indicated that the strain gage sensor was best suited to this feedback application.

FUTURE PLANS—A portable biofeedback cane with recording and monitoring capability has been successfully developed. It will be useful in establishing standards of training time, and criteria for cane selection. The portable biofeedback cane will facilitate the process of teaching the patient appropriate cane use and potentially reduce the staff time needed for training. It should increase the accuracy of desired cane loading. It will also be useful as a research tool for defining and validating criteria used to prescribe different types of canes. This information can be used to improve the cost effective selection of the appropriate cane.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Microprocessor-based biofeedback cane system. Moran P, Arcot K, Zhu H, Harris GF, Wertsch JJ. In: Proceedings of the Annual Conference of the IEEE Engineering in Medicine and Biology Society 1992:14:1542-3.

Portable biofeedback system to analyze cane loading. Moran P, Arcot K, Zhu H, Harris GF, Wertsch JJ. Arch Phys Med Rehabil 1992:73:1011.

[148] DEVELOPMENT OF A MINIATURE 'SHEAR' SENSING TRANSDUCER: A PILOT STUDY

Gerald F. Harris, PhD; Jacqueline J. Wertsch, MD; Ann M. Lebar, BS; Hongsheng Zhu, PhD
VA Medical Center, Milwaukee, WI 53295; Marquette University, Milwaukee, WI 53233;
Medical College of Wisconsin, Milwaukee, WI 53226

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #A91-264AP)*

PURPOSE—The purpose of this project was to develop a reliable miniature shear transducer to be used for measuring shear stress exerted on the sole of the foot during normal gait. Clinically, a transducer of this nature could be adapted to measure shear under the buttocks of bedridden patients, determine shear in upper extremity manipulation of objects during daily living activities, and determine shear associated with orthotic and prosthetic fitting.

METHODOLOGY—Specific tasks to be accomplished were 1) to design and develop a plantar shear sensor, (2) to characterize and calibrate the sensor, and 3) to validate the shear sensor during tests of five normal subjects. The two components of the case and support structure (dimensions being 15 mm in diameter by 3.8 mm thick) of the sensor consist of a naval bronze material chosen to withstand repetitive loading during weight-bearing. Within the structure, two flat springs permit movement of the top plate during gait. The top and bottom of the case and support structure are combined into one unit by a thin bead of silicone adhesive. Electro-optical circuitry within the support structure consists of a photodiode and a light emitting diode. The circuitry senses the displacement of the top plate of the transducer. The output of the photodiode amplification circuitry is then input into a data acquisition system on a PC, using a sampling frequency of 200 Hz. Computer software has been developed to convert the output of the sensor into pressure values.

RESULTS—The feasibility of the original concept to develop a minature shear transducer has been demonstrated. The reliability and dynamic range of the sensor has been tested through pilot clinical trials. Five able-bodied subjects (mean age 26, mean body weight 73 kg, and mean height 1.65 m) were studied. The sensor was placed under the left foot: 1st and 5th metatarsals, great toe, and posterior heel. The subjects walked for approximately 20 steps at a controlled cadence of 72 steps/min. Two trials for each pressure point comprised a total of 40 seconds of data per site. Anterior-posterior (AP) and medial-lateral (ML) shear stress measurements were made by orienting the sensor parallel (i.e., AP) and perpendicular (i.e., ML) to the center of the foot. Mean peak shear stresses ranged from 6.7 to 51.4 kPa in the AP direction and 5.4 to 43.5 kPa in the ML direction. The mean pressure-time integrals ranged from 0.8 to 26.3 kPa sec in the AP direction and 6.7 to 37.3 kPa sec in the ML direction. The maximum within-subject standard deviation was 35.5 kPa for the peak shear stress and 25.8 kPa sec for the pressure-time integral. The peak mean foot-to-floor contact time was 1.25 ± 0.1 seconds.

PROGRESS—A miniature shear transducer has been successfully developed.

FUTURE PLANS—Potential clinical applications for this sensor are impressively broad, encompassing use during orthotic andprosthetic design as well as in insole foot shear measurement, buttocks shear force quantification, orthotic and prosthetic fitting, and shear determination in upper extremity manipulation of objects during daily living activities. Veterans that may benefit from the development of the device include the spinal cord injured, post-stroke, and diabetic subjects.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Development of a miniature shear sensing transducer. Lebar AM, Harris GF, Zhu H, Wertsch JJ. In: Proceedings of the Annual Conference of the IEEE Engineering in Medicine and Biology Society 1992:14:1652-3.

Mechanisms to measure shear pressure in rehabilitation research. Lebar AM, Harris GF, Zhu H, Wertsch JJ. Arch Phys Med Rehabil 1992:73:1015.

[149] OCCUPATIONAL THERAPY FUNCTIONAL ASSESSMENT COMPILATION TOOL (OT FACT)

Roger O. Smith, PhD, OTR, FAOTA; Jay Hinkens, BS; Gregg C. Vanderheiden, PhD; Kathy Longenecker Rust, MS, OTR; Sharon Esser; Tereza Snyder, MFA
Trace Research and Development Center, University of Wisconsin, Madison, WI 53705

Sponsor: *American Occupational Therapy Association, Inc.; Apple Computer, Inc.*

PURPOSE—In 1985 the Standardized Assessment Committee of the American Occupational Therapy Association (AOTA), along with the American Occupational Therapy Foundation, awarded two grants to begin the development of a profession-wide standardized assessment. The University of Wisconsin-Madison was awarded one of these. For the past six years, faculty and staff in several programs at the university—including University of Wisconsin Hospitals and Clinics, the Occupational Therapy Program of the School of Education, and the Trace Center—have been working on the development and testing of a functional assessment system. As the development of the assessment progressed, it was named OT FACT (for Occupational Therapy Functional Assessment Compilation Tool).

Results from preliminary testing indicated that a properly designed computerized version of OT FACT would greatly facilitate administration, scoring and charting of results. This would make testing of the assessment more accurate (by reducing the possibility of calculation errors), and could serve to increase the number of researchers and clinicians interested in and able to evaluate the assessment.

METHODOLOGY—OT FACT software steps the user through the stages of the assessment, following the nodes of a decision tree. Scores are based on a simple trichotomous scale (total deficit, partial deficit, no deficit), avoiding the complexity and inconsistency of graded scales. The program solicits scores from the user, tabulates and totals scores automatically, keeps records, and automatically charts results. The data synthesized present a functional performance profile of the client, which can be used to summarize the client's functional performance, to justify therapy plans, and to document the client's change in status over time.

PROGRESS—OT FACT software has been completed and is now being distributed by the AOTA. Version 2.0 (for Macintosh and Microsoft Windows) will be released soon.

RESULTS—Version 1.0 was released by the AOTA in October of 1990. Version 2.0--which has an expanded functional category set and enhanced reporting capabilities--will be released in 1994. Validity and reliability studies of the new computerized OT FACT are currently under way at facilities around the country. The measurement methodology used in OT FACT is generically called TTSS, for Trichotomous Tailored Sub-branching Scoring. The model of TTSS from OT FACT is now being applied to other measurement settings.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Assessing the impact of assistive technology using OT FACT. Smith RO. In: Proceedings of the 16th Annual RESNA Conference; 1993, Las Vegas, NV. Washington, DC: RESNA Press, 1993:186-7.

Computer-assisted functional assessment and documentation. Smith RO. Am J Occup Ther 1993:47(11):988-92.

[150] DEVELOPMENT OF USER-, PROFESSIONAL-, AND PUBLIC-ACCESSIBLE DATABASE INTERFACE TECHNIQUES

Gregg C. Vanderheiden, PhD; Joseph M. Schauer, BSEE; David P. Kelso, MS; Tereza Snyder, BFA; Kelly Ford, BA; Roger O. Smith, PhD
Trace Research and Development Center, University of Wisconsin-Madison, Madison, WI 53705

Sponsors: *National Institute on Disability and Rehabilitation Research; Apple Computer, Inc.; IBM Corporation*

PURPOSE—Various electronic databases have been created to provide information on assistive technology and other disability issues. Electronic information, however, requires a user interface for presentation. Basic issues in the design of this interface must be resolved in order to assure the databases are optimally effective for all potential users. The strategies developed will apply not only to the particular databases currently being created, but also to other public information systems, such as electronic kiosks, automated teller machines, and cable-TV information services.

METHODOLOGY—Databases must simple and obvious for all users (disabled and non-disabled), especially novice users with little or no computer or database experience. They must allow independent use by people with disabilities.

The need for databases to be easy for novices to use is being met through extremely user-friendly database designs, including: familiar visual analogies on screen (such as book pages and index cards); context-sensitive instructions; prompts to the user to seek instructions; expanding-outline format for search terms; direct selection of choices from scrolling alphabetical lists; and location of geographic information by direct selection on a map.

To meet the need for databases to be accessible to users with disabilities, the Trace Center has developed interfaces which circumvent visual or movement-based features that may be difficult or impossible for users with visual or movement impairments. Some examples of strategies for users with visual impairments are: text enlargement; presentation of information and instructions in synthesized voice; and control from the keyboard rather than the mouse. Users with physical impairments are accommodated through providing alternatives to mouse movement.

The goal of this effort is to implement functioning examples of the Sean-Fless Human Interface Protocol. This protocol, being developed by the Trace Center, defines how a user interface can integrate different modes for users of widely varying abilities (e.g., mouse/keyboard, large print/standard print). Under the protocol, each mode of operation provides equivalent access to the functions of the software, but each mode is optimized for the needs of the users it is aimed at.

PROGRESS—Accessible database techniques were pioneered in the development of a blind access mode for Hyper-ABLEDATA. (The Hyper-ABLEDATA program provides easy access via personal computer to the ABLEDATA database of 19,000 assistive technology products.) Accessibility features are being incorporated into all the elements of the Trace Center's Cooperative Electronic Library on Disability, an integrated collection of disability resources in electronic form.

RESULTS—The first implementation of the Seanfless Human Interface Protocol was released as part of a prototype Publications, Media and Materials database. The PMM database was part of the Seventh Edition of the Co-Net CD-ROM, published by the Trace Center and containing the full Cooperative Electronic Library on Disability.

[151] ASSESSING INDIVIDUALS' PREDISPOSITIONS TO THE USE, AVOIDANCE OR ABANDONMENT OF ASSISTIVE TECHNOLOGIES

Marcia J. Scherer, PhD, CRC
National Technical Institute for the Deaf, Rochester Institute of Technology, Rochester, NY 14623

Sponsor: *National Science Foundation*

PURPOSE—Assistive technology (AT) use depends upon characteristics within four major areas: 1) the particular technology, 2) the person's abilities and personality, 3) the nature of the disability, and 4) the person's psychosocial environment. When variables within each of the above areas are organized by category of technology use and non-use, individuals can be profiled according to the likelihood of a good match with a particular AT.

METHODOLOGY—*Criterion-Related Validity.* Older adults (mean age 65) with normal hearing and comparably aged users of assistive listening devices or ALDs completed: 1) Hearing Handicap Inventory for the Elderly, 2) The Communication Profile for the Hearing Impaired (CPHI), and 3) the ADT PA. *Inter-rater Reliability.* Thirty rehabilitation professionals or graduate students rated videotaped interviews, supplemented with written information, of individuals using ATs. Item modes were calculated and the differences between the mode and individual rater responses were computed.

PROGRESS—The Assistive Technology Device Predisposition Assessment (ATD PA) is a consumer self-report checklist with items of varied format, including five-point Likert scales. Its purpose is to identify potential sources of person and technology mismatches for early intervention. The ATD PA has subscales to separately assess characteristics of the AT, the individual's temperament, and the environment in which the person will use the AT. A companion form completed by professionals assesses shared perspectives between consumer and professional.

Two concerns are 1) the extent to which the ATD PA adequately assesses the myriad influences on technology use and 2) the effect of "scorer variance" since items require subjective judgment. The ATD PA was created from the actual experiences of people who used or did not use a technology provided to them and has adequate content validity.

RESULTS—*Criterion-Related Validity.* Parts of both the CPHI and the ATD PA produced significant mean differences between ALD users and non-users, suggesting the value of assessing personality and psychosocial factors involved in technology use. Users in general attribute more value to ALDs, are psychologically readier to adopt technical assistance, and perceive fewer difficulties with technology use around family, friends, at work or school than do non-users.
Inter-rater Reliability. The items related to the AT itself and use of the technology within the family or workplace received the highest consistency in ratings. Items concerned with user characteristics and whether each was an incentive or disincentive to AT use had less consistent agreement.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Assessing the outcomes of AT use. Scherer M. In: Binion M, ed. Proceedings of the RESNA International '93 Conference: Engineering the ADA, 1993, Las Vegas, NV. Washington: RESNA Press, 1993:49-50.

Living in the state of stuck: how technology impacts the lives of people with disabilities. Scherer, M. Cambridge, MA: Brookline Books, 1993.

What employers want to know about assistive technology in the workplace. Scherer MJ, McKee BG. SHHH J 1993:14(1):23-7.

What we know about women's technology use, avoidance, and abandonment. Scherer MJ. Simultaneously In: Willmuth ME, Holcomb L, eds. Women with disabilities: found voices. New York: The Haworth Press, Inc., 1993; Women Ther 1993:14(3/4):117-32.

Applying the matching people with technologies model to individuals with hearing loss: what people say they want—and need—from assistive technologies. Scherer MJ, Frisina DR. In: Scherer MJ, ed. Tech Disabil 1994:3(1):62-8.

Matching people with technology. Scherer MJ, Galvin JC. Rehabil Manage 1994:7(2):128-30.

[152] BEDSORE BIOMECHANICS

Narender P. Reddy, PhD; Ramesh S. Candadai, PhD; Enrique P. Canilang, MD
Biomedical Engineering Department, University of Akron, Akron, OH 44325-0302

Sponsor: *University of Akron Faculty Research Grant #990*

PURPOSE—Bedsores (pressure sores or decubitus ulcers) are localized areas of cellular necrosis resulting from prolonged excessive stresses on soft tissues, and present a major problem in the comprehensive rehabilitation of spinal cord injured patients and others with paralyzing neurological diseases. The type and magnitude of stresses generated in the tissue depend on the body build, mechanical properties of the tissue, mechanical properties of the cushion, posture, etc. The objectives of this investigation are to study the effect of the following parameters on the internal stress distribution generated in the soft tissue of the buttock during vertical and inclined loading: 1) effect of bone and tissue geometry, 2) effect of mechanical properties of the soft tissue, and 3) effect of the mechanical properties of the supporting cushion.

METHODOLOGY—We have developed several types of 3-D physical models of the buttock. In each of these models, PVC gel simulating the soft tissue is cast around a wooden core, made with flat, sharp, or rounded edges, simulating the bone. Models vary in the bone core (wooden core) geometry, the mechanical properties of the soft tissue, and the aspect ratio (ratio of bone width to soft tissue thickness). Each of these models was placed on a cushion and loaded. A grid etched on the soft tissue model allowed photographic calculation of strains and stresses in the tissue. Cushion materials were compared in terms of the compressive and shear stresses generated in the soft tissue.

RESULTS—Shear stresses generated in the model soft tissue were significantly larger in magnitude in the case of the flat-edge bone core when compared to the rounded edge model. However, the compressive stresses in the flat edge case were lower than the rounded edge model. The peak shear and compressive stresses in the soft tissue produced in the sharp edge (V-edge) bone core model were larger than the round and flat edge models. Significant stress concentrations in the case of the sharp edge and flat edge models.

Foam cushions led to more uniform stress distribution in the model soft tissue when compared to all others tested during vertical loading. The gel cushion performed better during inclined loading. Inclined loading led to large magnitudes of shear stresses in the buttock model when the model was supported by air cushions. Hydrogel cushion was most effective in reducing the shear stress. A shorter bone core reduced the stress magnitudes at the cushion interface. With stiff cushions, the shear stress magnitudes were minimum at the cushion-tissue interface and increased to a maximum value near the bone tip. However, with soft foam and gel cushions, the reverse was true. Maximum shear stress was observed near the tissue cushion interface and minimum near the bone.

The present results suggest that the interface pressure measurements should be interpreted with caution and the body build, tissue properties and cushion properties should be taken into account when prescribing wheelchair cushions. Shape of the bone core plays a very important role in determining the stress distribution in the tissue.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Stress distribution in a physical buttock model: effect of simulated bone geometry. Candadai RS, Reddy NP. J. Biomech 1992:25:1403-11.

[153] INVESTIGATIONAL STUDY OF THE EFFECT OF PLATELET-DERIVED GROWTH FACTORS ON NON-HEALING PRESSURE ULCERS

David F. Apple, Jr., MD; Susan H. Vesmarovich, BSN, CRRN; Donald P. Leslie, MD
Clinical Research Department, Shepherd Spinal Center, Atlanta, GA 30309

Sponsor: *None listed*

PURPOSE—Human Platelet Derived Growth Factor (hPDGF) is a chemoattractant and potent mitogen for human fibroblasts, smooth muscle cells, neutrophils and mononuclear cells. Essential steps in the early phase of wound repair are the migration of macrophages and fibroblasts into the wound space. Macrophages are involved in phagocytic debridement and may release growth factors including hPDGF. Fibroblasts synthesize collagen and other extracellular matrix molecules required for tissue regeneration (Bauer, et.al. 1985). The release of hPDGF by platelet lysis within a wound space suggests that the chemotactic and mitogenic properties of this molecule play an important part in the initial cellular invasion of the wound space. As such, it is anticipated that this growth factor will have therapeutic utility in wound healing. Consequently it is hoped that chronic non-healing wounds such as decubitus ulcers may be stimulated to heal by the application of PDGF. PDGF, both natural and recombinant, has been shown to be efficacious in animal models of wound healing.

B. Robotics

[154] REHABILITATION ENGINEERING RESEARCH CENTER IN ROBOTICS

William Harwin, PhD; Richard Foulds, PhD; Tariq Rahman, PhD; Richard Mahoney, PhD; Shoupu Chen, PhD; Carol Stanger MS; James W. Fee, Jr.,MS; Sean Stroud, MS; Robert Piech; Rahamim Seliktar PhD
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The rehabilitation robotics program at ASEL is studying a number of aspects of robotics technology in rehabilitation. These technologies are designed to give a user with a disability more independence by having the robot assume the role of lost or impaired limbs. Issues related to the human/machine interface, applications, information, design, and assessment are being investigated.

METHODOLOGY—The rehabilitation robotics program has taken a liberal view of what constitutes a robot. This includes 'simpler' robots that achieve a functionality similar to that of a headstick or mouthstick, as well as force feedback systems that include a two robot, master-slave configuration wherein the person 'feels' what a remote (slave) robot is doing. This is accomplished by attaching an interface device (master) that transmits forces to the person. The robot thereby becomes a sensory extension of the person and becomes much easier to control. This idea is currently being applied to aid many people with a various disabilities, such as cerebral palsy, spinal cord injury, and muscular dystrophy.

Other projects include, 'multimodal user direction of a rehabilitation robot,' where a person is able to command a robot to get a cup of coffee from the table in front of him/her. This may be accomplished by a voice command or a laser pointer attached to the person's head. The hardware for this project includes; a vision system that senses where things are in the environment, a scanning range finder which identifies the object and how far it is. This is accompanied by a knowledge base of various objects and how to approach them.

Another project is investigating interfacing and control strategies for a powered upper extremity

orthosis intended for people with muscular atrophy, a condition where control and sensory abilities are intact, however strength in the residual limb is reduced to the point where the person cannot move his arms to feed himself. A powered exoskeleton would act as a power amplifier to aid in movement.

The application of existing robot systems is a also a major theme in this center. In conjunction with Ohio State University, ASEL is developing a robot-aided science education environment for students with severe physical disabilities. Application of robots in a vocational setting is also being investigated. Local and national companies are being surveyed to determine how best to integrate a robotic system with a disabled user into an existing environment that would enhance productivity and provide a better quality of life for an individual with a disability.

Other projects include; a consumer driven innovation laboratory; a modular adaptable mechanical robot; an assessment laboratory; predictive robot planning for individuals with sever disabilities; and finally an information wing that provides technical assistance, information and support to individuals, organizations.

RESULTS—A number of results have emerged: design and testing of a powered extensible mouthstick that is constructed of composite materials: experiments providing information on head movement and forces of persons with spinal cord injury have yielded encouraging results that will be used in designing a head controlled robotic system with sensory feedback: user trials on various robots as part of the robot assessment lab have yielded interesting results on issues such as safety, interfacc and acceptability criterion of robotic systems.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

The application of discrete-time adaptive impedance control to rehabilitation robot manipulators. Chen S. Harwin W, Rahman T. In: Proceedings of the IEEE International Conference on Robotics and Automation, 1994, San Diego, CA.

Bilateral control in teleoperation of a rehabilitation robot. Rahman T, Harwin W. Proceedings of SPIE-Telemanipulator Technology, 1992, Boston, MA.

The consumer, the interface, the needs, and the product. Harwin W, Rahman T, Stanger C, Fee J, Foulds R. In: Proceedings of the International Robots and Vision Conference, 1993, Detroit, MI.

Safe software in rehabilitation mechatronic and robotics design. Harwin W, Rahman T. In: Proceedings of RESNA International '92, 1992, Toronto, ON. Washington, DC: RESNA Press, 1992.

[155] IMPROVING THE FUNCTIONAL UTILITY OF REHABILITATION ROBOTICS THROUGH ENHANCED SENSORY FEEDBACK

William Harwin, PhD; Richard Foulds, PhD; Tariq Rahman, PhD
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—Recent rehabilitation robotics projects addressing the needs of individuals with quadriplegia due to spinal cord injury have primarily focused on the user input and, to a much lesser extent, on the feedback to the user. Because of the severe physical limitations that the disability places on the individual, and the loss of sensation below the spinal lesion, inputs such as voice recognition, joysticks, and switches have been common. Feedback has been primarily visual.

Considering the importance of proprioceptive and kinesthetic force feedback in prosthetics and telemanipulation, and the observed performance of the powered orthoses and the mouthstick, it is important to examine the use of such sensory feedback in assistive manipulation for quadriplegic individuals. This project is using teleoperation principles to provide force and proprioceptive feedback to the user. This will be accomplished by using a master-slave robot pair.

METHODOLOGY—In order to accomplish the primary objective of developing and testing a control system, a number of structured tasks are

defined. Taken together, the tasks yield a unified approach to addressing the various considerations inherent in developing a useful rehabilitation robot system.

First, it is necessary to assess the strength and range of motion of a number of spinal cord quadriplegic individuals to provide an understanding of the limitations associated with amplitude, strength (force), proprioception, and force sensation of head movements.

In order to provide the project with a robust research environment, a test-bed was constructed. This can be programmed to represent a number of control methods and will be used in subsequent tasks to determine the best human/machine interface or interfaces. Users will be given the opportunity to work with the test-bed for an extended period of time. The staff of the Applied Science and Engineering Laboratories (ASEL) will support the consumer trials, but will not specify their approach.

A human factors experiment studies the capacity of this human/machine interface to be successfully used without visual feedback. Reliance on proprioceptive feedback will be assessed.

Enhancements, including scaling of movement and force signals to allow more useful control, are being explored. In addition, the incorporation of orientation and/or gripping will be examined.

Consumer researchers will again be provided with extensive exploratory time to use the test-bed with the added enhancements. A second experiment will examine subjects' abilities to sense forces applied on the robot. Subjects will be asked to follow contours (squares, circles, triangles, etc.) and attempt to recognize shapes without visual feedback. We will then examine the successful control strategies which have been implemented on the test-bed and develop a prototype system which can be transferred to eventual commercialization.

The project will address transfer of technology through close collaboration with two organizations which have successfully brought commercial rehabilitation robots to the marketplace.

RESULTS—Results that show the range of head movement and forces/torques have been gathered and analyzed. These will now be used to implement in the test-bed. The control system test-bed has shown some interesting insight into human/machine interaction.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

The application of discrete-time adaptive impedance control to rehabilitation robot manipulators. Chen S, Harwin W, Rahman T. In: Proceedings of the IEEE International Conference on Robotics and Automation, 1994, San Diego, CA.

Bilateral control in teleoperation of a rehabilitation robot. Rahman T, Harwin W. In: Proceedings of SPIE-Telemanipulator Technology, 1992, Boston MA.

[156] REHABILITATION ROBOTICS INFORMATION PROGRAM

Richard Foulds, PhD; Michael Sandler, BS

Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Science Foundation, Information, Robotics & Intelligent Systems Division; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The Information Program in Rehabilitation Robotics will collect information, organize and/or synthesize it, and disseminate it to professionals, consumers and their families, manufacturers, and other researchers in rehabilitation robotics.

METHODOLOGY—The Information Program will produce technical reports, book chapters, journal articles, and conference and symposium presentations that describe the research, development, and evaluation work underway within ASEL. The project will also produce a number of resource materials to be used by the constituents it serves, including 1) a videotape comparing features of robotic devices; 2) *The Sourcebook on Control, Environmental Control, and Robotics* to be included in the Assistive Technology Sourcebook series published by RESNA Press; 3) a chapter on rehabilita-

tion robotics to be included in the *Atlas of Prosthetics and Orthotics* published by the Academy of Orthopedic Surgeons; 4) a white paper on funding for robotic devices and services; 5) the quarterly *Rehabilitation Robotics Newsletter*; 6) a comprehensive bibliography of robotics-related publications to be transferred to existing databases such as NARIC/ABLEDATA, ERIC, and COMPENDEX; and 7) the annual list of commercially available rehabilitation robotics products.

The 1994 International Conference on Rehabilitation Robotics and annual workshops on current robotics topics will also be sponsored by this program.

PROGRESS—Robotics research staff have produced 15 publications that will be disseminated through the Robotics Information Program. Inquiries for informational materials and technical assistance have been personally answered. The videotape of robotics products and laboratories is nearing completion and will be disseminated at the ICORR '94 Conference to be held in June 1994. The annual compilation of commercially-available robotics devices and their features has been disseminated. Surveys and questionnaires are being developed and distributed in preparation for writing the book for the *Assistive Technology Resource Series* and the *Atlas of Prosthetics and Orthotics*. The *Rehabilitation Robotics Newsletter* continues to be mailed quarterly. The ICORR '94 Conference will feature 35 scientific posters, 6 laboratory posters, and an attendance of about 150 robotics researchers, clinicians, students, and consumers. Cataloging and database creation of AAC literature and books continues in an effort to forward ASEL holdings to national databases.

[157] THREE-DIMENSIONAL POINTING INTERFACE FOR THE MANUS MANIPULATOR

Jasmina Miler, BASc; Stephen Naumann, PhD, PEng; Henry O'Beirne, MA, MASc, PEng; Geb Verburg, MA; Fraser Shein, MEng, PEng; Jonathan Kofman, MASc, PEng
Institute of Biomedical Engineering, University of Toronto; Rehabilitation Engineering Department, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsor: *Natural Sciences and Engineering Research Council*

PURPOSE—The ultimate goal of research in the field of rehabilitation robotics is the creation of an effective, reliable and interactive assistive device for persons with a limited range of motor functions. Several design aspects appear as challenges in the development process of a rehabilitation robot. The development of the appropriate control strategy and the design of a user-friendly interface are the focus of this project.

This project is investigating the means to reduce the degree of the active user's engagement in the process of direct manipulation control. The three-dimensional (3D) head pointer, employed as the interfacing device between the user and the robot, will be designed to accomplish this goal. By pointing to a particular object, or location within the robot's working space, the user will specify the Cartesian coordinates of the target point to which the robot end-effector should be moved. The exact positioning and orienting of the gripper will be performed automatically, under the control of the host computer.

PROGRESS—The system will incorporate several subunits which have been acquired: the REGENESIS Neil Squire Foundation robotic assistive appliance; the computer vision system comprising of two CCD cameras and image processing board with image capturing features and the laser head pointer and the voice recognition unit as the interfacing man-computer device. The PC in the role of host computer will integrate all subunits of the system.

[158] EYE POSITION INTERFACE FOR THE MANUS MANIPULATOR

Anastasia Cheetham, BASc; Morris Milner, PhD, PEng; Geb Verburg, MA
Institute of Biomedical Engineering, University of Toronto; Rehabilitation Engineering Department, The Hugh MacMillan Rehabilitation Centre, Toronto, Ontario M4G 1R8

Sponsors: *Ontario Ministry of Health, the Natural Sciences and Engineering Research Council; The Hospital for Sick Children Foundation*

PURPOSE—This project evaluates the feasibility of using eye position information to control the MANUS manipulator arm.

PROGRESS/METHODOLOGY—Computer software is used to interface between the BioMuse, a biosignal processing platform which includes the use of electrooculography (EOG) to record eye position information, and the MANUS manipulator, a wheelchair-mounted robotic arm. The movements of the MANUS manipulator end effector (gripper) are simplified to two planes of motion: horizontal and vertical. For simplicity, movements of the gripper itself are not controlled by the eye position interface. The computer software maps eye positions (up, down, left, right) to MANUS commands. Conceptually, the eyes are used to activate 'switches' in the field of view.

The interface will be evaluated in two stages. First, a computer simulation will evaluate the user's ability to target areas in the field of view with their eyes. The computer will record all activity for later analysis.

Second, the interface will be used to control the MANUS to perform tasks of various levels of difficulty to evaluate the user's ability to relate the eye positions to MANUS commands. The sessions will be recorded using an automated command monitoring system, and will be evaluated subjectively by an observer. In both phases, the interface will be compared to two other interfaces suitable for users with limited or no hand-function: the Nintendo Hands-Free Controller, a chin-operated joystick, and the Spaceball, an isometric joystick.

All data collected in the study will be evaluated to determine if eye position control of the MANUS manipulator is feasible and to recommend a control scheme.

The project is in progress. Preliminary data have been collected which indicate that the interface can successfully be used to target command zones in the field of view. Performance, as indicated by time taken to target a command zone, improved with practice.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Eye movement control of the manus manipulator. Cheetham A, Milner M, Verburg G. In: Proceedings of the 17th Annual RESNA Conference, 1994, Nashville, TN. Washington, DC: RESNA Press, 1994.

Vocational applications of robotic technology for persons with disabilities: overview and issues. Cheetham A, Verburg G, Milner M. In: Proceedings of the 12th Congress of the International Ergonomics Association, 1994, Toronto, ON. In press.

Rehabilitation robotics at Hugh MacMillan Rehabilitation Centre/Ontario Rehabilitation Technology Consortium. Verburg G, Milner M. In: Proceedings of the Fourth International Conference on Rehabilitation Robotics, 1994, Wilmington, DE. In press.

Manipulator developments at the Hugh MacMillan Rehabilitation Centre. Verburg G, Cheetham A, Bush G, Milner M. In: Proceedings of the Fourth International Conference on Rehabilitation Robotics, 1994, Wilmington, DE. In press.

C. Communication Methods and Systems

[159] RECOGNITION OF HAND GESTURES BY PEOPLE WITH MOTOR IMPAIRMENTS: A PILOT STUDY

Mark J. Sartori, BS; Lt Col Paul Morton, MD, PhD
Edward Hines Jr. VA Hospital, Hines, IL 60141; AL/CFHP Wright Patterson, Ohio 45433-7022

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #C92-453AP)*

PURPOSE—We propose to study the feasibility of two methods for computer recognition of hand gestures in the presence of noise caused by athetoid or spastic movements. Several schemes have been developed to recognize gestures of the face and hands; however, these gesture recognition algorithms are severely constrained by limitations in range of motion in the athetoid and spastic patients. We will study a feasibility scheme based on neural networks and statistical pattern recognition techniques. Our overall objective is to demonstrate the effectiveness of one or both of these techniques in recognizing hand gestures made by people with athetoid or spastic movements.

METHODOLOGY—To establish baseline data, 10 mixed-gender subjects with no motor abnormalities have been trained on 21 gestures from the American Sign Language, using the DataGlove for sensing finger articulation and a Polhomus Isotrack for 3-0 spatial position and orientation. Subjects will repeat the gesture 20 times each, using both the recognition and neural network algorithms, with data subjected to multiple analysis of variance to determine intersubject and intrasubject separability. This data will be compared to the same set of data takcn on a pool of 10 persons with athetoid hand movements. The Jebson-Taylor test is used as the standard test battery for both normal and impaired persons.

PROGRESS—To date a total of 10 normals and 2 patients have been tested and the data is in the process of being analyzed. Some unforeseen problems have been found and corrected regarding the computer software. The limiting factor in the project is the availability of patients who consent to the test. We are in constant communication with Occupational and Physical Therapy in order to recruit more patients. Progress is being made weekly in this area.

RESULTS—Data are currently being analyzed. No conclusions can be drawn as yet.

FUTURE PLANS—We plan to continue the study and the evaluation of the results in the following months.

[160] DEVELOPMENT OF EXTENSIONS FOR STANDARD COMPUTERS AND OPERATING SYSTEMS TO ALLOW ACCESS BY USERS WITH MOTOR IMPAIRMENTS

Mark Novak, BS, BS, PE; Gregg C. Vanderheiden, PhD; Jay Hinkens, BS; Joseph Schauer, BS; Peter A. Borden, MA
Trace Research and Development Center, University of Wisconsin, Madison, WI 53705

Sponsor: *IBM Corporation; Apple Computer, Inc.; National Institute on Disability and Rehabilitation Research*

PURPOSE—The most effective technique for providing access to computers for persons with disabilities is to have the computer designed in such a way that it is already accessible when manufactured. The purpose of this program is to develop extensions to operating systems which can be used to demonstrate

to computer and operating system manufacturers how their systems could be modified to make them more accessible.

METHODOLOGY—In some cases, the computer company has had its own programmers implement the accessibility features. In other cases the Trace Center has actually written the software for transfer to the company.

PROGRESS—The Trace Center has worked on the development of eight principal access features for computers, and worked for their adoptions as standard parts of computer operating systems: *StickyKeys* gives the user the capability to execute multiple key operation (such as shift-key) with a single finger, headstick or mouthstick. *RepeatKeys* and *SlowKeys* allow the user to set the speed of the auto-repeat function and to set the amount of time a key must be pressed before the computer accepts it as input. *BounceKeys* prevents accidental multiple keypresses ("bouncing" on a key), and *MouseKeys* provides the option of using the numeric keypad on the keyboard to perform all mouse functions on the computer. *SerialKeys* gives the user control of keyboard and mouse from an external assistive device (such as communication aid) connected to the computer's serial port. For the visually impaired, *ToggleKeys* sounds audible tones to indicate the status of the caps lock, num lock and scroll lock keys, and for the hearing impaired, *SoundSentry* flashes visual indications of computer sounds (such as warning beeps).

RESULTS—*StickyKeys, RepeatKeys* and *MouseKeys* are now shipped as a standard part of every Macintosh and Apple IIgs sold. Apple's System 7 includes a revised *MouseKeys* and *SlowKeys*. All eight features have been produced as an Access Pack for Microsoft Windows. The Access Pack is currently available from Microsoft Corporation at (206)637-7098.

StickyKeys and *RepeatKeys* have been available for eight years in a DOS program called One Finger. The Trace Center also recently worked with IBM to develop AccessDOS, including all eight features. It is available free from IBM at (800)426-7282. With the release of DOS 6.0, Microsoft is also distributing and supporting the AccessDOS features. The Trace Center has created a set of accessibility features for the UnixX Window graphical user interface. This Access X package was made publicly available with the X Window release XI I R6.

[161] EFFECTS OF GAIN AND MOVEMENT RANGE ON PERFORMANCE USING HEAD-CONTROLLED COMPUTER INPUT DEVICES

Robert G. Radwin, PhD; Gregg C. Vanderheiden, PhD; John A. Schaab, BS
Trace Research and Development Center, University of Wisconsin-Madison, Madison, WI 53705

Sponsor: *IBM Corporation; Apple Computer, Inc.; National Institute on Disability and Rehabilitation Research*

PURPOSE—Remote head-controlled computer input devices (i.e., headpointers) are a frequently used computer access adaptation for individuals who have limited ability to press keys on a keyboard, but who have an adequate range of head motion. Through a series of pointing device studies, the Trace Center is identifying methods for evaluating headpointer performance. The ultimate goals of this work include: the ability to compare remote headpointers to other input techniques; the ability to compare remote headpointer designs; and the ability to determine appropriate control settings for headpointers.

Previous studies tested the reliability of Fitts' law to describe performance in targeting with a headpointer, and analyzed the relationship of gain to performance. One of the key issues raised with gain control was whether user performance would be dependent on the distance from the headpointer's transmitter. It was hypothesized that a system which maintained a fixed amount of cursor displacement per degree of head movement would be independent of the transmitter's distance and thus be a preferred method for controlling this computer interface. This type of system is referred to as a movement range system, as opposed to a gain system.

METHODOLOGY—Gain for a headpointer is defined as the ratio of the operator visual angle, corresponding to cursor displacement, to the degree of head rotation or head extension/flexion. Movement range is defined as the amount of cursor displacement per degree of head rotation or head extension/flexion. The focus of this study is to determine whether user performance will change with viewing distance for predetermined settings of each type of control system. In addition, the study attempts to determine the optimal settings for each type of control system.

The target acquisition task based on Fitts' Law was used to measure subject performance. Twelve subjects participated in this comparison study. The three viewing distances studied were 50 cm, 65 cm, and 80 cm. At each distance subjects performed the task for each gain level of 0.5, 0.75, and 1.0. Subjects also performed the task for each range level of 0.5, 0.67, and 1.0 cm/°.

PROGRESS—An initial set of subjects has been run, and data analyzed. This study is continuing.

RESULTS—The data support the conclusion that an operator's optimal gain setting will depend on his/her distance from the transmitter. The drawback of a constant gain system for a headpointer, therefore, would be that users may need to select a new gain setting each time they use their computer. The results of the movement range data did not show a significant interaction between viewing distance and range. The benefit of a control system which is independent of viewing distance is that it allows a user to maintain consistent performance at a predetermined setting regardless of where they are positioned related to the transmitter.

[162] PROJECT LITERAAC: LITERARY INTERVENTIONS TO ENHANCE READING AND WRITING THROUGH AUGMENTATIVE AND ALTERNATIVE COMMUNICATION

David A. Koppenhaver, PhD; Patsy L. Pierce, PhD
Center for Literacy and Disability Studies, Department of Medical Allied Health Professions, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599

Sponsor: *US Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—The purpose of Project LITERAAC is to determine potential factors which enhance or interfere with literacy learning in elementary school-age children with severe communication impairments who use augmentative and alternative communication (AAC) systems.

To be as literate as possible is an important life skill for anyone but even more so for persons with severe communication impairments. To be able to read and write increases their face-to-face communication abilities as well as their employability. Approximately 90 percent of persons with severe communication impairments, however, lag significantly behind their nondisabled peers in their literacy-learning abilities. No clear relationship to date has been found between speech intelligibility, eye movement, or cognitive ability and literacy skills in this population. Empirically based reasons for these severe literacy problems or, more importantly, sound intervention strategies for enhancing literacy learning in this population, have yet to be developed.

METHODOLOGY—Ten subjects, ages 5-12, in eight different included and self-contained classrooms are being studied during Year 1 of the project (July 1993-July 1994). Qualitative research methodology (i.e., completing observations and interviews, writing field notes, videotaping) are used to describe the status of literacy instruction for these AAC users during Year 1. Constant comparative analysis of the description information in currently underway.

IMPLICATIONS—Initial patterns emerging from the data indicate that several factors affect literacy

learning among AAC users. AAC systems are often not being consistently, adequately, or appropriately used during literacy-related activities; students who use AAC are therefore passive rather than active participants and their passivity is sometimes interpreted as a learning problem.

Children with severe communication impairments who have been exposed to literacy at an early age and who have some means of physical accessing reading materials and writing tools seem to be developing literacy skills more so than children who must rely on eye pointing and/or scanning as selection techniques.

Parent-teacher and special education-regular education teacher collaboration appears to be an important factor in the quality and quantity of literacy opportunities these children are offered.

Teacher (regular and special education and teacher assistant) expectations, understanding of communication impairments and AAC strategies, and understanding of literacy learning processes also influences quantity and quality of interactions and access to communication aides and print/writing materials during literacy-related activities.

FUTURE PLANS—Based on the findings of Year 1, intervention strategies for improving use of AAC systems during literacy-related activities and overall literacy instruction for children with severe communication impairments will be developed, implemented, evaluated, and replicated during Years 2 and 3 of the project. Potential intervention strategies currently under consideration range from developing a team process model for literacy learning that includes parents, teachers, clinicians, and school administrators, to a consultative model offering technical assistance and inservice training relative to literacy and AAC.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Literacy issues in persons with severe physical disabilities. Koppenhaver D, Yoder D. In: Gaylord-Ross R, ed. Issues and research in special education. New York: Columbia University, Teachers College Press, 1992:2:156-201.

Contexts of early literacy intervention for children with developmental disabilities. Koppenhaver D, Pierce, P, Steelman J, Yoder D. In: Fey M, Windsor J, Warren S, eds. Language intervention in the early school years. Baltimore: Paul H. Brookes. In press.

[163] INTERFACE TRAINING AND USE BY PERSONS WITH COGNITIVE DISABILITIES

Cynthia J. Cress, PhD; Greta French, MS; Gregg C. Vanderheiden, PhD; Jon Miller, PhD; Tereza Snyder, MFA; Julie Gamradt, MS, CCC-SLP
Trace Research and Development Center, University of Wisconsin-Madison, Madison, WI 53705

Sponsors: *National Institute on Disability and Rehabilitation Research; University of Wisconsin-Madison Graduate School*

PURPOSE—The successful control of computer devices involves physical, cognitive, and perceptual/motor skills. Children operating computers must be able to physically control the devices, perceive and respond meaningfully to computer activities, and plan, understand, and modify their behaviors to accomplish a functional or educational task. While physical disabilities can interfere with the acquisition of necessary control skills, cognitive skill impairments, such as difficulty in responding to new information or applying learned skills to new situations, may interfere with the acquisition of computer control skills. Moreover, specific performance characteristics that are often associated with mental retardation, such as difficulty in sensory/motor integration, may cause particular problems in computer-based learning for children with mental retardation.

METHODOLOGY—The study examined children's skills at mastering the operation of five different computer controls: mouse, touchscreen, trackball, locking trackball, and keyboard. Thirty-nine normally developing children and fifteen children with mental retardation, with mental age measurements ranging from 2.5 to 5.0 MA, used each of these devices to move objects on a computer screen within a simple game-like task. Children received baseline measures of performance, criterion-based training in device operation, and samplings of maintenance and generalization of skills.

PROGRESS—Subjects have been run, and data have been compiled and analyzed.

RESULTS—Results examined potential factors which were predicted to contribute to group differences between normally developing children and children with mental retardation. Children with mental retardation achieved lower levels of mastery of the devices than their MA-matched peers. Factors associated with this difference included lower scores on cognitive measures of spatial problem solving, and poorer performance on sensory/motor integration subtests of a general developmental measure. Children with mental retardation did not perform significantly poorer on controls with highly simultaneous vs. sequential operation relative to normally developing peers. Children with mental retardation maintained and generalized newly acquired control skills as well as normally developing peers, which may have been related to content familiarity and clarity of instructions.

Differences in the impact of training factors on control skills were found for amount but not specificity of training. While expected levels of skill acquisition based on data from normally developing children were not reached by children with mental retardation, several learning characteristics typically associated with mental retardation did not differentially affect performance on these tasks.

[164] INTERFACE TRAINING AND USE BY YOUNG CHILDREN

Cynthia J. Cress, PhD; Greta French, MS; Gregg C. Vanderheiden, PhD; Jon Miller, PhD; Tereza Snyder, MFA; Julie Gamradt, MS, CCC-SLP
Trace Research and Development Center, University of Wisconsin-Madison, Madison, WI 53705

Sponsors: *National Institute on Disability and Rehabilitation Research; University of Wisconsin-Madison Graduate School*

PURPOSE—Given the relative difficulty of different computer controls and the performance characteristics of users identified in initial Trace Center studies of cognitive tasks in computer operation, it is necessary to translate these results into a form useful for application by educators and therapists. This study area is concerned with the process by which children who are still developing the cognitive skills necessary for interface operation learn to successfully control computer tasks.

PROGRESS—Training and learning profile data have been collected from 48 normally developing preschoolers between 2.5 and 5.0 years of age.

METHODOLOGY—First, a hierarchical training sequence was derived, to compare the kinds of instruction necessary for children with different levels of cognitive skills to learn interface operation. This training hierarchy also allowed identification of children who are in the process of acquiring interface skills but who are not yet independently proficient. Second, information about children's learning and error patterns was incorporated into learning profiles, to help predict children's long-term performance from short samples of behavior.

Children were given two simple demonstrations of interface function and allowed the opportunity to intuit the operation of the interface from practice given this experience. If this was unsuccessful, the children were given increasing levels of cues (from explicit demonstration to graded manual contact) until they could successfully operate the control. If children could not decrease their level of cueing within the task restrictions, the more complex movement and sorting tasks were not be given. Performance and error patterns were assessed both over time (by task) and between children (by cognitive skill).

RESULTS—Training and learning profile data have been collected from 48 normally developing preschoolers between 2.5 and 5.0 years of age. Results have been used in comparison studies of Interface Use by Persons with Cognitive Disabilities. Results have also been included in presentations on evaluation and training guidelines for interface training with young children, to assist in overcoming specific error patterns of individual children.

[165] GENERAL INPUT DEVICE EMULATING INTERFACE (GIDEI) STANDARD

Joseph Schauer, BS; Mark Novak, BS, BS, PE; Gregg C. Vanderheiden, PhD
Trace Research and Development Center, University of Wisconsin-Madison, Madison, WI 53705

Sponsor: *National Institute on Disability and Rehabilitation Research; Office of Special Education Programs*

PURPOSE—Certain people with physical disabilities cannot operate standard input devices for commercially available computers. Many of these individuals can, however, operate a special communication or computer access aid, using a control system such as an optical headpointer or a single switch. The aid in turn can be interfaced to the computer and used as an input device.

In the past, Keyboard Emulating Interfaces (KEIs) have been used to connect an aid to a computer. However, newer models of computers and software require the use of other standard input devices, particularly the "mouse" type of pointing device. Thus, the computer user must now be able to use the mouse in addition to the keyboard, to operate the computer.

To address the need for standard emulating interfaces for other input devices than just the keyboard, such as the mouse, the Trace Center developed a General Input Device Emulating Interface (GIDEI) standard.

METHODOLOGY—The GIDEI Standard is a document containing specifications for communicating desired actions to be performed with the standard keyboard and mouse. Communication and computer access aid manufacturers whose devices do not directly emulate input devices as a built-in feature are encouraged to design their devices with the capability to use the standard. Manufacturers who create general purpose emulating interfaces are also encouraged to support the GIDEI communication protocol.

PROGRESS—A standard has been developed and is in use.

RESULTS—The GIDEI Standard Version 1 is currently in circulation. Version 2 is in development. A hardware device designed at the Trace Center--the Trace Transparent Access Module (T-TAM) for Apple IIgs, Apple Macintosh, and IBM PS/2 and PC AT computers--has been programmed to operate according to the standard, and is now on the market. The commercial devices Darci Too and Ke:nx Version 2 also use the standard. The GIDEI is part of the keyboard/mouse adaptations the Trace Center has developed for Microsoft Windows and DOS.

FUTURE PLANS—The extension of the GIDEI to cover non-English character sets is currently being investigated, as are Macintosh and X Window System version of the standard.

[166] DEVELOPMENT OF DESIGN GUIDELINES FOR COMPUTERS AND OTHER ELECTRONIC DEVICES TO INCREASE USABILITY BY PERSONS WITH DISABILITIES

Gregg C. Vanderheiden, PhD; Mark Novak, BS, BS, PE
Trace Research and Development Center, University of Wisconsin-Madison, Madison, WI 53705

Sponsor: *National Institute on Disability and Rehabilitation Research; Information Technology Foundation*

PURPOSE—In order for people with disabilities to successfully use computers and electronic devices, the needs of such users must be integrated into the product design. This need becomes increasingly urgent as electronic information systems become more prevalent in the workplace, in school and in daily living.

Makers of computers, software, information systems, and consumer electronic products require information about the needs of consumers with

disabilities, as well as information on design strategies for accommodating these consumers. There is also a need for documents providing guidelines for implementing electronic accessibility in particular public settings.

PROGRESS—The Trace Center has so far developed five documents providing guidelines for accessibility: 1) computer guidelines, 2) consumer product guidelines, 3) software guidelines, 4) and 5) guides to implementing computer accessibility in higher education and in public libraries.

METHODOLOGY—Guidelines documents have been developed as cooperative projects among many interested parties. The Trace Center serves as coordinator, collecting the input from groups and individuals nationwide. The information collected is compiled into a summary document which is then circulated among the interested parties. The Task Force is open, in that anyone, including consumers, designers, manufacturers, researchers, and policy makers, can join the group . Membership in the group is defined as those individuals who remain active. A variety of communication channels are used, including mail, phone, TT/TDD, fax and e-mail.

RESULTS—The five documents created so far are:
1. *Considerations in the Design of Computers and Operating Systems to Increase Their Accessibility to Persons with Disabilities.* This document is used by computer companies to guide the development of access features.
2. *Accessible Design of Consumer Products.* Guidelines for the design of consumer products to increase their accessibility to persons with disabilities or who are aging.
3. *Making Software More Accessible to People with Disabilities: A Trace Center White Paper.* This document has been printed and circulated by the Information Technology Foundation (about 1,500 copies to members) and Microsoft Corporation (about 5,000 copies to software developers).
4. *Checklists for Implementing Accessibility in Computer Laboratories at Colleges and Universities.*
5. *Checklists for Making Library Automation Accessible to Patrons with Disabilities.*

The documents are available to any interested individuals from the Trace Center.

FUTURE PLANS—To deal with newly emerging information technologies such as automated teller machines, interactive television systems, and public information kiosks, the Trace Center plans to develop a set of guidelines for accessibility of new-generation information systems. The Center will also develop a set of focused guidelines dealing with specific communication technologies such as fax, voice mail, and text telephones (TTs/TDDs).

[167] RECOGNITION OF GESTURES FOR EXPRESSIVE COMMUNICATION

Richard Foulds, PhD; Roman Erenshteyn, PhD; Garland Stern, PhD; Lynn Messing, PhD; Scott Galuska, MS
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The goals of this project are to develop software for computer recognition of human gestures, to develop techniques to study structural and continuous human gestures, and to develop technology such that gesture recognition can be an effective technique for use in AAC devices.

METHODOLOGY—Using a CyberGlove (a glove-like device worn on the hand that contains strain gauges to measure the joint angles of the fingers and thumb) as an input device, examples of all 26 letters of the manual alphabet were collected for a single signer. A tree-structured system of neural networks were trained using standard backpropogation to recognize letters corresponding to the joint angles input from the CyberGlove. Once trained, these neural networks can then recognize in real time the letters formed by the same signer. Software devel-

oped on a Silicon Graphics computer displays the letters as the neural network recognizes them. (A blank is displayed if the handshape formed by the signer is not recognized as a letter of the manual alphabet.)

PROGRESS—The Gesture Laboratory at the Applied Science and Engineering Laboratories has been established over the past year. The initial stage of the project has been computer recognition of the American Manual Alphabet (used for fingerspelling).

RESULTS—The results of the fingerspelling recognition system have been satisfactory. When the same person who was used to train the neural networks also tests these networks, approximately 90 percent of the fingerspelled letters are recognized correctly.

FUTURE PLANS—Based on the success of fingerspelling recognition, the next stage of the project involves computer recognition of signs used in American Sign Language. Neural networks will be trained to recognize handshape, orientation, movement and place of articulation using two Cyberglove (one for each hand) as well as Flock of Bird sensors attached to both gloves, which measure the position and orientation of the hands in space.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Back propagation neural network for American Sign Language recognition. Erenshteyn R, Messing L, Foulds R, Stern G, Galuska S. In: Proceedings of the World Congress of Neural Networks, 1994, San Diego, CA.

Pattern recognition methods for translating American Sign Language into English. Erenshteyn R, Messing L, Foulds R, Galuska S, Stern G. In: Proceedings of the Sixth Biennial Conference of the International Society for Augmentative and Alternative Communication, 1994, Maastricht, The Netherlands.

[168] FLEXIBLE ABBREVIATION GENERATION

Gregg Stum, MS; Patrick Demasco MS; Kathleen McCoy, PhD
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The goal of this project is to increase the communication rate of physically disabled individuals via abbreviation expansion. Currently, abbreviation expansion systems require the assignment of a unique "code" to each word that the user wants to abbreviate. The user must then memorize all of these assignments. Flexible Abbreviation Expansion (FAE) seeks to eliminate these requirements. In this approach the expansion system recognizes any well-formed abbreviation for a word, eliminating the need to define and memorize specific coding assignments.

METHODOLOGY—Given an abbreviation, the system first looks up in the user's personal table whether there exists a defined expansion. If not the system retrieves all words from the dictionary that contain the same pattern of letters as the abbreviation (e.g., "gg" → gang going gong gorge). For efficiency, it also places a limit on the length of words retrieved for a given abbreviation (e.g., a word cannot be more than three times as long as the abbreviation). For this example, it would rule out words such as "Georgia."

The abbreviation rules are encoded as a set of scoring functions that rate each candidate word retrieved from the dictionary. Examples of scoring functions include frequency, vowel deletion, contraction, and letter distribution. In selecting the most likely abbreviation, the scores for each word are summed and the word list is sorted according to the total score. In addition, the user can control the rules by changing weighting values on each scoring function.

PROGRESS—The concept of FAE was demonstrated with a prototype developed in Lisp. This prototype implemented a dictionary and single expansion algorithm. For subsequent development there were two major goals: efficiency and flexibil-

ity; therefore, later prototypes were developed in C++ for efficiency. Also, the rules in the first prototype were fixed. A goal of later development was the ability for the user to have greater control over the way that the system expanded abbreviations.

Storage-Based FAE: The second prototype, written in C++, used nine different rules to categorize the possible expansions of an abbreviation. It has been tested on vocabularies of up to 1300 words. It is source-code portable between both Unix and DOS, and was compiled under a variety of distinct compilers. All of the abbreviation information required by this prototype is generated and stored in memory. Under Unix, it would consume as much memory as it needed. Under DOS, it would be sensitive to the amount of available memory and restrict its generation accordingly.

Dynamic FAE: While the storage-based prototype was efficient in terms of processor time, it required a significant amount of memory to store all of the possible abbreviations and expansions. Consequently, a third prototype was developed (also in C++) that was more dynamic in nature, computing and ordering the abbreviation expansion possibilities in real-time. The design of this was similar to the original Lisp prototype, but added flexible rules.

RESULTS—The storage-based FAE is being continued by GMS Systems with a Small Business Innovation Research Grant from the Department of Education. The grant supports the development of a more practical implementation that rates the possible expansions by the user's preferences, bases its information in a file rather than memory, and incorporates a user interface that can support a wide variety of configurations. At present, a prototype running under Microsoft Windows has been completed.

The dynamic prototype is fully functional and has been evaluated informally by a number of individuals. A formal evaluation is currently being planned. A number of companies have also been contacted about commercializing the system. Discussions are currently underway to coordinate the transfer process.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Flexible abbreviation expansion. Stum GM, Demasco P. In: JJ Presperin, ed. Proceedings of the RESNA International '92 Conference, 1992, Toronto, ON. Washington, D.C: RESNA Press, 1992:371-3.

[169] COMPANSION: A RATE ENHANCEMENT METHOD THAT UTILIZES NATURAL LANGUAGE PROCESSING TECHNIQUES

Patrick Demasco, MS; Kathleen McCoy, PhD; Chris Pennington, MS; Wendy McKnitt, BA
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The goal of this project is to increase the communication rate of physically disabled individuals via natural language processing techniques. We have developed a technique called Compansion which expands a compressed (telegraphic) sequence of words (input by the user) into a semantically and syntactically well-formed utterance. At the same time, we wish to do this by placing as little a burden on the user as possible. Thus, we are not interested in a simple coding system where sentences have been stored and are indexed by their content words.

METHODOLOGY—Input from the user will be the roots of the content words of the desired utterance; thus, many function words including determiners (e.g., the, a) and prepositions (e.g., of, in) will normally be left out. The system is responsible for filling in missing words as well as correctly conjugating the verb and forming a syntactically correct utterance. We attempt to form an utterance whose word order most closely reflects the word order given in the original input string. For example, if the system is given *apple eat John*, we would like the system to produce the sentence, *the apple is eaten by John.*

The Compansion project has been divided into four phases. The syntactic parser phase accepts input from the user and enhances it to designate modifier/clause attachments, compound noun struc-

tures, and in some cases, word sense disambiguation (sometimes resulting in multiple output structures). In the next phase, the semantic parser, the output from the syntactic parser is placed into a well-formed semantic structure. This phase is responsible for determining what role (semantic relationship) is played by each word of the input. To illustrate, in the example above, the parser recognizes that *eat* is a verb that prefers an animate actor and an inanimate/food object.

The semantic structure built from this phase is passed to the translator phase which is responsible for determining how each piece of the semantic structure can be realized in English. The translator is responsible for adding language-specific information to the semantic structure and for translating that structure into a representation appropriate for the sentence generation phase. The sentence generator uses a functional unification grammar to generate an English sentence from the specification constructed by the translator.

PROGRESS—A full prototype of the Compansion system has been completed in Common LISP and tested. Although the range of syntactic forms is not exhaustive, Compansion does handle declarative sentences that include multiple adjectives, prepositional phrases, possessive noun phrases, direct and indirect objects, and some verbal clauses (e.g., "I want to go to the store"). Questions, imperatives, complex verb tenses, and do-support are also provided. The present system has a vocabulary of over 1000 words and has the capability to infer the verb or subject in some situations. In addition, Compansion has been augmented to understand some metaphorical verb uses. A graphical interface emulating a word-based communication device has also been designed to demonstrate Compansion at conferences and for visitors at ASEL.

RESULTS—Discussions with the Prentke Romich Company and Semantic Compaction Systems have centered on taking some of the technology developed in this project and transferring it into the development of an intelligent therapy tool. Such an application provides us with a limited domain that allows us to fully specify the lexical knowledge required. Part of the technology developed in this project has been implemented in C++ which makes it available for quick and efficient transfer to future applications.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Generating text from compressed input: an intelligent interface for people with severe motor impairments. Demasco PW, McCoy KF. Commun ACM 1992:35(5):68-78.

[170] THE APPLICATION OF NATURAL LANGUAGE PROCESSING TO AAC

Patrick Demasco, MS; Kathleen McCoy, PhD; Chris Pennington, MS; Wendy McKnitt, BA; Peter Vanderheyden, BS; Denise Peischl, BS
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The goal of this project is to investigate the application of Natural Language Processing (a branch of Artificial Intelligence) to the development of more effective communication systems. The work proposed is based on the underlying concepts and model of Communicative Competence that suggests the need to support AAC system use on linguistic, operational, strategic and social levels. Natural language processing provides the computational techniques necessary to give communication systems the capability to reason about lexical, syntactic, semantic, and pragmatic knowledge.

METHODOLOGY—The project will conduct observational studies of language use in AAC systems using Conversational Analysis techniques. The data will contribute to the development of a conceptual model describing how the processing components of an intelligent system work together. It will build upon our previous research on applications of

syntax and semantics by considering the incorporation of pragmatic knowledge and the development of user models that will facilitate system learning. The model will be tested in the implementation of three prototype intelligent systems. This project also focuses on the transfer of previous research results into the commercial marketplace via collaboration with three corporate partners.

PROGRESS—A pilot study has been conducted involving the transcription of videotaped conversations between AAC users and their therapists. Preliminary analysis has revealed a number of interesting interactional patterns that occurred as conversational partners cooperatively constructed sentences. This sentence co-construction involved word finding (strategies used when a vocabulary item is unknown or unavailable), conversational repair (feedback, inferencing, correction) and confirmation. Supportive verbal feedback from the listener varied in its levels of incremental repetition and interpretation. In addition, linguistic observations of the therapist's interpretations of the AAC user's selections have provided evidence for the validity of the Compansion technique and have suggested areas of improvement as well.

As a result of this study, a detailed transcription system for recording verbal, gestural, and AAC device data has been created and revised. Also, we hope to further investigate the observed conversational patterns (possibly discovering new ones) through a series of additional studies in both controlled and natural settings. An initial experimental protocol has been completed and approved, allowing us to begin the process of selecting appropriate subjects for each planned task.

FUTURE PLANS—The anticipated results include 1) a better understanding of the language and interaction capabilities that should be incorporated into future intelligent communication aids; 2) unique contributions to our understanding of how Artificial Intelligence can be applied to AAC technology development; 3) the development of new research prototypes that demonstrate the use of Natural Language Processing and surpass existing efforts in terms of their ability to adapt to the user's language capabilities; and 4) the immediate commercialization of the Compansion and Flexible Abbreviation Expansion techniques that have been previously developed by the RERC as well as the transfer of the Intelligent Word Predictor prototype to be developed in this project.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

AAC-user therapist interactions: preliminary linguistic observations and implications for Compansion. McCoy K, McKnitt W, Peischl D, et al. In: Proceedings of the 17th Annual RESNA Conference, 1994, Nashville, TN. Washington, DC: RESNA Press.

Developing AAC systems that model intelligent partner interactions: methodological considerations. Vanderheyden P, Pennington C, Peischl D, et al. In: Proceedings of the 17th Annual RESNA Conference, 1994, Nashville, TN. Washington, DC: RESNA Press.

[171] HUMAN FACTORS STUDIES IN EYE MOVEMENTS RELATED TO AAC HEAD-MOUNTED UNIT

Richard Foulds, PhD; Arthur Joyce, PhD; Scott Galuska, M.S.
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—In order to overcome the many human factors obstacles in using eye movements to control AAC devices, a head mounted unit is being developed that will compensate for many of the complications which affect the ultimate utility of an eye tracking AAC system. A small, commercially available head mounted display (the Private Eye from Reflection Technologies) provides a convenient way to offer a computer display to an individual with a disability. The unit is worn on a head band and presents the image of the computer screen in the field of view of the wearer. This form of "heads up" display presents information that is independent of head movement.

The primary goal of this project is to retrofit the Private Eye with additional optics and optical sensors so that it becomes a small camera as well as being a display. The same software that is used to calculate the line of gaze in other eye tracking projects can be used to determine the line of gaze with respect to the "heads up" display. This system is potentially a portable eye gaze communication system that allows face-to-face communication.

FUTURE PLANS—A prototype of the system will be constructed beginning in late 1994 and evaluated for its ability to accurately detect the gaze. Clinical studies using the entire system as a communication device will follow.

[172] HUMAN FACTORS STUDIES IN EYE MOVEMENTS RELATED TO AAC HEAD-MOVEMENT STUDIES

Richard Foulds, PhD; Michael Sandler, BS
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The use of eye movements as a method of interaction in augmentative communication has been explored for many years with limited success. Significant data exists on the ability of individuals with severe disabilities to coordinate their oculomotor function with sufficient accuracy to use the line of gaze as an indicator of selection of a target. Instrumentation has been constructed using a camera to detect reflections of infrared light from the surfaces of the eye. This information allows the calculation of the line of gaze. Such a system can be used as a line-of-gaze typewriter or communication device.

The difficulties in the use of these instruments has been the human factors considerations associated with severe disability. Head movement is often unstable in individuals with disabilities. This project includes the development of an instrument which incorporates a pair of motorized mirrors that are servo-controlled and can follow the movement of the head in order to maintain a camera view of the eye.

METHODOLOGY—The major portions of this project involve the calibration and programming of the two servo-controlled mirrors connected to an IBM-compatible 386-PC. Once software libraries have been written to control the mirrors, these libraries can be integrated with other eye-tracking software routines to control the mirrors to compensate for head movement during the line-of-gaze calculations.

PROGRESS—The servo-controlled motorized mirrors have been successfully programmed to follow the movements of the head and makes the system considerably more appropriate for use with individuals with cerebral palsy and other disabling conditions.

FUTURE PLANS—Work is now underway to develop improved calibration techniques that will accommodate the movement of the head and allow for accurate calculation of the line of gaze.

[173] AUGMENTATIVE COMMUNICATION INFORMATION PROGRAM

Richard Foulds, PhD; Michael Sandler, BS
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—To serve as a leading source of materials and assistance to professionals, consumers, families, and agencies dealing with augmentative communication. In addition to disseminating techni-

cal reports and articles on research results obtained by ASEL staff, this program will also participate in activities to promote dissemination in the areas of technical assistance, consumer advocacy efforts, support to manufacturers, and support to other researchers.

METHODOLOGY—Materials to be developed include 1) a flipchart of features of portable communication devices, with accompanying vendor information notebook and color slide set; 2) *Augmentative and Alternative Communication*, a book to be included in the in the Assistive Technology Sourcebook series published by RESNA Press; 3) a resource book of effective advocacy strategies; 4) a white paper on Medicare funding for AAC devices and services; 5) a registry of researchers in the field of AAC; and 6) a comprehensive bibliography of AAC-related publication to be transferred to existing databases including NARIC/ABLEDATA, COMPENDEX, and ERIC.

Manufacturers' Forums and a Vision II Conference will be sponsored for discussion and promotion of technology transfer issues in the field of augmentative communication. The Information Program will also serve as a catalyst for a regional support network of individuals who use communication devices and their families and as support to "Tech Act" state projects in the AAC arena.

PROGRESS—The researchers in augmentative communication have produced 14 publications for dissemination through the Information Program. Inquiries from other researchers, clinicians, therapists, consumers, teachers, and families are each answered with a personal response and appropriate information materials. Initial questionnaires and surveys have been disseminated in preparation for producing the flipchart of features of portable communication devices, the Assistive Technology series book, and the collection of essays written by consumers who use augmentative communication. The *Guide to Funding Resources for Assistive Technology* in Delaware is written in draft form and soon ready for publication. Fifteen of the ASEL augmentative communication research staff traveled throughout Pennsylvania and Ohio visiting several AAC device manufacturers to discuss practical issues of device design that should be considered at the research and development stage. Cataloging and database creation of AAC literature and books continues in an effort to forward ASEL holdings to national databases.

[174] LANGUAGE FACILITATION THROUGH GRAPHICS AND GRAPHICAL ANIMATION

Beth Mineo, PhD; Denise Peischl, BS; Chris Pennington, MS
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—There are many products on the AAC market that use pictures as the means for transferring meaning, and we are beginning to see the emergence of animation capabilities in a subset of these products. We currently have very little knowledge about the manner in which individuals with disabilities operate with these kinds of two-dimensional representations. We can, however, rely on what we know about language acquisition and language behavior to provide the AAC field with a scaffold for exploration of the picture issue. This project will investigate the representation of actions in two-dimensional forms. It will determine the relative efficacy of a number of approaches for representing movement, including static pictures, video, and animated pictures. The results will provide guidance to those selecting and customizing AAC systems, as well as to manufacturers who are trying to make their products maximally responsive to the needs of people who rely on picture-based AAC systems.

PROGRESS—The RERC is preparing to launch a series of investigations regarding the ease with which individuals understand and use picture-based representations of action concepts. Progress to date

relates to the development of a computer-based system for presentation of the range of visual stimuli that will be studied. The system will be capable of simultaneous presentation of multiple video, animated, and static representations. Touch screen access will facilitate subject responses.

FUTURE PLANS—One of our intended outcomes is to provide the field with an empirically-based perspective on the relative difficulty of several types of picture-based representations. A very practical extension of this outcome would be that service providers may give greater consideration to the selection of representations to be included on communication displays, assessing individual skills beforehand and taking the pragmatics of language use into account in the resulting decisions.

Another intended outcome is the refinement of a methodology for examining issues related to picture-based representation that takes into consideration the interaction between various ways in which pictures are used (matching, comprehension, production) and the types of pictures available.

Finally, the research results should have direct applicability to manufacturers as they try to improve and refine their products. Given the demands of the commercial marketplace, manufacturers rarely have an opportunity to conduct field evaluations with a product prior to its introduction. The information from this research will provide some data-based guidance about the effect that their choices of representational systems will have on potential users of the system.

[175] SPATIALIZATION AND SPATIAL METAPHOR IN AAC

Patrick Demasco, MS
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—In this project, we are interested in exploring new methods for the organization and access of language based on principles of Spatialization and Spatial Metaphor that have emerged from the field of Human-Computer Interaction. The predominant approaches to language organization that currently exist (e.g., levels) are largely based in the physical constraints of current AAC hardware such as screen size. Language is often organized to "fit" into the display or keyboard of the device. As a consequence, many users who have manual communication boards with hundreds of words are forced into the use of spelling, multiple levels, coding and/or predictive systems. As an alternative approach, we would like to consider technology that supports expanded information spaces as a means to provide more natural communication for individuals with severe communication impairments.

The primary objectives of this project are to 1) investigate the comparative usage of large manual word boards versus electronic systems by the same user, 2) develop a theoretical framework for describing new spatial metaphors in AAC, and 3) develop and evaluate prototypes of new systems that offer large language spaces that can be accessed in a multi-modal fashion. We will utilize the technology available from the emerging field of Virtual Reality to create systems that consist of head-mounted displays that provide the user with a view of the information space, a tracking system that will adjust the view based on head position, and a selection interface based on hand and/or eye pointing. In addition, the VR approach will be balanced with the design of systems that use conventional computer screens.

The anticipated outcomes of this project are the contribution of a novel model of language organization and the demonstration, evaluation and commercialization of systems that exploit this model.

PROGRESS—An application of the virtual word concept is under development. VAL (Virtual Access to the Lexicon) is intended to support spatial equivalence between manual and electronic systems. It also supports evolutionary changes in the word board structure, by allowing the user to access a large lexical database that stores words and their relationships to other words. Display drivers that provide quick update rates for the Private EyeTM and VGA display have been implemented. A lexical database access module is under development.

[176] SPEECH PROCESSING PROGRAM

Timothy H. Bunnell, PhD; James B. Polikoff, MS; Shirley M. Peters, MS; Brian Rapp, BS; Guangsheng Zhang, MA
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The purpose of this project is to integrate computer hardware and software that will implement speech enhancement algorithms developed for dysarthric speech as a real-time prototype speech prosthesis. The device will accept speech produced by a person with a speech disorder, process the speech to make it more natural sounding, and then replay the processed speech on command. The prototype under development is to serve as a test bed for implementing new speech processing algorithms and for studying how users will interact with such a device.

METHODOLOGY—This program is based on ongoing work in the Speech Processing Laboratory to develop signal processing techniques capable of improving the intelligibility and naturalness of disordered speech. These techniques involve adjusting the timing of the speech as well as adjusting its spectral properties. Timing adjustments are performed by simply cutting out unwanted portions of the speech, or lengthening (by repeating) sections of speech that are too short. This form of signal processing is computationally simple and fast and therefore attractive from a practical standpoint. More complex rule-based systems are also being developed that will require recognition of general acoustic speech patterns to determine how segments should be shortened or lengthened. These systems will be able to automatically decide which parts of the original speech are important to keep and which parts can be safely discarded without losing important information. Once optimal timing has been accomplished, spectral characteristics of the speech can be adjusted to further enhance intelligibility.

Perceptual experiments are being performed to test the intelligibility of the disordered speech both before and after speech processing. In a typical experiment, normal-hearing subjects listen to samples of original and processed speech in a sound-attenuated chamber. In tests of segmental intelligibility, subjects listen to short nonsense sentences and must choose the words they thought they heard from a closed response set differing on a single phoneme. These experiments help to identify which speech production errors are common for specific disordered talkers, as well as which type of articulations are helped (or hindered) by speech processing.

RESULTS—From the first set of studies we concluded that time-adjustment leads to significantly better sounding speech and small but significant improvements in intelligibility for some phonemes. However, improvements in intelligibility were sometimes offset by artifacts of the signal processing techniques used for timing adjustment. A new version of the software for timing adjustment has been developed which minimizes such processing artifacts and at the same time incorporates a simple heuristic for determining which segments to alter in adjusting the timing of the signal.

[177] SPEECH SYNTHESIS PROGRAM

Debra Yarrington, BS; Richard Foulds, PhD, MS; Othman Mohamed, MS; Kathy Samworth, BS; Gatot Soemarwoto, MSEE
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The purpose of this program is to develop the software for the production of high quality, highly intelligible synthesized speech with an unlimited vocabulary. Research in the program includes the development of methods for customizing voices for each individual and the development of a Spanish speech synthesizer.

METHODOLOGY—The work in this program is based on diphone speech synthesis. Diphones are speech segments that run from the steady state of one phoneme through the transition between phonemes to the steady state of another phoneme. Because both diphone ends are at steady states of phonemes, diphones can be appended together to create any word or phrase. Yet with only a limited number of phonemes in any language, the number of possible diphones is limited as well. So, using diphones, a reasonable amount of memory is needed to create an unlimited vocabulary.

Diphones are obtained by recording a person saying words with the necessary transitions. The transitions are then extracted and stored in a library. A text-to-speech algorithm that converts text into its corresponding phonemic and then diphone representation is used to append the proper diphones together to create speech. Very little analysis is done of either the original recorded word or of the diphone transitions. In this way all of the qualities of the original speaker's voice are retained. As a result, the synthesized voice created is human sounding and recognizable as being the voice of the individual recorded.

Through the use of an automatic diphone extractor, synthesized voices that are tailored to each individual can be created in an acceptable span of time. Anyone with reasonable control over the vocal muscles can be recorded. The automatic extractor will then extract the diphones from those recordings, enabling the creation of a voice that sounds like that person.

To further extend the population being accommodated with the synthesizer, Spanish synthesized speech is also being created. Spanish uses a different set of phonemes and a different set of rules for converting Spanish text to speech. However, using the diphone method of speech synthesis, no other changes are necessary to create Spanish synthesized speech with the proper accent.

RESULTS—Work on a speech synthesizer with a child's voice and a male voice has been completed. Using the text-to-speech algorithm, the child's voice is very intelligible and retains the childlike quality. The male synthesized speech is also highly intelligible and uniquely identifiable. The automatic diphone extractor has not been tested on sounds with continual steady states (e.g. "l", "r", "w", and "y" sounds), but works well for the majority of diphones on which it has been tested. For the Spanish speech synthesizer, the inventory of recorded sounds, as well as the text-to-speech algorithm have been completed, and words created from Spanish diphones have the proper pronunciation and are highly intelligible to those who speak Spanish.

FUTURE PLANS—Future plans include research into incorporating prosodic information in voices created, and development of tools for improving the robustness of the diphone method for all voices.

[178] DEVELOPMENT OF AN AAC SOFTWARE ARCHITECTURE

John Dunaway, MS; Patrick Demasco, MS; Chris Pennington, MS
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The goal of this project is to facilitate more cost-effective development of Augmentative and Alternative Communication (AAC) software by developing a general framework for describing AAC systems and a supporting set of tools that will allow developers to produce new applications. This will effectively minimize the duplication of efforts in a field where resources are precious and promote sharing of ideas and software among developers. By utilizing object-oriented software technology, it is possible to develop a set of building blocks that can be used to realize this goal.

METHODOLOGY—The use of object-oriented analysis, design, and development provide significant advantages towards reusable software. Specifically we have chosen the C++ language for its support of the OOP paradigm, its efficiency, and its wide availability in the marketplace.

PROGRESS—We have previously reported the development of a model that is comprised of two major components. LASO (Library of Adaptable Software Objects) is a collection of C++ class hierarchies that represent AAC functional components. Adapt is an interpretive authoring language based on LOGO which is used to define object connections, provide functionality to vocabulary items (e.g., speak a message) and allow the development of high level scripts that could be used in a variety of situations (e.g., instructional sessions).

Progress over the last year has been made in all areas of design and development. We have devoted much time to issues involving portability among different hardware platforms and operating environments. We have also modified some of our class interfaces to be compatible with the work of the ComSpec group in Europe who have similar project goals.

RESULTS—We have implemented a MS-DOS screen class that supports the Microsoft DOS operating system on IBM personal computers. Two AAC applications, Letter Prediction and Graphcom, have been developed on this platform. We have also extended the screen class design to provide screen management support for windowing systems. The screen classes will provide a foundation for us to use to support windowing systems on the IBM personal computer and Macintosh platforms.

Additionally, we have designed and implemented a resource management mechanism that can store and retrieve resources such as screen palettes and PixShapes to and from files on a hard drive. The resource management class loads memory intensive resources into memory when they are needed and stores them in a file until they are requested by the application. This utility has been tested but not yet implemented with LASO resources.

We have also designed and implemented two related classes, the Selection Technique class and the Selection Set class that will support direct selection and scanning strategies, and manage the vocabulary selection and vocabulary page changing.

The first version of Adapt is now complete and runs on IBM personal computers running the MSDOS operating system. Adapt is compatible with Object LOGO which is commercially available for the Macintosh computer. Object LOGO adds a number of enhancements to LOGO that are similar to the extensions introduced by Adapt. By changing Adapt to be compatible with Object LOGO, we feel that it will ultimately receive greater acceptance within the developer community.

[179] DEVELOPMENT OF AAC SYSTEMS BASED ON PERSONAL COMPUTERS

Denise Peischl, BSE; John Dunaway, MS; Patrick Demasco, MS; Alice Smith
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—This project focuses on the development of new augmentative communication systems based on personal and portable computers. In addition, results from other REC research efforts are incorporated into systems through this project. Finally, this project serves to develop systems for experimental evaluation of research techniques.

METHODOLOGY—The primary goal is to research and develop techniques to increase an individual's communication rate. This project focuses on enhancing a user's input process, particularly multimodal input, and increasing a user's vocabulary selection rate through a variety of prediction strategies and abbreviation expansion. Projects address the needs of specific target populations.

PROGRESS—Development of a software based communication system named Meta4 is nearing completion. The Meta4 package consists of a main program, which turns any PC into a dedicated augmentative communication device, and three supporting utilities that make Meta4 easier to set up and maintain. Progress in the last year has centered around the completion of all parts of the package in preparation for transfer out of the laboratory.

Meta4 is designed for users with severe speech impairments in addition to physical disabilities. It is also designed for the user with visual and/or perceptual difficulties. With this in mind, much of the emphasis in developing the system has been on flexibility of system configurations and screen displays. This flexibility allows Meta4 to be set up, or configured, for each individual and changed to follow that individual's needs.

Work has begun on another prototype communication system called Graphcom. Graphcom uses gray-scale images to display the contents of a vocabulary set. Images are captured by a small, inexpensive camera and put into the vocabulary set in a designated location. New images can be imported at any time. The vocabulary set is comprised of pages of images arranged in rows and columns. A VGA monitor displays one page of the vocabulary set at a time and the user constructs a message by selecting one or more images from the set.

This system is designed for individuals who have difficulty dealing with abstract symbol sets but work well with more life-like images. At this point, the system has been developed as a demonstration program; therefore, the only input method is by mouse and only minimal control over the arrangement of the vocabulary set is possible.

Version 1.5 of Graphcom has been completed and version 2.0 is underway to provide more enhanced input and output control, including support for a printer and speech synthesizer. Another feature of version 2.0 is the ability to support more pictures. Graphcom currently supports a fixed number of pictures that can be loaded into memory during system initialization. Version 2.0 will allow pictures to be loaded dynamically from a disk.

Letter Prediction, a letter-prediction acceleration technique for use with a scanning system, is designed to increase the rate at which someone spelling messages can enter them into his/her communication system. This is accomplished by using the statistical redundancy of language and quadgram data derived from the Brown Corpus. As the user begins to spell a word, the system monitors each letter and predicts the three most likely letters to follow. It then automatically highlights each of these letters in succession giving the user the chance to select one if it is correct. If the user does not select any of the three, the system returns to its normal scanning technique. Using this approach, the time required to spell a word will decrease because accurately predicted letters will become highlighted much sooner than if the normal scanning technique had been used.

FUTURE PLANS—This project may investigate communication applications for hand held, pen-based computers and telecommunication applications.

[180] EVALUATION OF HUMAN-SYSTEMS INTERACTION IN AAC

Beth Mineo, PhD; Denise Peischl, BSE, John Dunaway, MS; Richard Lytton, MS
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—Each user of AAC brings a unique set of skills to the communication process, thereby making it important to consider what techniques are most appropriate for the user given the circumstances involved. The goal of the Evaluation Project is to conduct an in-depth evaluation of the relationship between technological capability and functional use by individuals using AAC devices. The topic that is currently being addressed is that of acceleration techniques, which are employed to improve the efficiency of communication. Efficiency in this sense refers not only to rate but also to the ease with which messages are generated.

METHODOLOGY—To determine the efficacy of these new approaches, the Evaluation Project will subject the systems to rigorous evaluation with both typical communicators and those with significant communication limitations, starting with the Letter Prediction system. Subjects will be asked to generate standard texts via scanning with and without the use of letter prediction. As part of the objectives, the effects of familiarity of the material and communicative context on generation will be investigated. It is expected that the results from the clinical evaluations will identify keystroke savings, the influence of various contextual factors, and the comparative performance of individuals with and without severe communication limitations. It is also expected that results from this study will indicate whether the letter prediction technique offers more efficient text generation capability than the systems being used by daily users of AAC devices. The results from the clinical testing will be analyzed and recorded and shared with the community of AAC professionals.

PROGRESS—Building on technological developments to date, two novel acceleration techniques that combine the best of what exists with techniques designed to minimize known drawbacks have been developed. The first, a scanning Letter Prediction system, was created as an alternative to existing word prediction systems that require the user to monitor both the selection area and the prediction menu. The second, a Flexible Abbreviation Expansion (FAE) system, was designed to reduce the profound memory load placed on users as a result of having to remember codes for each available expansion.

To establish baseline measures, a simulation program has been developed. The validation process consisted of comparing simulator output for a small text file with manually calculated results. Simulations were run on large corpora with a variety of parameter settings. Initial results from the simulations showed a rate enhancement of approximately 25 percent, based on a one second scan rate and a one second switch closure time.

FUTURE PLANS—Upon completion of the evaluation of the Letter Prediction system, we will analyze the Flexible Abbreviation Expansion (FAE) system to determine if modifications should be made prior to the initiation of field testing with that system.

Once analysis of FAE is complete, we will evaluate FAE relative to other word prediction techniques as well as to other abbreviation techniques. Clinical testing will be performed using both typical communicators and those with significant communication limitations. Similar to the evaluations performed using letter prediction, the FAE evaluations will compare results between generating text with and without the FAE implemented as well as results implementing FAE with and without generated prediction lists.

[181] ENHANCING PICTURE-BASED COMMUNICATION VIA COMPUTER-ASSISTED DESIGN AND INSTRUCTION

Beth A. Mineo, PhD; Patrick W. Demasco, MS; John G. Gray, MS; Rachel S. Bender, MA
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—Pictorial representations of language are crucial to access to augmentative communication systems for many individuals who cannot read and spell. Currently, there are no guidelines or protocols available for systematic evaluation of picture-related skills. The purpose of this research is the development of a computer-based tool for the generation, manipulation, and display of pictures at a variety of abstraction levels. The second goal is the creation and field testing of application packages for the assessment of picture-matching skills and the training of increasingly sophisticated picture matching.

PROGRESS—The development of the computer-based system is sufficiently complete to support development of application packages. Applications for picture assessment and training have been designed and implemented. Field testing commenced in 1994. Refinements to the computer system will be based on the outcomes of field testing, both in terms of the pedagogical integrity of the application as well as the functioning of system hardware and software.

RESULTS—The system is capable of generating multiple versions of a picture (e.g., black-and-white line drawings, cartoons, black-and-white photos) from a single color photograph or video frame. Representations can be arranged on the screen automatically in response to the specifications described in an application protocol. The system presents the application to the user, using the screen sequencing, verbal and visual prompts, and reinforcement and correction sequences specified in the application protocol. The system also collects response data.

FUTURE PLANS—The computer-based system was designed with sufficient flexibility to support a wide range of applications. It is a powerful tool for the design and delivery of research, assessment, and instructional protocols.

If field testing indicates that the assessment and training applications developed in this project are useful for defining and improving picture-based skills, we will be able to offer the field a systematic manner in which to approach the evaluation and training of picture matching skills.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Design and development of a computer-based system for assessing and training two-dimensional language representation. Demasco P, Mineo B, Gray J, Bender R. In: Proceedings of the RESNA Annual Conference, 1994, Nashville, TN. Washington, DC: RESNA Press. In press.

Systematic assessment of picture-based language performance via computer. Mineo B, Demasco P, Gray J, Bender R. In: Proceedings of ISAAC '94, 1994. In press.

[182] MODELING OF PERFORMANCE WITH COMPUTER ACCESS AND ALTERNATIVE COMMUNICATION SYSTEMS

Heidi Horstmann Koester, MS; Simon P. Levine, PhD
University of Michigan, Rehabilitation Engineering Program, Graduate Bioengineering Program, Ann Arbor, MI 48109-0032

Sponsors: *National Science Foundation, Graduate Fellowship Program, Washington, DC 20418; University of Michigan, Rackham School of Graduate Studies, Rackham Dissertation Grant, Ann Arbor, MI 48109-1070*

PURPOSE—This project explores the application of engineering modeling techniques to improve understanding of the user interface of augmentative communication (AAC) systems. There are two

prongs to this work. The first is empirical, involving the observation of behavior and measurement of performance during use of AAC systems. The second is analytical, involving the development of quantitative models that accurately represent these observations. The goal of the modeling process is to provide developers and clinicians with a framework that can improve the design and delivery of AAC systems. If we are successful, the models will be able to quantitatively predict user performance with these systems and simulate the effects of varying user and system characteristics. The modeling process also offers a valuable qualitative analysis, since it provides the opportunity to analyze the interaction between the user and an AAC system under a wide range of conditions.

PROGRESS—Modeling techniques used in the field of human-computer interaction continue to be the foundation of the models developed in this project. Models have been developed to estimate quantitative performance measures (e.g., text generation rate) for row-column scanning and direct selection interfaces with and without word prediction. Additionally, a more general cost-benefit model has been developed that is independent of the specific input method or rate enhancement technique. Two empirical studies have been performed in order to validate the models and gain more understanding about user performance with AAC systems.

RESULTS—In the first study, able-bodied subjects transcribed text using two row-column scanning systems, one with and one without a word prediction feature, for ten consecutive trials each. The word prediction system was not substantially more difficult to learn, but it did not yield a significant improvement in text generation rate. This suggests that the cognitive and perceptual costs of using this word prediction system (e.g., the time required to search the word list) balanced the benefit of the keystroke savings achieved by these subjects.

In the second study, fourteen subjects transcribed text with and without a word prediction feature for seven test sessions. Eight subjects were able-bodied and used mouthstick typing, while six subjects had high-level spinal cord injuries (SCI) and used their usual method of keyboard access. Use of word prediction significantly decreased text generation rate for the SCI subjects and only modestly enhanced it for the able-bodied subjects. Performance was analyzed in more detail by deriving subjects' times for keypress and list search actions during word prediction use. All subjects had slower keypress times during word prediction use as compared to letters-only typing, and SCI subjects had much slower list search times than able-bodied subjects. These results are consistent with the scanning study, in demonstrating that there can be a substantial time cost associated with the cognitive processes during use of a word prediction system.

Two keystroke-level models of user performance were developed to predict the improvement in text generation rate with word prediction relative to letters-only typing. Model predictions were tested against the actual performance of subjects in the second study above. For Model 1, user parameter values were determined independently of subjects' actual performance. The percent improvements predicted by Model 1 differed from the actual improvements by 11 percentage points for able-bodied subjects and 53 percentage points for SCI subjects. Model 2 employed user parameter values derived from subjects' data and yielded more accurate simulations, with an average error of 6 percentage points across all subjects. Use of Model 2 to simulate subjects' word entry times produced an average error of 16 percentage points.

FUTURE PLANS—Ultimately we hope to determine guidelines for the efficacy of word prediction, as well as validate general modeling techniques that support the development of guidelines for other AAC systems.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Model of performance cost versus benefit for augmentative communication systems. Koester HH, Levine SP. In: Proceedings of the 15th IEEE Engineering in Medicine and Biology Society Conference, 1993:1303-04.

Effect of a word prediction feature on text generation rate. Koester HH, Levine SP. Proceedings of 17th Annual RESNA Conference, 1994, Nashville, TN. Washington, DC: RESNA Press.

Quantitative indicators of cognitive load during use of a word prediction system. Koester HH, Levine SP. In: Proceedings of 17th Annual RESNA Conference, 1994, Nashville, TN. Washington, DC: RESNA Press.

Learning and performance of able-bodied individuals using scanning systems with and without word prediction. Koester HH, Levine SP. Assist Tech. In press.

Modeling the speed of text entry with a word prediction interface. Koester HH, Levine SP. IEEE Trans Rehabil Eng. In press.

[183] WIVIK 2REP: RATE ENHANCEMENT PACKAGE

Fraser Shein, MEng, PEng; Gil Hamann, MASc, PEng; Tom Nantais, Bc; Morris Milner, PhD, PEng, CCE
Microcomputer Applications Programme, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsors: *The Ontario Rehabilitation Technology Consortium funded by the Ontario Ministry of Health; IBM Canada Ltd.; IBM Corporation; University Research Incentive Fund of the Ontario Ministry of Colleges and Universities; National Research Council of Canada*

PURPOSE—The purpose of the WiViK 2 Rate Enhancement Package is to increase typing efficiency of users of WiViK 2, an on-screen keyboard for Windows 3.1. Typing is relatively slow when using a pointing device or a scanning method because only single keys are selected. Although macro keys may be defined, large user vocabularies make it impractical to include entire vocabularies as macro keys.

PROGRESS—WiViK 2 (version 2.1) was released in July 1993. WiViK 2 enables people with physical disabilities complete access to any Windows 3.1 application (including DOS windows) by creating an on-screen image of the familiar standard keyboard. WiViK 2 can be controlled by any pointing device that works like the standard mouse. Simply clicking or dwelling on the desired key's image activates that key's function.

WiViK 2 REP includes two powerful rate enhancement features word prediction and abbreviation-expansion. By reducing the number of key selections, WiViK 2 REP features greatly increase user efficiency.

Word prediction completes letters of words that the user begins typing. Its frequency-of-use sensitive dictionary automatically adapts to the user's writing style. Separate custom dictionaries are easily created by reading in one or more of the user's own documents a great help when writing about specific or specialized topics. These dictionaries, each with a 10,000-word capacity, may be viewed or edited at any time.

Abbreviation-expansion saves time by allowing frequently used words, phrases, sentences or other sequences to be replaced with abbreviations. Typed abbreviations are instantly converted into their corresponding, user pre-programmed expansion. All characters and functions of the standard keyboard may be used when creating expansions. Several sets of abbreviation-expansions may be created for different needs, each set containing up to 80 abbreviation-expansions.

FUTURE PLANS—The rate enhancement portion of WiViK 2 is being re-worked to be equivalent to the keyboard-only rate enhancement package called KeyREP. OS/2 versions of this software are being developed and will become available in 1994.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Usability considerations for on-screen keyboards. Shein F, Hamann G, Treviranus J, Nantais T, Galvin R. In: Proceedings of the 12th Congress of the International Ergonomics Association, 1994 August, Toronto, ON. In press.

[184] WIVIK 2 SCAN: 1-5 SWITCH SCANNING ACCESS

Fraser Shein, MEng, PEng; Russell Galvin, BSc; Jutta Treviranus, BSc OT(C); Gil Hamann, MASc, PEng; Morris Milner, PhD, PEng, CCE
Microcomputer Applications Programme, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G1R8

Sponsors: *The Ontario Rehabilitation Technology Consortium funded by the Ontario Ministry of Health; IBM Canada Ltd.; IBM Corporation; University Research Incentive Fund of the Ontario Ministry of Colleges and Universities; National Research Council of Canada*

PURPOSE—Individuals who cannot use a keyboard or a pointing device can still access a computer through a technique called scanning. Scanning involves the successive highlighting of items in a visual keyboard and selection by the activation of a switch when a desired item is highlighted.

PROGRESS—WiViK 2 Scan was released in July 1993 and adds the ability to select keys using one to five switches to WiViK 2 REP. WiViK 2 Scan includes automatic, inverse, and directed scanning methods. When automatic scan is selected, a highlight moves sequentially across successively smaller groups of items until the desired key is highlighted for selection. With inverse scanning, the highlight is moved manually by repeated or maintained switch activation. Directed scanning uses separate switches for each highlight movement direction. A switch connection box is available separately or bundled.

WiViK 2 Scan includes keyboard layouts specifically designed for the various scan methods. It allows each scanning method to be customized to meet the needs of the user. Several patterns of movement can be used with both automatic and inverse scanning. The function of each switch can be individually customized in all methods. Timing of the moving highlight can be adjusted to match the abilities of the user.

Scanning within a graphical user interface (GUI) such as Windows is difficult because the user must manipulate objects with a pointing device. We addressed this issue and developed a new approach that permits manipulation without using a pointing metaphor. Our approach is to apply the scanning directly to the objects typically manipulated with the mouse. WiViK 2 Scan lets the user scan windows, menus, scroll bars and other thing usually manipulated with a mouse. Menu choices can be highlighted or scanned in succession. Similarly, the text cursor will scan for easy editing. A scanning mouse cursor and button actions may also be selected.

FUTURE PLANS—It is recognized that scanning systems have a limited potential in terms of speed of access and overall productivity. Therefore, future research will de-emphasize the need for scanning systems and emphasize approaches that provide greater direct control and take better advantage of the users' skills (e.g., imprecise pointing). Combining scanning with direct selection will be another area of study.

[185] THE DEVELOPMENT OF 'TALKSBAC,' A COMPUTER-BASED COMMUNICATION SYSTEM

Annalu Waller, PhD; David M. Millar; Alistair Y. Cairns, PhD; Peter Gregor, PhD; Alan F. Newell, PhD; Fiona Dennis; Janet K. Brodie; Ketron Morrison
MicroCentre, Department of Mathematics and Computer Science, University of Dundee, Dundee, DD1 4HN, Scotland, UK; Dundee Speech and Language Therapy Service, Dundee Royal Infirmary, Dundee DD1 9ND, Scotland, UK

Sponsor: *The Leverhume Trust; Scottish Home and Health Department; Esmee Fairbairn Charitable Trust; Hydro Electric*

PURPOSE—TalksBack, a computer-based predictive communication system, was initially developed for physically disabled non-speaking people, but pilot studies with dysphasic adults proved promising. A two-year research project at Dundee University's MicroCentre is evaluating a modified system,

renamed TalksBac (Talking and Learning Knowledge System for Better Aphasic Communication), with dysphasic adults.

Most computerized communication systems rely on the user's linguistic and memory skills to retrieve prestored conversational information. Not only must the user remember where information is stored, but he/she must know what message is needed to convey thoughts. TalksBac reduces this cognitive load by predicting utterances based on pragmatic information specific to the client and information about the conversational partner and the topic. TalksBac also has the facility to store and retell conversational narratives. A database of client specific information is built up as the system is used.

PROGRESS—The original system, simplified to meet the needs of a group of dysphasic adults, has been rewritten in C++ and runs on a portable Macintosh PowerBook. The concept of using "person" and "topic" to facilitate retrieval of prestored sentences and stories has been retained. The software prompts the user for selections, thus making it easier for the dysphasic user to access prestored data.

The system has two aspects: the user interface and the carer interface. The user interface allows the user to retrieve and "speak" prestored information. The system first asks the user to select the person to whom he/she is talking and then offers a list of probable topic items. Once the topic has been selected, predicted sentences and story titles are presented for selection. Sentences are automatically spoken once they have been selected. When a story title is selected, the story text is presented and the user selects individual sentences for speech output.

A separate carer interface facilitates the input of new information by the carer. The information management is the responsibility of the carer as the dysphasic user does not have the skills to produce the necessary language.

The predictive retrieval system driving the user interface has been further developed to take more control of conversational patterns in order to make it easier for the dysphasic user to identify target conversational items.

RESULTS—A single case study approach is being used to evaluate the use of the system with four non-fluent dysphasic adults. The evaluation involves assessing the clients' communication at the beginning and end of a 12-month period during which clients have constant access to personalized versions of TalksBac. Clients and their carers have been trained to use the system and are currently building up their conversational databases.

IMPLICATIONS—Preliminary observations indicate that the training of carers in the collection of conversational information is critical to the success of such a communication system. The results of this research project will identify guidelines as to the use of a predictive system with dysphasic adults. The data collected over the next six months will be analyzed in terms of speed and content. The clients will be re-assessed to provide comparative data which will be analyzed against the original test results.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Providing narratives in an augmentative communication system. Waller A. (Dissertation) Dundee, Scotland: University of Dundee, 1992.

Improving assisted communication with narrative texts. Alm N, Waller A, Arnott JL, Newell AF. In: Proceedings of ECART 2, 2nd European Conference on the Advancement of Rehabilitation Technology, 1993, Stockholm, Sweden, 201-3.

Using TalksBack with dysphasic adults: augmentative communication in practice. Waller A, Dennis F. Scotland: Collected Papers: Study Day, 1993:31-3.

Investigating the use of a predictive conversation aid with dysphasic adults. Dennis F, Waller A, Millar D et al. Commun Matters J. In press.

D. Private and Public Programs

[186] REHABILITATION ENGINEERING RESEARCH CENTER: TECHNOLOGY EVALUATION AND TRANSFER

Joseph P. Lane; William C. Mann; Kenneth J. Ottenbacher
Center for Assistive Technology, University at Buffalo, Buffalo, NY 14214

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education.*

PURPOSE—The Rehabilitation Engineering Research Center on Technology Evaluation and Technology Transfer (RERC-TET), commenced operation on September 1, 1993. The RERC-TET conducts technical, consumer, and business evaluations of new assistive devices. Entrepreneurs, businesses, research centers, and consumers participate by sending prototypes of new assistive devices for evaluation and possible commercialization. The RERC-TET determines which devices have promise, refines the devices as needed, and works with corporations to move selected devices into manufacture and distribution for the commercial marketplace. The RERC-TET essentially offers a migration path from concept to market for promising assistive devices.

METHODOLOGY—The RERC-TET's central program involves three collaborating organizations. The Center for Assistive Technology directs the technical evaluations. The Western New York Independent Living Center, Inc. directs the local, statewide, and national consumer evaluations. The Western New York Technology Development Center, Inc. conducts the intellectual property and marketing research, and performs business plan evaluations. The three organizations draw upon their national networks of affiliated organizations to reach developers, researchers, consumers, and businesses anywhere in the country. The RERC-TET's Advisory Board has national experts from industry, academe, government, consumer agencies, and foundations.

The RERC-TET's process model has five phases. Phase I identifies and screens potential submissions to determine if they already exist as products, if they are assistive devices, and if a functioning prototype exists. Phase II reviews accepted devices for their conceptual merit. Phase III performs the research and development to advance alpha prototypes into beta designs. Phase IV performs extensive testing of pre-production product designs. Phase V moves devices into local production if the RERC-TET cannot identify an outside partner for commercialization.

PROGRESS—The process model fully integrates technical, consumer, and market evaluations, repeating all three in each successive phase. Most importantly, the process model pursues the option of technology transfer to an outside sponsor or licensee during each evaluation phase. During the evaluation phases, the project team searches for a partner to move the product into the commercial marketplace. The RERC-TET is currently evaluating 16 devices. About 90 inventors are in a queue awaiting their turn to submit a device. Device submissions are taken in the order they are first received for their evaluation.

FUTURE PLANS—The RERC-TET is working to become self-sufficient by accruing revenues from patent and license royalties, securing extramural grants to develop promising new devices, generating receipts from the sale of devices, and collaborative projects with private and public sector partners. Toward this end, the RERC-TET has established a community-based business venture, AZtech, Inc., directed by persons with disabilities. The RERC-TET will gradually migrate its internal operations into AZtech, Inc.

[187] THE EVOLUTION OF INDEPENDENT LIVING PROGRAMS: A LONGITUDINAL STUDY

Margaret A. Nosek, PhD; Carol A. Howland; Laurel Richards; Laurie Gerken
ILRU Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The purpose of this project is to maintain a database on the status of independent living programs (ILPs) nationally, and to identify trends in the development of ILPs, the emergence of issues encountered in the delivery of independent living services, and changes in the characteristics of consumers of these services.

PROGRESS—Profiles of each ILP responding to the 1988 full-length survey have been published in the ILRU Registry of ILPs. In early 1992, a revised and updated survey instrument was mailed to 475 ILPs listed in the ILRU Directory. Information was solicited concerning populations served, services provided, characteristics of persons providing services, methods by which services are provided and programs administered, sources and amounts of funding, and relationships between programs and their communities. Responses from 257 ILPs were received and analyzed, an improved response rate compared to previous years. A follow-up telephone interview of these respondents was conducted to obtain more in-depth information about funding, perceived needs of centers and boards, and ADA-related services provided. Data have been analyzed; a short report of results for consumers and a journal article are in preparation.

RESULTS—Although most of the results were similar to those in 1988, average total number of paid staff, particularly those with disabilities, increased. Mean funding amounts for various budget categories also changed significantly, with more centers receiving other direct federal funds, private contributions and dues, fees for service, and other business activities in 1992. Mean dollar amounts of other direct federal funds, state funds, and city and county government funds increased in 1992, while amounts of Federal Title VII Part A funds and private contributions decreased. Of those centers that charge fees for service, only 28.5 percent charge consumers and 62.5 percent charge other organizations, 62.7 percent actively market their services to the community, and 68 percent are developing consultant services for the ADA. Centers providing services to consumers with a variety of disabilities account for 90.4 percent, while 9.6 percent serve a single disability group, such as blindness. Nearly all respondents provide the five core independent living services of peer counseling, independent living skills training, information and referral, individual advocacy, and community advocacy.

Of the 182 centers responding to the telephone interview, 85.7 percent offer ADA technical assistance services to the community, center staff have received ADA-related training in 88.6 percent, and 48 percent are developing their own ADA educational materials. The majority (88.4 percent) of centers provide ADA services to consumers with disabilities, nearly all (92.1 percent) provide services to businesses, 12.3 percent to nonprofit organizations, and 18.5 percent to government agencies. A mean of 36.6 percent of ADA service clients are consumers. About half of centers charge for ADA services, and a typical cost is $50 per hour.

FUTURE PLANS—The Directory of Independent Living Programs is updated and reissued approximately five times per year. ILRU staff will continue to update the Directory and respond to specific inquiries with individualized data runs and reports. Analysis will continue on the ILRU National Database on Independent Living Programs, with trends published as they emerge. A new survey reflecting changes in minimum requirements for independent living centers based on reauthorization of the Rehabilitation Act in 1993 is underway. New data describing independent living centers will be published in a monograph in 1995.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Evolution of independent living programs. Nosek MA, Zhu Y, Howland CA. Rehabil Counsel Bull 1992:35:190-9.

Independent living. Nosek MA. In: Parker RM, ed. Rehabilitation counseling: basics and beyond. 2nd ed. Austin, TX: Pro-Ed 1992:103-33.

Political responses to long-term disability. Nosek MA. In: Whiteneck GG, ed. Aging with a spinal cord injury. New York: Demos 1992:263-74.

Relationships between compliance with federal standards for independent living centers and diversity and amount of funding. Nosek MA, Zhu Y, Howland CA. Rehabil Counsel Bull 1992:35:174-89.

Independent living centers and private sector rehabilitationists: a dynamic partnership for implementing the ADA. Howland CA, Walden E, Nosek MA. NARPPS J 1993:8.

[188] ASSISTING COMMUNITY-BASED RURAL INDEPENDENT LIVING PROGRAMS

Margaret A. Nosek, PhD; Carol A. Howland; Earl Walden, DEd
ILRU Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Under a 3-year grant from NIDRR, ILRU identified community-based independent living programs (ILP) delivering services to persons with disabilities who live in rural areas. Criteria were established for exemplary operational practices, and ILPs were selected that best meet these criteria. Materials were solicited from exemplary programs for inclusion in ILRU's Resource Materials Directory. Six programs, two in isolated rural communities, two in moderately rural communities, and two in urban settings that do outreach to rural communities, were selected as demonstration sites for receiving intensive supportive services by ILRU over the duration of the project. The outcomes of these efforts were assessed using a comprehensive approach to evaluation. The final goal is to make rural-focused technical assistance services and supportive materials available to all rural ILPs.

PROGRESS—An advisory committee composed of persons representing the Association of Programs in Rural Independent Living (APRIL), the National Council on Independent Living (NCIL), the Council of State Administrators of Vocational Rehabilitation (CSAVR), researchers and practitioners in rural rehabilitation service delivery, and the Research and Training Center on Rural Rehabilitation Services has been established. A Delphi questionnaire was prepared and sent out to ILPs requesting the staff to list the five most pressing problems confronting providers of independent living services to rural areas. Next, a composite listing of these problems was sent to these programs, asking that they rank order the top ten problems. Five exemplary rural service providers were identified, and two emerging rural independent living centers were selected as demonstration sites for technical assistance and materials. Five monographs were written about the most problematic areas for rural centers; they are currently in production. Cluster analysis was completed and three distinct profiles of rural independent living centers identified. An article entitled "Profiles of Independent Living Centers that Provide Services to Rural Areas" is currently in progress.

RESULTS—A questionnaire sent to ILPs in 1991 identified 300 programs that offer services to rural persons with disabilities. These programs received a second questionnaire covering center location, service delivery, and staff and board with and without disabilities, and budget; 123 centers responded. Analysis of the Delphi survey revealed the top five problems faced by rural ILCs to be attitudes, transportation, housing, funding, and accessibility. Cluster analysis based on five criteria: 1) total annual budget in proportion to the number of consumers served, 2) percentage of staff time spent

providing services in the consumer's home rather than at the center, 3) number of miles traveled to deliver in-home services in proportion to the number of staff traveling annually, 4) number of miles traveled to deliver in-home services in proportion to the number of consumers served annually, and 5) number of information and referral requests received during the past fiscal year. Of the 123 respondents, 100 met the criteria to fit into one of three profiles: 1) Prototype profile, representing the typical center providing services to rural areas, with the smallest budget to spend per consumer and the highest percentage of consumers with mobility impairments served (n = 77); 2) Outreach profile, with the highest rate of travel to deliver in-home services and the highest percentage of elderly consumers (n = 13); and 3) Peak expenditure profile, the most atypical, with few in-home services and the highest average budget per number of consumers served (n = 10). Overall differences between profiles were highly significant at $p < 0.00001$.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Delivering independent living services in rural communities: options and alternatives. Potter CG, Smith QW, Quan H, Nosek MA. Rural Spec Educ Q 1992:11(1):36-40.

Expanding independent living services: rural exemplary practices in transportation. O'Day B, Walden E, Roy D. Houston: ILRU. In press.

Role of independent living centers in delivering rehabilitation services to rural communities. Nosek MA, Howland CA. Am Rehabil 1992:18:2-6.

[189] LIFE SATISFACTION OF PEOPLE WITH PHYSICAL DISABILITIES: RELATIONSHIP TO PERSONAL ASSISTANCE, DISABILITY STATUS, AND HANDICAP

Margaret A. Nosek, PhD; Marcus J. Fuhrer, PhD; Carol G. Potter, RhD
ILRU Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The preponderance of available studies indicates that persons with chronic physical impairments rate their satisfaction with life somewhat lower than non-disabled individuals. To understand how chronic physical conditions affect life satisfaction, this study is intended to explore possible moderating factors that are associated with those conditions and with life satisfaction. Three possible moderating factors were investigated: 1) level of disability, 2) level of handicap, and 3) self-appraised adequacy of personal assistance.

PROGRESS—Staff in eight centers for independent living in Federal Region VI recruited subjects for the study and distributed questionnaire packets. The questionnaire consisted of demographics, the Personal Assistance Satisfaction Index (PASI), the Arthritis Impact Measurement Scale (AIMS) to assess disability, the Craig Handicap Assessment and Reporting Technique (CHART) to assess handicap, and the Life Satisfaction Index-A. Approximately 81 percent of subjects returned surveys and participated in telephone interviews. A sample of 45 respondents used personal assistance. Data analysis is complete, and a manuscript presenting the results has been submitted for publication.

RESULTS—Self-appraised adequacy of personal assistance in terms of availability, quality, consumer control, and cost was found to be a significant factor in the life satisfaction of people with severe disabilities. Appraisal of personal assistance was not associated with whether assistance was obtained through a formal agency or whether it was provided on a paid or unpaid basis. Life satisfaction was positively related to social integration and occupation, two measures of handicap. Life satisfaction was not related significantly, however, to severity of physical disability. Whereas environmental or social limitations associated with disability had an adverse impact on life satisfaction, functional limitation had little impact. People who were mobile in their homes

and communities and involved in occupational and avocational interests were generally satisfied with their lives. These findings suggest that satisfaction with personal assistance positively impacts life satisfaction, an effect that is relatively stable across disability levels.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Life satisfaction of people with physical disabilities: relationship to personal assistance, disability status, and handicap. Nosek MA, Fuhrer MF, Potter C. Rehabil Psych. In press.

[190] DEVELOPMENT OF AN INSTRUMENT TO MEASURE ADEQUACY OF PERSONAL ASSISTANCE SERVICES

Margaret A. Nosek, PhD; Marcus J. Fuhrer, PhD
ILRU Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—This series of studies is designed to develop and test an instrument for assessing the adequacy of various systems for delivering personal assistance services to persons with diverse severe physical disabilities, their satisfaction with these services, and the effects of personal assistance on employability and health.

PROGRESS—A working draft of the instrument, the Personal Assistance Satisfaction Index (PASI), has been used in several studies to evaluate model personal assistance services and to assess the role of personal assistance in the health and employability of people with severe disabilities. Statistical analyses to determine the internal validity of indicators and factor analysis to test the validity of criteria categories have been performed, and a final version of the instrument has been completed. An article entitled, "Personal Assistance Satisfaction Index: An Assessment Tool for Individuals with Severe Physical Disabilities" has been submitted for publication.

RESULTS—Literature review revealed 9 factors that influence the effectiveness of personal assistance services: source of control, source of funding, focus of training, scope of services, intensity or availability of services, flexibility of options, characteristics of assistants, eligibility criteria, and efficiency of services. A universe of items defining each of the 9 factors comprised the first draft of the instrument. Item analysis and ratings by a panel of 12 experts indicated the construct of satisfaction with personal assistance services to be composed of four salient elements: availability, cost, control, and quality. Reliability studies were done by administering the instrument to 100 consumers recruited by 10 independent living centers nationwide. Cronbach alpha of 0.91 established the reliability of 16 items, which comprise the final PASI. Concurrent validity was established by correlating the PASI's mean score with the mean score of the Life Satisfaction Index; the moderate correlation ($r = 0.43$) found between the two instruments was highly significant at $p < 0.0005$.

Of the 88 consumers who responded to the PASI, 92 percent paid for personal assistance and three-quarters obtained their assistants through an agency. Respondents had been using paid personal assistants for a mean of 8 years (range 1–33 years). To pay for personal assistance, one-fourth used personal or family funds, 79 percent got funds from a personal assistance agency, and 15 percent obtained payment through an insurance agency. Persons who needed more than 2 hours of assistance with personal hygiene daily were more likely to use paid assistance for these tasks.

Sixty-one percent of respondents used unpaid assistance, either exclusively or in combination with paid assistance. Of the 54 respondents who used unpaid assistance, 74 percent used relatives and 43 percent used nonrelatives, with 17 percent using both. Respondents had been using unpaid assistants for a mean of 15 years.

Significant relationships were found between 1) who provides assistance and whether they are paid ($p<0.00001$), 2) living with spouse ($p<0.001$) or children ($p<0.05$) and using unpaid assistance, 3) who provides assistance and with whom participants live ($p<0.00001$), 4) amount of assistance received and severity of disability ($p<0.00001$), and 5) amount of assistance received and number of assistants used ($p<0.01$).

FUTURE PLANS—The PASI is being used to assess satisfaction with personal assistance of 150 persons with severe disabilities who use at least an hour of assistance daily, as part of a study of adequacy of personal assistance, negative health incidents, and health care utilization.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Matching available options for receiving personal assistance services to the needs of adults with severe physical disabilities. Nosek MA, Sonehara J, Sanbonsugi. Studies on Social Work (Japanese). In press.

Personal assistance services: the hub of the policy wheel for community integration of people with severe physical disabilities. Nosek MA, Howland CA. Policy Stud J 1993:21:789-800.

[191] USE OF PERSONAL ASSISTANCE SERVICES BY PERSONS WITH SPINAL CORD INJURY

Margaret A. Nosek, PhD
Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—This study is designed to examine patterns of usage of personal assistance among a community-based sample of 284 persons with spinal cord injury and to assess the relationship of the provision of personal assistance by family with the independence and productivity of persons with disabilities.

PROGRESS—The Baylor College of Medicine Research and Training Center on Spinal Cord Injury and Independent Living Research Utilization (ILRU) have used a registry of 661 persons with spinal cord injury (SCI data base) to assess relationships between living arrangement and provision of personal assistance by family, nonfamily, or a combination of both. This now comprises the control group for all subsequent studies of quality, control, availability, and cost of personal assistance services. The sample for the present study was a subset of 284 individuals who reported needing assistance with self-care activities on structured telephone interviews. Data were analyzed and correlates of the amount of personal assistance received and arrangements for receiving personal assistance were identified. Productivity was categorized as 1) high: full-time worker, student or volunteer; homemaker; or both part-time worker and part-time student; 2) moderate: part-time worker, student, or volunteer; or 3) low: retired, other.

RESULTS—More than half of participants had only relatives providing their assistance while 46 percent paid for some or all of their assistance. Although there was a significant relationship between having nonrelatives provide assistance and having paid assistance, it is notable that 24 percent of relatives were paid, and that of the nonrelatives who assisted, 34 percent were not paid. No significant relationships were found between living alone or with parents, friends, or attendants and whether or not paid assistants were used.

Only two demographic variables had a strong relationship with who provides assistance: marital status and educational attainment. Those who were

married predictably relied on relatives more than those who were single. Those who were more highly educated tended to rely more on nonrelatives. Productivity did not have a statistically significant relationship with who assists or payment for services.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Use of personal assistance services by persons with spinal cord injury: policy issues surrounding reliance on family and paid providers. Nosek MA, Fuhrer MlJ, Rintala DH, Hart KA. J Disabil Policy Stud 1993:4(1):1-11.

[192] EFFECT OF PERSONAL ASSISTANCE SERVICES ON THE LONG-TERM HEALTH OF A REHABILITATION HOSPITAL POPULATION: PERCEPTIONS OF REHABILITATION PROFESSIONALS

Margaret A. Nosek, Ph.D.
Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—This study was designed to test the hypothesis that personal assistance with activities of daily living significantly affects the ability of persons with severe physical disabilities to maintain good physical health.

PROGRESS—A sample of 41 subjects (7 physicians, 10 nurses, 9 social workers, 8 physical therapists, and 7 occupational therapists from 5 medical rehabilitation centers) recruited through the American Congress on Rehabilitation Medicine (ACRM) were interviewed by phone. Frequency analysis was conducted on all responses to questions, and techniques of qualitative analysis were used to code comments and establish a grounded theory.

RESULTS—Results supported our hypothesis; rehabilitation professionals believe that inadequate personal assistance contributes to poor physical and mental health for individuals with severe physical disabilities and their families. The most commonly cited health condition was skin breakdown, followed by urinary tract infections, pulmonary infections, and contractures. Inadequate personal assistance also led to extended hospital stays, threats to safety, poor nutrition, and poor personal hygiene. Nearly all those interviewed considered reliance on family alone for assistance to be inadequate, common effects being burnout, family role changes, and economic strain.

The more the time commitment and sophisticated the tasks needed, the more difficult was obtaining sufficient assistance. Families were often unable to provide adequate assistance due to a pre-existing struggle to survive, a dysfunctional family structure, or unwillingness to fill the role of assistant. Persons with the best health seemed to have a combination of family and nonfamily providing assistance. More than half of those interviewed observed the lack of agencies providing affordable, comprehensive, home services. Also needed is a pool of screened personal assistants available for respite and emergency back-up. Quality of assistance was compromised by inadequate training, unreliability, turnover, and regulations limiting hours and tasks assistants are allowed to perform. Nearly half also mentioned lack of financial resources as a major cause of inadequate personal assistance. Regulations that require medical supervision of assistance with basic activities of daily living unnecessarily inflate fee scales and limit the options for receiving assistance from outside the family. When assistance from outside the family is available, persons with disabilities often lack the ability to locate, interview, hire, instruct, supervise, terminate, and otherwise manage personal assistants.

Solutions suggested for improving adequacy of personal assistance focused on establishing a comprehensive system for delivering services that could coordinate services from home health agencies, independent living centers, and rehabilitation hospitals. Most interviewees advocated reform of current insurance policies, including Medicare, to allow coverage of expenses for personal assistance services.

FUTURE PLANS—More sensitive measures of health status and extent of personal assistance needed must be developed. The effects of the inability to control the quantity and quality of personal assistance received on individuals who desire to take charge of their health also needs to be studied.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Personal assistance: its effect on the long-term health of a rehabilitation population. Nosek MA. Arch Phys Med Rehabil 1993:74:127-32.

[193] DEMONSTRATING A MODEL APPROACH TO INDEPENDENT LIVING CENTER-BASED ASSISTIVE TECHNOLOGY SERVICES

Margaret A. Nosek PhD; Thomas Krouskop, PhD
Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—This project is designed to establish, operate, and evaluate the effectiveness of an independent living center-based assistive technology service. The main objectives of this service are to provide appropriate, timely, and affordable repair of assistive equipment and devices; teach preventive maintenance practices to increase the longevity of assistive equipment and devices; refer consumers whose equipment is irreparable to appropriate service providers or vendors who can assist them in obtaining new equipment; and counsel consumers about sources of sponsorship for equipment repair or the acquisition of new equipment. In addition to wheelchairs, assistive technology includes telecommunication devices for hearing-impaired persons, computerized communication boards for persons with aphasia, environmental control systems for persons with movement restriction, and microprocessor controls on wheelchairs.

PROGRESS—Surveys have been completed to identify gaps between consumer need and technology services available in the Houston area. The Houston Center for Independent Living (HCIL) interviewed 30 consumers from various parts of the city and 22 vendors of equipment and equipment repair services. ILRU staff surveyed independent living centers (ILCs) who responded affirmatively to the equipment services questions in the 1988 ILRU national survey of ILCs.

Based on the results of these surveys, a wheelchair maintenance clinic is held monthly at TIRR as a demonstration model service. A system is now in place where HCIL advertises the clinic, schedules appointments, maintains a data base on equipment repair services and resources, does intake when consumers arrive at the clinic, offers counseling and referral services while they wait, and documents maintenance services received. TIRR rehabilitation engineers recruit volunteer workers, supervise and instruct volunteers during the clinic, and perform some of the more complicated maintenance services. ILRU research staff supervise the clinics and conduct evaluation activities.

The first clinic, held at TIRR in January 1992, is now operating at capacity, serving 12-15 consumers every month. The first satellite clinic, in the Clear Lake area, was implemented in February 1993 and now provides services for 6 to 8 people monthly. A satellite clinic in North Houston had its inception in January 1994.

A 25-item questionnaire was sent to all consumers of the wheelchair clinics in May 1993 to evaluate the service. Results were analyzed and are being submitted in an article to Assistive Technology.

RESULTS—The experience of ILCs nationwide shows equipment repair services are difficult and cost-ineffective to offer, generally operating at a deficit. The foremost problem identified from the survey of consumers was the unavailability of preventive services and the costly nature of repair services offered through commercial vendors. Transportation problems further complicate efforts to obtain repairs; few vendors offer pick up/delivery or in-home services. The result is that consumers postpone seeking repairs until equipment problems reach crisis proportions. By that time repairs are very costly and consumers are often without their equipment and immobile for long periods of time.

Follow-up satisfaction surveys of consumers who used the wheelchair maintenance clinic showed exceptionally positive responses to the helpfulness of volunteers, quality of services, relatively short waiting time, and extent to which they learned something new about their equipment. Of the respondents, 97 percent felt the preventive maintenance clinic was a worthwhile program. These clinics have saved consumers hundreds of dollars in unnecessary repairs. Before the clinic began operations, only 25 percent of respondents did preventive maintenance on their wheelchairs.

FUTURE PLANS—We plan to continue the wheelchair clinics at the present locations because evaluations indicate they have been highly successful. The service schedule for clinics will be evaluated to ensure that it is accessible to the largest number of consumers. New ways will be explored for marketing the program to the community. Information will be sent to community vendors on how they can be more responsive to consumer needs and desires. Periodic follow-up telephone calls will be made to randomly selected consumers to determine consumer satisfaction with the program and responsiveness of the program to overall consumer needs.

[194] INCREASING THE ABILITY OF INDEPENDENT LIVING CENTERS TO SERVE THE HISPANIC POPULATION

Margaret A. Nosek, PhD; Doris Georgiou, MA, DArch
ILRU Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The purposes of this project are to obtain information on best approaches for providing independent living services to Hispanic persons with disabilities and to provide centers around the country with appropriate service information and technical assistance to assist them in providing services to Hispanic constituencies in an effective manner.

PROGRESS—Ninety-three independent living centers (ILC) have been identified as providing services to Hispanic consumers. Executive directors of 17 ILCs who report that at least 10 percent of their consumers are Hispanic are being surveyed by telephone about such topics as the amount and type of services received by Hispanic consumers, their representation on boards of directors and center staff, materials targeted to the Hispanic population and provided in Spanish, differences in service provision compared to services to other consumer groups, and problems encountered in meeting the needs of this population.

FUTURE PLANS—Data from the interviews will be analyzed to develop a profile of each center providing services to Hispanic consumers. Profile data will be analyzed to identify similarities and differences in service delivery to Hispanic consumers compared to other persons with disabilities. Results will be published and disseminated to all independent living centers so that they may more effectively serve Hispanic consumers with disabilities.

[195] INCREASING THE ABILITY OF INDEPENDENT LIVING CENTERS TO SERVE THE POPULATION OF AFRICAN AMERICANS WITH DISABILITIES

Margaret A. Nosek, PhD; Doris Georgiou, MA, DArch
ILRU Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—This project will investigate the role of family in supporting the independence of African-Americans with disabilities. Objectives are to offer research training in independent living to African American students in the Department of Family Life and Home Economics as Texas Southern University and assess the quality of the learning experience in terms of knowledge, skill enhancement, and student satisfaction with the experience. It will also characterize appropriate roles that persons with preparation in family life and home economics might play in facilitating delivery of independent living services to persons with disabilities.

PROGRESS—Dr. Hammonds-Smith and two students have recruited African-American students with disabilities at TSU and are conducting interviews to address issues of personal care skills, interpersonal skills, and consumer skills such as managing personal assistance, advocacy, and participation in support groups. Principal investigator Margaret Nosek has presented to Dr. Hammonds-Smith's home economics class on concepts of independent living in order to train family life specialists to be part of the team of human services professionals that arrange services for disability populations.

FUTURE PLANS—Results from interviews will be used to identify skills that will lead to a more independent lifestyle for African Americans with disabilities; ascertain how family members can help students with disabilities gain independence; develop a Field Placement Model to expose family life and home economics students to independent living situations that include rehabilitation or other human services fields; and integrate independent living concepts into existing courses into the human services and consumer sciences curriculum.

[196] RELATIONSHIPS AMONG AGE AT ONSET, ADEQUACY OF PERSONAL ASSISTANCE, NEGATIVE HEALTH INCIDENTS, AND HEALTH CARE UTILIZATION FOR PERSONS WITH PHYSICAL DISABILITIES

Margaret A. Nosek, PhD; Carol A. Howland
ILRU Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The purpose of this longitudinal study is to determine the strength of relationships among age at onset of disability, use of personal assistance services for activities of daily living, health status, and use of health care services by persons with a variety of severe physical disabilities.

PROGRESS—To date, 120 persons, ages 18 to 65, living independently in the community, who use at least one hour of personal assistance daily have been recruited to complete weekly checklists recording any changes in their personal assistance or health status; visits to hospitals, emergency rooms, or physicians; and, when health incidents occur, effects on productivity and levels of distress. Special efforts were made to oversample persons from minority ethnic backgrounds. Subjects were given a choice of reporting by written checklist, telephone, or computer to accommodate disability-related limits in communication method. All survey instruments

have been developed and are currently being pilot tested on 10 subjects.

METHODOLOGY/FUTURE PLANS—Survey packets will be mailed to 150 subjects with the objective of having at least 100 complete the study, allowing for attrition. Data collected will be used to construct a profile on each participant and his/her health service use and health conditions over a 12-month period. These profiles will be used to identify differences between participants divided into four categories based upon whether the disability was acquired in childhood or adulthood and whether personal assistance services are provided exclusively by family members, or by nonproviders alone or supplementing family assistance.

In year 2, open-ended, qualitative interviews will be conducted with two subsets of the original sample: Ten participants whose scores on the Personal Assistance Satisfaction Index (PASI) fall into the top quartile and ten in the bottom quartile, and ten participants whose total number of negative health incidents fall into the top and ten in the bottom quartile. The sample for this segment of the study will be strictly limited to 40 participants to allow in-depth exploration of PAS and health issues.

[197] APPLICATIONS OF TECHNOLOGY TO ENHANCE QUALITY OF LIFE: A MULTIDISCIPLINARY CONSORTIUM APPROACH

Ian R. Pumpian; Andrew Y.J. Szeto; Caren L. Sax
Department of Special Education, Department of Electrical & Computer Engineering, Interwork Institute, San Diego State University, San Diego, CA 92182

Sponsor: *U.S. Department of Education, Dept. of Special Education & Rehabilitation*

PURPOSE—This 36-month project focused on developing customized adaptations (assistive devices) that will enable public school students with severe and multiple disabilities to more fully participate in their education. The project demonstrated that 1) individualized technological adaptations can significantly benefit a student's quality of life and inclusion into the school environment, 2) strategies seeking close collaborative ties between functional curriculum and rehabilitation engineering can be established, and 3) a local community approach can effectively coordinate the resources, roles, and expertise of many agencies and disciplines. During the past 18 months, a more vocational and community emphasis was placed on assessing and meeting the technology needs of transition-aged students (18-22) who were being targeted for placement out of high schools.

METHODOLOGY—In a cooperative effort between SDSU's Interwork Institute and the San Diego Unified School District, the project provided individualized adaptations to students at over 45 integrated comprehensive school sites in the San Diego area. The adaptation projects targeted students who were candidates for increased participation and inclusion in general education classes. A series of twelve milestones—a request for assistance, research and data collection, design, prototype construction, and field-testing—systematically assessed and monitored progress of each referral and insured that the assistive technology services would be consumer-driven and integrated into the planning processes.

One key project component has been the use of multidisciplinary Tech Teams, which were individually organized according to the specific needs of the consumer. The Tech Teams included friends, family members, and employers as well as addition to special educators, engineering students, OTs/PTs, speech therapists, and community-based rehabilitation technologists. A Technology Mini-center coordinated various demonstration, training, research, and dissemination activities associated with the project.

To increase school staff's awareness of assistive technology and its proper utilization, the project team has conducted a variety of in-services and conducted teacher certification courses offered through the University. A number of engineering students and teacher interns jointly enrolled in a special class that provided "hands-on experience" of being involved in a Tech Team. The class also provided students opportunities to interact with

other special educators, rehabilitation personnel, and engineering professionals.

RESULTS—Major accomplishments of the last 18 months include 1) achieving a more efficient collaboration between the school district and the project staff through better utilization of each other's assistive technology resources and expertise, 2) expanding key intra-state and inter-state linkages and refining referral information forms, 3) designing, building, and delivering numerous simple and complex technical adaptations, 4) documenting completed individualized adaptations with photographs, videotape, technical drawings, and case study descriptions, 5) making over 40 presentations at the local, state, and national levels, 6) evaluating the completed projects in terms of the reasons for success or failure, and 7) implementing a local area network of computers at the Technology Minicenter to facilitate information retrieval.

Examples of adaptations which have enhanced integration include: a special seat made from a wooden chair with padding and customized supports that allows a student to sit at a desk rather than just in his wheelchair, a sliding hand support to increase keyboard usage accuracy and endurance for persons with upperlimb weakness, a switch-operated spray bottle (to keep clay wet on a potter's wheel) to enhance participation in art classes, a customized environmental control unit for use while the student was tube-fed at school, a plexiglass communication board for inclusion into general education classes, a high powered portable light and magnifier as a reading aid, an electromechanical kick ball launcher for inclusion into physical education classes, and a transportable "ladder" to permit independent egress and ingress from a wheelchair.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Becoming part of the team: technology as a path to social integration: Part II. Sax CL. Supported Employment Networker 1992:1(2):4.

Creative adaptations to foster job success. Sax CL. Supported Employment InfoLines 1992:3(3):1.

Interwork institute: seizing opportunities for integration. part I. Sax CL. Supported Employment Networker 1992:1(1):6.

Technology in a twist, a roll and a fold. Sax CL. Team Rehab 1992:3(6):34-7.

Comparison of speed and accuracy for selected electronic communication devices and input methods. Szeto AYJ, Allen EJ, Littrell MC. Augmentative Alternative Commun 1993:9:229-42.

[198] APPLICATIONS OF TECHNOLOGY: A MULTIDISCIPLINARY CONSORTIUM AND SERVICE DELIVERY MODEL

Ian R. Pumpian; Andrew Y.J. Szeto; Caren L. Sax
Department of Special Education, Department of Electrical & Computer Engineering, Interwork Institute, San Diego State University, San Diego, CA 92182

Sponsor: *U.S. Department of Education, Dept. of Special Education & Rehabilitation*

PURPOSE—The project seeks to demonstrate the effectiveness of a community approach that coordinates resources, roles, and expertise of many agencies and disciplines to provide individualized and cost-effective rehabilitation engineering services. In conjunction with job development and placement activities, multi-disciplinary technology teams have endeavored to conceptualize, fabricate, deliver, and implement customized technical adaptations (assistive devices) that will enhance an adolescent or adult's employment and community integration.

METHODOLOGY—During the 36-month project, referrals were solicited and received from individuals with severe disabilities and/or their families, as well as from professionals providing employment and living supports. A series of twelve milestones were established, moving a referral from research and data collection to the design, prototype construction, and field-testing of an adaptation. The milestones represented a systematic process for assessing and providing assistive technology services that would be consumer-driven and integrated into the planning processes used by agency personnel. A key component of this project has been the use of multidisciplinary Tech Teams, which are individually organized according to the specific needs of a consumer and which may include friends, family

members, and employers in addition to profcssionals with various technical skills. A Technology Mini-Center also has been established to better gather and disseminate information about rehabilitation engineering resources in the San Diego community. The center also supports several courses on thc application of technology in rehabilitation that arc given through the Departments of Electrical Engineering, Rehabilitation, and Special Education at SDSU.

PROGRESS—Customized adaptations designed and constructed through this project have enhanced meaningful integration in home, school, work and other community environments. A database has been developed to track information about each adaptation according to the environment in which it is used. Detailed case studies have been completed for a number of the more complex adaptation projects. Circuit schematics, mechanical drawings, and blueprints of those adaptations have been made available upon request. Dissemination efforts include local workshops and in-services to agency personnel to infuse problem-solving and decision-making processes into vocational rehabilitation and other supported employment efforts. Presentations have also been made at major state and national conferences, addressing special educators, rehabilitation personnel, rehabilitation engineering professionals, consumers, and their families.

RESULTS—Examples of adaptations which have resulted in employment and/or other quality of life improvements for individuals (including several who have exited from a sheltered workshop) are as follows: we designed a modified lever for a watering wand and custom mounting system for attachment to an clcctric wheelchair for a job watcring plants at Kmart and developed a switch-operatcd (with mouth stick or chin) page turncr, designed to hold 24 single pages, movable in either direction. Wc produced a security label adaptation to attach plastic warning tags to clothing for shoplifting prevention and a switch-opcratcd highlighter and papcr holdcr to facilitate computcr data entry office work. Additionally, we have developed an clcctromechanical switch-operated condiment dispenser for filling salt/pepper shakers and other condiment dispcnsers in a restaurant, a customizcd, portablc handle to stock coolers in a specialty food store, and adaptations for aquatic activities (i.e., kayak scat modifications, jet ski leg supports, and modificd boogie board for persons with paraplegia).

FUTURE PLANS—Although this project endcd in September 1993, many of its activities will continue under a successor grant that began in Octobcr 1993. The focus of the new grant is to incrcase cfforts in establishing rehabilitation engineering technology serviccs as a more integral part of pre-service and in-servicc training at San Diego State University as well as expanding resources to selected agencies that provide cmployment and living supports to individuals with severe disabilities.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Successful integration of assistive technology and job development for an individual with a disability: a case study. Sax C, Smaby N, Tung D, Grant J, Kozole K. In: Proceedings of the 17th Annual RESNA Conferenee, 1994, Nashville, TN. Washiington, DC: RESNA Press, 1994.

Consumer-driven tech teams: creating customized adaptations. Sax C, Kozole K. Proceedings of the 9th Annual International Conference of Teehnology and Persons with Disabilities, 1994, Cal SU, Northridge, CA.

[199] ASSESSING THE CAPABILITIES OF INDEPENDENT LIVING CENTER STAFF TO DELIVER ADA-RELATED SERVICES

Margaret A. Nosek, PhD; Lex Frieden, MS; Earl Walden, DEd
ILRU Research and Training Center on Independent Living; Center for Researeh on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *U.S. Department of Education*

PURPOSE—Since the passage of the Americans with Disabilities Act (ADA), independent living centers have been getting requests for information from persons with disabilities who want to know what ADA will mean to them, and from employcrs, businesses, and service organizations who want to

know what will be required to comply with the new law. Under a three-year grant from the U.S. Department of Education, ILRU will investigate the types of ADA-related services offered by independent living centers and the capability of their staff to deliver these services.

PROGRESS—ILRU conducted an open-ended, paper-and-pencil survey of independent living center involvement in ADA service delivery; 22 centers responded. These data have been analyzed and published.

An ADA Scale Pre-Test consisting of 50 multiple choice, true and false, and matching items was constructed to compare independent living center staff (N = 124) knowledge of the Americans with Disabilities Act to that of 89 controls. Item analysis was conducted using factor analysis to assess scale and item dimensionality, IRT modeling to determine item discrimination and difficulty and scale reliability. Groups were then compared using the independent sample t-test on three methods of scoring the primary scale dimension. Based on these results, the test was revised and re-administered after training intervention.

RESULTS—According to the results of the in-depth study of 22 subjects, the executive director is the staff member who is most likely to answer ADA-related inquiries. Centers receive the most frequent telephone inquiries about access to public accommodations, evaluation of structural barriers, implementation dates of different sections of the ADA, and how to define reasonable accommodation. The segment of the population who makes the most ADA-related inquiries per month is consumers (M = 7.30), followed by rehabilitation professionals (M = 4.40), government entities (M = 4.35), businesses that are public accommodations with more than 25 employees (M = 3.30), community or social service organizations (M = 2.80), and building owners or managers (M = 2.40). The vast majority of ILCs (86.36 percent) claim that the number of ADA-related inquiries received per month is increasing.

The majority of center-sponsored ADA-related workshops have been for center staff (27 percent), consumers (23 percent), and small businesses (19 percent). Other workshop recipients have included Chambers of Commerce; hospital social workers; representatives of the local deaf community; personnel directors; building design professionals; city, state, and county government representatives; and public and private schools.

Staff of ILCs obtain information on the ADA from training programs, hotlines, and written or videotaped materials from such organizations as the Department of Justice, the Department of Transportation, the Equal Employment Opportunity Commission (EEOC), the Architectural and Transportational Barriers Compliance Board, the Disability Rights Education and Defense Fund (DREDF), the President's Committee on the Employment of People with Disabilities and the U.S. Chamber of Commerce.

Dimensionality analyses of the pre-test responses indicated one prominent dimension, with no indication that response format contributed to the dimensionality of the data. A subset of 17 items, including the matching section, did not load on the primary dimension and were thus excluded from the post-test. The final recommended scale consists of 33 items from all response formats. Since these items contain a preponderance of low to middle ability items, thus providing poor measurement for subjects high in knowledge of the ADA, 7 difficult items were added to the post-test. Results indicate that independent living center staff need more ADA training and library materials.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

ADA—will it work? Nosek MA. Am J Occup Ther 1992:46(5):466-7.

Enlightened set of paradoxes. Nosek MA. In: Barton J, ed. Disability: The necessity for a socio-political perspective. Durham, NH: World Rehabilitation Fund, 1992.

Effect of the Americans with Disabilities Act on the delivery of medical services. Matson CC, Holleman WL, Nosek, MA, Wilkinson W. NARPPS J 1993:8(3):115-20.

Impact of the Americans with Disabilities Act on family physicians. Matson CC, Holleman WL, Nosek, MA, Wilkinson W. Arch Fam Pract 1993:36(1):1-6.

Independent living centers and private sector rehabilitationists: a dynamic partnership for implementing the ADA. Howland CA, Walden E, Nosek MA. NARPPS J 1993:8.

Implications of the Americans with Disabilities Act for private rehabilitation professionals. McMahon B, Nosek MA, eds. NARPPS J 1993:8(2).

VIII. Muscles, Ligaments, and Tendons

A. Muscles

[200] EFFECT OF CHRONIC THEOPHYLLINE TREATMENT ON QUADRIPLEGIA

Catherine S. H. Sassoon, MD; Richard W. Light, MD
VA Medical Center, Long Beach, CA 90822

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B660-RA)*

PURPOSE—This study aimed to assess the effect of chronic theophylline administration on diaphragm muscle function in patients with chronic quadriplegia.

METHODOLOGY—Patients with C4-C8 quadriplegia of more than one year duration were studied. Eight weeks of theophylline and 8 weeks of placebo were administered in a double blind crossover fashion with a 1 week washout period in between the two drugs. Maximum inspiratory pressure (PImax), and both diaphragm muscle strength and endurance were evaluated 3 days (acute) and 8 weeks (chronic) after theophylline and placebo administration. Diaphragm muscle strength was estimated from measurement of maximum transdiaphragmatic pressure (PDimax). Diaphragm muscle endurance was estimated from the endurance time of breathing against threshold load of 67 percent of the PImax to a maximum of 10 min; which ever comes first. PDi was obtained by subtracting Pes (measured using an esophageal balloon) from gastric pressure (Pga, measured using a gastric balloon).
Statistical Analysis. Mean and SD of each of the variables were calculated. Comparison between the effect of theophylline and placebo was performed using two-way analysis of variance.

PROGRESS—This study has been completed.

RESULTS—Nine male patients with low cervical quadriplegia (C4 = 3; C5 = 3; C6 = 3) completed the study. Their mean age was 51.3 ± 11.6 ($\pm$SD) yrs. Mean drug levels on theophylline at 3 and 8 weeks were 12.4 and 13 mg/L, while on placebo were 3.0 and 2.5 mg/L, respectively. PImax after 3 days on theophylline was 52.3 ± 14.0 cm H_2O compared to 54.6 ± 15.8 cm H_2O on placebo; and after 8 weeks on theophylline was 59.3 ± 16.9 cm H_2O compared to 49.4 ± 14.4 cm H_2O on placebo. These were not significantly different. Similarly, acute or chronic theophylline administration had no significant effect on PDimax or endurance time despite therapeutic serum levels of theophylline.

IMPLICATIONS—Chronic theophylline administration in patients with low cervical chronic quadriplegia has no significant effect on respiratory muscle function. Although for the group theophylline had no effect on respiratory muscle function, in one patient (C5 level), theophylline improved respiratory muscle strength and endurance significantly. PImax after acute and chronic theophylline administration was 68 and 92 cm H_2O, respectively; while after placebo the corresponding values were 56 and 50 cm H_2O. The endurance time breathing against a threshold load of 67 percent of the PImax after both acute and chronic theophylline was 600 s, compared to 63 and 165 s after acute and chronic placebo, respectively. Spirometry was unchanged. This was also associated with subjective improvement of breathing less strenuously. In fact, the patient requested to continue theophylline.

[201] PEDALING COORDINATION: IDENTIFICATION OF MUSCLE CONTROL STRATEGIES

Christine C. Raasch, MS; Benjamin J. Fregly, PhD; Felix E. Zajac, PhD; Christine A. Dairaghi, BS
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—The goal of this study is to better understand central nervous system coordination of muscles in the lower limb. Pedaling is a good task for this, because it is amenable to laboratory experimentation and modeling, yet complex enough that its control is interesting. Pedaling a stationary bike also does not involve the complicating factors of balance and posture. Still, while it may seem trivially easy to us because it is so well-learned, some neurologically impaired patients have difficulty pedaling smoothly or quickly, and tend to rely heavily on the nonaffected leg. We hope to gain some insight into how biomechanical factors (including gravity, mechanical constraints, and muscle properties) and neuromuscular coordination influence pedaling. Computer models allow us to interpret experimental results and predict the consequences of different muscle-control strategies, including pathological muscle groupings or synergies. This will help us in developing better assessment, intervention, and rehabilitative strategies.

METHODOLOGY—Our model of the person pedaling includes the legs and stationary bicycle (ergometer), and nine muscle groups on each leg. Muscle excitations were found using an optimization algorithm which set the timing and magnitude so that the simulation pedaled as fast as possible. For constant-speed pedaling, the model was driven by net muscle joint torques derived from measured data.

PROGRESS—Experimental data was collected from healthy subjects pedaling a specially designed and instrumented ergometer. One group of subjects was asked to pedal at a smooth cadence with the ergometer emulating both normal load conditions and the higher inertial load characteristics of actual road bicycle riding. Other subjects pedaled from rest to maximal speed.

RESULTS—Analysis of a simulation that closely matched experimental data revealed that ankle and hip extensor muscles work together to deliver power to the crank during the downstroke. In contrast, our results indicate that the torque generated at the knee functions independently to propel crank through the top and bottom of the stroke, respectively, which prevents freewheel decoupling. During the upstroke, ankle extensor muscle activity aids in recovering the limb rather than propelling the crank.

Subject data showed changes in driving force to the crank and decreased cycle-to-cycle cadence variability when the inertial load was increased. We conclude that the neuromuscular control at higher inertial load may be simplified by the system's slower response to perturbations. That is, coordination must be finer at lower inertial loads to meet task demands. Thus, the use of gradually decreasing inertial loads may be a helpful strategy for training stroke patients to regain fine control of the affected limb.

IMPLICATIONS—Simulations of maximal-speed pedaling agreed with measured data from subjects performing the same task. Optimization results showed that different ankle muscle control strategies may be used; however, the calf muscles must be activated near the end of downstroke to prevent knee hyperextension. Although pedaling might be considered a simple, "push-pull" task, simulations with muscles excited in this synergistic manner did not produce smooth continuous motion. These results suggested that pedaling is more of a four-phase task, requiring timely deactivation of flexors/extensors followed by active propulsion through the

top and bottom of stroke, provided mainly by two-joint muscles (e.g., hamstrings). Since some neurologically impaired subjects exhibit problems similar to those seen in the simulation, we theorize that they may have difficulty breaking out of synergistic activation patterns.

[202] MUSCLE COORDINATION OF MULTIJOINT MOTOR TASKS: AN INTERACTIVE COMPUTER WORKSTATION ENVIRONMENT

Felix E. Zajac, PhD; J. Peter Loan, PhD; Michael Gordon, PhD
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—Multijoint movement involves a complex coordination of many muscles. The complexity arises because a muscle acts to accelerate all joints and segments, even joints it does not span and segments to which it does not attach. A biarticular muscle can even act to accelerate one of the joints it spans in the direction opposite to its anatomical classification. For example, gastrocnemius, which anatomically is classified as a knee flexor, can act to accelerate the knee into extension during upright standing.

The underlying neuromuscular principles of these complex multijoint movements will remain a mystery unless kinesiological data can be analyzed and interpreted in the context of dynamic musculoskeletal models sophisticated enough to study coordination. The effort required to develop models has been so large, however, that few simulations of motor tasks have actually been performed. To facilitate the creation of such models, we are developing an interactive computer workstation environment that will allow researchers to develop neuromusculoskeletal control models, generate simulations of motor tasks, and display both kinesiological and modeling data in an animated format.

METHODOLOGY—Our interactive workstation environment includes several modules. The SIMM module (Software for Interactive Musculoskeletal Modeling, by Musculographics, Inc.) is used to model the skeletal geometry, the joint kinematics, the muscle attachments and lines of action, and the force-generating parameters of the muscles and tendons. The SDFast module (by Symbolic Dynamics, Inc.) is used to generate dynamic models that simulate the movement of the limb segments in response to particular muscle activation patterns.

The heart of the dynamical model are the equations of motion (state equations) which define how the joint torques produced by the muscles, and by gravity and segmental motion, contribute to the angular acceleration of the joints. Because of the coupling of the segments, soleus, a uniarticular muscle which only produces a torque at the ankle, nevertheless contributes to the angular acceleration of the hip and the knee as well. Moreover, gastrocnemius, a biarticular muscle which produces torques at both the knee and the ankle, can contribute either positive or negative accelerations at the these joints and thus can act either to flex the knee and extend the ankle (consistent with its anatomical classification), to flex both joints, or to extend both joints.

PROGRESS—The dynamical models can be used in conjunction with empirical or theoretical muscle activation patterns to generate simulations of movement, or they can be used with optimization procedures to predict what muscle activation patterns are needed to accomplish certain movements. Both experimental and simulated data can be displayed either as time plots or by means of animated stick figures. Feasible acceleration sets can also be computed and displayed.

[203] MUSCLE FIBER STRENGTHENING WITH ELECTRICAL STIMULATION

Richard L. Lieber, PhD; M.J. Kelly; P. Silva; Dale Daniel, MD
Biomedial Sciences Graduate Group, University of California and VA Medical Center, San Diego, CA 92161

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B591-RA)*

PURPOSE—The purpose of this project was to determine the factors which influenced the magnitude or torque generated by the human quadriceps muscles during electrical stimulation and the influence of frequency and duty cycle on fatigue magnitude.

METHODOLOGY—Three differenct types of electrodes were used which varied in material properties and size. Forty subjects were asked to maximally extend their quadriceps muscles and then were stimulated with each electrode type. For each subject, maximum voluntary torque, electrode size, electrode area, electrode impedance, stimulation voltage, stimulation current, and skinfold thickness were measured. These factors were entered into a stepwise regression equation to determine those which most dramatically effected the magnitude of stimulation-induced torque.

PROGRESS—We have successfully tested 40 subjects in this program.

RESULTS—It was determined that in spite of the fact that several factors correlated individually with maximum electrically induced torque, the factor which most strongly determined torque magnitude was stimulation efficiency (defined as stimulation current per unit torque). From these experiments we concluded that, although factors such as electrode size, stimulation current, etc. influenced the magnitude of torque which can be generated using electrical stimulation, the most important factor determining torque magnitude was intrinsic to the individual. Fatigue magnitude increased with increasing frequency and decreasing duty cycle. These effects were statistically independent.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Skeletal muscle mechanics: implications for rehabilitation. Lieber RL, Bodine-Fowler SC. Phys Ther. 1993:73:844-56.

Torque history of electrically stimulated human quadriceps: implications for stimulation therapy. Lieber RL, Kelly MJ. J Orthop Res. 1993:11:131-41.

[204] MODELLING OF EMG SIGNALS

Roberto Merletti, PhD; Loredana R. Lo Conte, MS; Elena Avignone, BS; Guido Sandri, PhD; Serge H. Roy, ScD; Edward Kupa, MS
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Politecnico di Torino, Italy

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B595-RA); NeuroMuscular Research Center, Boston University, Boston, MA 02215; Camera di Commercio di Torino*

PURPOSE—Many anatomical and physiological parameters of a muscle can not be measured directly. Since most of these parameters are of clinical interest and are affected in a number of pathological situations, indirect estimation through the use of models is desirable.

METHODOLOGY—We use a model developed at the Department of Physics of the University of Torino and based on the representation of the muscle fiber action potential by means of a current tripole. This is equivalent to approximating the membrane action potential with a triangular shape. Each motor unit is modeled as a number of fibers uniformly scattered in a cylindrical volume with innervation and end points uniformly distributed in regions of specified width. The entire muscle is simulated as a hemispace of anisotropic conductor material with motor units located in specified positions and firing either synchronously or asyn-

chronously at given rates. Intensity, width and propagation velocity of the tripoles, diameter and location of the motor units and of the surface electrodes are selectable.

RESULTS—This model has been used to simulate and interpret EMG evoked potentials (M-waves) obtained *in vitro* from the soleus of rats. A first finding from these simulations is that the innervation zone of the rat's soleus is not at the point of entry of the nerve into the muscle and the innervation zone of the tibialis anterior muscle is not necessarily underneath a motor point. A second finding is that the electrode dimension is very important in determining the shape of the response. In addition, this testing has outlined the relative importance of the model parameters in determining the surface potential. The most important parameters of the model have a narrow range of values that allows matching a specific real signal.

PROGRESS—The model is expected to allow estimation of the location and territory of motor units as well as fiber length, geometry of innervation and end zones. For the time being, the model has been used to simulate only electrically evoked potentials, but its capabilities extend to voluntary EMG signals as well.

[205] MULTICHANNEL SURFACE EMG SIGNALS

Roberto Merletti, PhD; Silvestro Roatta, BS; Yan Fan, BS
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Politecnico di Torino, Italy

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA); Camera di Commercio di Torino*

PURPOSE—Electrode location along the muscle fibers is a critical factor in surface electromyography. Conduction velocity, amplitude and spectral variables are affected by electrode position, as well as the shape of the signal evoked during electrically elicited contractions.

METHODOLOGY—In order to study this effect, an array of 16 contacts with 5 mm interelectrode distance was used to detect multichannel EMG during voluntary and electrically elicited contractions. Isometric contractions of the tibialis anterior muscle in normal individuals were performed at different voluntary torque levels, and M-waves were obtained by stimulation of the main muscle motor point. The array was located between the motor point and the distal tendon. At contraction levels of about 50 percent MVC, some waveform complexes can be visually traced along a few of the array contacts. As a contraction is sustained, the interferential pattern becomes less rich and the waveforms wider, resulting in a progressively greater number of waves traceable along the array. At higher contraction levels the initial EMG interference signal is richer and travelling waves harder to detect. It is also evident that individual waves, when visually detectable, are propagating at different velocities underneath the array and some appear simultaneously under most of the contacts. These phenomena are present in very different degrees in different subjects.

PROGRESS—This preliminary work shows the potential of multichannel EMG for the noninvasive evaluation of muscle anatomical and physiological features.

RESULTS—We conclude that estimates of conduction velocity are very fuzzy and affected by the relative weight of components travelling at different speeds. Furthermore, non-travelling signals, not completely eliminated by the double differential technique, lead to an overestimation of the propagation velocity. Techniques much more sophisticated than those presently in use are required to identify and track individual signal components under the array. These components are presumably due to individual motor units. The array technique may be expected to facilitate their detection and therefore to estimate their propagation velocity, the location of their generation and of their extinction. Anatomical parameters of the most superficial motor units might then be estimated.

[206] ESTIMATION OF MUSCLE FIBER CONDUCTION VELOCITY

Roberto Merletti, PhD; Loredana R. Lo Conte, MS
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Politecnico di Torino, Italy

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B595-RA); Camera di Commercio di Torino*

PURPOSE—The estimation of muscle fiber conduction velocity through the surface EMG is a clinically important but technically problematic task.

METHODOLOGY—It is common to measure conduction velocity by estimating, with the crosscorrelation technique, the delay between two EMG signals detected by two sets of electrodes displaced along the muscle between the most distal motor point and the tendon. These two signals usually differ not only in timing but also in amplitude, width and shape. These facts make the estimate of delay rather fuzzy and subject to the particular definition of delay being adopted. In some cases, the crosscorrelation technique has led to perplexing results. This fact is more evident when the EMG is evoked by electrical stimulation. In particular, as the action potentials travel along the muscle fibers with different velocities, the differential surface EMG detected in two adjacent locations have different widths depending on the scattering of the neuromuscular junctions and conduction velocities. The two signals used for estimation of velocity therefore show a relative delay, amplitude and scale factors, and change of shape.

RESULTS—Two new algorithms have been developed to simultaneously estimate scaling factors and delays and have been tested with computer generated signals. One algorithm finds the values that minimize the mean square error between the two signals, another is based on the normalized integrals of the signals. In presence of noise or of wave truncation consequent to stimulation frequency higher than about 35 Hz, the crosscorrelation algorithm, and these two algorithms provide three different estimates of the delay and show different sensitivity to noise and shape changes.

PROGRESS—This study shows the need for agreement on the definition and estimation method of the delay between two noisy signals having differences in width and shape. Part of the disagreements indicated in the literature about the quality of the estimate of muscle fiber conduction velocity may well depend on the different methods used.

[207] EMG AND MECHANICAL MANIFESTATIONS OF MUSCLE FATIGUE

Roberto Merletti, PhD; Carlo J. DeLuca, PhD; Yan Fan, BS
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA); NeuroMuscular Research Center, Boston University, Boston, MA 02215*

PURPOSE—EMG manifestations of muscle fatigue precede mechanical manifestations of fatigue. In this project we intended to investigate whether the pattern of EMG signal variables at the beginning of a contraction could be used to predict the point of mechanical breakdown or to identify signal features useful for a non-invasive characterization of the muscle. The first point was discussed in the 1992 report. In this report we focus mostly on the second.

METHODOLOGY—Voluntary isometric contractions of the tibialis anterior were performed in normal subjects at levels of 50 percent, 60 percent, 70 percent and 80 percent MVC. They were sustained for at least 30 s beyond the point of

mechanical breakdown which was defined as the time at which force dropped permanently by more than 5 percent below the target level. This point was reached after about 20 s at 80 percent MVC and 100-120 s at 50 percent MVC. The initial value and the time course of conduction velocity, amplitude, and spectral variables are affected by electrode position. As a consequence, the parameters obtained from certain locations may be preferable to those obtained from others, either because of quality of the estimate, sensitivity to fatigue, reproducibility, or other factors. To investigate this issue, a detection system of 16 contacts with 5 mm interelectrode distance was used to detect multichannel EMG. The three differential signals detected from a subset of four bars were used, as described elsewhere, to estimate conduction velocity, amplitude, and spectral variables. Initial values, slopes or time constants of conduction velocity, mean and median spectral frequencies, and amplitude variables were estimated along the array.

RESULTS—In the six subjects studied we found that these parameters are considerably affected by electrode location. In particular, conduction velocity has reasonable values only in 2-4 locations, and fatigue indices based on spectral variables are sensitive to electrode position. We are now investigating whether the capability of the EMG parameters to predict endurance is the best in a consistent location or may be better studied by some multivariate approach using information from a number of detection sites.

[208] BIOCHEMICAL AND MYOELECTRIC EVENTS DURING FATIGUE

Serge H. Roy, ScD; Edward Kupa, MS; Carlo J. DeLuca, PhD; Susan Kandarian, PhD; L. Donald Gilmore, ABEE
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Sargent College of Allied Health Professions, Boston University, Boston, MA

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA); the Liberty Mutual Insurance Company*

PURPOSE—Basic research studies are being conducted in the Electrophysiology Laboratory to provide a better understanding of how the biochemical events associated with fatigue influence the median frequency and conduction velocity estimates of the EMG signal.

METHODOLOGY—We have designed an *in vitro* method in an animal model to provide a firmer scientific basis for surface EMG spectral techniques that assess muscle fatigue in humans. Our studies are currently focused on how the histochemical fiber type composition of a muscle influences the EMG signal and its spectral parameters. EMG signals from the diaphragm muscle and two different hindlimb muscles of the rat (the extensor digitorium longus and soleus muscles) have been successfully recorded during sustained stimulated contractions. Eight neuromuscular preparations were studied for each muscle group. Changes in the EMG waveform (the M-wave) during fatiguing contractions were analyzed for the different muscles studied.

PROGRESS—The relationship between the percentage of fiber type and the spectral parameters of the EMG signal were described using multivariate regression equations. On the basis of these equations we are able to estimate the the percentage of fiber type of a muscle with a higher degree of accuracy than previously reported. These results are a first step towards predicting the percentage of fiber type in humans.

RESULTS—Muscles with higher proportions of fast glycolytic enzymes demonstrated longer time durations of the M-wave and a greater distortion of the repolarization component of the waveform than muscles with a slow oxidative enzyme content. The corresponding differences in the initial values of the median frequency and conduction velocity and their rates of decay during fatigue paralleled the distinct differences in the fiber type composition of these muscles.

[209] SKELETAL MUSCLE ARCHITECTURAL DESIGN: IMPLICATIONS FOR TENDON TRANSFER

Richard L. Lieber, PhD; Mike Botte, MD; Mark Jacobson, MD; Babak Fazeli, BS; Reid Abrams, MD
Department of Orthopaedics, Biomedical Sciences Graduate Group, University of California, La Jolla, CA 92093; VA Medical Center, San Diego, CA 92161

Sponsor: *American Society for Surgery of the Hand*

PURPOSE—The purpose of this project was to elucidate the design of the various human forearm muscles. Our goal was to better understand which muscles would provide appropriate function for other muscles secondary to surgical tendon transfer.

METHODOLOGY—This study was based on the fact that skeletal muscle architecture dramatically influences function. The detailed fiber arrangement from 255 muscles taken from 27 cadaveric specimens was measured and submitted for discriminate analysis for determination of the structural factors which most strongly differed between functional groups.

PROGRESS—We found that the five most important discriminators for all muscles were: physiological cross-sectional area, fiber length, fiber length to muscle length ratio, mass, and muscle length. These five discriminating parameters were then used to create an architectural difference index which represented the overall differences between muscles in a single value. Then, various tendon transfer pro cedures were evaluated based on architectural difference indices. Future studies are designed to evaluate the efficacy of various surgical treatments based on architectural difference indices.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Architectural design of the human intrinsic hand muscles. Jacobson MD, Raab R, Fazeli BM, Abrams RA, Botte MJ, Lieber RL. J Hand Surg 1992:17:804-9.

Architecture of selected muscles of the arm and forearm: anatomy and implications for tendon transfer Lieber RL, Jacobson MD, Fazeli BM, Abrams RA, Botte MJ. J Hand Surg 1992:17:787-98.

Quantitative method for comparison of skeletal muscle architectural properties. Lieber RL, Brown CG. J Biomech 1992:25:557-60.

Skeletal muscle architecture: implications for muscle function and surgical tendon transfer. Lieber RL. J Hand Ther 1993:6:105-13.

Relationship between muscle fiber types and sizes and muscle architectural properties in the mouse hindlimb. Burkholder TJ, Fingado B, Baron S, Lieber RL. J Morphol 1994:220:1-14.

[210] MUSCLE ADAPTABILITY DURING PROLONGED SPACEFLIGHT

Serge H. Roy, ScD; Carlo J. DeLuca, PhD; Mark Emley, MS; Daniel Merfeld, PhD; Laurance Young, ScD; Anthony Rodrigues, ASEE; L. Donald Gilmore, ABEE
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Massachusetts Institute of Technology, Cambridge, MA; National Aeronautics and Space Administration, Washington, DC 20546

Sponsor: *NASA through the MIT Man-Vehicle Laboratory and the NeuroMuscular Research Center*

PURPOSE—Prolonged spaceflight has profound affects on the vestibular and motor systems of the body. Our experience in measuring muscle fatigue noninvasively and objectively in humans has been applied to two recent NASA Spacelab Life Science shuttle missions (SLS-01 and SLS-02). These missions represent the first space shuttle flights dedicated entirely to the medical and biological studies.

METHODOLOGY—Changes in surface EMG spectral measures of fatigue were studied for several muscles of the lower limb. Measurements were conducted pre-flight and immediately post-flight on 4 members of each shuttle crew.

PROGRESS—For SLS-01 (a 9 day mission), calf muscle strength was diminished post-flight by ap-

proximately 25 percent and recovered to baseline within several days. The antagonist muscles to the calf, which have less antigravity function, were insignificantly changed in strength post-flight. Changes in strength for the longer duration (14 day) SLS-02 mission were similar for the calf muscles but distinctly different for the antagonist muscles which in 3 of the 4 astronauts was diminished by 20 percent and did not recover by the ninth day post-flight.

RESULTS—EMG signal parameters have only been analyzed to date for the SLS-01 mission. A reduction of median frequency post-flight, consistent with muscles atrophy, was present in 3 of the 4 astronauts tested. The reduction in median frequency was typically between 10 percent and 20 percent and returned to baseline in most cases by the sixth post-flight day. Changes in the rate of decay in median frequency also occurred post-flight indicating an adaptation toward greater fatigue.

[211] MECHANISM OF TORQUE GENERATION IN THE FROG HINDLIMB

Richard L. Lieber, PhD; Scott Shoemaker, MD; Cindy Brown
Department of Orthopaedics, Biomedical Sciences Graduate Group, University of California; VA Medical Center, San Diego, CA 92161

Sponsor: *National Institute of Arthritis and Musculoskeletal and Skin Diseases Muscle Biology Program*

PURPOSE—The purpose of this project was to determine the relative influence of muscle intrinsic properties, moment arm and tendon compliance on the nature of the torque profile on the frog hindlimb.

METHODOLOGY—Muscle sarcomere length, moment arm and tendon strain were measured in the frog hindlimb (Rana pipiens) at 100 increments over the hip joint range 130-1500. Hip torque was also directly measured over the same range. Sarcomere length-joint angle relationship was also measured in a number of other muscle-joint systems.

RESULTS—The relationship between sarcomere length and joint angle were as previously measured (Mai and Lieber, 1990). We found that in this system, moment arms dominated the shape of the torque profile, accounting for over 75 percent of the experimental variability. Muscle force accounted for almost 20 percent of the variability, and tendon compliance for less than 5 percent of the variability. These data suggest that in the frog muscle-joint system, since muscle fiber length is relatively long compared to the moment arm, moment arm will dominate the nature of the torque profile. The slope of the sarcomere length-joint angle relationship varied significantly among muscles.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Muscle, joint, and tendon contributions to the torque profile of frog hip joint. Lieber RL, Shoemaker SD. Am J Physiol 1992:263:R586-90.

Sarcomere length-joint angle relationships of seven frog hindlimb muscles. Lieber RL, Brown CG. Acta Anat 1993:145:289-95.

[212] MUSCLE FIBER DAMAGE DUE TO ECCENTRIC CONTRACTIONS

Richard L. Lieber, PhD; Jan Fridén, MD, PhD
Department of Orthopaedics, Biomedical Sciences Graduate Group, University of California; VA Medical Center, San Diego, CA 92161

Sponsor: *National Institute of Arthritis and Musculoskeletal and Skin Diseases Muscle Biology Program*

PURPOSE—The purpose of the project was to determine the mechanism of damage in muscle fibers from the rabbit tibialis interior. Muscles were cyclically stretched 25 percent of their fiber length at two different times during the contractile cycle. In this way, muscle stress was varied between treatment

groups, but muscle strain and strain rate were exactly the same. We also investigated cytoskeletal structure using monoclonal antibodies to the desmin and titin proteins.

RESULTS—In spite of the dramatically different stresses experienced by the two different groups, skeletal muscle force following eccentric contraction induced injury dropped to the same extent in both treatment groups ($p > 0.4$). These data suggest that muscle fiber damage is due primarily to the magnitude of the length change during the eccentric contraction rather than the absolute stress reached during the contraction. Muscle injury resulted in a dramatic loss of cytoskeletal desmin in certain fibers across the entire muscle and the result was more dramatic for the EDL than the TA. Clearly abnormal muscle fibers were observed in the normally dense-staining Z-disk. This loss of cytoskeleton occurred even though in serial sections stained immunohistochemically, myofibrillar contractile proteins were clearly present.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Structural and mechanical basis of exercise-induced muscle injury. Friden J, Lieber RL. Med Sci Sport Exerc 1992:24:521-30.

Muscle damage is not a function of muscle force but active muscle strain. Lieber RL, Friden J. J Appl Physiol 1993:74:520-6.

[213] INTRAOPERATIVE MEASUREMENT OF HUMAN MUSCLE SARCOMERE LENGTH

Richard L. Lieber, PhD; Jan Fridén, MD, PhD
Department of Orthopaedics, Biomedical Sciences Graduate Group, University of California; VA Medical Center, San Diego, CA 92161

Sponsor: *National Institute of Arthritis and Musculoskeletal and Skin Diseases Muscle Biology Program*

PURPOSE—The purpose of the project was to determine the physiological sarcomere lengths in human muscles during normal joint rotation. Subjects undergoing surgical lengthening of the extensor carpi radialis brevis muscle for lateral epicondylitis were studied. Biopsies from the same region were also taken and studied with electron microscopy in order to quantify actin and myosin filament length.

RESULTS—With the elbow fully extended, as the wrist joint was passively flexed from full extension to full flexion, ECRB sarcomere length increased from 2.5 μm to 3.6 μm at a rate of 7.4 nm/° joint angle rotation. Correcting for tendon elongation during muscle activation yielded an active sarcomere length range of 2.34 μm to 3.56 μm. Maximal predicted sarcomere shortening accompanying muscle activation was dependent on initial sarcomere length and was always less than 0.15 μm suggesting a minimal effect of tendon compliance. Thin filament lengths measured from electron micrographs of muscle biopsies obtained from the same region of the ECRB muscles were $1.30 \pm .027$ μm while thick filaments were $1.66 \pm .027$ μm long, suggesting an optimal sarcomere length of 2.80 μm and a maximum sarcomere length for active force generation of 4.26 μm. These experiments demonstrate that human skeletal muscles can function on the descending limb of their sarcomere length-tension relationship under physiological conditions.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Sarcomere length changes during fish swimming. Lieber RL, Raab R, Kashin S, Edgerton VR. J Exp Biol 1992:169:251-4.

In vivo measurement of human wrist extensor muscle sarcomere length changes. Lieber RL, Loren GJ, Friden J. J Neurophysiol 1994:71:874-81.

Physiological consequences of surgical lengthening of extensor carpi radialis brevis muscle-tendon junction for tennis elbow. Friden J, Lieber RL. J Hand Surg 1994:19A:269-74.

B. Ligaments and Tendons

[214] PHYSIOLOGICAL BASIS OF STRENGTH FOLLOWING SURGICAL TENDON TRANSFER

Richard L. Lieber, PhD
VA Medical Center, San Diego, CA 92161

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A745-RA)*

PROGRESS—Since this project began, we have completed detailed studies of human muscle architecture, tendon compliance, and muscle-joint interaction. Currently, the project is meeting (in fact, exceeding) its scientific goals proposed in the original narrative. We have recently refined the intraoperative laser diffraction method such that it can be used during normal tendon transfer procedures. In addition, we have tested the method on a simple surgical procedure, the lengthening of the extensor carpi radians brevis tendon for treatment of lateral epicondylitis (tennis elbow). Thus the new method is rapid, accurate, and yields important information regarding sarcomere length during the transfer itself.

We have also nearly finished our architectural studies of the human arm which began with a simple study of the five prime movers of the wrist, and has now been extended to include finger flexors and extensors and the intrinsics. We have also developed a quantitative method from comparing the architectural properties of donor and recipient muscles.

FUTURE PLANS—With this experience and publication record, we are now in a strong position to examine the tendon transfer procedures commonly used in neuromuscular reconstructive surgery.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Architectural design of the human intrinsic hand muscles. Jacobson MD, Raab R, Fazaii BM, et al. J Hand Surg 1992:17:804-9.

Architecture of selected muscles of the arm and forearm: anatomy and implications for tendon transfer. Lieber RL, Jacobson MD, Fazeli BM, Abrams RA, Botte MJ. J Hand Surg 1992:17:787-98.

Quantitative method for comparison of skeletal muscle architectural properties. Lieber RL, Brown CG. J Biomech 1992:25:557-60.

[215] COMBINED FUNCTIONAL LOADING AND LASER PHOTOSTIMULATION OF REGENERATING TENDONS

Chukuka S. Enwemeka, PhD, FACSM; Vasundara Venkateswaran, PhD; Tammy Basham, BS
VA Medical Center, Kansas City, MO 64128; Department of Physical Therapy Education, University of Kansas Medical Center, Kansas City, KS 66160-7601

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A534-2RA)*

PURPOSE—The overall goal of this study was to utilize our well-established paradigm of tendon repair, to determine the biomechanical, ultrastructural, biochemical, and molecular effects of combined functional loading and laser photostimulation on healing of repaired tendons.

METHODOLOGY—*Calibration of NK "Z" Tendon Transducer.* Eight male white rabbits 9 weeks of age were weighed, anesthetized and the right lower hind limb shaved along the Achilles tendon. A longitudinal incision was made and the tendon sheath separated from the adjoining tissue along the dorsal

surface. The tendon diameter was measured and subsequently the cross-sectional area of the tendon was calculated. With the tendon intact, steel monofilament sutures were attached 8 mm above the calcaneal insertion. The needle was sutured to the tendon to form two loops and a medium gauge wire attached to the loop and used to anchor the standard weights for the calibration of the transducer. After the sutures were in place a NK "Z" tendon transducer was placed on the tendon midway between the calcaneal insertion and the musculotendinous junction. The transducer was attached to a peak-hold meter that was specially designed for our laboratory by Rochester Electronics, Rochester, MN. Weights were added to the wire in 0.45 kg increments up to a total weight of 2.2 kg. The peak force for each weight was recorded. Upon completion of the experiment the rabbits were sacrificed by lethal inhalation of CO2.

Peak Force Tolerated by the Achilles Tendon (Without Rupture) upon Electrical Stimulation of the Triceps Surae. Eighteen male white New Zealand rabbits, 9 weeks of age, were divided into three groups of six rabbits each. Animals were weighed, anesthetized and the right lower hind limb of each rabbit was shaved, then scrubbed and rinsed with betadine. Using sterile technique, tenotomy and repair of the Achilles tendon was carried out. Upon completion of surgery, a cast was fitted and secured on the rabbit. All tenotomized rabbits received electrical stimulation of the triceps surae on Day 1, 3 or 5 following surgery as follows: Under the influence of the anesthetic the skin sutures were removed, the tendon exposed, freed from the surrounding tissue, just enough to allow placement of the transducer. The transducer was placed proximal to the site of tenotomy. The transducer was connected to the peak-hold meter as previously described. Muscle stimulation was achieved with the use of a Mettler Electronics, Sys Stim 207. The pulse frequency was set at 120 pps. The current pattern was set on wide pulse and surge. The intensity was maintained approximately around 10 volts. The peak volts transmitted from the electrical stimulator was recorded along with the peak force recorded by the peak-hold meter. After the triceps surae was stimulated the condition of the sutures were monitored. Upon completion of the experiment the rabbits were sacrificed by lethal inhalation of CO_2.

PROGRESS—The "Z" force tendon transducer has been calibrated and the correlation coefficient (r) so obtained was 0.997. An intensity setting that displayed approximately 10 volts on the electrical stimulation system was the maximum dose tolerated by the animals without rerupture of the tendon. We are currently studying the ultrastructural, morphometric, biomechanical, and biochemical aspects of the effects of short term treatment of combined functional loading and laser photostimulation (1J cm^{-2} He-Ne laser) on repaired tendons as compared to their nontreated controls.

IX. Neurological and Vascular Disorders

A. General

[216] TREATMENT OF MUSCLE SPASTICITY USING PHENOL NERVE BLOCKS

Michael J. Botte, MD; Sue Bodine-Fowler, PhD
VA Medical Center, San Diego, CA 92161

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B740-RA)*

PURPOSE—Each year there are approximately 195,000 patients who sustain a stroke, 20,000 to 40,000 hospitalized for severe brain injuries, and over 25,000 who sustain a spinal cord injury. Spasticity affects a large portion of these patients, and if spasticity cannot be properly managed, further complications such as fixed soft tissue contractures, joint ankylosis, hygiene problems, chronic pain, pressure sores, and severe functional deficits can occur. In a comprehensive rehabilitation program, long-acting peripheral nerve blocks are among the most effective adjuvants used to manage muscle spasticity following spinal cord injury, traumatic brain injury, or stroke. Intraneural or perineural phenol injection is one of the most common types of peripheral nerve block.

Despite the acceptance of phenol as a means to produce a nerve block, it has been poorly evaluated from both a clinical and basic science standpoint. The overall goal of this study is to determine the optimal method for producing a nerve block that reduces motor activation of the muscles for a limited period of time, but does not inflict permanent damage to the nerve. A second criteria is that the muscles regain normal function and that the reinnervation of the denervated muscles is appropriate (i.e., the motor axons must make it back to their original muscles). Inappropriate reinnervation or a reduction in the number of axons that reinnervate could result in permanent motor dysfunction.

METHODOLOGY—The sciatic nerve of female Sprague-Dawley rats (^{1}250 gm body weight) was exposed to phenol using either intraneural injection or extraneural application. Forty adult female Sprague-Dawley rats were assigned to one of four experimental groups. Half (20) of the animals underwent sciatic nerve block with a low phenol concentration (3 percent) and half with a high concentration (7 percent). Within each of these groups, half (10) were blocked by intraneural phenol injection and half by bathing the nerve in phenol solution. Treatment was continued until complete conduction block occurred. Ten control animals underwent a sham operation in which saline rather than phenol was used for the injection or bath. Eight weeks after nerve block, sciatic nerve conduction velocities and *in situ* soleus maximum tetanic tension (Po) were measured.

RESULTS—The Po of the 3 percent phenol group was 67 percent of control ($p<0.0001$) and that of the 7 percent phenol group was 38 percent of control ($p<0.0001$) at 8 weeks. The difference between the treatment groups was also highly significant ($p<0.0001$). This effect was apparent even when Po was normalized to the weight of the soleus muscle being tested ($p<0.0001$). The conduction velocity of the 3 percent phenol group was 38 percent of control ($p<0.0001$) and the 7 percent phenol group was 35 percent of control ($p<0.0001$). The phenol application technique had no significant effect on either Po or the conduction velocity.

PROGRESS—These data suggest that phenol does not cause a pure axonotmetic lesion as originally thought. In retrospect, this is not surprising since phenol's mechanism of action is indiscriminate denaturation of proteins. It would be expected to damage both neural and supporting endoneural components of the peripheral nerve. In our study, the application technique had no effect on functional recovery of the muscle or nerve. The animals treated with a high phenol concentration had a much poorer functional recovery of the muscle at 8 weeks. The differences may be due to less complete or delayed reinnervation of the 7 percent phenol muscles. These results suggest that 3 percent phenol is preferred to 7 percent phenol if maximal function recovery is desired. Longer time periods of recovery and the specificity of reinnervation are under investigation.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Morphologic and functional effects of phenol on peripheral nerve and muscle. Bodine-Fowler SC, Dulbecco FL, Kitabayashi LR, Botte MJ. Soc Neurosci Abstr 1992:18:1304.

Treatment of acquired muscle spasticity using phenol peripheral nerve blocks. Botte MJ, Abrams RA, Bodine-Fowler SC. Orthopaedics. In press.

[217] DEVELOPMENT OF SPASTIC TOLERANT STICK CONTROLLER: A PILOT STUDY

Daniel W. Repperger, PhD, PE; Chandler A. Phillips, MD, PE
Armstrong Laboratory AL/CFBS, Wright Patterson Air Force Base, Dayton, OH 45433;
School of Biomedical and Human Factors Engineering, Wright State University, Dayton, OH 45435

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B90-119AP)*

PURPOSE—This effort has the specific goal of the identification in the phase plane of characteristics of a spasm which distinguish it from a voluntary commanded quick movement. A force reflecting stick controller is being used to see spasms identified in this manner with and without force applied. The spasms are substantially reduced through the use of force reflection. The long-term goal of this research is to develop wheelchair stick controllers for the VA for use by spastic patients. Normally a spastic patient cannot pass a wheelchair driving test because he cannot control the wheelchair stick controller. With the force-reflecting stick controller developed in this study, the spastic patient has more mobility and better quality of life because he can now control a powered wheelchair.

METHODOLOGY—We have tested stroke patients, head trauma patients, and some other types of spastics (cerebral palsy and Parkinson's). We also have run tests on a comparable number of normal subjects including college students and military personnel at Wright Patterson Air Force Base.

PROGRESS—Twenty subjects have completed the first two experiments related to wheelchair control. Ten of these subjects were spastic in the categories of head trauma injured and stroke survivor; several cerebral palsy patients were also run. The first experiment was a compensatory tracking task with the use of three different target speeds, four different perturbation disturbances (to help elicit a spasm), and the force, no force condition. The second experiment studied the speed-accuracy tradeoffs using a Fitts' Law scenario. The force reflection regime used in the second experiment had force reflected as a function of space which was correlated to what the patient observed on the visual display. This produced a Virtual Force paradigm in which the spastic patient obtained force feedback in conjunction with what he observed on the visual display.

RESULTS—Of the twenty subjects run so far, the spasticity in controlling a stick controller has been shown to be reduced over 30 percent when comparing involuntary responses of the spastics to the controlled responses of the non-spastics. The effects of force reflection mitigate both the incidence of a spasm as well as its magnitude. With sufficient exposure to the force reflection test bed facility, it appears that exposure to the force reflection (with

repeated practice) may act as a form of therapy which could transfer to other activities of daily living.

FUTURE PLANS—We see three new directions where this research would be of great value to the mission of the VA: 1) The spastic subject has improved rate of learning much higher than a normal subject and this rate of learning is apparent even after 9 days of data collection. Thus the continuous exposure to the force reflection seems to continuously improve his tracking ability. A future effort should investigate how this improvement may transfer to other activities of daily living as well the duration of this improvement should be studied to see if it ever asymptotes. 2) After training with the force reflection test bed facility, patients should then be tested in an actual wheelchair scenario to see if the training they have received during this simulation would then allow the operation of a wheelchair in a safe manner. 3) The use of the Virtual Force study in experiment 2 has shown that certain spatially sensitive force reflection regimes can be coordinated with the display to improve the patient-machine interaction. This scenario should be then taken to the situation of using force reflection joysticks for inputs into computers to assist patients to locate a cursor on the screen using this type of assistive aid.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Management of spasticity via an electrically operated force reflecting stick. Repperger DW. In: Proceedings of the Annual Meeting of the Rehabilitation Engineering Society of North America, 1992, Kansas City, MO.

Advances in robotics, mechatronics, and haptic interfaces. Chelette TL, Repperger DW, Phillips CA. DSC 1993:49(1):111-8.

Application of force feedback control schemes from studies on robotic systems to analyze a teleoperation system involving humans. Repperger DW, Phillips CA, Chelette TL. In: Proceedings of the Second IEEE International Conference on Control Applications, 1993, Vancouver, BC.

Application of fuzzy logic for the neuromotor disabled. Chelette TL, Repperger DW, Phillips CA. Engineering in Medicine and Biology Society, Vol 2. IEEE 93CH3339-9:1993:469-70.

Robotic force feedback control and teleoperation. Repperger DW, Phillips CA, Chelette TL. In: Proceedings of the IEEE Annual Northeast Bioengineering Conference, IEEE 0-7803-0925-1:1993:113-5.

[218] IMPROVEMENTS TO THE TECHNIQUE OF SYNCHRONIZATION EVALUATION

Hans P. Batra, BS; Carlo J. DeLuca, PhD; Zeynep Erim, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B594-RA); Liberty Mutual Insurance Company*

PURPOSE—Synchronization of motor units is the tendency of the firings of two motor units to occur at a fixed latency from each other. In order to quantify this tendency reliably and accurately, sophisticated statistical methods are needed. This year we have embarked on a project to systematically examine and improve our existing techniques for evaluating the amount of synchronization between the firings of a pair of motor units.

METHODOLOGY—We investigated several specific points. The first was the determination of the existence of synchronization. Since motor units fire somewhat randomly, it is possible that firings of two motor units appear synchronous simply due to chance. We established empirical criteria for reliably detecting the existence of synchronization beyond the level caused by randomness. This was accomplished by estimating a baseline level for the amount of synchronization arising from chance. Once synchronization is determined to exist between the firings of two motor units, its level must be quantified. This is achieved thorough the calculation of a Synchronization Ratio which represents the percentage of synchronous firings with respect to the total number of firings.

PROGRESS—This year we fine tuned several technical parameters to improve the accuracy of this index.

FUTURE PLANS—Our next steps will be to investigate the effects on synchronization of the variation among the firing intervals and the similarity of the firing rates of the motor units under study, and to establish the minimum length of EMG record that can provide reliable estimations of synchronization.

[219] EFFECTS OF HAND DOMINANCE ON MOTOR UNIT FIRING BEHAVIOR

Alexander Adam, BS; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B594-RA); Liberty Mutual Insurance Company*

PURPOSE—Daily preferential use of a muscle has been shown to alter the tissue's physiological and mechanical properties. Previous studies at the NMRC, as well as the work of other researchers, showed differences in the EMG signals recorded from the dominant and nondominant hand of a subject. There exist data suggesting a higher fatigue resistance and possibly a higher percentage of slow-twitch Type I fibers in the dominant hand. The present study is aimed at revealing any differences in the physiology and control properties of contralateral muscle pairs in individuals who show a clear use preference for one hand.

METHODOLOGY—The first dorsal interosseous muscle in the dominant and non-dominant hand of three right-handed male subjects were tested at force levels of 10, 30, and 50 percent of maximal voluntary contraction.

PROGRESS—Preliminary results suggest that the average firing rate of motor units in the dominant hand differs from that of motor units of similar recruitment thresholds in the contralateral hand. No lateral difference was seen in the initial firing rate behavior of motor units, nor were maximal voluntary contraction values significantly different between the dominant and non-dominant sides.

The observation of lower average firing rates in the dominant hand is consistent with the notion of an increased percentage of slow twitch fibers, which allows for twitch fusion to occur at lower firing rates.

[220] NEUROSIM: INVESTIGATIONS IN COMPUTATIONAL NEUROSCIENCE

David Albert, MS; James J. Collins, PhD; Carlo J. DeLuca, PhD; Zeynep Erim, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B594-RA)*

PURPOSE—The drive to motor units is completely inaccessible to the researcher studying voluntary contractions. This makes it difficult to perform experiments where the input to the system is varied and the resulting output is studied in order to gain an understanding of the organization and operation of the system.

METHODOLOGY—A software package, called NEUROSIM, was developed at the NMRC that simulates a population of motoneurons which receive signals both from common drives and independent sources (i.e., excitatory and inhibitory sources). The package enables the user to interactively set each parameter affecting the modelled system. The

objective of this preliminary study was to conduct a series of computer experiments to explore the orderly recruitment of motor units and the phenomenon of common drive.

RESULTS—Through numerical experimentation, we found that there may be a definitive relationship between a motor unit's firing threshold, initial firing rate, and relative refractory period. These factors also appear to influence the rate at which a motor unit's firing rate changes during a ramp contraction. With regard to the phenomenon of common drive, we found that a small amount of uncorrelated noise superimposed on the network's common driving signal could significantly affect the firing rates of active motor units. We are currently testing a number of null hypotheses concerning the possible form of the common drive (e.g., whether it is a noisy periodic signal, a noisy quasiperiodic signal, etc.). These hypotheses will be tested by comparing the output of the computer model with experimental motor-unit firing data.

[221] MOTOR UNIT FIRING RATES DURING SUSTAINED ISOMETRIC CONTRACTIONS

Patrick J. Foley, MS; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B594-RA); Liberty Mutual Insurance Company*

PURPOSE—There are contradictory reports in the literature regarding the firing behavior of motor units during sustained constant-force contractions. Decreasing, constant and increasing firing rates have all been reported. Furthermore, some researchers have observed that all motor units in a muscle modify their firing rates in a similar fashion while others have reported that motor units change their firing rates independently. This study was undertaken to investigate and clarify the behavior of motor unit firing rates in contractions where different force levels were sustained for 15 to 25 seconds.

METHODOLOGY—A total of 122 contractions at 30 percent, 50 percent and 80 percent of maximal voluntary contraction (MVC) level were analyzed in the tibialis anterior and first dorsal interosseus muscles.

RESULTS—In the region where the force output was maintained constant, mean firing rates of motor units showed a continual decrease. Various aspects of motor unit activity were observed to be influenced by the recruitment threshold of the motor unit. For instance, motor units with higher recruitment thresholds decreased their firing rates faster than motor units with lower thresholds. Also, motor units with greater average firing rates had lower rates of decrease than units with lower firing rates. These two observations were indicative of the negative correlation between the average firing rate and recruitment threshold of a motor unit. The rate of decrease in firing rates was also found to be proportional to the force level of the contraction; the rate of decrease became more accentuated at greater force levels. Contractions at 80 percent MVC of the first dorsal interosseus presented an exception to this rule, possibly due to fatigue being more predominant in this case.

Partial results of this work were presented at the 23rd Annual Meeting of the Society for Neuroscience in 1993.

[222] RANK-ORDERED REGULATION OF MOTOR UNITS

Zeynep Erim, PhD; Carlo J. DeLuca, PhD; Kiyoshi Mineo, MD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Keio Medical School, Tokyo, Japan

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B594-RA); Liberty Mutual Insurance Company*

PURPOSE—The behavior of motor units in the complete range of muscle force outputs has not been investigated before due to technical difficulties. Current literature contains information regarding activities confined to the lower portion of a voluntary force output.

METHODOLOGY—Data were recorded from the tibialis anterior muscle in experiments where muscle force was linearly increased up to 100 percent of the subject maximal voluntary contraction. The firing behavior of motor units was investigated as a function of force output and time, in order to reach a better understanding of the control strategies that the central nervous system employs in producing muscle force.

RESULTS—Our investigations revealed a highly systematic behavior among motor units, based on how early in the contraction they became recruited, or equivalently, their recruitment threshold. Various aspects of the firing behavior of motor units were found to be governed by their recruitment rank. Most striking was the orderly behavior of motor unit firing rates. At any given instant in a contraction, motor units that had lower recruitment thresholds had higher firing rates than units with higher thresholds. The initial firing rates were directly proportional to the recruitment thresholds: motor units that had higher recruitment thresholds started firing at higher rates. The investigation of firing rates as a function of force revealed three distinct linear regions in the activation of motor units. The firing rate versus force slopes in two of these regions also exhibited a dependence on recruitment threshold, higher threshold units having higher slopes. The slope in the main operation region was found to be the same for all motor units.

These findings supported our conviction in the concept of common drive and provided invaluable insight which was incorporated into the previously established mathematical model of motor unit control. A simple analog of the model, employing height, pressure and distance as parameters was advanced for visualization of concepts.

[223] COMMON DRIVE OF MOTOR UNITS: A MODEL FOR MOTOR UNIT CONTROL

Carlo J. DeLuca, PhD; Zeynep Erim, PhD; Patrick J. Foley, MS; Takafumi Aoki, MD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Nippon Medical School, Tokyo, Japan

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B594-RA); Liberty Mutual Insurance Company*

PURPOSE—We have been reporting on a concept termed common drive for several years. This concept is based on the observation that motor units active in a contraction modulate their firing rates in a highly interdependent manner, whereby an increase or decrease in the firing rate of one motor unit is accompanied by similar changes in the firing rates of other units. The implication that this observation has for motor control is that in effecting a desired muscle force, the central nervous system regulates the activities of motor units belonging to the same motoneuron pool collectively, as opposed to controlling the firing behavior of individual motoneurons. A change in the force output of the muscle is achieved by the nervous system through the regulation of the net sum of excitation and

inhibition to the motoneuron pool. This net excitation is received by all the motor units belonging to the pool, thereby affecting the firing patterns of all the motor units.

METHODOLOGY—Recruitment thresholds and mean firing rates were calculated from data collected in various experiments. Behavior of single motor units as well as motor unit groups active in the same contractions were studied.

RESULTS—Our ongoing research has continued to provide support and further understanding into the phenomenon of common drive. We have recently developed a simple model, based on the common drive concept and our recent findings, that explains mechanisms governing the firing behavior of motor units. This model encompasses widely accepted tenets of motor control such as the *size principle*, as well as the recent findings in our current research on the firing rates of motor units during voluntary contractions.

This work was presented at the 23rd Annual Meeting of the Society for Neuroscience in 1993.

[224] EXERCISE TESTING AND TRAINING OF MULTIPLE SCLEROSIS PATIENTS

Janet A. Ponichtera-Mulcare, PhD; Thomas Mathews, MD; Kathleen O. Glaus, PhD, PsyD; Mary M. Rodgers, PhD, PT; Satyendra C. Gupta, MD; Roger M. Glaser, PhD
VA Medical Center, Dayton, OH 45428; Wright State University School of Medicine, Dayton, OH 45435.

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B747-RA)*

PURPOSE—The purpose of this project was to provide a basis for objective exercise testing and training, as well as to provide a better understanding regarding expected rehabilitation outcomes in persons with MS. Specific objectives were to develop stress testing techniques to accurately document arm/leg exercise muscle performance and cardiopulmonary fitness in MS patients, and to evaluate the efficacy of an aerobic exercise training program in improving exercise performance and other functional and psychological parameters.

METHODOLOGY—All subjects performed a multistage leg-cycling test on a recumbent ergometer designed and developed by these investigators in order to evaluate pre-, mid-, and posttraining aerobic power. Upper and lower extremity muscle performance was also evaluated using a KinCom isokinetic dynamometer. Gait characteristics were studied using both kinematics and force plate measurements. Psychological status (i.e., affect, mood, and cognition) was measured pre- and posttraining using appropriate, validated tests for each (e.g., SCL-90-R, 16 PF, CES-D, SADS, Q-LES-Q, Wechsler Memory Scale: Revised, Aphasia Screening Test, Shipley Institute for Living Scale).

PROGRESS—Upon completion of 1.5 years of this 2-year project, 12 ambulatory (MS1) patients, 8 semi-/nonambulatory (MS2), 6 non-exercising MS patients (MS3) and 11 non-MS, healthy controls (non-MS) have completed all pretraining testing. Of the MS1, MS2 and non-MS subjects, all have completed at least 3 months of aerobic exercise training and have been retested at the midpoint. Of the entire sample, 25 subjects have completed 6 months of aerobic exercise training and have completed all posttraining testing. Seven patients who were enrolled at the beginning of the project have since terminated participation at various stages of the protocol.

Preliminary Testing. All subjects were able to successfully perform the exercise stress testing protocol without any adverse reaction. This test was also successfully repeated at the 3- and 6-month training points. Acute physiologic responses from baseline, pretraining measurements indicated that the MS1 and MS2 group had a significantly lower maximal aerobic power (VO2max) than non-MS controls. These data were accompanied by a significantly lower minute ventilation, respiratory exchange ratio, blood lactate, heart rate, and systolic blood pressure during maximal effort aerobic leg cycling. Evalua-

tion of gait showed that individuals with MS had a significantly slower stride velocity, stride length, and stride rate. Preliminary analysis of mood state revealed that both groups of MS patients were significantly more depressed. Baseline levels of fatigue were significantly higher for the two MS groups than the non-MS group. Perceived quality of life was significantly lower for the MS2 group, but not for the less-impaired MS1 group.

Mid-Training (3 Months). Most individuals in all groups showed some improvement in VO2max. Maximal power output improved by 10 percent and 23 percent for the MS1 and MS2 group, respectively. Three-month gait analysis for a small sample revealed an increased range of motion for the left ankle. Psychological testing showed that depressive symptoms were significantly reduced for the MS1 group, but not in the more severely impaired MS2 group. Indicators of cognitive ability also improved for the MS1 group following 3 months of aerobic exercise. Six-month posttraining testing is not complete at this writing.

FUTURE PLANS—Further research is needed to evaluate other modes of exercise for testing and training, more aggressive protocols, and the efficacy of body cooling upon acute and chronic physiological, psychological, and functional outcomes following aerobic exercise training.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Evaluation of muscle performance and cardiopulmonary fitness in patients with multiple sclerosis: implications for rehabilitation. Ponichtera-Mulcare JA, Glaser RM. NeuroRehabil 1993:3(4):17-29.

Maximal aerobic exercise in ambultory and semi-ambulatory patients with multiple sclerosis. Ponichtera-Mulcare JA, Mathews T, Glaser RM, Gupta SC. Med Sci Sports Exerc 1993:26(5):S29.

Multiple sclerosis. Ponichtera-Mulcare JA. In: Durstine DL, Figoni SF, et al. eds. Exercise management in chronic disease and disability. Indianapolis, IN: American College of Sports Medicine. In press.

[225] REGROWTH OF CORTICOSPINAL AXONS FOLLOWING CO-IMPLANTATION OF CARBON FILAMENTS AND FETAL CNS TISSUE.

Michael F. Dauzvardis, PhD; Talat Khan, PhD; Scott Sayers, PhD; T. Trausch, BS
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—The presence of a suitable substrate and neurotrophic influences play an important role in axonal elongation during development and regeneration. Carbon filament implants have been shown to provide a good substrate for the growth of neural and other tissue both *in vitro* and *in vivo*. In our laboratory, carbon filament implants have been shown to promote limited axonal regrowth following partial and total transection of the rat spinal cord. In an attempt to augment the axonal growth supporting properties of carbon filaments, they were cultured with fetal spinal cord tissue and co-implanted into a mid-thoracic spinal cord corticospinal tract lesion.

METHODOLOGY—Fetal spinal cord harvested from day E-16 rat embryos was cultured on bundles of approximately 10,000 (5 μm diameter) carbon filaments affixed to the bottom of petri dishes.

Adult rats weighing between 150 to 250 grams were anesthetized with an intramuscular injection of Xylazine (0.055 mg/100 g body wt) and Ketamine (0.087 mg/100 g body wt). Using a posterior approach, the T7 to T8 vertebrae were dissected from the surrounding tissue. A two level laminectomy was performed at T7 and T8. The dura mater was incised, and using a #11 scalpel blade and microdissecting forceps, the dorsal funiculi were transected at the T7 level.

Three or four sections of carbon filaments approximately 0.5 cm long containing one spinal cord tissue explant which had been cultured for 2-3 days, were implanted into the dorsal funucular lesion site. In an attempt to prevent the infiltration

of connective tissue from surrounding injured bone and muscles, a piece of dura film sheeting was placed extradurally over the spinal cord covering the transection site and its edges were tucked under the bone. All animals received daily post-operative care in accordance with AAALAC guidelines.

The other control groups were either implanted with carbon filaments or fetal tissue. One group of animals did not receive any implants and served as a control for the lesion.

After a 6-week survival period, all animals received bilateral intracortical injections of WGA-HRP. After 48 hours, the animals were perfused and the spinal cord lesion sites were sectioned and reacted with TMB to visualize WGA-HRP labeled axons.

PROGRESS—Preliminary histological data, using the axonal tracer WGA-HRP, has been performed on animals in which the corticospinal tract was cut at the mid-thoracic level and which either received carbon filament implants with fetal spinal cord tissue, carbon filament implants alone, fetal spinal cord tissue alone, or no implant.

RESULTS—Histological evaluation after cortical injection of WGA-HRP revealed labeled axons as far as four millimeters below the implantation site in the animals which received fetal tissue/carbon filament implants. This finding was not observed in surgical control animals. These results indicate that by combining the neurotrophic and neurogenic properties of fetal spinal cord tissue, with the tissue polarizing and scaffolding effects of small diameter carbon filaments, the repair of descending motor pathways may be accomplished.

FUTURE PLANS—Future studies are planned to determine whether the histological findings correlate with behavioral and electrophysiological recovery after injury and implantation.

[226] REGROWTH OF INJURED AXONS ON NON-BIOLOGICAL SUBSTRATES

Talat Khan, PhD; Michael Dauzvardis, PhD; Scott Sayers, PhD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—The main objective of this study was to evaluate the neurogenic properties of non-biological substrates for promoting regrowth of injured spinal cord fibers. Enhanced axonal regrowth across the site of a spinal cord lesion may lead to improved motor and sensory recovery after spinal cord injury. Positive results in the laboratory with implanted substrates, in combination with other proven agents, could readily translate to clinical applications in the treatment of spinal cord injury.

METHODOLOGY—Adult rats weighing between 150 to 250 g were anesthetized with an intramuscular injection of Xylazine (0.055 mg/100 g body wt) and Ketamine (0.087 mg/100 g body wt). Using a posterior approach a two level laminectomy was performed at T7 and T8. The dura mater was incised and a fine wire with a blunt end was inserted subdurally so that it lay ventral to the spinal cord. Using a #11 scalpel blade, the spinal cord was completely transected at the level of T8 and the wire was drawn up through the lesion site to ensure complete transection. In an attempt to prevent the infiltration of connective tissue from surrounding injured bone and muscles, a piece of dura film sheeting was placed extradurally over the spinal cord covering the transection site and its edges were tucked under the bone. All animals received daily post-operative care in accordance with American Association for Accreditation of Laboratory Animal Care guidelines.

The study was divided into five groups; group 1 served as a surgical control with transection only, group 2 received carbon filament implants in the transection gap, group 3 received ceramic filament implants, group 4 received cotton implants, and

group 5 received carbon filaments implanted in a transverse orientation.

After a 6-8 week survival period, 5 animals from each group received injections of WGA-HRP in the motor cortex for anterograde tracing. For retrograde tracing, 5 animals from each group received lumbar cord injections of WGA-HRP and 5 animals received lumbar cord injections of Fast Blue. Electrophysiological evaluations were performed on all animals.

PROGRESS—Our anatomical and electrophysiological results suggest that carbon filament implants are a superior substrate for the regrowth of injured spinal cord axons.

RESULTS—Somatosensory evoked potentials (SSEPs) were elicited by applying a constant current stimuli to the distal tail. SSEP responses were present in all animals below the lesion. No SSEPs were recorded at any time across the transection site in any group except group 2 which received carbon filament implants. Within 1-2 weeks after injury, 19 percent of the animals with carbon filament implants showed the presence of responses at the thoracic level across the lesion site. These responses were present in 36 percent and 50 percent of the animals after 2-4 and 4-6 weeks post trauma, respectively. Eight weeks after injury and carbon filament implantation, thoracic responses were recorded from 80 percent of these animals. The presence of cervical responses across the injury site were present in 20 percent of the animals after eight weeks. Motor evoked potentials (MEPs) were recorded across the transection site after an eight week survival period in animals which received carbon filament implants, while the animals implanted with ceramic fibers and carbon filaments in transverse orientation did not exhibit any MEP responses.

No labeled fibers were observed across the lesion area in groups 1,3,4 and 5 when HRP tracer was injected either above (anterograde) or below (retrograde) the lesion. The spinal cords from 68 percent of the animals with carbon filament implants were found to contain labeled axons as far as two spinal segments below the transection site.

FUTURE PLANS—Experiments are underway to determine whether the composition or the morphology of the filaments play a role in promoting axonal regrowth.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Carbon filament implants used as substrate for regenerating spinal cord axons. Khan T, Dauzvardis M, Sayers S. In: Proceedings of the 14th International Conference of the IEEE Engineering in Medicine and Biology Society 1992:2802-3.

[227] MOTOR UNIT CONTROL STRATEGIES DURING SUSTAINED ISOMETRIC CONTRACTIONS

Patrick J. Foley, MS; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

PURPOSE—Our previously discussed project, *Motor Unit Firing Rates During Sustained Isometric Contractions*, established that all active motor units continually decrease their firing rates. The question arises as to how the force output of the muscle can be maintained constant when the firing rates are shown to decrease. In this project we aimed to answer this question and gain a better understanding ofthe control strategies used by the central nervous system in sustaining a constant force output.

METHODOLOGY—Three mechanisms could possibly result in the sustaining of muscle force in the presence of decreasing firing rates: recruitment of motor units to compensate for a decrease in the force contributions of motor units decreasing their firing rates, compensatory activity in the agonist or antagonist muscle groups, and twitch potentiation which would increase the force contribution of a motor unit per firing and hence result in forces comparable to initial values even

when the firing rates decreased. In order to investigate which of these mechanisms prevailed, EMG data recorded in 122 contractions of the Tibialis Anterior and First Dorsal Interosseous muscles were scrutinized for recruitment of motor units. Wrist extensor and flexor muscles were employed to investigate if compensatory action, such as a decrease in antagonist activity or an increase in agonist activity, could explain the sustained force output.

RESULTS—No recruitment was observed after the aimed force level was initially reached, ruling out the possibility that recruitment was responsible for maintaining of a constant force level. No compensatory activity in the agonist or antagonist muscles was observed. In the absence of recruitment and complementing agonist/antagonist activity, twitch potentiation was accepted as the only plausible mechanism that could cause the firing rates to decrease during sustained contractions.

[228] SYNCHRONOUS BEHAVIOR OF MOTOR UNIT FIRINGS

Hans P. Batra, BS; Carlo J. DeLuca, PhD; Zeynep Erim, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

PURPOSE—Albeit in low levels, synchronization has been shown to exist among firings of concurrently active motor units. However, it is yet unclear what mechanisms cause this phenomenon or whether it has any physiological purpose. In this project, we are investigating the factors that influence the level of synchronization as a means to better understand if synchronization has a purpose, and in a broader sense, to gain insight into the organization and operation of the central nervous system. Specifically we are studying the effects on synchronization of force level of the contraction, recruitment thresholds of the motor units, the difference in the recruitment thresholds of the two units of the pair under investigation, and the changes in synchronization throughout the course of the contraction.

METHODOLOGY—A total of 839 motor unit pairs identified in contractions of the first dorsal interosseus and tibialis anterior muscles at various force levels were analyzed. The Synchronization Ratio, described previously, was used to quantify and compare the amount of synchronization at different force levels. Procedures were also established to study the changes in the level of synchronization through the time course of a contraction. These will be used to investigate any correlation between changes in synchronization level and changes in other physiological parameters, such as temporary increases in force.

RESULTS—Preliminary findings indicate that synchronization does in fact increase with increasing force level of contraction.

[229] SYNCHRONIZATION ACROSS MUSCLES

Takafumi Aoki, MD; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; Nippon Medical School, Tokyo, Japan

Sponsor: *Liberty Mutual Insurance Company*

PURPOSE—Even though synchronization has been shown to exist among the firings of motor units, the mechanisms that may be responsible for it are not clearly understood. In our efforts to gain a better understanding of the synchronization phenomenon and the mechanisms it arises from, we considered the case of synchronization across motor units belonging to different muscles. It was hypothesized that one of the possible physiological purposes for the existence synchronization could lie in the coordi-

nation of the activities of different motor units. If this were the case, synchronization might exist among motor units of different muscles when they were activated simultaneously.

METHODOLOGY—The first dorsal interosseous, the abductor digiti minimi, the extensor carpi radialis longus, the extensor carpi ulnaris and the tibialis anterior muscles, among others, were studied. Subjects were asked to contract different pairs of these muscles simultaneously. Synchronization among motor units belonging to different muscles were evaluated with our synchronization software.

RESULTS—The level of synchronization, although non-zero, was much lower than the level observed for motor units belonging to the same muscle. This observation supported our earlier conviction that synchronization may not have a physiological purpose. We are still collecting data and analyzing previously collected data in order to reach our final conclusion on the issue of synchronization across simultaneously contracting muscles.

[230] NEUROMUSCULAR FUNCTION IN POSTPOLIO SUBJECTS: A THREE-YEAR FOLLOW-UP STUDY

James C. Agre, MD, PhD; Arthur A. Rodriquez, MD
Department of Rehabilitation Medicine, University of Wisconsin, Madison, WI 53792

Sponsor: *United States Department of Education, Office of Special Education and Rehabilitative Services, National Institute of Disability and Rehabilitation Research, Washington, DC 20202*

PURPOSE—The purpose of this research is to determine whether unstable postpolio (those acknowledging progressive loss in muscle strength and/or endurance) lose strength, endurance, work capacity, or ability to recover strength after activity at a greater rate than stable postpolio (those not acknowledging progressive loss in muscle strength and/or endurance) or control (non-postpolio) subjects over a three year period of time.

METHODOLOGY—We studied 26 unstable postpolio as compared to 15 stable postpolio and 26 control subjects. Subjects were evaluated initially and at yearly intervals for 3 years. Isokinetic peak torque was determined in the quadriceps femoris, hamstring, and biceps humerus muscles. Isometric peak torque of the quadriceps and biceps were determined. An isometric endurance test was performed at 40 percent of maximal isometric strength of the quadriceps until the subject could no longer maintain torque at the assigned level. Isometric work capacity was defined as the product of torque and time during the endurance test. Recovery of isometric strength was determined 30 sec after the endurance test. Analyses were by ANOVA and repeated measures ANOVA.

RESULTS—Initial measures showed significant ($p<0.05$) deficits in all variables in the unstable postpolio group as compared to the stable postpolio and control groups except for endurance time, in which no significant difference ($p>0.05$) was found. The mean strength of quadriceps and hamstrings in the unstable postpolio group were only 50-60 percent of the control value, while biceps strength was 70 percent of the control value. The mean work capacity in the unstable postpolio group was only 46 percent of the control value and recovery of strength was 10 percent less in the unstable postpolio group than the control group. All variables in the stable postpolio group were similar ($p>0.05$) to the control values.

Over time, all three groups significantly ($p<0.05$) lost strength in the quadriceps and hamstrings, but no significant ($p>0.05$) difference was found among groups in rate of change. The biceps strength, endurance, work capacity, and recovery did not significantly ($p>0.05$) change over the three year time interval in any group. We conclude that the unstable postpolio group does lose strength in leg musculature but not the arm musculature over a 3-year period of time. The loss of strength, however, appears to be gradual rather than rapid and may be

related to aging as no difference was found in rate of change comparing the unstable postpolio group to that of the stable postpolio and control groups.

IMPLICATIONS—Obviously, further research is required. We have recently completed the fourth year of follow-up in this group and data will soon be analyzed. We are presently in the process of assessing our subjects for the fifth year of follow-up. We plan to continue this for several more years to better delineate decline in function in our postpolio groups as well as for our control group.

[231] EFFECT OF A 12-WEEK NON-FATIGUING MUSCLE STRENGTHENING EXERCISE PROGRAM IN POSTPOLIO PATIENTS

James C. Agre, MD, PhD; Arthur A. Rodriquez, MD; Robert L. Harmon, MD
Department of Rehabilitation Medicine, University of Wisconsin, Madison, WI 53792

Sponsor: *United States Department of Education, Office of Special Education and Rehabilitative Services, National Institute of Disability and Rehabilitation Research, Washington, D.C. 20202*

PURPOSE—The purpose of this research study was to examine the effect of a 12-week non-fatiguing quadriceps strengthening exercise program on muscle strength as well as on motor unit organization and muscle viability in postpolio subjects.

METHODOLOGY—We studied 12 postpolio subjects (mean age 49 ± 8.4 years) with grade 3+ or greater quadriceps strength on manual muscle testing. Isometric quadriceps strength, endurance time (the time the subject could isometrically contract the quadriceps muscles at 40 percent of maximum strength), work capacity, and initial and final ankle weights lifted were determined before and after the 12-week training program. Additionally, before and after the training program, fiber density, jitter, and blocking were determined by single fiber electromyography (EMG), and median macroEMG amplitude was determined and serum creatine kinase (CK) was determined. Exercise was performed at home every other day for the 12-week study period.

Exercise was performed by the subject seated in a chair. A sandbag ankle weight was attached to the subject's ankle. For each repetition, the subject started with his/her foot resting on the floor and the knee flexed to 90 degrees. Then the subject fully extended the knee and the weight was held in full extension for 5 seconds. The weight was then lowered and the subject rested for 25 seconds. The subject performed 6-10 repetitions of this exercise. After completing 6 repetitions, the subject rated the perceived exertion (RPE) within their quadriceps muscles from the activity. The subject continued with repetitions of the exercise until RPE was ≥ 17 (a rating of "very hard") or 10 repetitions were performed. The ankle weight lifted was increased on the following exercise day after the RPE was < 17 after 10 repetitions. Analysis was by matched-pair Student t-test.

RESULTS/IMPLICATIONS—Initial values for isometric strength, endurance, and work capacity were 106 ± 54 Nm, 143 ± 50 sec, and 6017 ± 2560 Nmsec, respectively. Initial EMG values for fiber density, jitter, blocking and macroEMG amplitude were: 2.0 ± 0.4; 82.8 ± 25.2 msec; 20.6 ± 14.4 percent; and 1.4 ± 0.7mV, respectively. After the exercise program, the dynametrically determined strength variables, the EMG variables, and the serum CK did not significantly ($p > 0.05$) change while the amount of weight lifted significantly ($p < 0.05$) increased from 7.1 ± 2.7 kg at the end of the second week of exercise to 11.2 ± 4.7 kg at the end of the training program.

Thus, this program significantly increased the amount of weight postpolio subjects could lift, did not adversely affect motor unit organization or muscle viability, but did not improve strength, as determined by the isometric variables measured. Thus, such a program appears to be safe, although the lack of improvement in the dynametrically measured strength variables is consistent with the specificity of training theory. Further study is needed on the safety and the efficacy of muscle strengthening exercise in the postpolio population.

[232] VESTIBULAR STIMULATION AND CEREBRAL PALSY

James W. Fee, Jr., MS; Kathy Samworth, MS
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The purpose of this work is to quantitatively analyze the effect of whole body vertical accelerations on muscle tone and limb function in individuals with cerebral palsy (CP).

METHODOLOGY—Active and passive leg motion was measured using three testing procedures. The two active tests evaluated functional abilities such as kicking and swinging the leg. The passive test was used to evaluate the degree of spasticity in the leg. Seventeen attributes, including velocity and position of leg motion as well as spectral information, were measured.

PROGRESS—Using a magnetic sensing device, leg position data for ten subjects with CP (age ranging from 5-18 years) was collected before and after vestibular stimulation. Stimulation consisted of fifteen minutes of vertical reciprocal motion at an amplitude of 3.5 inches, a frequency of 1.6 Hz and an acceleration of 0.7 g. Stimulation was performed with the subject seated in an upright position.

RESULTS—Results showed that 9 of the 10 subjects made a statistically significant change ($p < 0.05$) in 2 or more of the 17 attributes with the highest achiever showing change in 16 of the 17 attributes. Trends in the data show that the less severely involved clients showed the most change. The greatest amount of change was seen in the passive motion test which is designed to test spasticity whereas the least amount of change was seen in the active tests which measure functional capabilities.

[233] MODELLING OF FORCE PRODUCTION IN THE MUSCLE

Zeynep Erim, PhD; Ruth A. Santos, BS; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *The NeuroMuscular Research Center*

PURPOSE—Our previous research on the tibialis anterior muscle revealed three distinct linear rates against force. The slope, describing the rate of change of firing rate with respect to force, was moderate in the first region, low in the second and high in the last. Although very limited in size, preliminary data recorded from the first dorsal interosseous muscle suggests a different activation pattern for this muscle. Specifically, the last region appears to have almost zero slope, equivalent to a plateau of the firing rates; whereas in the TA, this region has the highest slope. In order to investigate whether the different activation strategies seemingly employed by the central nervous system for these two muscles could be due to a need to accommodate their different mechanical properties, we have taken a computer modelling approach.

METHODOLOGY—Building on the model we previously advanced to account for the generation of firing rates based on the concept of common drive, we have appended a mechanical component to complete the force production process. The implementation of this model on the computer will allow for the simulation of the behavior of different muscles by choosing appropriate twitch waveforms, recruitment thresholds and distribution of motor unit types. We will use this model to simulate the characteristics of the two muscles and determine if the different activation patterns can be a result of differing mechanical properties.

[234] EFFECT OF WAX THERAPY ON THE PLANTAR SKIN IN LEPROSY

V.N. Kulkarni, BSc (PT) PGDR; J.M. Mehta, MD
Dr. Bandorawalla Leprosy Hospital Kondhawa, Pune, 411048, India

Sponsor: *Poona District Leprosy Committee (PDLC)*

PURPOSE—Peripheral neuropathy due to leprosy, autonomic dysfunction on the plantar skin results is followed by involvement of the posterior tibial nerve. The resulting lack of sweat function renders the plantar skin dry and brittle. Cracks and fissures develop easily in the dry skin. If proper care is not taken, the initial minor cracks tend to deepen and become major, acting as portals of infection. Callosities also form (in the insensitive skin) and become sites of overloading leading to eventual plantar ulceration following repetitive stress of walking. The primary aim for preventing these complications is to make the plantar skin smooth and supple. Soaking feet in plain water has been a part of foot care treatment of insensitive feet in leprosy. It was decided to study how effective the wax therapy would be on the plantar skin to overcome these problems.

PROGRESS—Wax therapy treatment on the plantar skin was done at the Dr. Bandorawalla Leprosy Hospital, Kondhawa. The trial study was conducted on 20 patients. Wax therapy (paraffin wax, with a mixture of liquid paraffin and petroleum jelly, temperature below 120°F with a thermostatically controlled machine) was administered daily for a period of 20 minutes. The patient group was comprised of those having sensory loss, fissures, minor cracks, and callosities. Patients having infected cracks and plantar ulcers were not selected. The results were judged after 3 weeks. Petrolcum jelly application was advised after wax release to maintain skin suppleness. All the patients were using tailor-made micro-cellular rubber (MCR) footwear. Preventive measures for recurrence of fissures and cracks (which included oil or petroleum jelly application, MCR footwear, and avoidance of barefoot walking) were continued even after thc discontinuation of wax therapy.

RESULTS—Subjective findings included 1) increased range of motion, 2) reduction of tingling numbness, and 3) reduction in pain during walking. Objective findings showed 1) definite obliteration of fissures, 2) softening of scars, 3) reduction in minor cracks, 4) no change observed in skin around major cracks and thick callouses. The skin had to bc finally treated with soaking and scraping, and 5) callosities softcned temporarily.

IMPLICATIONS—Based on the above findings, use of wax therapy for feet as an institutional mcthod is recommended. However, we wish to includc a larger group of patients for the samc study.

B. Low Back Pain

[235] DATABASE DEVELOPMENT FOR A CLINICAL BACK ANALYSIS SYSTEM

Rudi Buijs, MSc; Serge H. Roy, ScD; L. Donald Gilmore, ABEE; Peter Maloof, ASCS; Carlo J. DeLuca, PhD
Delft University of Technology, Delft, The Netherlands; NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B593-RA); Liberty Mutual Insurance Company*

PURPOSE—During the past year, we have been working on developing a clinical version of the Back Analysis System (BAS). This surface EMG acquisition and analysis system is being developed to allow clinicians with minimal EMG proficiency to identify and monitor back muscle impairment in their patients.

METHODOLOGY—A key element of the clinical version under development is a new interactive software to be used in conjunction with a new digital signal processing hardware card. The entire implementation of the clinical BAS software was approached as a database management problem. The reason for this approach is the need for acquisition of different types of data that have to be manipulated in different ways to produce specific results. Data organization was achieved by systematically designing a logical database model and implementing the corresponding physical database model using a commercial database package.

RESULTS—Major improvements to the present BAS have been specified and implemented. The general approach of developing a database management system was followed. As a result, requirement specifications were developed and data and process modeling were integrated. For the requirements specification, two major objectives needed to be met: LBP Diagnosis and LBP Treatment Outcome. We are currently able to systematically evaluate EMG data for the purpose of defining statistical modules that can be implemented to generate clinical reports pertaining to diagnosis and outcome. Model and Process Integration are under continuing development.

[236] MUSCLE PERFORMANCE IN THE BACK ANALYSIS SYSTEM COMPARED TO LIFTING TASKS

Serge H. Roy, ScD; L. Donald Gilmore, ABEE; Lars Oddsson, Dr Med Sci; Mark Emley, MS; Sean McNelis, BS; Brett Bu Sha, BS
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B593-RA); Liberty Mutual Insurance Company; NeuroMuscular Research Center*

PURPOSE—The potential application of the Back Analysis System (BAS) to predicting functional ability has not been fully explored. Although the presence of back muscle impairment is likely to limit one's ability to function during tasks requiring forceful or repetitive trunk extension, it is not known how muscle performance during a constrained task such as the BAS is related to muscle performance during a functional activity such as lifting. If a relationship between these tasks can be established, then the BAS may provide a useful adjunct to ergonomic assessment procedures that are currently in use to evaluate work capacity.

METHODOLOGY—We have recently begun a study comparing EMG manifestations of fatigue

during the BAS test and a standardized dynamic lifting test. EMG signals from extensor muscles of the trunk and legs are monitored during the standard test protocol of the BAS. This protocol generates muscle fatigue by requiring the subject to maintain an isometric constant-force contraction for a fixed period of time. EMG signals from these same muscle groups are monitored during a second test session in which the same subjects perform repetitive lifting using a dynamometer specifically designed to standardize lifting and monitor its kinematics. Changes in the median frequency and amplitude of the EMG signals are analyzed to compare the characteristic patterns of fatigue and muscle activation for the two tasks.

PROGRESS—The preliminary aspects of the study have been completed and data collection has begun.

[237] DEVELOPMENT OF TEST PROTOCOLS RELATED TO THE BEHAVIOR OF BACK MUSCLES

Lars Oddsson, Dr Med Sci; Johan Erik Giphart, MSc; Serge H. Roy, ScD; Rudi Buijs, MSc; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Delft University of Technology, Delft, The Netherlands

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B593-RA); Liberty Mutual Insurance Company; NeuroMuscular Research Center*

PURPOSE—Test protocols developed at the NMRC to evaluate the function of back muscles in different populations of subjects have mainly been based on high level force contractions. Certain populations (e.g., subjects in pain at the time of testing) may have problems complying with such protocols. We are currently in the process of investigating other types of test protocols to assess the function of back muscles in normals and patients with low back pain.

METHODOLOGY—We are quantifying the behavior of EMG spectral and amplitude parameters during different types of low level force contractions and force varying contractions. Spectral parameters, including median frequency (MF) and amplitude (RMS) of EMG signals are monitored during isometric trunk extension using the Back Analysis System (BAS). Two kinds of tasks are performed by the subjects: one at a low level of constant isometric force for long durations, and the other at different isometric force levels for short durations.

PROGRESS—Preliminary results in normals indicate the presence of three distinct phases of EMG parameter behavior during long duration contractions. Initially, RMS increases slowly as MF decreases; then RMS reaches a plateau while MF continues to decrease; and towards the end of the contraction, RMS decreases while MF stabilizes at a low level. The decrease in RMS appears earlier and is most marked in the multifidus muscle. If the contraction is maintained beyond this point, the force drops to a lower level with concurrent reductions in RMS, especially in the longissimus muscle. The results indicate that metabolic fatigue processes during low level as well as force-varying contractions cause reproducible changes in MF and RMS of the EMG signal.

[238] EMG PARAMETERS OF LUMBAR BACK MUSCLES

Lars Oddsson, Dr Med Sci; Johan Erik Giphart, MSc; Serge H. Roy, ScD; Rudi Buijs, MSc; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Delft University of Technology, Delft, The Netherlands

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B593-RA); Liberty Mutual Insurance Company; NeuroMuscular Research Center*

PURPOSE—The dynamic interaction between muscles of the lower back during an isometric contraction can be partly monitored as concurrent changes in spectral properties of the surface EMG signals.

Previous analysis of surface EMG signals from lower back muscles assessed with the Back Analysis System (BAS) has mainly focuscd on the behavior of the initial median frequency (IMF) and the rate of decrease of the median frequency (MF slope) during fatiguing constant force contractions. Previous studies at the NMRC have suggested the presence of spectral imbalances between muscles of the lower back in patients with lower back pain (LBP) as compared to normal control subjects. In this project we plan to develop new parameters that further describe these imbalances even at low level force levels of contraction. Discrimination scores between different categories of patients with LBP and normals should improve as a result of this study.

METHODOLOGY—Two new sets of EMG parameters are being investigated. One is related to the behavior of the root mean square (RMS) of the surface EMG signal and the other to the behavior of ratios of spectral properties in contralateral as well as ipsilateral pairs of muscles of the lower back.

PROGRESS—The behavior of these parameters was monitored using the BAS during isometric contractions at 40 percent of MVC in a group of 96 LBP patients and 23 controls.

RESULTS—A discriminant analysis was performed which successfully classified 81 percent of the subjects in the study. The parameters selected by the discriminant analysis included several RMS as well as MF ratios. We are currently in the process of investigating the behavior of these parameters using test protocols which include several different levels of low force contractions.

[239] BACK ASSESSMENT OF ATHLETES FROM VARSITY AND FRESHMAN CREW TEAMS

Mark Emley, MS; Serge H. Roy, ScD; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B593-RA); Liberty Mutual Insurance Company*

PURPOSE—We have completed the fourth year of a prospective study to determine if EMG spectral parameters from lumbar muscles can correctly predict individuals who will develop low back pain (LBP). The study has focused on collegiate rowers because they share similar physical characteristics and are at high risk for developing LBP. A similar retrospective study had previously been successful in correctly identifying individuals with LBP within a group of varsity rowers.

METHODOLOGY—Tests using the Back Analysis System (BAS) are being conducted biannually on male Northeastern University crew teams. Results from this investigation will be helpful in identifying whether EMG measures of back muscle insufficiency can identify an individual's predisposition to LBP. To date, members of two men's freshman crew teams have participated in this study: 55 from Boston University and 15 from Northeastern University. Sixteen women from the Boston University freshman crew team and eight women from the Northeastern University freshman crew team have also participated in the study.

RESULTS—The testing of novice crew members after a winter training period demonstrated an increase in static strength of back extensors and a resistance to fatigue as measured by the rate of spectral shift in the EMG signal. The experienced rowers did not show a significant gain in either of these measures, but instead maintained their high level of function. These findings indicate that extensive training and level of fitness have a measurable effect on the EMG signal. Because this is a prospective study requiring several more years of research, predictive results must await further data collection.

[240] NORMATIVE DATABASE STUDY OF BACK MUSCLE FUNCTION

Mark Emley, MS; Joanne Levins, MS; Serge H. Roy, ScD; Howard Taylor, MD; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B593-RA); Liberty Mutual Insurance Company*

PURPOSE—An important part of our efforts to study muscle insufficiency associated with lower back pain (LBP) is to characterize the normal, pain-free behavior of back musculature. Our interest in accumulating normative electromyographic (EMG) data from back muscles began several years ago when we first developed the Back Analysis System (BAS), a device that assesses back muscle function on the basis of EMG spectral measurements. These preliminary studies were usually limited to relatively small numbers of subjects from distinct populations. We have described normative data in young adult male subjects, collegiate rowers, and women. Our interest in developing the clinical applicability of the BAS technique to LBP populations necessitates that we establish normative data profiles that take these inter-individual differences into account.

METHODOLOGY—In addition to the testing conducted at the NMRC, we are acquiring normative EMG data from the orthopedic practice of Dr. Howard Taylor in Methuen, MA, and the Edith Nourse Rogers Memorial Veterans Hospital in Bedford, MA. We have recruited male and female collegiate athletes, manual laborers, and subjects over the age of 65. Data from these test sites have given us an opportunity to more closely match our patient data with normative data according to age, gender, height, weight, and job characteristics.

RESULTS—This study demonstrates that back muscles from healthy populations function according to a recognizable pattern of muscle activity and fatigue. Secondly, there appear to be recognizable differences in EMG spectral parameters according to age, gender, and athletic training.

This study has resulted in a database structure that will provide a useful framework for our lower back pain data. With the completion of these databases, comparisons between subjects with and without LBP disorders can be made more effectively.

[241] CLINICAL VALIDATION OF THE BACK ANALYSIS SYSTEM FOR TREATMENT OUTCOME FOLLOWING REHABILITATION

Serge H. Roy, ScD; Mark Emley, MS; Joanne Levins, MS; Ksenia Kozak, MS; Rudi Buijs, MSc; Johan Erik Giphart, MSc; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Delft University of Technology, Delft, The Netherlands

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B593-RA); Liberty Mutual Insurance Company*

PURPOSE—Our success in implementing the Back Analysis System (BAS) for laboratory use to characterize normal muscle functioning has led us to evaluate its efficacy as a clinical tool among patients with lower back pain (LBP).

METHODOLOGY—We are currently conducting clinical trials of the BAS by integrating its use into local rehabilitation programs for LBP. Over the past year, testing has taken place at the Liberty Mutual Medical Service Center (LIMBER program), Boston, MA, the Center for Occupational Rehabilitation at Braintree Hospital, Braintree, MA and the Department of Physical Therapy at the VA Medical Center Bedford, Bedford, MA. These different clinical facilities have offered us the diversity of

patients and rehabilitation programs needed to understand the present limitations of the technique among the population at large. We have recruited male and female LBP patients spanning a broad range of ages, clinical diagnoses and occupations. Our focus has been toward selecting rehabilitation programs that are based on physical performance criteria and functional outcomes.

PROGRESS—To date, our testing has been conducted in conjunction with work hardening, work conditioning, and a modified multi-disciplinary treatment approach for the geriatric patient with LBP. At each of these sites we have implemented a standardized BAS protocol developed from prior research. Tests are typically conducted at baseline and at fixed intervals during and following rehabilitation. Additional data from standard physical capacity assessments and disability scales are collected at the time of BAS testing for concurrent validation of the BAS technique.

RESULTS—Our results to date have demonstrated that significant changes occur in the EMG signal and force parameters following rehabilitation. These changes are indicative of significant gains in back muscle endurance and strength which have led to improvements in LBP diagnosis. The sensitivity and specificity of the baseline BAS test for LBP was close to 90 percent accurate and was not significantly influenced by differences in age, height, weight and strength among the patients tested.

[242] BACK ANALYSIS SYSTEM (BAS) UPDATE

Carlo J. DeLuca, PhD; Serge H. Roy, ScD; L. Donald Gilmore, ABEE; Mark Emley, MS; Lars Oddsson, Dr Med Sci; Rudi Buijs, MSc; Johan Erik Giphart, MSc; Joanne Levins, MS; Peter Maloof, ASCS
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114; Delft University of Technology, Delft, The Netherlands

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B593-RA); Liberty Mutual Insurance Company*

PURPOSE—We continue to refine methods for evaluating muscle performance in individuals with and without low back pain. The Back Analysis System (BAS) continues to be the key component in these investigations.

METHODOLOGY—The BAS is a computerized electromyographic (EMG) spectral analysis system coupled to a postural restraining device, designed to isolate and stabilize the musculature of the trunk as well as to analyze the patterns of muscle activity observed during isometric fatiguing contractions of the back. Our approach, unlike other techniques, measures and then compares individual fatigue patterns that are associated with each of the contributing muscle groups. These detailed observations of muscle performance are used as a basis for comparison between individuals with and without lower back pain.

RESULTS—This year, BAS development continued the process of producing a prototype for a clinical back assessment system that incorporates new technology and applications software. The latest BAS prototype specifically addresses the clinical issues of diagnosis and treatment outcome measurement of back muscle dysfunction. The key elements of the new clinical prototype are an improved digital signal processing hardware card, enhanced interactive software, and a new postural restraint apparatus. The card calculates the EMG spectral parameters in real time, and the new software guides the clinician and patient through the entire assessment procedure. The new system will have safeguards that insure proper operation and will provide the clinician with a detailed written report of the patient's performance and clinical progress.

In conjunction with the technological development, we are continuing our evaluation of the BAS protocols at selected clinical sites. Our results from these beta sites will further validate the use of this technique for objective clinical assessment of muscular performance and dysfunction in the lower back.

[243] SECONDARY PREVENTION OF BACK PAIN AND THE DEVELOPMENT OF CHRONICITY: THE OIOC-NIOSH MODEL CLINIC

M. Nordin; M.L. Skovron; P.B. Brisson; J. Kula; E. Devaney; M. Campello; S. Weiser; K. Harwood; R. Hiebert; M. Crane; S. Lewis

Occupational & Industrial Orthopaedic Center, Hospital for Joint Diseases, New York University, New York, NY 10014; Consolidated Edison Co., of New York, Inc., Brooklyn, NY 11217; New York City Transit Authority, Brooklyn, NY 11201

Sponsor: *Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, Atlanta, GA 30305*

PURPOSE—The factors contributing to the development of chronic non-specific low back pain (NSLBP) are poorly understood. The Biopsychosocial Model (Fordyce 1976, Loeser 1982, Wadell 1992) emphasizes the benefits of a multifactorial approach including individual, occupational and psychosocial factors. In addition, two studies have successfully demonstrated that early goal-oriented care delivered within 4-12 weeks after first occurrence of NSLBP can substantially reduce work loss days, and reduce chronicity by returning employees to gainful employment (Choler et al. 1985, Lindstrom et al 1992).

The purpose of this project was to develop and implement a Model Clinic utilizing a multidisciplinary, goal-oriented approach. The clinic was to address the prevention of chronicity in individuals with NSLBP in industrial settings. A concurrent goal was to undertake research in the factors associated with treatment outcome.

METHODOLOGY—The Model Clinic is based on a coordinated system of primary and secondary care. Patients presenting with acute low back pain or injury are seen by primary health care practitioners at their workplace (e.g. company physician or nurse) who have been instructed in proper management of acute low back pain. Workers who are still unable to return to work after 4 weeks are invited to enroll in a program at the secondary health care facility (an independent university-based clinic).

Treatment involves 4 weeks of half-day multidisciplinary outpatient programs. The patient receives daily aggressive physical therapy, stress management, instruction in biomechanical and ergonomic principles and additional lifestyle classes. The goal of the program is to return the patient to gainful employment.

PROGRESS—An educational program for the clinical staff at two primary facilities (workplaces) has been developed and implemented by the multidisciplinary treatment group. A referral network of physicians has been established for patients requiring specialized evaluations. A multidisciplinary treatment team at the secondary health care facility has been established. Protocols for evaluation and treatment have been developed and implemented. Twenty-five patients have completed the program to date. A database has been established to collect patient information on medical, psychosocial, and workplace factors. This data will be used to establish bascline information and to determine factors associated with outcome at 3, 6 and 12 months after treatment.

FUTURE PLANS—The overall effectiveness of the Model Clinic will be evaluated by comparing back pain incidence, duration, and recurrence rates before and after implementation at each participating occupational setting. In addition to duration and frequency of work loss, which is examined by analyzing workplace clinic visit and absence data, the evaluation of the Model Clinic includes assessment of pain, functional limitation, and quality of life 3, 6, and 12 months after episode onset for all individuals reporting back pain.

The effectiveness of the educational program for the primary care facility providers will bc measured by standardized implementation of patient management and interphysician agreement regarding patient evaluation. The effectiveness of the intensive multidisciplinary treatment program for workers absent for four weeks due to back pain, the Return to Work Program (RTW) will be evaluated by a means of a randomized controlled clinical trial.

Treatment success in the randomized trial is primarily measured by return to original full-time work, and by recovery of functional capacity at the end of the treatment period. In additional, frequency of recurrence and new episodes during the follow-up are compared in the RTW and standard treatment groups as secondary outcomes.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Common low back pain: prevention of chronicity. Nordin M, Vischer T, eds. Bailliere's clinical rheumatology. Vol. 6. London: Harcourt Brace Jovanovich Limited, 1992:3.

[244] VERMONT REHABILITATION ENGINEERING RESEARCH CENTER FOR LOW BACK PAIN

Martin H. Krag, MD
Vermont Rehabilitation Engineering Research Center for Low Back Pain, Burlington, VT 05401

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Washington, DC 20202-2305*

PURPOSE—The Vermont RERC, now in its twelfth year, is committed to improving the employability of people with back disorders through an integrated program of basic and applied research and information services. At the Center, rehabilitation engineering is directed toward the prevention of low back pain and disability, and the accommodation of those with back disorders, through device design and development and through both clinical and workplace intervention research. Specific objectives of this multidisciplinary center include the following: developing and testing assistive devices to improve functioning and employability; developing and testing workplace adaptations and modifications; identifying and minimizing workplace risks for back pain and injury; developing and testing models to help improve return to work of back-injured workers; and disseminating research findings, facts and figures, and information about goods and services to people with back disorders, their families and employers, as well as state and government agencies, centers, and services.

Affiliates of the Vermont RERC include the Spine Institute of New England, which operates a comprehensive rehabilitation program for chronic low back patients, Rehabilitation Technology Services, which provides service delivery to people with low back and other disabilities, and the McClure Musculoskeletal Research Center at the University of Vermont.

PROGRESS—The RERC is engaged in ongoing engineering design and development projects in several areas:

Posture. This project addresses the relationships among postures, discomfort, fatigue, and work performance.

Seating. A research team is studying seated posture and comfort, and developing accommodations for people with back disorders who must sit on the job.

Vibration. The Vermont RERC is developing a simple, low-cost vibration assessment and feedback system to be used directly by both employers and employees.

Manual Material Handling. A research team is studying characteristics of safe lifting and developing accommodations for those whose jobs involve heavy lifting.

Worksite Assessment. Research engineers are developing a system to help employers, industrial health and safety officers, and others evaluate their own work environments for back injury risk factors.

Comparative Study of Exercise Programs. This project compares a program of exercises that address specific physical signs and symptoms with one that does not.

Evaluation of an Assistive Device for Drivers. Researchers are conducting a prospective study to see whether continuous passive motion of the lumbar spine reduces back pain, injury, and lost work time.

Statewide Program for Reducing Disability Among Back-Injured Workers. Three strategies for reducing chronic occupational back disability are being tested: a disability prediction questionnaire, a physician surveillance program, and a rehabilitation engineering intervention program.

Evaluation of the Smart Corset. The Smart Corset, a gravity-based inclinometer that emits a beep when the wearer bends too far, takes the place of a traditional cloth corset. Current research will determine its effectiveness in reducing back pain and in improving function, comfort, and satisfaction.

In addition to research and engineering, the Center provides information and referral services, publications, education and training activities, public education and consumer forums, and research evaluation. The Vermont RERC offers assistance in locating rehabilitation and research programs and searching for information.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Krag MH. Vermont spinal fixator. Spine 1992:6(1):121-45.

C. Swallowing Disorders

[245] BIOMECHANICAL MEASUREMENTS AND CLASSIFICATION OF DYSPHAGIA

Narender P. Reddy, PhD; Enrique P. Canilang, MD; Sujat Sukthankar, MS; Vineet Gupta, MS; Patricia Green, MA, CCSP; Srikanth Suryanarayanan, MS; Surekha Palreddy, MS
Biomedical Engineering Department, University of Akron, Akron, OH 44325;
Rehabilitation Engineering Research Lab, Edwin Shaw Hospital, Akron, OH 44312

Sponsor: *NIH(NIDCD 1R15- DC01564-01), National Institute for Deafness and other Communication Disorders, Bethesda, MD 20892*

PURPOSE—Current clinical practice of diagnosis of dysphagia involves qualitative assessment based on bedside clinical evaluation or videofluorography examination. Recently, we have developed techniques for noninvasive measurement of several biomechanical parameters that characterize the oral and pharyngeal phases of swallowing. The oral phase measurements included lateral and forward tongue thrust and lip pulling force. We have found significant differences in these parameters measured in normal and dysphagic patients. To quantify the pharyngeal phase, we have placed an ultraminiature accelerometer on the throat at the level of the thyroid cartilage and simultaneously measured the swallow suction pressure with a catheter placed in the oral cavity. The objectivc of this study was to find if dysphagic patients at risk of aspiration can be identified and classified using the biomechanical measurements, and to develop biofeedback devices.

METHODOLOGY—We have made clinical correlation of the biomechanical measurements with videofluorographic findings. Also, we have developed and clinically evaluated an expert system to classify the patient into four categories using the set of measurements obtained from each patient. We have developed and clinically evaluated a set of neural network models to classify the dysphagic patients using the biomechanical measurements. A fuzzy decision system was developed to classify the pharyngeal dysphagia into four categories using the set of biomechanical measurements.

Since the acceleration signal provides a measure of the mechanical events (rate of laryngeal elevation), we have correlated the acceleration signal with electrical events during the pharyngeal phase of swallowing by simultaneously measuring acceleration and EMG signals in normal individuals during dry and wet swallowing.

We have developed biofeedback devices which provide audiovisual feedback of tongue thrust and lip pulling force. The visual feedback is in terms of increasing number of LEDs lighted with increased amount of force exerted by the tongue or the lips. The system can be used for self training and therapy. In order to provide improved motivation, we have developed a computerized Tongue Music System in which the patient can play various keys on the computer with different levels of force exerted on the tongue or lip transducer, and thus can aid in the therapy.

RESULTS—Swallowing in normal individuals gave rise to a characteristic acceleration pattern which was absent, delayed or distorted in the dysphagic patients. We have found significant differences, in the magnitudes and median frequencies of acceleration, between normal subjects and dysphagic patients. In a double blind study, the biomechanical classification completely agreed with clinical classification based on videofluorography examination in 58 percent of the subjects, overestimated by one category in 31 percent and underestimated by one category in 11 percent.

The neural network model results were in complete agreement with clinician classification in 92 percent of patients for the oral and 88 percent of patients for the pharyngeal phase. The oral models overestimated the severity by one category in 4 percent and underestimated by one category in 4 percent of the cases. The pharyngeal models results overestimated by one category in 12 percent of cases. The fuzzy decision system completely agreed with clinicians in 88 percent of the cases, overestimated by half a category in 6 percent and underestimated by half a category in 6 percent of the cases. The surface EMG correlated well with the throat acceleration (correlation coefficient 0.8). The acceleration patterns were significantly different in dry swallowing when compared to wet swallowing.

IMPLICATIONS—The noninvasive biomechanical measurements, together with neural network and fuzzy decision systems, can be used to assess the risk of aspiration to compliment the videofluorography examination, and can aid the physician in continuing patient assessment on a daily basis. The biofeedback systems, including the Tongue Music System, can be used in treating oral dysphagia.

PUBLICATIONS RESULTING FROM THIS RESEARCH

Acceleration and EMG for sensing pharyngeal swallow. Gupta V, Reddy NP, Canilang EP. In: Proceedings of the IEEE-Engineering in Medicine and Biology Society 15th International Conference, 1993, San Diego, CA, 1221-2.

Computer based music system for biofeedback and recreational therapy: tongue music for oral dysphagia. Sukthankar S, Reddy NP, Canilang EP. In: Proceedings of RESNA'93 Conference, 1993, Las Vegas, NV. Washington, DC: RESNA Press, 1993:470-1.

Cybernetic method of diagnosis and treatment of dysphagia. Reddy NP, Sukthankar S, Palreddy S, et al. In: Ghoshal A, Murthy P, eds. Recent advances in cybernetics and systems. New Delhi:Tata McGraw-Hill 1993:397-405.

Design and development of portable biofeedback systems for use in oral dysphagia rehabilitation. Sukthankar S, Reddy NP, Canilang EP, et al. Med Eng Phys. In press.

Toward classification of dysphagic patients using biomechanical measurements. Reddy NP, Thomas R, Canilang EP, et al. J Rehabil Res Dev 1994:31(4). In press.

D. Vascular Disorders

[246] PREDICTING ISCHEMIA IN USE OF THE LOWER-LIMB PROSTHESIS: A PILOT STUDY

Bok Y. Lee, MD
VA Medical Center, Castle Point, NY 12511

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #A91-211AP)*

No report was received for this issue.

[247] NONINVASIVE MEASUREMENT OF CHANGES IN MUSCLE OXYGENT WITH CLAUDICATION

Bok Y. Lee, MD
VA Medical Center, Castle Point, NY 12511

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A774-RA)*

No report was received for this issue.

[248] OMENTAL ANGIOGENIC FACTOR TO REVERSE PERIPHERAL VASCULAR INSUFFICIENCY: A PILOT STUDY

Bok Y. Lee, MD; Harry S. Goldsmith, MD; Lee E. Ostrander, PhD; Burt Cagir, MD; David Santoro
VA Medical Center, Castle Point, NY 12511; New Rochelle Hospital Medical Center, New Rochelle, NY; Rensselaer Polytechnic Institute, Troy, NY

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #A90-124AP)*

PURPOSE—Peripheral vascular disease (PVD) of the lower extremity continues to be a major medical problem in the United States, causing significant patient morbidity and mortality. PVD can eventually lead to tissue loss and major amputation. Salvage of the limb in end-stage PVD is not amenable to conventional surgical procedures. In the medical literature, many chemical or biologic factors have been proposed for treatment of PVD. Presently there is no method available for reversing or compensating severe PVD.

The purpose of this experimental study was to determine the angiogenic effect of Guanphylline alpha adrenoceptor agonist (GPH). Previously reported studies have shown that alpha-2 receptor stimulation in the hypothalamus releases growth hormone releasing factor and other growth related hormones. Thus, GPH was evaluated as a new angiogenic factor for promoting increased blood levels of growth related hormones.

METHODOLOGY—The experiment utilized 12 beagles. Initial studies were performed to measure the normal vascular perfusion in the canine hind limbs. Noninvasive measurements were taken of transcutaneous partial oxygen pressure ($TCPO_2$ at 42°C) and laser Doppler flow (LDF). After these baseline measurements were established, the femoral and popliteal arteries with all branches were ligated under general anesthesia. After one week recovery, vascular perfusion in the hind limbs was measured to determine level of circulation in the post-ligation period. Six canines received GPH injections (0.5 mg/kg) and the remainder received saline injections intravenously for one week. Post injection measurements at weekly intervals were obtained to determine the angiogenic effect of GPF.

RESULTS—At the end of the third week post injection the GPH dogs had a significant improvement in both $TCPO_2$ and LDF measurements as compared to postoperative measurements. In contrast, the saline dogs showed no statistically significant difference between the postoperative and the post-injection data. These results suggest that GPH has strong angiogenic properties for limbs with PVD and may prove to be of value in treatment of end-stage vascular insufficiency.

[249] VISCOELASTICITY OF THE LIMB IN COMPARTMENT SYNDROME: A PILOT STUDY

Bok Y. Lee, MD; Lee E. Ostrander, PhD; Burt Cagir, MD; A. Wisaksana
VA Medical Center, Castle Point, NY 12511; New Rochelle Hospital Medical Center, New Rochelle, NY; Rensselaer Polytechnic Institute, Troy, NY

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #A90-98AP)*

PURPOSE—The increase in tissue pressure within a confined space is the primary pathophysiological factor in compartment syndromes. Increased pressure compromises tissue blood flow and leads to severe ischemia. The compartment syndrome is a serious limb threatening condition which affects members of the aging population. Primary vascular thrombosis and embolectomy as well as elective bypass surgery can leave the patient at risk for reperfusion injury and compartment syndrome. Other etiologies of compartment syndromes are trauma, bleeding due to anticoagulation therapy, application of external casts, splints, and burns with eschar.

METHODOLOGY—The aim of this study was to test a new noninvasive method for measuring viscoelasticity of the limb that can replace or supplement invasive compartment measurements. In the laboratory study, it was shown that as compartment pressure increases, the bulk mechanical properties of the limb became more nearly pure elastic. This pilot study examined differences in mechanical properties between edema and parameters: DLEB, DOH and SFT fell outside the 95 percent confidence intervals of sample values for subjects in all other categories.

PROGRESS—It is concluded that noninvasively measured mechanical properties observed in this study were significantly different between normal tissue and tissue with pitting and nonpitting edema. Furthermore the mechanical properties of limbs with compartment syndrome were different from those with edema.

FUTURE PLANS—Additional measurements in subjects with compartmental syndrome are planned. Further attention is to be given to the effect of peak indentation pressure to discriminate among pathophysiological conditions.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Measurements of mechanical properties of soft limb tissue as a diagnostic tool. Wisaksana A, Ostrander LE, Cagir B, Lee BY. In: Proceedings of the 1993 IEEE Nineteenth Annual Northeast Bioengineering Conference, 1993, Newark, NJ.

[250] TREATMENT OF DYSPHAGIA IN AGE-RELATED DISEASE: STROKE

John C. Rosenbek, PhD
William S. Middleton Memorial Veterans Hospital, Madison, WI 53705

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E728-GA)*

PURPOSE—A critical need in dysphagia is for randomized clinical trials to determine treatment efficacy. Before such studies can be designed, however, treatment methods, outcome measures, estimates of treatment schedules, and data for calculation of sample size must be established. Previous projects have led to the refinement of a treatment procedure: thermal application, the refinement of visual perceptual methods for evaluating swallowing, and the development of a computer-based visual imaging program for measuring range and duration of movements during swallowing.

We require data on the variability of impaired swallowing behavior, both with and without treat-

ment, so that adequate sample size for a group study can be calculated. The purpose of this study is to establish intra- and intersubject variability of selected swallowing duration, range, and descriptive measures of 3 ml semisolid bolus swallows in stroke patients with dysphagia. Variability of both untreated swallows and swallows treated with thermal application are being established.

METHODOLOGY—This study employs a one-group matched pairs design, each subject being studied in the untreated and treated conditions. The study population consists of medically stable subjects with evidence of two or more ischemic stroke lesions and with neurogenic dysphagia characterized by increased duration of stage transition or DST. A single videofluoroscopic swallowing examination divided into no-treatment and treatment phases is completed with each subject. In the no-treatment condition, each subject swallows 10, 3 ml semisolid barium boluses. In the treatment condition, each subject swallows 10, 3 ml semisolid barium boluses, each preceded by thermal application. Random assignment, guaranteeing that half of the subjects will have the treatment condition first, is employed. Testing is done on 1 day with 30 minutes between the two conditions. Three duration, two descriptive, and two range measures of swallowing are employed.

PROGRESS—Findings from the first 22 subjects are being prepared for publication. The findings from this pilot study prompted us to seek additional funds for a follow-up study. We have applied through the Cooperative Studies program to conduct a clinical trial to establish the efficacy of thermal application; this application was to be evaluated in October. The Penetration-Aspiration Scale used in this study is also ready for publication.

RESULTS—Data from the first 22 patients have been analyzed. Inter- and intrajudge variability and a treatment effect for thermal application have been established. Interestingly, the treatment decreased DST only when treated swallows were preceded by untreated ones. This unusual finding is being tested further.

FUTURE PLANS—We will continue work on the Cooperative Studies proposal to establish the efficacy of thermal application.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Swallowing after unilateral cerebral stroke. Robbins JA, Levine RL, Maser A, Rosenbek JC, Kempster G. Arch Phys Med Rehabil. In press.

X. Orthopedics

A. General

[251] MULTIMODALITY IMAGE REGISTRATION OF THE CERVICAL SPINE

John Drace, MD; John Adler, MD; Inder Perkash, MD; Sandy Napel, MD; Paul F. Hemler, PhD; Thilaka Sumanaweera, MD
Palo Alto VA Hospital, Palo Alto, CA 94304; Stanford University School of Medicine, Stanford, CA 94305-5488

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B762-RA)*

PURPOSE—Traumatic and degenerative disorders of the spine have a staggering effect on society. These types of disorders are frequently seen among the population served by the VA. Proper diagnosis and treatment of spinal disorders is one important medical challenge faced by the VA. This research is to develop a useful clinical system to register and visualize (image fusion) Computed Tomography (CT) and Magnetic Resonance (MR) Images of the cervical spine.

METHODOLOGY—High resolution CT and MR images are acquired using an optimal imaging protocol. The MR images are then corrected for susceptibility distortion. Sets of two-dimensional boundaries in each modality are determined. An interactive segmentation technique is used to isolate the boundaries of similar anatomical structures. The CT boundaries are tiled in three dimensions forming planar surface patches, creating a more accurate surface description than other methods. An adaptive gradient descent technique determines the optimal transformation that minimize the sum-squared distances between points on the MR surface and the planar CT surface patches. Registered image sets are visualized by displaying the location of the corresponding points on resampled image planes of each modality or by merging selected structures from one modality with those of the other.

PROGRESS—A preliminary system to fuse CT and MR images using accurate surface representations of anatomical structures has been developed. Imaging protocols which emphasize the surfaces used in the registration process is fundamentally important to generating these accurate representations. There are many parameters that need to be tuned to produce adequate MR images for our system. Spatial resolution, signal-to-noise (SNR), tissue contrast mechanisms, and imaging time are all interrelated and suitable tradeoffs must be evaluated. Through extensive experimentation, we have developed a reasonable protocol for MR images of the cervical spine which highlight the disc/bone boundary. This boundary is of interest for registration because it appears in CT images as well. We have found that a 3-D fast gradient echo sequence with a sagittal imaging plane, an in-plane resolution of, and a through-plane resolution of gives acceptable resolution, contrast, and SNR.

The current image fusion system requires human interaction to identify (segment) similar anatomical landmarks in each image set. Once the surfaces are identified, the system automatically and quickly determines the set of registration parameters between the image sets. This system has been used successfully on both images of the brain and the cervical spine. An algorithm to correct the geometric distortion in the MR images due to magnetic inhomogeneity variations (previously developed by Dr. Sumanaweera) is incorporated into the system. This type of distortion results from local nonuniformities of the magnetic field in the MR scanner. These nonuniformities result from the interaction of different tissues with the main mag-

netic field. Examination of the standard MR images and the distortion corrected images revealed a significant amount of distortion in the cervical spine which should be corrected prior to image registration.

RESULTS—Preliminary results in 10 VA patients (brain = 7, spine = 3) visually show excellent registration accuracy. The average mean square error between the points and the surfaces is less than the through-plane resolution of the higher resolution modality (1 mm). The entire process for either the brain or spine requires less than 1 hour.

FUTURE PLANS—Next year's work is aimed at reducing the amount of human interaction currently required by the image fusion system. A quantitative analysis of the registration accuracy achieved by this system will also be determined. Additional imaging studies will also be processed by the system.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Correction and quantification of geometric distortion in MR1. Sumanaweera TS, Glover GH, Song SM, Adler JH, Napel S. In: Proceedings of the AAA1 1994 Spring Symposium Series, Application of Computer Vision in Medical Image Processing, 1994, Stanford University, Stanford, CA, 203-6.

Grey value correlation techniques used for automatic matching of CT brain and spine images. van den Elsen PA, Pol ED, Sumanaweera T, et al. Visualization and Biomedical Computing, 1994, Rochester, MN.

System for multimodality image fusion. Hemler PF, Sumanaweera T, van den Elsen PA, Napel S, John Adler. In: Proceedings of the Seventh Annual IEEE Symposium on Computer-Based Medical Systems, 1994, Winston-Salem, NC.

System for multimodality image fusion of the spine. Hemler PF, Sumanaweera T, Pichumani R, et al. In: Proceedings of the AAA1 1994 Spring Symposium Series, Application of Computer Vision in Medical Image Processing, 1994, Stanford U, Stanford, CA, 42-5.

[252] SUITABILITY OF TITANIUM ALLOY AS A JOINT REPLACEMENT BEARING SURFACE

Michael J. Kabo, PhD; Douglas J. Kilgus, MD
West Los Angeles VAMC, Los Angeles, CA 90073

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A625-2RA)*

No report was received for this issue.

[253] MECHANICAL REGULATION OF SKELETAL TISSUE IN NORMAL AND PROSTHETIC JOINTS

Dennis Carter, PhD; Gary Beaupré, PhD
VA Rehabilitation Research and Development Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A501-2RA)*

PURPOSE—The purpose of this study is to examine the influence of mechanical stress histories in the development, maintenance, and adaptation of skeletal tissues. Investigations in the rapidly developing field of mechanobiology will play a critical role in better understanding a variety of orthopedic issues including fracture healing, cartilage repair and regeneration, initial implant fixation, and long-term bone remodeling after joint arthroplasty.

In this study we are developing theoretical and computational models which can be used to emulate skeletal development, maintenance, and adaptation using a multiple loading, stress history approach. The end product of this work will be a consistent framework of theories and models which can be used to predict the biological events associated with the initial fixation and the subsequent bone remodeling around prosthetically replaced joints. This work

will have a direct benefit for the aging and infirm veteran requiring total joint replacement.

METHODOLOGY—In this study we will use both theoretical and computational (nonlinear optimizations and finite element modeling) approaches to examine the role of mechanical loading histories in skeletal tissue biology. Our computational models will include linear and nonlinear, two- and three-dimensional models. Simulations using these models will be validated by comparison with both existing and new histomorphological studies. These simulations will involve both simple model systems having idealized geometries, as well as highly complex systems and geometries such as the proximal femur, knee, vertebra, and calcaneus.

PROGRESS—We have made significant advances in two areas, nodal-based bone remodeling and the determination of bone and joint loads from bone density distributions. The nodal-based remodeling approach has lead to a significant reduction in the amount of computer time required for each simulation. These advances are described in the publications below.

RESULTS—A significant outcome of this study has been the development of a quantitative theory relating skeletal tissue to the imposed mechanical stimuli. This theory has been integrated into a computer algorithm which we are using to examine initial skeletal development (morphogenesis), growth, maintenance, adaptation, and aging. This algorithm shows great promise for better understanding skeletal pathologies as well as the nature of bone remodeling caused by the presence of orthopaedic implants (e.g., total joint replacements, fracture fixation devices).

FUTURE PLANS—We have recently incorporated anisotropy into the bone remodeling algorithm using an approach which permits a determination of the bone density and orientation without depending upon the introduction of any new morphological parameters.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Cell shape and pressure may mediate mechanical control of tendon tissue composition. Giori N, Beaupre GS, Carter DR. J Orthop Res 1993:11:581-91.

Computer simulations of stress-related bone remodeling around noncemented acetabular components. Levenston ME, Beaupre GS, Schurman DJ, Carter DR. J Arthrop 1993:8:595-605.

Determination of bone and joint loads from bone density distributions. Fischer KJ, Jacobs CR, Carter DR. Trans Orthop Res Soc 1993:18:529.

Mechanobiologic influences in long bone cross-sectional growth. van der Meuien MCH, Beaupre GS, Carter DR. Bone 1993:14:635-42.

Role of loading memory in bone adaptation simulations. Levenston ME, Beaupre GS, Jacobs CR, Carter DR. Bone 1994:15:177-86.

Numerical instabilities in bone remodeling simulations: the advantages of a node-based finite, element approach. Jacobs CR, Levenston ME, Beaupre GS, Simo JC, Carter DR. J Biomech. In press.

[254] CARTILAGE REPAIR: EFFECTS OF MECHANICAL LOADING

R. Lane Smith, PhD; David J. Schurman, MD; Dennis R. Carter, PhD; B. Donlon, BS; B.E. Ellison, BA; M. Gupta, BS; M. Mohtai, MD
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—Our studies tested the hypothesis that mechanical loading, applied at levels of a magnitude approximating forces generated during normal joint activity, would modulate cartilage extracellular matrix synthesis. These studies address, at a molecular level, the basic mechanisms by which mechanical loading may influence articular cartilage metabolism. The long-term goal of this work is to develop fundamental knowledge that will contribute to connective tissue repair.

METHODOLOGY—Hydrostatic pressure was applied to high-density chondrocyte cultures for 4 hours using computer-controlled servo-hydraulics.

The mRNAs were identified by northern blotting and quantified by slot blots and densitometry. GAG synthesis was quantified by $^{35}SO_4$ uptake; matrix deposition was determined by immunohistochemistry.

We also tested the effects of deviatoric (shear) stress on adult articular chondrocyte metabolism *in vitro*. High density monolayer cultures of normal bovine and human chondrocytes were exposed to continuous fluid flow-induced shear stress (1 Pascal) for varying periods up to 72 hours. Under culture conditions in which the cells were distorted by the fluid-induced shear, articular chondrocytes elongated and aligned in the direction of applied stress within 48 hours of treatment.

RESULTS—Intermittent hydrostatic pressure (IHP) increased chondrocyte mRNA signals for aggrecan by 7 percent ($p<0.05$) in serum-free medium and by 15 percent ($p<0.05$) in medium containing 1 percent fetal bovine serum (FBS). Intermittent hydrostatic pressure increased type II collagen mRNA signal by 15 percent ($p<0.05$) in the presence of 1 percent FBS. Intermittent and constant hydrostatic pressure stimulated glycosaminoglycan (GAG) synthesis by 59 percent ($p<0.001$) and 35 percent ($p<0.05$), respectively, in serum-free medium. Extracellular matrix deposition was enhanced by intermittent and constant hydrostatic pressure in serum-free and serum-containing cultures as determined by immunofluorescence using antibodies specific for aggrecan and type II collagen.

IHP also stimulated GAG synthesis in full thickness cartilage explants by 37 percent ($p=0.06$, $n=4$) at 12 hours of exposure, 32 percent ($p<0.05$, $n=5$) at 24 hours, 55 percent ($p<0.01$, $n=5$) at 48 hours, and 64 percent ($p<0.01$, $n=5$) at 72 hours. GAG synthesis in cartilage control explants increased for the control values by 1.2 fold, 2.7 fold and 3.3 fold at 24, 48, and 72 hours over that of the 12-hour time point. With IHP GAG synthesis was stimulated by 1.0-fold, 4.1-fold and 6.4-fold increases at the same 24-, 48- and 72-hour time intervals. All explants were maintained in serum-free medium.

Shear stress stimulated glycosaminoglycan (GAG) synthesis (50-80 percent, $p<0.05$) and increased the hydrodynamic size of proteoglycan monomers, in part by lengthening the GAG side chains. Prostaglandin E2 release into the culture medium was elevated 12-fold; IL-6 was significantly elevated in the culture medium following shear stress. In addition mRNA levels for tissue inhibitor of metalloprotease (TIMP-1) was increased 8-fold.

[255] DEVELOPMENT OF ARTICULATING JOINTS: THE ROLE OF MECHANICAL FORCES

Jean H. Heegaard, PhD; Gary S. Beaupré, PhD; Dennis R. Carter, PhD
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—During morphogenesis, the future articulating joints first appear as divisions in the cartilaginous skeletal template. During this stage of development, the opposing joint surfaces are convex in shape. In many joints however, as development proceeds, one of the contacting surfaces progressively loses its convexity and eventually becomes concave, while the other surface remains convex. Understanding how such changes occur will provide new insights into the relative importance of biological (e.g., genetic) and mechanical (e.g., epigenetic) factors in skeletal development and adaptation.

METHODOLOGY—A computer model is used to simulate bone growth and to study the influence of mechanical stimuli on the developing articulating joint. This model includes two opposing cartilaginous segments, both initially convex in shape. These segments are linked together through a pair of elastic members representing ligaments. Flexion-extension forces are applied to one of the segments through tendons, while the other segment is rigidly fixed. Flexion-extension forces are alternatively applied to the joint, causing the joint to articulate and giving rise to contact stresses at the joint surfaces. With this model isometric (i.e., shape-preserving)

growth is modulated locally by the mechanical stimuli resulting from the flexion-extension process.

Available numerical methods for computing joint kinematics as a function of external applied loads fail to be effective when the joint geometries become complex, as is the case in human joints. Hence the current modeling approach is to decouple the problem into 1) a rigid body analysis for the determination of the overall joint motion and 2) a deformable body analysis for the determination of ligamentous forces and joint contact pressure. In the rigid body problem, equations are formulated within a Lagrangian framework by introducing adequate quasi-coordinates for expressing the contact conditions. The deformable body problem is solved, in turn, using standard finite element methods. Emphasis is put on obtaining objective constitutive relations for the cartilaginous segments and ligaments.

RESULTS—Preliminary results indicate that during flexion-extension, the contact region remains almost stationary on the movable (concave) joint segment, while the contact region on the fixed (convex) segment sweeps across a much larger area. Under the hypothesis that hydrostatic pressure will inhibit or retard growth, the concave-convex pattern can be understood as a result of locally controlled growth rates at the joint surface, with the concave segment having a lower growth rate than the convex segment.

[256] HIP FRACTURE RISK ASSESSMENT USING AUTOMATED 3-D FINITE ELEMENT MODELING

Harry B. Skinner, MD, PhD; Joyce H. Keyak, BSME; Irving Y. Lee, BSME
Department of Veterans Affairs Medical Center, San Francisco, CA 94121

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A371-3RA)*

PURPOSE—The purpose of this project is to establish a technique for assessing the risk of proximal femoral (intertrochanteric and femoral neck) fracture in elderly patients.

In this study, finite element (FE) modeling and mechanical testing will be used to predict and measure the strength of cadaveric femora. The ultimate goal of this project is to develop a fracture risk index. Values of this index for an individual patient would be derived from patient-specific three-dimensional (3-D) FE models.

METHODOLOGY—Forty cadaveric femora from subjects over 50 years of age will be used in this study. Twenty of the femora will be examined under loading conditions simulating the stance phase of gait. The remaining 20 will be studied under conditions simulating a fall. A patient-specific 3-D FE model of each femur will be automatically generated from CT scan data. The mechanical properties of the elements of these models will be derived from the CT scan data, thereby enabling the inhomogeneity of the femur to be represented. Based on the FE model and CT scan data, the strength of each bone will be estimated. The FE models will be verified by mechanically testing the femora to failure.

PROGRESS—Approximately one-half of the femora required for this study have been procured. Our existing automated FE modeling software has been modified for operation on a Silicon Graphics workstation. A graphical interface that enables rapid preprocessing of CT scan data and postprocessing of FE analysis data has been written. This software will be useful for the current study as well as for future applications in the clinical setting. FE analysis and mechanical testing of femora is underway.

FUTURE PLANS—We anticipate that the technology being developed in present study will allow us to identify patients who are at great risk for hip fracture so that preventative measures can be taken. Our new software will enable analysis of a patient's femur to be performed by a technician in under one day, thereby making such analyses economically feasible.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Three-dimensional finite element modelling of bone: effects of element size. Keyak JH, Skinner HB. J Biomed Eng 1992:14:483-9.

Validation of an automated method of three-dimensional finite element modelling of bone. Keyak JH, Fourkas MG, Meagher JM, Skinner HB. J Biomed Eng 1993:15:505-9.

Post-failure compressive behavior of trabecular bone in three anatomic directions. Keyak JH, Lee IY, Nath DS, Skinner HB. Trans Orthop Res Soc 1994:19:430.

Correlations between orthogonal mechanical properties and density of trabecular bone: use of different densitometric measures. Keyak JH, Lee IY, Skinner HB. J Biomed Mat Res. In press.

Three-dimensional finite element modeling of a cervical vertebra: an investigation of burst fracture mechanism. Bozic KJ, Keyak JH, Skinner HB, Bueff HU, Bradford DS. J Spinal Disorders. In press.

[257] PATIENT-SPECIFIC FINITE ELEMENT MODELING OF BONE FROM CT SCAN DATA

Harry B. Skinner, MD, PhD; Joyce H. Keyak, BSME; Irving Y. Lee, BSME; Christopher E. Cann, PhD; C. Dan Mote, PhD
Department of Veterans Affairs Medical Center, San Francisco, CA 94121

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A371-2RA)*

PURPOSE—The purpose of this project was to develop methods for deriving the mechanical properties of inhomogeneous trabecular bone from computed tomography (CT) scan data for the definition of three-dimensional (3-D), patient-specific finite element (FE) models. These models would be used for research and for clinical applications such as assessing femoral fracture risk due to osteoporosis or metastatic bone tumors.

METHODOLOGY—Cubic specimens of trabecular bone were cut from human proximal tibiae, and CT scans of the specimens were obtained. Specimen stiffness in three orthogonal directions was measured using nondestructive compressive testing, and compressive strength and post-failure behavior were measured in one randomly selected direction. Correlations were derived to relate the modulus, strength, (post-failure) plastic modulus, and first post-failure minimum stress to the CT scan density of the specimens. The inhomogeneity of each specimen was assessed from the CT scan data; data from inhomogeneous specimens form the basis for developing methods of modeling the material properties of inhomogeneous bone. To develop this method, software for automatically generating FE models of bone from CT scan data was developed. FE models of each test specimen were generated from CT scan data using the CT scan density-modulus relations obtained in this study and also by using other relations. Each element in an FE model corresponded to one CT scan pixel so that the variation in material properties within the specimen was modeled with the same resolution as that of the CT scan. The stiffness in each direction of mechanical testing was predicted and compared with measured stiffness to establish the degree of accuracy of the FE models.

PROGRESS—The elastic moduli and strength of cubic human trabecular bone specimens were measured in three orthogonal directions. Post-failure mechanical behavior was also measured, and attempts were made to describe this behavior. CT scans of the specimens were obtained and the CT scan density data were correlated with the mechanical property data. Several methods of computing the mechanical properties of finite elements were examined. The specimen stiffness predicted by FE analysis was compared with the measured specimen stiffness.

RESULTS—Modulus, strength, plastic modulus, and first post-failure minimum stress were correlated significantly with CT scan density. The correlations were best described by power relations. The

correlations for modulus, strength, and plastic modulus depended on test direction. The correlation between first post-failure minimum stress and density was nearly independent of test direction, suggesting that this measure is relatively independent of initial trabecular orientation.

The CT scan data showed significant variations in density within the specimens, indicating that the specimens were inhomogeneous with respect to this property. The effects of inhomogeneity were evidenced in the FE models by nonuniform strain distributions. In addition, the stiffness values predicted by the FE models depended on direction, and were not simply proportional to the average CT scan densities. This is consistent with our belief that inhomogeneity of the bone specimens affects their mechanical behavior. FE models can account for inhomogeneity, and therefore may improve mechanical property predictions. Even so, cube stiffness as predicted by the FE analyses using the experimentally obtained density-modulus correlations did not differ greatly from the stiffness calculated directly from the density-modulus correlations. Models that used nonlinear density-modulus correlations were more sensitive to inhomogeneity of the specimens than models that used linear relations. These results suggest that nonlinear density-modulus relations may be more appropriate for computing the finite element moduli for inhomogeneous bone.

FUTURE PLANS—The software for automatically generating FE models of bone, in combination with the modulus and strength correlations developed in this study, will be used to generate models for assessing femoral fracture risk due to osteoporosis and metastatic bone tumors.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Compressive mechanical properties of human cancellous bone after gamma irradiation. Anderson MJ, Keyak JH, Skinner HB. J Bone Joint Surg 1992:74-A(5):747-52.

Three-dimensional finite element modelling of bone: effects of element size. Keyak JH, Skinner HB. J Biomed Eng 1992:14:483-9.

Validation of an automated method of three-dimensional finite element modelling of bone. Keyak JH, Fourkas MG, Meagher JM, Skinner HB. J Biomed Eng 1993:15:505-9.

Post-failure compressive behavior of trabecular bone in three anatomic directions. Keyak JH, Lee IY, Nath DS, Skinner HB. Trans Orthop Res Soc 1994:19:430.

Correlations between orthogonal mechanical properties and density of trabecular bone: use of different densitometric measures. Keyak JH, Lee IY, Skinner HB. J Biomed Mat Res. In press.

Three-dimensional finite element modeling of a cervical vertebra: an investigation of burst fracture mechanism. Bozic KJ, Keyak JH, Skinner HB, Bueff HU, Bradford DS. J Spinal Disorders. In press.

[258] VERTEBRAL FUSION BY NEW OSTEOGENIC AGENTS TO ACCELERATE REHABILITATION

Basil S. Strates, MD, PhD
VA Medical Center, Gainsville, FL 32602

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A736-RA)*

No report was received for this issue.

[259] BIOCHEMISTRY OF CARTILAGE IN A MODEL OF DISUSE AND DIFFERENT TYPES OF RECOVERY

David S. Howell, MD; Ofelia E. Muniz, DSc; Anthony Ratcliffe, PhD; Roy D. Altman, MD; Guy A. Howard, PhD; Bernard A. Roos, MD

VA Medical Center, Miami, FL 33125; University of Miami School of Medicine, Miami, FL 33101; Department of Orthopedic Surgery, Orthopedic Research Laboratory, College of Physicians and Surgeons of Columbia University, New York, NY 10032

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A739-RA)*

PURPOSE—In disuse atrophy the accepted dogma is that, providing there is adequate positioning of the limb and absence of rigid fixation, most or all of the disturbed cartilage metabolism represents an effect on chondrocytes of reduced physical forces and secondary reduced synthesis of matrix components. However, the evidence in several previous studies of accelerated breakdown of proteoglycan and/or abnormal loss of aggregates as a sign of accelerated proteolysis, has been overlooked. More strikingly, recent evidence of elevated levels of proteoglycan fragments in synovial fluid of our disuse atrophy dog model provided clear evidence of abnormally high cartilage degradation rates.

METHODOLOGY—We currently wish to extend observations on this dog model of disuse atrophy to examine in 4 separate study modes the existence and nature of proteolytic action in forming disuse atrophy as well as observing the effect of a rehabilitative exercise program versus an over-exercise program on the same parameters of cartilage structure and proteolysis. Age-matched controls at 4 and 6 weeks (group 1,2). Experimental animals will be kept in a special sling allowing weight-bearing on 3 limbs for 4 weeks and 7 weeks of disuse atrophy (group 3,4). After 4 weeks of disuse atrophy either conservative (walking, rehabilitative exercise) or treadmill exercise (overexercise) for 2 weeks will be studied (group 5,6). After sacrifice, parameters of proteoglycan synthesis (including MRNA determinations) proteoglycan structural change and enzyme activities relevant to their degradation as well as hallmark degradation products of enzymic cleavage in synovial fluid will be measured.

PROGRESS—In the past year, we have processed 16 dogs: 4 were control (freely ambulatory); 8 were immobilized using a special sling for 4 and 7 weeks (4 dogs each); and the last group of 4 dogs were immobilized for 4 weeks, then the sling was removed for 3 weeks allowing mobilization and recovery with conservative walking.

RESULTS—Synovial fluid proteoglycan levels were elevated after 4 weeks of disuse, indicating increased cartilage catabolism. There was also an increase of neutral metalloprotease, but not collagenase activity with a decrease in TIMP (tissue inhibitor of metalloprotease), (a new finding) in the upper region of the cartilage. The rate of proteoglycan synthesis was decreased. Safranin O staining of histologic sections indicated loss of proteoglycan from the matrix, particularly from the upper zones. These findings suggest that decreased anabolism is accompanied by increased proteolytic catabolism of matrix constituents, similar to some bone atrophies.

In the recovery dogs we have a significant decrease of neutral metalloprotease activity together with an increase in TIMP. The ratio of TIMP to neutral metalloprotease (72kDA gelatinase and stromelysin) which became reduced in atrophy, returned toward normal. This is the first description of how proteolysis is occurring in a disuse atrophy model and demonstration of recovery from tissue changes after removal of immobilization.

We had originally proposed to determine the level of mRNA specific for aggrecan and link protein by northern hybridization. However, our preliminary studies indicated that too large an amount of articular cartilage would be required to provide enough mRNA for northern hybridization analysis. Therefore, we have developed a new quantitative polymerase chain reaction (PCR) procedure, together with an extraction procedure, that will allow determination of mRNA in the cartilage. This has been developed for bovine cartilage using primers specific for bovine sequence. However,

these primers are not useful for canine sequence. We now are therefore generating sequence for canine aggrecan and link protein, in order to allow us to synthesize canine-specific primers.

FUTURE PLANS—These are 1) to characterize whether atrophy is progressive or in equilibrium by 7-12 weeks; 2) whether osteoarthritis and collagenolysis routinely develop on use of a treadmill and irreversible cartilage swelling as opposed to reversible swelling; and 3) to characterize mRNAs in the reduced synthesis of aggrecan versus link protein in disuse model.

[260] PREDISPOSING FACTORS IN DISC PROLAPSE

William C. Hutton, DSc; William A. Elmer, PhD
VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A627-RA)*

PURPOSE—The purpose of this research was to characterize the proteoglycans within the lumbar intervertebral disc and to compare the chemical structure of the proteoglycans (particularly in reference to their degree of sulfation) at two different stages of disc degeneration.

METHODOLOGY—Twenty-eight (28) lumbar intervertebral discs were obtained from four different cadaveric spines (aged 52-67 years). Each spine yielded Tll/12, T12/Ll, Ll/L2, L2/L3, L3/L4, L4/L5 and L5/Sl. Discograms were then carried out on each disc, and they were classified as follows: grade 1 was a disc with no degeneration and grades 2, 3 and 4 showed progressive degeneration.

The discs were bisected and from each disc six regional segments were removed using a scalpel. The six segments were the anterior lateral, left (AL(L)) and right (AL(R)); posterior lateral, left (PL(L)) and right (PL(R)); posterior central (PC) and nucleus (N). Proteoglycans were extracted at 4° C in 4 M guanidine HCL in 0.05 M sodium acetate buffer (pH = 6.0) containing proteinase inhibitors. The preparation was desalted through a Sephadex G-50 column. Sulfation was determined by the alcian blue assay, and uronic acid by the carbazole reaction. Samples were digested with 0.5 U Streptomyces hyaluronidase and rechromatographed on a Sephadex G-50 to remove unsulfated sugars contributed by hyaluronic acid. The high molecular weight fractions were pooled and divided into equal aliquots. One aliquot was treated with $NaOH/NaBH_4$. The GAGs were applied to a DEAE-Sephacel column and eluted with a linear gradient (120 ml) of 0.15 M-1.2 M NaCl in 0.05 M sodium acetate buffer, pH 6.0. The other aliquot was digested with 0.2 U chondroitinase AC for 48 hr and treated with ETOH. The ETOH was evaporated and the disaccharides ADi-6S (chondroitin-6-sulfate) and ADi-4S (chondroitin-4-sulfate), were separated by HPLC using a weak anion-exchange resin 0.01 M sodium acetate buffer (pH = 5.0) containing 0.02 M sodium sulfate as the mobile phase.

RESULTS—DEAE-Sephacel profiles of the GAGs in the AL and PL segments showed a major peak coincident with the chondroitin sulfate standard. The profile for the posterior segments for grade 2 discs as compared to a grade 4 showed a predominant peak eluted at 0.5 M NaCl. Thus, it appears that the posterior segment had a substantial proportion of undersulfated chondroitin sulfate. Integration of peak areas revealed that the undersulfated chondroitin sulfate in the grade 4 posterior segment was 40 percent higher than the grade 2. Conversely, the amount of chondroitin sulfate that eluted coincident with the standard chondroitin sulfate was 40 percent lower in the grade 4 posterior segment. Differences in the amount of undersulfated chondroitin sulfate in GAGs extracted from the nucleus followed the same pattern except that undersulfated chondroitin sulfate values were 30 percent higher in the nucleus of the grade 4 disc.

The GAG samples were enzymatically digested with chondroitinase A-C for analysis of the disaccharides. There was a proportional decrease in the amount of ADi-6S to ADi-4S in the grade 4 posterior and nucleus segments which was concomi-

tant with an increase in the ADI-OS from the grade 4 posterior segment.

The results of this study show that a decrease in the sulfation of the GAG chains occurs with higher grades of disc degeneration. The GAG sulfation was proportionately lower in the posterior central and nucleus regions. Neither the anterior nor the lateral regions seemed to be significantly affected by degeneration. The appearance of a major undersulfated peak for both the grade 2 and 4 posterior and nucleus segments suggests a substantial amount of undersulfated chondroitin is present in this region. This is further verified by a similar increase in the chondroitin (ADi-OS) isomer observed for these two segments isolated from the grade 4 discs.

[261] CHANGES IN BLOOD FLOW ASSOCIATED WITH INTRAMEDULLARY NAILING

Stephen D. Cook, PhD; Lee C. Schlesinger
Department of Orthopaedic Surgery, Tulane University School of Medicine, New Orleans, LA 70112

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A708-RA)*

PURPOSE—The purpose of this study is to measure *in vivo* through the use of small implantable probes the changes in bone blood flow associated with intramedullary nailing of the dog tibia and subsequent healing. The dynamic changes in bone blood flow will be measured for both reamed and non-reamed medullary canals to determine if unreamed canals result in enhanced blood flow post-operatively.

METHODOLOGY—Blood flow probes based on transit time ultrasound technology have been utilized. Fifteen skeletally mature mongrel dogs were used in the experimental study. Heart rate and rhythm were monitored using standard electrocardiographic leads, and blood pressure was recorded on a chart recorder. In order to visualize the nutrient artery of the tibia, a lateral linear incision was made from the fibular head to the junction of the middle and distal thirds of the fibula. The nutrient artery and vein were separated and a site for stable attachment of the flow probe was selected. The canine tibial nutrient artery consistently measured approximately one millimeter or less in diameter in all dogs. In order to directly measure cardiac output, a left thoracotomy was used to gain access to the aorta.

PROGRESS—A method of directly measuring nutrient artery blood flow using ultrasonic probes has been developed. Advantages of ultrasonic probes include the direct measurement of nutrient artery blood flow, ease of use, accuracy of measurement and applicability to a wide range of vessel diameters.

Thirty adult male mongrel dogs are being studied. The dogs are divided into four experimental groups allowing comparisons to be made as to the effect of reamed and non-reamed tibial intramedullary canals, intramedullary nail placement, and the effect of an osteotomy.

Group I consists of five dogs (control). Measurements of blood flow are being made after bilateral placement and biweekly for a period of 90 days.

Group II consists of 10 animals. The standard surgical approach to the nutrient arteries is made bilaterally, flow probes implanted, and measurements made. A unilateral osteotomy is created in the diaphysis and an intramedullary nail is inserted. In five animals, the intramedullary canal is reamed, and in five animals, the intramedullary canal is not reamed. Measurements of blood flow are made for a period of 90 days.

Group III consists of 10 animals. An osteotomy is not created in the tibial diaphysis of this group. Intramedullary nails are placed into reamed medullary canals in five animals, and unreamed canals in five animals.

Group IV consists of five animals. In this group, unilateral reaming of the intramedullary canal without prior osteotomy or subsequent nailing is performed.

RESULTS—In 15 mongrel dogs (10 male, 5 female; mean weight, 27.2 kg), the cardiac output averaged 1.90 ± 0.65 l/min and the mean heart rate was 133 ± 27 beats per minute. Tibial endosteal blood flow averaged 1.46 ± 0.72 ml/min. As a percentage of cardiac output, the mean blood flow was 0.09 ± 0.05 percent. When expressed as a function of bone mass, the blood flow averaged 2.75 ± 1.95 ml/min per 100 g. No significant differences were observed between right and left tibias or between male and female tibias despite the fact that the cardiac output in females was less than males (1.5 ± 0.2 versus 2.1 ± 0.7 l/min, respectively; $p = 0.02$). In addition, the tibial weights were likewise significantly greater in females than in males (60.6 ± 10.3 ml vs 51.3 ± 6.2 milligrams, respectively; $p = 0.02$). Despite these differences, no significant difference in blood flow as a function of bone mass were observed.

[262] BONE SUBSTITUTE MATERIAL

Myron Spector, PhD; Susan L. Mitchell, DVM; Tracy E. Orr, PhD; Philip Villars, BS
Brigham and Women's Hospital, Harvard Medical School, Boston, MA 02115; VA Medical Center, West Roxbury, MA 02132

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A655-RA)*

PURPOSE—The goal of this research is the development of an off-the-shelf substitute for allograft bone currently used for grafting procedures. Bone grafts are often required during reconstructive orthopedic, maxillofacial, craniofacial, oral, and plastic surgery procedures. Often more bone graft is required than can be obtained from the patient (autogenous bone). Problems with allograft bone include 1) transmission of disease, 2) difficulty of procurement and processing, 3) uncertain immune response, and 4) premature resorption. Recent studies have focused on the production of synthetic calcium phosphate ceramic materials as bone substitutes. However, these substances do not undergo physiological resorption and remodeling, and because of their high stiffness can lead to undesirable changes in surrounding bone. There is need for a bone substitute material that behaves more like natural bone.

The central hypothesis is that natural bone mineral particles (e.g., 0.5-1.0 mm in diameter) prepared by deorganifying bovine bone (anorganic bovine bone—ABB) can serve as an effective off-the shelf bone substitute material by virtue of their osteoclast-mediated resorption and replacement by host bone, and their stiffness, which more closely resembles natural bone than synthetic calcium phosphate ceramics. A second hypothesis is that the compressive strength of anorganic bone particles in osseous defects increases rapidly within 6 weeks as new bone incorporates the particles.

METHODOLOGY—Deorganified bovine bone mineral particles, 0.5-1.0 mm in diameter, and commercially available synthetic hydroxyapatite ceramic have undergone elemental analysis using electron spectroscopy for chemical analysis (ESCA) and x-ray diffraction to determine crystalline structure. Mechanical testing of the particulate specimens has also been performed using a confined compression test.

An animal model, a cylindrical hole drilled in a region of cancellous bone on the medial aspect of the distal femur of the rabbit, is being employed to evaluate the tissue both histologically and mechanically. From one limb, histology samples are being examined for the amount of bone formation on the surface of the anorganic bone, synthetic particles and unimplanted controls after 2, 6, and 26 weeks. The percentage of the surface of the particles undergoing osteoclast-mediated resorption will also be determined. The compressive strength of contralateral defects filled with particles of the experimental and control materials is also being determined by use of a mechanical testing system.

PROGRESS—There are similarities in the chemical composition of the bulk of the ABB and synthetic HA substances as determined by EDX and in survey

scans of the surface using XPS. However, high resolution XPS reveals slight differences in the calcium binding energies that could be reflective of differences in the chemistry of the substance. High resolution XPS also reveals that chemistry consistent with carbonate, identified in the ABB, is absent from the HA. XRD demonstrates significant differences in crystallinity between ABB and synthetic HA materials. The diffraction pattern of the ABB particles is comparable to the XRD pattern of mammalian bone.

RESULTS—The rabbit model for the contained defect in cancellous bone has been successfully established. Instrumentation has been developed to ensure reproducibility of the hole and subsequent removal of the material within the defect after sacrifice. The instrumentation has been designed to be fixed in place at the time of surgery to produce the hole, 5 mm from the distal aspect and 5 mm from the cranial aspect of the femur. At sacrifice a jig, affixed to the instrumentation, allows for material to be trepanned from the implant site. These samples are then tested in unconfined compression. The mechanical properties of the trabecular bone at this site in the distal femur of the rabbit have been measured in an untreated group to provide reference values.

In the mechanical testing of the ABB particles, the stress-strain data under confined axial compression are highly nonlinear, with a generally increasing slope at higher strain levels. Cortical samples of ABB have a compressive strength of 35 MPa, compared with approximately 140 MPa for normal cortical specimens. At two weeks of implantation the compressive strength of osseous sites filled with ABB particles achieves the mean strength of the normal trabecular bone at the site. This rapid increase in strength is due to the rapid rate of incorporation of the particles into host bone (due to bone bonding at the surface and bone bridging the particles). The compressive modulus of the sites filled with ABB approaches normal values by 6 weeks postimplantation.

FUTURE PLANS—Samples of rabbit bone implanted with ABB particles are currently undergoing processing and will be examined in the next two months. Thereafter, evaluation of HA and unimplanted control samples will begin. Tissues will be evaluated for the amount of bone resorption and formation after 2, 6, and 26 weeks. Further mechanical testing will be completed as specimens become available.

[263] BIOCHEMICAL ANALYSIS OF SYNOVIAL ACTIVATION IN JOINT DYSFUNCTION

Christopher H. Evans, PhD
University of Pittsburgh School of Medicine, Pittsburgh, PA 15261

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A052-6RA)*

PURPOSE—The overall purpose of this research is to increase the longevity of prosthetic joints. As aseptic loosening is the most common reason for failure of these devices, we have chosen to study this phenomenon. Particular reference has been paid to the pseudosynovial membrane which develops at the junction between the implanted material and the surrounding bone. This membrane secretes osteolytic factors with the potential to resorb bone, and is thus likely to make an important contribution to loosening. We have concentrated on identifying pathophysiological stimuli which provoke the synthesis of osteolytic factors by the pseudosynovium, and to understand their mode of action at the biochemical and molecular levels. This information should then be of use in developing biological methods to prevent aseptic loosening.

PROGRESS—Our data have permitted us to alter genetically synovial cells *in vitro*, so that they are no longer activated by particles. As wear particles are likely to be the major stimuli which induce the synthesis of steolytic agents by cells of the pseudosynovium, this is a remarkable result. It

provides optimism that we may be able to render these cells resistant to the deleterious effects of wear particles, and thus delay or prevent aseptic loosening.

METHODOLOGY—Rabbit synovial fibroblasts have been used as a model system. To cultures of these cells have been added particles of latex, carbon, cobalt-chrome, titanium, polyethylene etc. and the induction of matrix metalloproteinases (MMPs), prostaglandin E_2 (PGE_2) and interleukin-1 (IL-1) measured. The responses of these cells to IL-I have also been studied. For mechanistic studies, particles or IL-I were added to cultures in the presence of $^{32}P0_4^{3-}$. Phosphorylated proteins were then separated by SDS-PAGE and visualized by autoradiography. In certain cultures, the interleukin-I receptor antagonist protein (IRAP) was added to block cellular response to IL-1. Certain synoviocyte cultures were stably transduced with IRAP using a retrovirus.

RESULTS—All types of particles that were tested, and IL-1, induced synthesis of MMPS, PGE_2 and IL-I. Activation by IL-1 resulted in the phosphorylation of a 27 kDa protein, which is probably the small heat shock protein. Surprisingly, metal particles also phosphorylated this protein. Addition of IRAP blocked phosphorylation not only in response to IL-1, but also in response to metal particles, suggesting that these particles activated the cells indirectly, by stimulating an autocrine production of IL-1. Cells which had been stably transfected with a human IRAP gene also resisted activation by particles.

FUTURE PLANS—We now intend to explore the use of gene transfer technology to prevent intraosseous reactions to wear particles *in vivo*, in a rabbit model.

[264] ORIGIN AND CHARACTER OF REGENERATE BONE

Herbert S. Schwartz, MD; John Dawson, PhD; Kenneth D. Johnson, MD; Marcus Sciadini, MD
Department of Surgery, Nashville VA Medical Center, Nashville, TN 37203; Department of Orthopaedics and Rehabilitation, Vanderbilt University, Nashville, TN 37232-2550

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A793-RA)*

PURPOSE—The purpose of this ongoing experiment is to elucidate the origin and character of regenerate bone utilizing plain radiography, histology, immunohistochemistry, and biomechanics. The effects of growth factor addition will also be analyzed. Our goal is to characterize quantitatively regenerate bone as a reconstructive agent of a skeletal defect.

PROGRESS—Funding for the project was approved to begin in January 1994. Thus far, four dogs have had cortical osteotomies applied and are completing bone transportation. X-ray documentation has been performed on each. Docking with distal bone union has occurred in two. No complications have resulted which have compromised dog handling or experimentation. We have completed ipsilateral ulnar osteotomies, for control, and have harvested the regenerate bone and ulnar fracture callus to begin histological and immunohistochemical analysis. The preliminary trials with our immunohistochemical collagen antibodies and stains for mineralized bone specimens are successfully working.

We are entering four more dogs into the protocol. The regenerate bone from these specimens will be used in biomechanical analysis. Testing of specimens from these pilot animals will validate our experimental systems and work out unforseen snares in our protocol.

METHODOLOGY—A canine survival model is used to establish regenerate bone behind a transported segment after a segmental one inch defect is created. We wish to quantitatively answer the question of how regenerate bone compares to native bone. We utilize an external control that is the contra-lateral limb and an internal control that is the ipsilateral fibular fracture callus. The overall schema

is based upon a three year plan. Year one is protocol testing with control validation and involves no growth factor injections. Initially eight dogs will be used to test the experimental systems. Following this, 17 dogs will be used to determine base line values for histology, immunohistochemistry in biomechanics.

In years 2 and 3, 34 dogs will be used annually. TGFβ-1 injections will be given and its effects on regenerate bone formation quantitatively and qualitatively examined. Control placebo injections with normal saline will also be performed.

A gigli-saw corticotomy is performed. Ilizarov bone transport occurs with an external fixator. The speed of transport is one revolution per day equalling one millimeter advancement per day. The corticotomy is immobilized for three to five days prior to initiating transportation. Plain radiographs are done periodically during the transport to assess bone formation and distance of transport. Histology will be performed using hematoxylin and eosin preparations on demineralized bone and toluidine blue stains on mineralized specimens. Torsion testing of whole bones after potting will determine bio-mechanical characteristics of the regenerate bone. Several controls are built into the system for comparative analyses. TGFβ-1 and placebo injections into the early regenerate bone will commence in the later years of the study. We chose Foxhound canines, purchased from a breeder in Texas. They are advantageous because they have long legs which facilitate segmental osteotomy and subsequent bone transport. The dogs weigh approximately 25-30 kilos.

RESULTS—The current status of our work is that bone transportation harvest and tissue analysis are proceeding without complication. No results have been attained as we have been up and running for only four months.

FUTURE PLANS—We will continue to accrue dogs, material, and data. We anticipate comparative results to be available by 1996.

[265] RESTORATION OF ORAL FUNCTION WITH MAXILLARY BONE GRAFTS AND IMPLANTS

Jon Tom McAnear, DDS; Christopher Smith, DDS; Suzanne Neil, DDS; John I. Hudson, DDD; Michael C. Duggan, DDS; Michele Saunders, DMD; Carol Venus, PhD
Audie L. Murphy Memorial Veterans Hospital, San Antonio, Texas 78284-0001

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A649-RA)*

PURPOSE—We seek to demonstrate that autologous cortical/cancellus bone grafts from the ilium to the maxillary sinuses will mature and (consolidate) and support a fixed prosthesis that will withstand the masticatory forces of a similar prosthesis in the mandible. It is expected that the subject's biting force, taste, mastication, deglutition, dietary intake, nutritional knowledge and attitudes, and reported self-esteem will improve subsequent to implant therapy and nutrition education, while his or her speech articulation and speech acceptability will remain unaffected.

Our goal is to provide those veterans who are not able to have implants placed into the maxilla, secondary to pneumatization of the maxillary sinuses into the maxillary ridges, with a procedure which will allow implants to be placed. Of necessity these implants must have a stable base in bone which can withstand the forces of mastication.

METHODOLOGY—Prior to any surgical procedures, subjects undergo baseline evaluation of their bite force, taste, speech, deglutition, dietary intake, nutritional knowledge and reported self-esteem. Each subject will then receive five cylindrical implants (Stage I) in the anterior mandible and bilateral sinus lift surgical procedures with cortical/cancellus, autologous bone grafts to the bony sinus areas. Two months later they receive any needed soft tissue surgical procedure on the mandible (they usually receive a mandibular vestibuloplasty, mouth floorplasty with a skin graft from the thigh to the mandible). Four months after Stage

I, they receive Stage II on the mandibular implants and, when healed, a fixed bridge on the mandibular implants. Five months after the sinus bone grafts, the subjects have six cylindrical implants placed into the maxilla, at least two on each side into the grafted bone, followed at six months with stage II on the maxillary implants. When healed they receive a fixed bridge on the maxillary implants. One year after the maxillary fixed prosthesis is in place each subject will have all baseline studies repeated for comparison.

PROGRESS—To date, 20 bilateral maxillary sinus lifts with autologous corticocancellous bone grafts from the ilium to the maxillary bony sinuses have been performed. One hundred Branemark implants have been placed into 20 anterior mandibles (5 each). Eighteen mandibular vestibuloplasties with skin grafts from the thigh to the mandible have been accomplished to provide soft tissue for placement of the mandibular abutments attached to the mandibular implants (these were scheduled to be accomplished by July 1994).

One hundred and eight implants have been placed into 17 maxillas. Fifteen subjects have received a mandibular fixed bridge and a new maxillary overdenture for temporary use. Seven subjects have progressed far enough into the study to receive a maxillary fixed bridge. Three of these seven subjects have lost one or more implants in the cuspid region secondary to an overloading of forces on these particular implants.

Overloading is thought to have occurred because two implants were placed in the cuspid region, while four were placed into the bone grafts (two on each side). This resulted in too long of a lever arm in the anterior portion of the maxillary prosthesis, creating a significant lever force concentrated at the crest of the bone in the maxilla. This force led to loss of bone around the implants. To prevent overloading from occurring in future subjects, we have modified the protocol (with IRB approval), and are now placing two additional implants in the anterior maxilla. It is believed that this will lead to more even distribution of forces over the implants and eliminate bone/implant loss.

[266] CONTINUATION OF THE CENTER FOR RETRIEVED ORTHOPEDIC PROSTHESES

John P. Collier, DE
Thayer School of Engineering, Dartmouth College, Hanover, NH 03755; VA Medical Center, White River Junction, VT 05001

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A473-2DA)*

PURPOSE—The overall objective of this study is to assess the long-term feasibility of porous coating as a mechanism for fixing orthopedic prostheses to bone. Additionally, the role of design and material on the performance of these prostheses is being determined through this analysis.

METHODOLOGY—This examination of clinically retrieved, porous-coated hip and knee prostheses will assess the importance of such variables as material composition, design, location of porous coating, pore size, and surface roughness on the resulting interface between the prosthesis and bone. The study will address the issues of stress shielding, ion release and wear debris formation and, where possible, clarify causal relationships with prosthesis parameters.

Retrieved prostheses are fixed in formalin and examined macroscopically and graded for wear, corrosion, fretting and tissue adherence. The metal components are mapped for both soft and hard tissue apposition prior to being embedded, cut into standard histological sections, and stained. Serial sections permit the assessment of bone resorption or of stress shielding for prostheses that are retrieved intact as postmortem specimens. The polyethylene bearing surfaces are graded for damage and defects and then sectioned on the microtome to determine the degree of polyethylene consolidation.

PROGRESS—In the past 12 months we examined 621 components of retrieved prostheses of which 282 were porous coated: 114 components of knee prostheses from 50 surgeons and 168 (9 cadaveral) components of hip prostheses from 81 surgeons. In the first 4 years of this project, we examined more than 2000 joint replacement components made available to us from more than 600 participating surgeons.

We have continued our study of the corrosion of the head/neck taper of modular, femoral hip components. Mixed-alloy prostheses (titanium-alloy stems with cobalt-alloy heads) continue to comprise the largest percentage of corroded samples. We have also noted corrosion of all-cobalt alloy components, which in one case resulted in femoral neck fracture. A common factor in the most severely corroded examples was heterogeneous metallurgy; as-cast heads in many of the mixed-alloy components and carbides at the grain boundaries of the corroded, porous-coated cobalt-alloy specimens.

Most recently we have observed corrosion of all-titanium-alloy components which indicates that no modular head/neck system may be immune from potential corrosion. Careful machining, proper metallurgy, and surgical technique which ensures clean mating surfaces and proper impacting of the heads are all critical to reducing the potential for corrosion and fretting.

RESULTS—It has become increasingly clear that the major reason for failure of all types of cemented and uncemented knee and hip prostheses is a result of osteolysis due to particulate debris. While bone cement, metal and polyethylene debris have all been associated with the osteolysis, it appears that the most prevalent and perhaps the most active debris type is that produced by the wear and breakdown of the polyethylene bearing surfaces. Our research indicates that implant design influences the extent and severity of wear of the polyethylene. Recently, we have also determined that there is significant variability in the polyethylene and that much of the material in retrieved components presents evidence of not having been fully consolidated.

Specifically, all of the polyethylene bearings begin their life as polyethylene powder, which is then either molded into components or formed into bar stock or sheet stock subsequently machined into components. Ideally, molding or the production of extruded bar or compressed sheet stock will provide a fully consolidated material. Unfortunately that is not the case, and our analyses of retrieved knee prostheses indicates that there appears to be a direct correlation between the severity of fatigue damage to the articular surfaces and the extent of defects or a lack of consolidation of the polyethylene.

We have developed a collaborative project with the producers of both the powder and the extrude bar stock as well as several of the manufacturers to fully investigate and develop a methodology to produce defect-free polyethylene from which all manufacturers can produce high quality, defect-free, fully consolidated polyethylene bearing surfaces. As part of this project we have initiated a quality assurance program with one of the two providers of extruded bar stock and have assayed samples of every piece of material they have produced during an entire run (approximately 10,000 feet of material).

IMPLICATIONS—It should be possible through optimizing the control systems to develop defect-free material which should significantly reduce the production of particulate debris from orthopedic prostheses which may significantly reduce the incidence of osteolysis: the most severe problem in joint replacement today.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Failure of a well-fixed bone-ingrown titanium hip prosthesis. Hodge WA, Collier JP, Surprenant VA, Jensen RE, Surprenant HP. Orthop Rev 1993:719-23.

Interface between host and unsuccessful cementless prostheses: the knee. Collier JP, Williams IR, Mayor MB, Surprenant HP, Kidd K. In: Morrey BF, ed. Biological material and mechanical considerations of joint replacement. New York:Raven Press 1993:197-207.

Loss of hydroxyapatite coating on retrieved total hip components. Collier JP, Surprenant VA, Mayor MB, et al. J Arthroplasty 1993:8(4):389-93.

Examination of the interfaces between the host and on uncemented femoral hip prosthesis and the correlation with pain relief. Collier JP, Mayor MB, Surprenant VA, et al. In: Hurley R, ed. Bone implant interface. Mosby Year-Book Inc. 1994:287-305.

[267] CONTACT PRESSURE IN THE HIND FOOT

B.J. Sangeorzan; A.F. Tencer
Harborview Medical Center, Seattle, WA 98104

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A553-RA)*

PURPOSE—This study was designed to define the effects of surgical procedures on the foot, related in our first project to fractures, and in this phase, to pathologic deformities, such as painful flatfoot.

PROGRESS—Using cadaver specimens, and measurements of contact pressures between the articular surfaces of the talus and calcaneus, we modeled the normal foot, and the effects on contact properties of a displaced fracture of the talar neck or a two-part fracture of the calcaneus.

In the second phase of the study, the cadaver model has been enhanced by the application of physiologic loads through the seven major tendons that control foot position. In addition, since considerable load is transferred from the talus to the navicular and the forefoot, we developed an approach to measuring the contact pressures in the talonavicular joint as well is the talocalcaneal joint Another addition to the experiment was the use of a sensing system which permits the measurement of the three dimensional spacial positions of four hindfoot bones (talus, calcaneus, navicular and cuboid) in relation to the tibia during loading of the foot.

In order to accurately simulate the deformity we are attempting to model, a study has been initiated to quantify the positions of the hindfoot and midfoot bones in patients with painful flatfoot. In this protocol, a device has been built which allows a 200 N load to be applied down the lower leg and across the foot using a plexiglass clamp. While wearing the device, patients have their foot scanned by CT, from which a 3-D model of the foot bones can be reconstructed and orientations of the hindfoot bones noted.

RESULTS—In the normal foot, the contact area of the posterior facet is greater than that of the anterior-middle facet of the talocalcaneal joint, and the posterior facet area decreases in the normal foot with inversion. With fracture and a 2 mm malalignment of the talar neck in with dorsal, medial, directions, the anterior-middle facet becomes essentially unloaded. We found no significant change in the contact area or pressure in the posterior facet, and therefore postulate that with this fracture the talus must transfer the part of the load previously carried by the anterior-middle facet either to the talanovicular joint or through an external load path. This study demonstrated the importance of realignment of the joint surfaces after fracture, even with displacements as small as 2 mm.

In a second study, the same approach was used to model a two-part fracture of the calcaneus. In contrast to the study of talus fractures, we found that calcaneus fracture altered contact characteristics in the posterior facet only; however, 2 mm of displacement again was able to create measureable differences in contact in comparison to the normal case.

In the present study, we have completed contact pressure testing on normal feet, using the enhanced model of tendon loading stimulating 3 positions of the gain cycle; heel strike (5 percent of the gait cycle), stance (30 percent) and toeoff (68 percent). We found the greatest contact area to be in the posterior facet of the talocalcaneal joint, followed by the talonavicular joint, and the anterior-middle facets of the talocalcaneal joint. The mean contact pressures in all three joints were remarkably similar; therefore, the proportion of the load transmitted by each joint corresponded to its contact area.

FUTURE PLANS—The present experiment provides baseline data for our study of the effects of foot deformities and surgical approches for correction. A basic assumption underlying these studies is that excessive contact pressures resulting from deformity, compared to normal values, will ultimately lead to articular cartilage degeneration.

[268] IN VIVO MEASUREMENT OF VERTEBRAL DISPLACEMENT AFTER LUMBAR FUSION

Thomas A. Zdeblick, MD
William S. Middleton Memorial Veterans Hospital, Madison, WI 53705

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A738-RA)*

PURPOSE—Posterior spinal fusion is performed for a large variety of clinical problems, including spinal trauma with spinal cord injury, degenerative changes of the lumbar spine, tumors, and scoliosis. Spinal instrumentation systems have increased the fusion success rate. However, this increased rate comes attendant with higher risks of device-related osteoporosis, as well as accelerated degeneration of adjacent vertebral levels near a stiff fusion segment. An optimal spinal implant system would promote successful fusion, prevent spine displacement during healing, and prevent further neurologic damage without vertebral body osteopenia or adjacent vertebral degeneration. To date, there are no data on the absolute mechanical environment that leads to fusion and/or non-union of the spine.

In this study, we propose to use a goat model both to characterize and quantify the blomechanical environment in which a lumbar spine fusion occurs and to define the optimal range of motion which will result in a solid spinal fusion. This will be accomplished by 1) developing a system to measure the intervertebral motion in the disc space and the facet joint, 2) establishing a baseline of motion during normal activities; performing decompressive laminectomy, 3) measuring the motion following this destabilization, 4) measuring the motion after standard lumbar posterolateral fusion using bone graft only and after fusion augmented by rigid and semirigid spinal instrumentation, and 5) correlating these mechanical data with histologic data as to successful fusion and vertebral body density.

METHODOLOGY—The study will be conducted in three phases. Phase 1: *in vitro* goat cadaver lumbar spine specimens are used to monitor displacement between vertebral bodies using a Hall-effect transducer which generates an electrical signal based on magnetic field strength. The goat spines are mounted on a MTS tester with Hall-effect transducers and magnets mounted across the disc and the facets of L4-5. Each specimen is subjected to axial compression, torsion, sagittal rotation, and lateral bending. The transducers are calibrated by simultaneous measurement of displacement using needle-tipped extensometers. Thus, we calculate vertebral displacement and relate it to Hall-effect transducer output.

In Phase 2 of this study, Hall-effect transducers are surgically implanted across the L4-5 disc space and facets of live goats. The output of the transducers is measured during a variety of postures, exercises, and manipulated positions for the 6 to 12 weeks preceding sacrifice of the animals. The transducer systems are then recalibrated by placing the spine on the MTS machine. Two additional goats have the transducers implanted followed by L4 and LS laminectomy. They serve as destabilized controls.

In Phase 3, three experimental treatment groups of six goats each will be studied. Surgery will consist of laminectomy, foraminotomy, and transducer implantation in all goats. A posterolateral boney fusion across L4 and L5 will be performed in six (Group I). Group II will have fusion augmented with a semirigid pedicle screw device. Group III will have a rigid pedicle screw system. Mechanical data will be collected for I2 weeks. Goats will be sacrificed and spines extracted. Radiographs and histologic sections through the fusion mass will determine the success of the fusion. Axial sections through the vertebral bodies will be studied to document bone trabecular density. We will correlate on an individual basis the success of fusion and the amount of vertebral osteopenia with the displacement data. This will allow us to determine the magnitude of intervertebral displacement over a particular time course that will lead to the greatest percentage of successful fusions.

PROGRESS—To date, we have completed Phase I *in vitro* testing and calibration of the sensor system. Implantable Hall sensor systems have been developed and implanted. Preliminary results have quantified the surgical artifact of the sensor in implantation surgery. Sensors have been implanted in goats with L4-5 destabilized by laminectomy and facet capsule resection.

[269] 3-D ANALYSIS OF SPINAL DEFORMITIES BY MEANS OF THE AUSCAN SYSTEM

Giorgio C. Santambrogio; Antonio Pedotti; Paolo Sibilla MD
Dipartimento di Bioingegneria, Politecnico di Milano, Milan, Italy; Centro di Bioingegneria, Fondazione Pro Juventute IRCCS, Politecnico di Milano, Milan, Italy; Unita' di Ortopedia, Reparto Scoliosi e Patologie Vertebrali, Fondazione Pro Juventute IRCCS, Milan, Italy

Sponsor: *Italian Ministry for University & Scientific Research, Telethon-Italy.*

PURPOSE—The main aim of this research is the non-ionising analysis of the spine, performed by means of a specially developed measurement system and suitable experimental protocols, in order to monitor the evolution of the deformity without any risk for the patient and to improve the diagnostic, prognostic and rehabilitative processes.

METHODOLOGY—The equipment adopted for this research is essentially composed by an optoelectronic based system, called AUSCAN (Automatic Scoliosis Analyser), which was specially developed for the measure of the kinematic variables associated with the dynamic control of the spinal morphology. Such a system, equipped with four CCD cameras and a suitable architecture for parallel processing of video signals, permits the reconstruction of the three-dimensional coordinates associated with a number of small passive skin markers applied on the patient's front and back on suitable skeletal reference points. Eleven markers are used to point out the spinal processes (every second vertebra from C7 to S3). A specific SW package, supporting all the main functions of the system, allows the computation of many parameters such as the spinal angles, the stiffness of the spinal segments, thc vertebral torsion. The experimental protocol included various motor tasks: orthostatsis, left and right lateral bending, double bending, voluntary spine lenghthening.

RESULTS—The experimental activity has concentrated on two areas: the analysis of data variability and the correlation between the acquired data and the clinical findings. Under the first, we have quantified the single rate of data variability associated with: the HW and SW accuracy and precision, the marker positioning, the control of the orthostatic standing, and the effects of circadian modulation. Under the second, we have surveyed 145 subjects (47 normals and 98 patients with scoliotic/kyphotic/lordotic deformity of different seriousness) and monitored them during their therapeutic treatment. Together with a good correlation with the most used clinical parameters, the results are particularly promising for the estimation of the spinal recovery after a treatment with plaster brace.

FUTURE PLANS—The preliminary results confirm the validity of this approach and suggest the development of additional software for the future use in clinical practice. The creation of a specific data base is particularly essential to provide an exhaustive base for reliable mathematical modeling and statistical analysis.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Frequency content of bending test kinematics: a study to determine the optimal data filtering. D'Amico M, Ferrigno G, Santambrogio GC. Surface topography and spinal deformity, vol. VI. Alberti, Drerup, Hierholtzer eds. New York: Gustav Fischer, 1992:1-5.

Back surface reconstruction by the AUSCAN system. D'Amico M, Chiarelli G, Ferrigno G, Santambrogio GC, In: Dansereau J ed. Proceedings of the International Symposium on 3-D Scoliotic Deformities. New York: Gustav Fischer, 1992:165-70.

Gradient polygon based method for computation of Cobb angles from X-ray images. D'Amico M, D'Amico G, Dell'Era S, Santambrogio GC, Technology and health care, New York: Elsevier 1993:289-90.

[270] ORTHOPAEDIC RESEARCH UNIT

R.A.B. Mollan, MD, FRCS, FRCSI; George Kernohan, PhD, CPhys, MinstP, FIMA; Ian Brown, MD; Andy Barr, PhD
The Queen's University of Belfast, Belfast BT7 1NN, N. Ireland

Sponsor: *The Queen's University of Belfast; Green Park Heathcare Trust, Musgrave Park Hospital, Belfast; Advanced Medical Technology Ltd, Belfast; Industrial Research & Technology Unit, European Commission; International Fund for Ireland; Northern Ireland Chest Heart and Stroke Association*

PURPOSE—Teaching and researching in the wide area of medical technology mainly as applied in orthopaedic surgery, we are keen to continue collaboration with other schools and research units around the world.

METHODOLOGY—We apply physics and engineering to the problems facing orthopaedic surgery. Studying the clicks and clunks from diseased joints, we have developed a method of recording these vibrations using accelerometers and portable computer datalogging systems. We conduct stationary and ambulatory gait analysis; we have developed a portable strain gauge plethysmograph for early detection of deep vein thrombosis, and we study synovial fluid using Capillary Zone Electrophoresis (CZE) and rheometry.

PROGRESS—New accommodation in a refurbished building includes new research laboratories, offices, library, clinical rooms and teaching facilities.

RESULTS—Vibration arthrometry is useful in early detection of human joint disease. Unstable hips, for example, generate low frequency vibrations during testing using accelerometers. Laser systems may be used for orthopaedic surgery both at low power, for surface measurement of articular cartilage, and high power, for surgical cutting and ablation particularly during revision surgery. Our portable Strain Gauge Plethysmography apparatus is able to detect deep vein thrombosis more accurately than any method other than venography. Our ambulatory gait analysis tools allow yield valuable information about the dynamic variability of human locomotion, and our synovial fluid analysis by CZE and rheometry is able to detect critical changes in chemical and mechanical properties with progression of arthritic disease.

FUTURE PLANS—A tissue-culture facility is planned which will permit patients at Musgrave Park Hospital to benefit from the latest developments in bone cell culture which have been perfected by orthopaedic researchers in the biomedical sciences.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Deep venous thrombosis in orthopaedic patients: improving the specificity of diagnosis. McNally MA, Kernohan WG, Croal SA, Mollan RAB. Clin Orthop 1993:295:275-80.

Pressurization of bone cement under standard, flanged and custom acetabular components for total hip replacement. Beverland DE, Kernohan WG, Nixon JR, Orr JF, Watson P. Proc Inst Mech Eng (H) 1993:207:19-23.

Statistical analysis of hip scores. Bryant MJ, Kernohan WG, Nixon JR, Mollan RAB. J Bone Joint Surg 1993:75B(5):705-9.

Continuous passive motion in computer assisted auscultation of the knee. Barr DA, Long L, Kernohan WG, Mollan RAB. Comput Methods Programs Biomed. In press.

How continuous is continuous passive motion? Barr DA, Kernohan WG, Mollan RAB. Knee 1994:1:27-32

Measurement of the forces and movements involved in neonatal hip testing. Chow T, Turner I, Kernohan WG, Mollan, RAB. Med Eng Phys 1994:16:181-7.

B. Hip Implants

[271] INFLUENCE OF COLLAR GEOMETRY IN FEMORAL COMPONENTS

J.A. Mandell, MS; G.S. Beaupré, PhD; S.B. Goodman, MD; D.J. Schurman, MD; D.R. Carter, PhD
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A652-RA)*

PURPOSE—In this study, we compared micromotion and load transfer among four prostheses: flat-collared, 30° and 60° conical-collared, and tapered. Our goal was to quantify the relationship between collar angle, micromotion, and the details of load transfer in the early post-operative period.

METHODOLOGY—According to our definition of collar angle, the flat collar and taper are equivalent to 0° and 80° conical collars, respectively. To isolate the effects of collar geometry, the implant models were straight-stemmed and cylindrical, and collar angle was the only design variable.

RESULTS—The flat (0°) collar used direct axial compression to transfer loads from the joint to the adjacent bone. In contrast, the 30°, 60°, and 80° collars transferred loads by "wedging" into the bone. Micromotion was lowest in the flat collar model, due to the flat support provided by the bone, and increased with collar angle, as increased wedging was accompanied by increased sinking into the bone. Load transfer to the bone adjacent to the joint increased with collar angle.

IMPLICATIONS—The results suggest that femoral loading can be maintained with conical-collared or tapered prostheses, but that increased loading is accompanied by increased micromotion, which may prevent stable long-term bony fixation. Current work includes efforts to predict long-term bone adaptation around these prostheses.

[272] THE EFFECT OF FEMORAL COLLAR GEOMETRY IN HIP REPLACEMENT

Gary Beaupré, PhD; Stuart Goodman, MD
VA Rehabilitation Research and Development Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A652-RA)*

PURPOSE—In this study we are examining the design of the collar region of the femoral stem component. Femoral stems are currently manufactured both with and without calcar collars. The collar region is critical since load transfer between prosthesis and bone is influenced greatly by the presence or absence of a collar. Inappropriate load transfer is known to lead to adverse bone remodeling and implant loosening, which in turn can necessitate surgical revision. The maintenance of adequate levels of stress and strain in the calcar region is considered essential for the long-term success of total hip replacements in the aging veteran population. Without better designs, the longevity of hip replacements in the active or overweight patient will remain limited.

METHODOLOGY—In the present study we are using three approaches to study the effect of collar design on the performance of total hip replacements. These approaches include 1) computational modeling (based upon the finite element technique),

2) *in vitro* testing (including strain gage studies using different collar geometries in synthetic femora and bone analogs), and 3) *in vivo* implantation (in sheep).

PROGRESS—The results to date have provided new insights into the influence of collar design and load transfer in total hip arthroplasty. We are optimistic that this study will lead to a better understanding of current designs and will elucidate future design concepts for hip replacements with improved long-term survivorship. This should lead to a direct improvement in the quality of life of not only the aging and infirm veteran but also any individual requiring total hip replacement.

RESULTS—We have used the finite element technique to analyze a series of two- and three-dimensional models. We have used these models to compare four uncemented prosthesis collar designs: flat collar (0° collar angle), conical collar (30 and 60°), and near-collarless (80°). We have also analyzed a subset of three-dimensional models. One significant observation from the computational modeling is the sensitivity of the results on the conformity or geometric mismatch of the bone-prosthesis interface. This may have important implications for all total joint arthroplasties, not only hip replacements.

Laboratory testing has been completed on a series of simplified prostheses. These prostheses have been implanted in bone analogs (paper-based phenolic). Subsequent to these tests, results from the computational models have indicated the necessity for additional levels of strain gages. The additional gages have been attached and testing is currently underway. Pressure sensitive film has been used to record the distribution and extent of collar-bone contact.

Implantation of human-sized prostheses (both titanium and chrome-cobalt) in synthetic human femora has begun. The synthetic femora were chosen to eliminate the variability inherent in cadaver bone that could mask differences due to collar design.

Twenty-one animals have received a hemi-arthroplasty of the left hip. The animals are sacrificed 1-year post-operatively. Five animals have completed the 1-year study. Histological processing of the retrieved femora and acetabtuli is in progress.

FUTURE PLANS—By correlating the results of the histological analysis with surgical and design variables we will be able to identify the parameters which most affect implant longevity.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

The influence of femoral component collar or taper on stress transfer and micromotion. Mandell JA, Beaupre GS, Goodman SB, Carter DR. Trans Orthop Res Soc 1994:19:224.

[273] TISSUE DIFFERENTIATION AND MAINTENANCE: THE INFLUENCE OF MECHANICAL STIMULI

Nicholas J. Giori, MS; Gary S. Beaupré, PhD; Dennis R. Carter, PhD
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—Many current problems relating to the repair of skeletal and connective tissues, and to the design and fixation of joint replacement prostheses, are closely related to the responses of regenerating skeletal and connective tissues to mechanical loading. An understanding of the mechanical factors involved in controlling the proliferation and differentiation of cells in skeletal and connective tissue regeneration, and in influencing the maintenance or modulation of mature connective tissues, is needed to improve treatment of orthopedic injury and to prevent or reverse some processes of connective tissue degeneration.

We hypothesize that loads which cause compressive hydrostatic stress in the tissue will stimulate the net production of cartilaginous matrix constituents, while loads which cause significant distortional (octahedral shear) strain in the tissue stimulate the

net production of fibrous matrix constituents. In the case of differentiating pleuripotential tissue, we hypothesize that low distortional strain and low hydrostatic stress permit the direct formation of bone, as in primary fracture healing.

We have conducted computational, *in vitro*, and *in vivo* studies to test and refine our mechanically based tissue differentiation concepts.

PROGRESS—Prior *in vitro* studies have shown that a region of fibrocartilage develops in certain tendons which wrap around bones. This fibrocartilage goes away when the tendon is removed from the channel which guides it over the bone and returns when the tendon is replaced. Using finite element analysis, we mechanically modeled this situation and found that intermittent *in vivo* loads create a pattern of hydrostatic stress in the tendon tissue which matches the pattern of fibrocartilage development in these tendons.

Based on the results of this study, we conducted an *in vitro* study in which pieces of mature bovine tendon were placed in a medium containing radioactively labeled sulfate. Sulfate is an important building block of proteoglycans, and thus is taken up by tissue synthesizing cartilaginous extracellular matrix. Experimental specimens were intermittently or statically pressurized to 6 MPa while control specimens were unpressurized. After 8 hours of pressurization, there was a statistically significant doubling of sulfate incorporation among pressurized tendon explants compared with controls. This effect was also seen in a parallel set of experiments on cartilage explants. Though additional work must be done to more carefully examine this tissue biochemically, preliminary results support our tissue differentiation concepts. Further *in vitro* studies such as this one may prove very useful in developing a detailed understanding of mechanical control of tissue modulation.

A prior histological analysis of retrieved knees which had undergone cemented Marmor hemiarthroplasty revealed that beneath the central portion of the tibial component a thick, mature layer of fibrocartilage consistently developed, while fibrous tissue separated the bone from cement elsewhere. Finite element analysis was used to mechanically model this situation, and it was found that the region of fibrocartilage development corresponded to a region in which the differentiating tissue was subjected to intermittent compressive hydrostatic stress of greater than approximately 0.7 MPa. In almost the entire immature interface, the distortional strain was estimated to be greater than 10 percent, suggesting that this level of distortional strain is sufficient to stimulate fibrous extracellular matrix production.

Fifty years ago, researchers conducted a surgical experiment in which a cylindrical plastic implant with cup-shaped ends was placed between the osteotomized bone stumps of a rat fibula. They found that in some cases, they were able to generate within the healing differentiating tissue a structure closely resembling a joint surface. In this study, we repeated the experiment to verify the results, but modified this experiment such that mechanical control of the differentiating tissue could be more accurately studied. We analyzed retrieved tissue 3 weeks following surgery, and compared the histologic results with the results of a finite element model of this experiment.

RESULTS—It appears that fibrous tissue develops in regions subjected to intermittent distortional strains greater than approximately 10 percent, and that cartilage and endochondral ossification may only form in regions of lower distortional strain. In addition, inflammation or particulate debris discourage nearby tissue from developing into cartilage and bone.

[274] WEAR DEBRIS GENERATION IN HIP MODULAR HEAD AND NECK COMPONENTS

Stephen D. Cook, PhD; Lee C. Schlesinger
Department of Orthopaedic Surgery, Tulane University School of Medicine, New Orleans, LA 70112

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A672-RA)*

PURPOSE—Modular stems are widely used in total hip replacement. Modular head/neck components provide the ability to vary neck length and head size independent of the stem while also reducing inventory and modular heads allow for mixed alloy systems.

Because of the concerns over the possibility for corrosion and wear at this interface, we examined retrieved uncemented femoral stems with modular heads. In an effort to quantify the amount of wear debris generated at modular interfaces, mechanical testing and electrozone particle analysis was used to evaluate titanium and cobalt-chromium alloy femoral tapers mated to cobalt-chromium alloy and ceramic femoral head materials.

METHODOLOGY—Test specimens of the femoral taper were fabricated from both titanium/6 aluminum/4 vanadium (STM F-136) and cobalt-chromium (ASTM F-75) alloys. The specimens had a nominal diameter of 14.05 mm and a taper angle of $5.655 \pm 0.045°$. Femoral tapers of each material were studied with a smooth-as-machined surface (<20 μin), a roughened (>100 μin) surface and a nitrogen ion implanted surface.

Mating femoral heads were fabricated from wrought cobalt-chromium alloy (ASTM F-799) and zirconium oxide (Yttrium stabilized). The metal and ceramic femoral heads had a 28 mm diameter and a standard neck length.

The head-taper combinations were cleaned, assembled, and the interface sealed in Tygon tubing with 3 ml of filtered (0.2 μm filter) physiologic saline. An inverted haversine load with a range of 225 to 2250 N was applied at 10 Hz for 10 million cycles to the femoral head at an angle of 45° to the long axis of the taper component.

After 1, 5, and 10 million load cycles, the saline contained within the tube was removed for analysis of particle generation. After removal of the saline at 10 million cycles, the components were disassembled and the particles contained at the interface of the components collected by rinsing with fresh saline. The collected saline was analyzed for the number of particles and the size distribution of the particles using electrozone particle analysis.

RESULTS—A significant number of particles were generated by all test combinations. The number of particles generated far exceeded the number of particles determined in the stock saline solution or untested assembled test specimens. The wear debris was relatively uniform in size with over 99 percent of the particles in the range of 0.255-2.306 μm. The greatest number of particles was generated during the first one million cycles. The number of particles generated declined in number generated per million cycles thereafter. There was no significant difference in the number of particles generated for the different femoral head materials. The roughened and nitrogen implanted surfaces generally reduced the number of particles generated while the addition of 10 mm of neck length tended to increase particle generation. In general, cobalt-chromium alloy tapers were found to result in a greater number of particles generated regardless of surface finish or head material.

The number of particles was found to be related to the dimensional mismatch between taper and head. All components were within design and manufacture specification; however, the number of particles generated generally increased with increased dimensional mismatch, particularly at the one million cycle test interval. The effect of dimensional mismatch appeared to be more significant for cobalt-chromium alloy tapers.

FUTURE PLANS—Analysis of the data generated by the mechanical testing continues. Additionally, various surface preparations and treatments are further being examined in order to minimize particulate debris generation. Tolerance and dimensional mismatch are also being evaluated in order to recommend optimal manufacturing design specifications.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Corrosion and wear at the head-neck interface of retrieved modular uncemented femoral stems. Cook SD, Barrack RL, Clemow AJ. J Bone Joint Surg 1994:76-B(1).

Wear and corrosion of modular interfaces in total hip replacements. Cook SD, Barrack RL, Baffes GC, et al. Clin Orthop 1994:298(1).

[275] PULSED LASER DEPOSITION OF COATINGS FOR PROSTHESIS-BONE BONDING

Myron Spector, PhD; Catherine M. Cotell, PhD

Brockton/West Roxbury VA Medical Center, West Roxbury, MA 02132; Naval Research Laboratory, Washington, DC 20375-5345

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A714-RA)*

PURPOSE—The concept of using a calcium phosphate coating as surface treatment that can be applied to total joint replacement devices has proven to be a value in clinical studies employing coatings prepared by plasma-spraying techniques. However, deficiencies in the strength of attachment of plasma-sprayed coatings to the underlying titanium 6-aluminum 4-vanadium alloy (Ti-6Al-4V) have placed at risk the large number of patients already implanted with these devices, and limit the utility of such coatings for future applications. Moreover, questions remain about the solubility of these coatings because of the presence of noncrystalline calcium phosphate substances and beta-tricalcium phosphate, which are more soluble than hydroxyapatite (HA). It is critical that other methods for applying pure HA coatings to metallic devices be found.

The goal of this research is the development of a pure HA coating with a high-strength, long-lasting bond to Ti-6Al-4V for fixation to the musculoskeletal system through bone bonding. The hypothesis is that a pulsed laser deposition (PLD) process produces an HA coating with significantly higher bond strength to Ti-6Al-4V than can be achieved with plasma-spraying, while providing equivalent or more favorable bone-bonding behavior. The benefit of the new PLD method is that the process can proceed under a variety of environmental conditions, yielding HA coating of high purity.

METHODOLOGY—The specific objectives are first to produce an HA coating by PLD on Ti-6Al-4V. *In situ* deposition parameters will be varied to optimize the coating with respect to composition (both chemical identity and distribution of calcium phosphate and amorphous phases), morphology, and adhesion between film and substrate. Among these parameters are the substrate temperature, the gaseous environment, and the use of an ion source to ion beam mix the interface between the substrate and the HA coating, the laser power density, and repetition rate. The elemental composition, crystalline structure, and topography of the coatings will be evaluated. Secondly, we will eterminе the bond strength of the coatings to the Ti-6Al-4V substrate using scratch, torsion and push-out tests before and after immersion in phosphate buffered saline. Finally, we will determine the time course of bone-bonding to cylindrical specimens with the PLD and plasma-sprayed control coatings in a canine model. Bone bonding will be quantified biomechanically and histologically.

PROGRESS—In the initial phase of the project progress has been made in identifying the operating conditions to be employed in producing HA coatings on titanium alloy substrates using PLD. Cylindrical rods of the metallic implants to be coated with HA and implanted in the animal model have been prepared. Procedures for implanting the HA-coated

specimens in the animal model have been determined. The protocol for mechanically testing specimens after selected implantation times has been executed with trial implants.

RESULTS—Work has shown that HA coatings of high purity can be applied to titanium alloy substrates by PLD. Animal experimentation has demonstrated that the time course of bone bonding can be determined biomechanically *in vivo*.

FUTURE PLANS—The future plans are to conduct experimentation to achieve the specific aims.

[276] OPTIMIZED SURFACE BONDING AND STIFFNESS OF FEMORAL ENDOPROSTHESES

Tracy E. Orr, PhD; Myron Spector, PhD; Sarah Trilling, BS; Craig Simmons, MS
Rehabilitation Engineering, VA Medical Center, West Roxbury, MA 02132; Orthopaedic Biomechanics Laboratory, Brigham and Women's Hospital, Boston, MA 02115

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A498-RA)*

PURPOSE—The objective of this investigation is to determine the optimal surface characteristics and material properties for a femoral endoprosthesis to avoid loosening. The specific short-term objectives are to investigate the following design parameters using finite element modeling techniques: 1) surface distribution of bone-prosthesis bonding for porous or ceramic-coated stems; 2) elastic modulus of the prosthesis; 3) stem design, including the shape and the presence of the collar for calcar contact; and 4) the role of Coulomb friction at the bone-prosthesis interface. In addition, an experimental model is required to validate the finite element results.

METHODOLOGY—A three-dimensional (3-D) finite element model of an intact femur was developed which was then modified to include a conventional straight stem femoral component with a collar for calcar contact. A third 3-D model was developed by replacing the straight-stem component with a contemporary canal-filling femoral stem. The applied loads represented three phases of gait, stair ascent, and various isometric exercises. Constraint equations were defined at the bone-implant interface to simulate bone ingrowth at porous-coated surfaces or bone bonding at hydroxyapatite-coated surfaces. Nonlinear gap elements were used to simulate frictionless contact where the stem was not coated. A mathematical scheme for optimization of the distribution of bone-implant bonding was developed and successfully applied to the 3-D model of the canal-filling prosthesis for titanium, cobalt-chromium and carbon composite materials.

An unique experimental model was also developed to study the effect of varying the surface coating distribution on stress shielding and relative motion. The experimental model consisted of a synthetic femur implanted with a titanium prosthesis fixed with a cyanoacrylate gel to simulate bone-stem bonding. Validation tests were conducted to determine four parameters: the moduli of the synthetic femur components, the friction between the stem and the bone, the bonding strength of the glue, and the controllability of the bonding distribution. The results of these tests confirmed that the experimental model was adequate for the purposes of this study. However, the moduli of the synthetic femur components are low compared to human bone and, therefore, the model should only be used for intercomparison studies. With this prosthesis, bonding of the distal 20 to 30 percent of the prosthesis was not possible, because of inadequate stem-bone contact in that region.

PROGRESS—The finite element analyses investigating the optimum surface distributions were completed for the three material properties. The objective function of the numerical optimization was to minimize the summation of the peak interface shear stress, shear motion at the interface, and stress shielding of the proximal femur. The results demonstrated that extending the bonding distally reduced

the interface micromotion but created higher interface shear stresses. The optimum titanium, cobalt-chrome, and composite prosthesis had a surface coating over 60 percent, 60 percent, and 100 percent surface area of the prosthesis respectively. Finite element analyses varying the material property distribution and stem geometry are in progress.

For the experimental model, three synthetic femurs were tested with six bonding distributions per bone. The degree of stress shielding was measured by surface strains and the relative motion was measured at the stem-bone interface. The experimental results were compared with the results of a finite element analysis. There was generally good agreement between the trends observed experimentally and those predicted by the finite element analysis. As well, there was good agreement in the magnitudes of the surface strains. The most obvious discrepancies between the FEA and the experiment were the differences in strain and motion with full coating. Thus the FEA further supports the experimental observation that full bonding could not occur. The trends in the data suggest that the optimal distribution (which minimized the combination of stress shielding and relative motion) is to coat the proximal 65 percent to 81 percent of the stem length. More generally, this study experimentally demonstrated the complicated interaction between relative motion and surface strains with variation in bonding distribution.

FUTURE PLANS—Parametric studies investigating the optimum material property and stem shape will continue to be performed. More samples of the experimental model are required before statistically significant conclusions can be made from the preliminary results. In addition, the experimental model will be repeated using a straight stem prosthesis to determine if full bonding can be achieved.

[277] COATINGS/SURFACE TREATMENTS FOR PROSTHESIS-BONE BONDING

Myron Spector, PhD; Michael G. Wilson, MD; Edward J. Cheal, PhD; Philip Villars; Sarah L. Trilling
Brigham & Women's Hospital, Boston, MA 02115; West Roxbury VA Medical Center, West Roxbury, MA 02401

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A654-RA)*

PURPOSE—A major problem associated with the use of internal skeletal prostheses is the fixation of the device to bone. Deficiencies in current methods of fixation limit the function and longevity of total joint replacement prostheses. Recent studies have indicated that bone will bond (chemically) to a variety of calcium-containing substances. Current work is focused on the implementation of calcium phosphate coatings that have been plasma-sprayed onto metallic hip replacement prostheses. Histological evaluation of specimens retrieved from animals and human subjects has revealed that bone forms directly on the surface of these calcium phosphate coatings within a few weeks of implantation. However, investigations also indicate that the strength of attachment of the calcium phosphate coating to the metallic substrate degrades with time, and thereby leads to detachment of the coating. Moreover, recent histological evaluation of autopsy-retrieved plasma-sprayed hydroxyapatite-coated stems has revealed resorption of as much as 20 percent of the coating by osteoclast-like cells after 1 year. The goal of this project is to evaluate calcium-containing coatings produced by three methods; these coatings are evaluated with respect both to bond strength between the coating and the metallic substrate and to the time course and strength of bone bonding.

METHODOLOGY—Implant coating and surface treatment techniques employed in these studies include ion-beam sputtering of hydroxyapatite, ion implantation of calcium, and pulsed laser deposition of hydroxyapatite. In all cases titanium alloy is used as the substrate. The elemental composition of the coating and surface treatments is performed using electron spectroscopy for chemical analysis (ESCA, also referred to as x-ray photo-electron spectroscopy, XPS). The crystalline structure is determined using x-ray diffraction. A scratch test is used to

quantify the strength of attachmcnt of the coating to the underlying metallic substrate.

Parametric studies are performed using finite element methods to evaluate various test configurations for the measurement of interface shear strength. The parameters include the applied loads (axial, or push-out, and torsion), the dimensions of the cylindrical implant, the dimensions of the surrounding bone, and the boundary or support conditions. These parametric analyses provide relationships between the various test parameters with the uniformity of interface shear stress, and thus indicate the optimal test configuration for measuring bond strength.

The bond strength of the coatings to the titanium alloy substrate is determined using scratch tests and using torsion tests of cylindrical specimens in epoxy. A commercially available plasma-sprayed hydroxyapatite coating serves as a reference.

The time course of bone-bonding is determined using cylindrical specimens in a canine animal model. Time periods of 2 and 6 weeks are used in these studies. Specimens implanted in the distal femur are used for histological and morphological analysis. The bond strengths of specimens implanted in the proximal femur are measured using torsion tests, with the test parameters established by the finite element studies. Quantitative morphological measurements of the tissue surrounding the implants are made using backscattered scanning electron microscopy and custom computer software.

PROGRESS—We have made considerable progress toward our objectives: 1) production and analysis of hydroxyapatite (HA) coatings and calcium-ion-implanted titanium alloy, 2) determination of the bond strength of the coatings to the titanium alloy substrate, and 3) assessment of the time course of the bone bonding to the implant in a canine model. Specimens with plasma-sprayed HA coatings and calcium-ion-implanted surfaces were analyzed to determine surface chemistry and crystalline structure. Wc determined the depth profile of calcium ions implanted into titanium alloy substrates. In addition, we identified a new method of producing more highly crystalline adherent HA coatings using pulsed laser deposition. A new testing technique for measuring interface shear strengths, utilizing torsional loads, was developed using finite element methods and implemented in the laboratory. The strength of attachment of the coatings has been determined by torsion tests. Cylindrical specimens of the trial coatings and surface treatment are being implanted in the proximal and distal femur of dogs to determine the time course of bone bonding biomechanically and histologically. Computer software for analyzing backscattered scanning electron images of the tissue surrounding the implants was developed to provide quantitative morphological data.

RESULTS—Results obtained to date indicate that a new treatment method, using pulsed laser deposition, has significant advantages over the plasma-sprayed HA coatings currently being employcd clinically. Analysis of titanium alloy specimcns with a plasma-sprayed hydroxyapatite coating has demonstrated noncrystalline calcium phosphate as well as a small percentage of nonapatitic crystalline material (probably tricalcium phosphate) in the coating. These constituents affect the solubility of the coating. Preliminary results from the implants in the canine model indicated negligible bond strengths for polished titanium surfaces. Histological studies of the tissues surrounding these implants are in progress.

Based on the parametric finite element analyses, we concluded that the optimal dimensions for the interface bond strength tests were to keep as much bone as possible around the implants and to keep the interface length as short as possible. With these optimal dimensions, applied torsion resulted in less than 30 percent variation in the interface shcar stresses whereas an axial or push-out load resulted in almost 90 percent variation in the interface shear stresses. The advantage of torsional loading is due primarily to the lack of normal stresses at the interface, in contrast to the push-out or pull-out loading. The relatively uniform shear stresses should result in more reliable and repeatable laboratory measurements of interface bond strength.

FUTURE PLANS—Our ongoing biomechanical and histological analysis of trial coatings and surfacc treatments implanted in dogs will be completed. Wc also hope to extend these studies during an additional funding period to include further laboratory and animal experiments. These may include 1) torsional fatigue testing of coatings in an environmental chamber, and 2) implantation of coated

femoral stems in a canine animal model. These additional animal experiments will allow us to test the most promising coatings in a mechanically loaded, and clinically relevant, condition.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Computer analysis of backscattered electron images of cortical bone (Thesis). Christensen RE. Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, 1992.

Chemical structure and properties of calcium-containing coatings and modified surfaces for titanium alloy orthopedic prostheses. Spector M, Hanlon JG, Tucker BE, Mukhapadhyay S, Nancollas GH. In: Proceedings of the Materials Research Society Meeting, 1993, San Francisco, CA.

Chemistry, structure, and solubility behavior of calcium-containing surfaces. Nancollas GH, Tucker BE, Paschalis EP, et al. In: Proceedings of the meeting of the Society for Biomaterials, 1993, Birmingham, AL.

[278] A BONE CEMENT COLLAR FOR SEALING THE FEMORAL CANAL AROUND NONCEMENTED PROSTHESES: A PILOT STUDY

Tracy E. Orr, PhD; Philip Villars, BS
Rehabilitation Engineering R&D Lab, VA Medical Center, West Roxbury Division, Brockton/West Roxbury, MA 02132

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #A513-AP)*

PURPOSE—The problem to be investigated is how to prevent the migration of polyethylene (PE) debris, produced in the joint space by the articulating surfaces, from tracking down the femoral stem of the noncemented prosthesis and initiating an inflammatory tissue response. The number of reports of osteolytic lesions at distal sites along noncemented femoral stems, identified radio-graphically, is increasing. Tissue from these lesions, retrieved at revision arthroplasty, has been found to contain PE particles. The fact that there have been few findings of such osteolytic lesions around cemented stems has led to the working hypothesis that the interdigitation of cement with bone surrounding the stem serves as an effective barrier to PE migration and that such a barrier may serve the same function if it was designed for noncemented prostheses as a physical barrier which was not load-bearing.

The objective of this investigation is to develop a method to produce a bone cement collar (BCC) around existing noncemented collarless femoral prostheses. The purpose of the BCC is to seal the femoral canal in order to prevent the migration of ultra high molecular weight polyethylene (PE) wear particles along the implant-tissue interface. The central hypothesis of this study is that a BCC will reduce the number of PE particles invading the implant-tissue interface and thereby reduce the inflammatory response that is responsible for bone resorption and prosthetic loosening. This hypothesis requires *in vitro* testing to ensure a configuration of the interdigitating cement such that it will not be load-bearing and will withstand both static and dynamic loading without itself breaking up and becoming a source of particulate material. Once this is established, the BCC also requires *in vivo* testing since it is likely that complicated hydraulic motion as well as other physical, chemical, and biological factors effect the propulsion of PE particles along the interface which could not be simulated fully by mechanical means.

While bone cement might have value as a seal for the femoral canal and is the method of choice for fixation of stems in the older patient, its lack of fatigue strength continues to limit its value as an attachment vehicle for the younger individual. The BCC should act as a physical barrier rather than as a load-bearing component of the prosthesis, thereby circumventing the potential problem of fatigue failure of the cement.

METHODOLOGY—Canine femurs were employed to determine the correct configuration of the BCC. Noncoated (smooth surfaced) collarless canine femoral stems (titanium-alloy), such as those conventionally employed in humans, were implanted into canine femurs. The implants were press fit into place

in the conventional manner. Unfortunately, the femurs fractured in four attempts to implant the component into the bone. A simplified model was then developed to represent an idealized femur, using fiberglass cylinders to represent cortical bone and polyurethane foam to represent cancellous bone. The canine femoral component was then implanted into the idealized femur. The idealized femur was then subjected to a single cycle of quasi static loading. The prosthesis was removed and the foam was prepared to accept the BCC. A specially designed broach and reamer was used to produce a shallow cone-like region in the bone around the proximal end of the stem. After the same stem was implanted into the canal PMMA b one cement was finger-packed into this proximal site to produce the BCC. Rosette strain gages were then applied to the exposed cement and to the surface of the cylinder. Quasi static loading was then repeated. Cyclic fatigue tests were also performed and evidence of cracks were investigated using light microscopy.

A finite element model has been generated to investigate the best BCC configuration. Several parameters of the BCC will be investigated including thickness, depth, and angle of conical shape.

PROGRESS/RESULTS—In order to begin testing of the BCC configuration in cadaveric canine femurs, a testing apparatus was designed for the Instron to accommodate the canine femur and the idealized femur. Two idealized femurs have been tested. The initial collar configuration was approximately 0.25 inches deep and had a thickness between 0.125 and 0.25 inches. The preliminary results indicated that the BCC did affect the strain distribution of the surface strains of the idealized femurs, increasing them approximated 5 times the magnitude of the prosthesis without a BCC. Significant strain was measured in the cement itself. However, during cyclic loading the collar was well maintained and did not show any evidence of cracking. Finite element analyses will determine if a BCC configuration exists which will decrease the amount of strain in the cement and not affect the surface strains.

FUTURE PLANS—Further *in vitro* testing will be performed once the best configuration of the BCC has been established through the finite element analyses. A smaller canine component will be employed so that the canine femurs can be used for the mechanical testing. Press fit implants will be compared with press-fit implants sealed with the BCC. For final confirmation that the BCC meets the criteria that it is not load bearing, transverse sections of the BCC with the implant will be examined by scanning electron microscopy to ensure that fragmentation of the BCC did not occur.

[279] NEW STRATEGIES FOR LONG-TERM PERFORMANCE OF FEMORAL PROSTHESES

Dennis A. Chakkalakal, PhD; Kevin L. Garvin, MD; Michael H. McGuire, MD
VA Medical Center, Omaha, NE 68105; University of Nebraska Medical Center, Omaha, NE 68198-1080; Creighton University School of Medicine, Omaha, NE 68131

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A667-RA)*

PURPOSE—In hip arthroplasty with noncemented, porous-surfaced femoral prostheses, it is important to develop procedures that would allow prostheses to remain functional for several years in active, older people as well as in younger people so that repeated revisions can be avoided. The purpose of this project is to develop new strategies to enhance long-term performance of femoral prostheses by adjuvant treatments with selected therapeutic agents applied locally during hip arthroplasty in an experimental model.

METHODOLOGY—The main experimental model is a canine femoral prosthesis implanted in the right femur of the dog. Dogs implanted with the femoral component of the canine hip prosthesis are sacrificed at 6 weeks and 6 months for evaluation of short- and long-term performance, respectively. The

femur with the implant is sectioned transversely and adjacent sections are used for push-out tests, histology, and scanning electron microscopy in the back-scattered electron mode (SEM/BSE). Osseous and soft tissue formation within the pores of the prosthesis and around it and remodeling changes in the femur are quantified from SEM/BSE and histology using a computer-aided morphometry system. Standard statistical methods are used to determine correlations between mechanical and morphological data from adjacent transverse sections along the entire length of the prosthesis-femur composite. Statistical comparisons between groups (untreated controls, treated groups) are done by paired analysis of transverse sections obtained from a given anatomical site.

PROGRESS—The canine prostheses were supplied to us by Zimmer, Inc. But due to delays caused by patent negotiations and technical difficulties in manufacturing the prostheses the experiment using the *in vivo* canine model started only in March 1993. In the meantime we developed two supplementary models: a rat medullary chamber model and a canine bone marrow cell culture model. In the rat model the medullary canal of the femur is reamed to mimic the procedure in the canine model. In the culture model, marrow cells from the proximal medullary canal of the canine femur are maintained in culture medium. These models are used mainly for two purposes. First, both models may be used to screen potential therapeutic agents and carriers for osteogenic efficiency. Second, studies of osteogenic differentiation of marrow cell culture on solid titanium and titanium fiber-mesh surfaces provide supplementary information on the nature and extent of early osteogenic response of the host tissues after the prosthesis is implanted in the *in vivo* model. Pilot studies using the rat model involved the use of chitosan preparations, hydroxyapatite, TGFβ and PDGF in the medullary chamber with and without a thin (0.3 mm dia) titanium wire.

RESULTS—Preliminary results suggested that PDGF may stimulate medullary osteogenesis. However, due to large variability in this model, we concluded it would not be useful as a screening system. Canine marrow cultures were grown on Ti-Al-V alloy, Co-Cr alloy and plastic discs for up to two weeks. These cultures demonstrated the beginning of osteogenic differentiation of a subset of cells starting on day 7 of culture. In the experiments using the *in vivo* canine model, push-out data at 6 weeks (from transverse sections of the femur-prosthesis composite) were analyzed for a preliminary group of 6 dogs (3 saline controls, 2 chitosan-treated, and 1 hydroxyapatite-treated) and more stringent selection criteria were adopted to further reduce variability in the data. Since then, 19 more dogs (13 for 6 week study; 6 for 6 month study) were entered into the protocol. Five of the 6 week dogs and all of the 6 month were sacrificed and push-out strengths (two samples per dog) were determined. Morphometric measurements from histological sections and SEM/BSE images are in progress. Additional dogs are being entered into the protocol to complete 7 dogs in each treatment group.

[280] CALCIUM PHOSPHATE CERAMIC COATINGS AS VANCOMYCIN CARRIERS

John M. Cuckler, MD; Paul Ducheyne, PhD; John Campbell, MD; Shulamith Radin, PhD
VA Medical Center, Philadelphia, PA 19104; University of Pennsylvania, Philadelphia, PA 19104

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A356-2RA)*

PURPOSE—Infection in the setting of total joint arthroplasty remains a challenging clinical problem. Attention has turned to developing methods of local delivery of antibiotics for prophylaxis. A method of loading antibiotics into calcium-phosphate ceramic coatings on titanium-alloy substrates which results in a system that slowly releases the therapeutic agent is more relevant to noncemented arthroplasty. We report the *in vitro* validation of a new, efficacious synthesis route to incorporate vancomycin into a calcium phosphate coating.

METHODOLOGY—Titanium alloy (Ti-6AI-4V) rods were cut into 12.5 mm diameter by 3 mm thick discs. Calcium-deficient hydroxyapatite was electrophoretically deposited onto the discs and sintered. Drug loading was carried out by several techniques. Solutions of vancomycin in a simulated physiologic solution (SPS) with ion concentrations similar to plasma were created. Coated titanium dics were then immersed in these drug-SPS solutions, varying both drug concentration (1 vs. 10 mg/ml. Groups I and II) and immersion time (6 vs. 24 vs. 72 hours vs. 72 total hours with fresh solution replacement every 12 hours. Groups III-VI). A second technique consisted of disc immersion in vancomycin 10 mg/mL in a (1:1) mixture of methanol and deionized water (Group VII). A third technique consisted of standard 24-hour immersion in vancomycin 10 mg/mL in SPS and then second-stage immersion in methanol containing vancomycin 1mg/mL and egg phosphatidylcholine (10 vs. 20 mg/mL, Groups VIII and IX). A fourth technique consisted of electrophoretically codepositing CDHA (2 percent w/v) and vancomycin (5 mg/mL) in isopropanol onto uncoated titanium alloy discs; these discs were not sintered (Group X). Functional efficacy was measured by plating elution aliquots versus *Staphylococcus aureus* by Mueller-Hinton agar and measuring zones of inhibition.

RESULTS—Both the controls and vancomycin-PMMA beads showed no release capable of inhibiting bacterial growth at any time point. The degree of bacterial inhibition varied with the concentration of vancomycin in the SPS immersion solution. Group II had statistically significant bacterial inhibition in I hour only, while Group I was not different from controls. Varying the time of immersion (Groups III-VI) yielded no statistical difference; all the groups had significant inhibition at 1 hour. The two lipid groups (Groups VIII and IX) had significant inhibitory effect at 1 and 24 hours compared to controls, while the 10 mg/mL EPC (Group VIII) was significantly greater at 72 hours. Both EPC concentration groups (Groups VIII and IX) have significant greater inhibition than the SPS immersion group at 24 hours and the 10 mg/mL EPC group (Group VIII) was significantly greater at 72 hours.

IMPLICATIONS—Several drug-loading techniques are effective and demonstrated superior release of vancomycin when compared to drug-laden PMMA. The high initial drug release with subsequent rapid decline indicates that simple absorption and desorption are the mechanisms at work. The time of effective drug release was limited to the first hour for the SPS immersion group, and the first 24 hours for the methanol immersion and coelectrophoretic deposition groups. The groups secondarily loaded with lipid yielded longer functionally effective release, up to 72 hours. The lipid coating may act to decrease water penetration and thereby retard desorption from the coating. The new synthesis route for incorporating antibiotics in controlled release calcium-phosphate coating represents a valuable approach to attaining clinically relevant drug release regimens.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Fracture toughness of titanium fiber reinforced bone cement. Topoleski LTD, Ducheyne P, Cuckler JM. J Biomed Mater Res 1992:26:1599-1618.

Effect of porous coating geometry on interfacial stress under a shear load. Wolfarth D, Ducheyne P. J Biomed Mater Res 1993:27:1585-9.

Microstructural pathway of fracture in poly(methyl methacrylate) bone cement. Topoleski LTD, Ducheyne P, Cuckler JM. Biomat 1993:14:1165-72.

Effect of changing the interfacial geometry on the fatigue strength of porous-coated Ti-6Ai-4V. Wolfarth D, Ducheyne P. J Biomed Mater Res 1994:28:417-26.

In vivo inflammatory response to polymethylmethacrylate particulate debris; the effect of size, morphology and surface area. Gelb H, Baker D, Schumacher R, Ducheyne P, Cuckler J. J Orthop Res 1994:12:83-92.

Comparison of the inflammatory response to particulate PMMA debris with and without barium sulfate. Baker DG, Lazarus MD, Schumacher HR, Ducheyne P, Cuckler JM. J Orthop Res. In press.

Effect of porosity and titanium fiber reinforcement on fatigue failure mechanisms in poly(methylmethacrylate) bone cement. Topoleski LTD, Ducheyne P, Cuckler JM. J Biomed Mater Res. In press.

In vivo and in vitro failure mechanisms of PMMA bone cement. Cuckler J, Topoleski T, Ducheyne P. J Bone Joint Surg. In press.

[281] FIBER REINFORCED POLYMER FEMORAL COMPONENTS FOR HIP ARTHROPLASTY

H. Del Schutte Jr., MD; Robert A. Latour Jr., PhD; Jonathan Black, PhD; John M. Kennedy, PhD
Department of Orthopaedic Surgery, Medical University of South Carolina Charleston, SC 29425-2239; Ralph A. Johnson VA Medical Center, Charleston, SC 29403; Departments of Bioengineering and Mechanical Engineering, Clemson University, Clemson, SC 29634

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A670-RA)*

PURPOSE—Carbon fiber reinforced polyetheretherketone (CF/PEEK) composite materials are currently being developed and evaluated as femoral components with reduced bending stiffness compared to metallic components as a means of achieving a noncemented hip replacement which does not induce severe bone resorption in the proximal femur. The prevention of proximal bone resorption following total hip arthroplasty should increase component life, reduce component revision rates, and enable successful revisions to be performed when necessary throughout a patient's life. These benefits are especially important today as hip joint replacement surgery is being conducted more frequently in patients less than 50 years of age.

In order to confidently design low stiffness composite femoral components using CF/PEEK composite, basic mechanical property data are needed for the material following long-term exposure in the *in vivo* environment. The purpose of this research program was therefore to conduct accelerated testing to determine the long-term mechanical property durability of CF/PEEK in a simulated *in vivo* environment (physiologic saline) to provide mechanical data necessary for component design.

METHODOLOGY—The CF/PEEK composite material evaluated in this research was AS4/APC2 (ICI Fiberite, Tempe, AZ). Test methods included fabrication of test samples of the fiber, matrix, fiber/matrix interface, and composite laminates followed by exposure of the samples to specified time-temperature treatments in either a dry or physiologic saline immersed environment. Exposure times evaluated were 1 hr, 100 hr, 300 hr, 1000 hr, 3000 hr, and 5000 hr. Exposure temperatures were 37°C, 65°C, and 95°C. Following environmental conditioning, samples were tested in room temperature air to determine strength and modulus. Fiber samples were tested for ultimate strength and modulus; matrix samples for tensile, compressive, and shear yield strength and modulus; interfacial bond samples for ultimate bond strength; and composite laminates for 0° and 90° tensile and compressive strength and modulus, and inplane shear strength and modulus.

PROGRESS—This research clearly demonstrates the extreme durability of this material system in a simulated *in vivo* environment and provides basic mechanical property data which is necessary for femoral component design. These results are very important for the development of more durable composite femoral components for hip joint arthroplasty with the potential for providing a longer lasting hip replacement system which is able to be repeatedly and successfully revised when necessary throughout a patient's life time. The development of improved femoral components will have direct benefit to the VA and the VA patient population by reducing the need for revision surgeries following hip joint arthroplasty.

RESULTS—Experimental results have shown that there is no significant difference in strength and modulus between any of the treatment conditions and the initial dry properties of the AS4/APC2 laminate material even following 5,000 hours post-saturation exposure in 95°C physiologic saline. The results of this research thus indicate that the dry properties of this CF/PEEK composite material can be confidently utilized in femoral component design to represent the mechanical properties of the material following long term physiologic saline saturation.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Long-term durability of interfacial bonding in carbon fiber/polyetheretherketone and carbon fiber/polysulfone composites following exposure to simulated physiologic saline. Meyer MR, Latour Jr RA. Trans Soc Biomater 1993:16:15.

Long-term compressive strength durability of carbon fiber reinforced PEEK composite in physiologic saline. Zhang G, Latour Jr RA, Kennedy JM, Schutte Jr HD, Friedman RJ. Trans Soc Biomater 1994:17:160.

Long-term shear strength durability of CF/PEEK composite in physiologic saline. D'Ariano MD, Latour Jr RA, Kennedy JM, Schutte Jr HD, Friedman RJ. Trans Soc Biomater 1994:17:184.

Effects of long-term saline exposure on the tensile properties of carbon fiber reinforced polyetheretherketone (PEEK). Klett LB, Kennedy JM, Latour Jr RA, Schutte Jr HD. In: Proceedings of the International Conference on Carbon, Carbon '94, 1994, Granada, Spain. In press.

Long-term durability of the interface in FRP composites after exposure to simulated physiologic saline environments. Meyer MR, Latour Jr RA, Schutte Jr HD, Friedman RJ. J Biomed Mater Res. In press.

[282] THE EFFECT OF AUTOLOGOUS BONE PASTE, HYDROXYAPATITE, AND BONE MORPHOLOGIC PROTEIN ON BONE FIXATION INTO POROUS COATED DEVICES

Aaron A. Hofmann, MD
Bone and Joint Research Laboratory, VA Medical Center, Salt Lake City, UT 84148; Division of Orthopedic Surgery, University of Utah School of Medicine, Salt Lake City, UT 84132

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—In the early 1980s, porous coated joint replacements were introduced for the treatment of younger, more active patients with arthritis and combat related joint injuries. The hope was to achieve reproducible skeletal fixation of the joint replacements through bone ingrowth into the porous structure of the implant and prevent the problems of failure with cemented implants.

It was soon demonstrated that reproducible bone ingrowth was not going to be easily obtained, and knowledge of the response of human bone tissue to porous coated implants was required if reproducible skeletal attachment was to be achieved.

The goal of this investigation was to develop a clinical model to investigate the use of autologous bone paste, hydroxyapatite, and bone morphologic protein to improve and assure reproducible bone fixation into porous coated devices. The human model developed by Hofmann, et al. recently received the International SIROT Prize for excellence in orthopedic research.

METHODOLOGY—This IRB approved clinical model seeks patients with bilateral knee arthritis to consent to the placement of small porous coated cylinders in the contralateral condyle of the femur after the first total joint arthroplasty procedure is completed. Weeks to months later, depending on the patient needs, the implant cylinders and surrounding bone are removed and analyzed for bone ingrowth and the rate of bone remodeling measured. The bone containing the cylinders is normally resected and discarded. This procedure does not compromise the total joint replacement.

RESULTS—The results showed that bone formed slowly at 1 μm/day whether autologous bone grafts or hydroxyapatite were used (1 μm/day). Although the bone mineral apposition rate was 25 percent faster at the interface, compared to the peripheral bone, this data did not support that bone ingrowth could be achieved within 4-12 weeks as previously reported.

The results of these studies have helped orthopedic surgeons after the postoperative therapy to limit patient activity during the bone ingrowth phase for the first six months of implantation. The application of the autologous bone graft at the interface has shown the reproducible bone ingrowth can be achieved clinically in porous coated implants.

FUTURE PLANS—Future studies are required to determine if the rate of bone ingrowth can be accelerated and if gaps can be bridged with bone

stimulating therapies such as bone morphogenic protein.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Bone ingrowth into porous-coated tibial components implanted with autograft bone chips: analysis of ten consecutively retrieved implants. Bloebaum RD, Rubman MH, Hofmann AA. J Arthroplasty 1992:7(4):483-93.

Microscopic analysis of autograft bone applied at the interface of porous-coated devices in human cancellous bone. Hofmann AA, Bloebaum RD, Rubman MH, Bachus KN, Plaster R. Int Orthop (SIROT Prize) 1992:16(4):349-58.

Comparative study of human cancellous bone remodeling to titanium and hydroxyapatite coated implants. Hofmann AA, Bachus KN, Bloebaum RD. J Arthroplasty 1993:8(2):157-16.

Mineral apposition rates of human cancellous bone at the interface of porous coated implants. Bloebaum RD, Bachus KN, Momberger NG, Hofmann AA. J Biomed Mater Res 1994:28(5):537-44.

C. Knee Implants

[283] ALL-PLASTIC TOTAL KNEE REPLACEMENT

Myron Spector, PhD; Edward J. Cheal, PhD; Sarah L. Trilling; Tae Kang
Brigham & Women's Hospital, Boston, MA 02115; Harvard Medical School, Cambridge, MA 02115; West Roxbury VA Medical Center West Roxbury, MA 02132

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A217-3RA)*

PURPOSE—The major problem in total joint replacement today is wear of the polyethylene component that serves as the articulating surface. In total knee replacement prostheses, particulate debris is generated as a result of adhesive, abrasive, and fatigue wear mechanisms. The goal of this project is to develop a total knee replacement made entirely from carbon fiber reinforced polymeric (CFRP) or silicone carbide composites. These devices will be more resistant to wear than the ultrahigh molecular weight polyethylene (UHMWPE) that is currently employed as the articulating surface. These devices also will be more flexible than currently used metallic components and should result in less osteopenia of underlying bone due to stress shielding.

PROGRESS—The design of the distal femoral component for the canine all-plastic total knee replacement has been completed. A prototype implant was produced using stereo lithography for *in vitro* evaluation of the geometric fit and for testing of surgical instrumentation. We have selected a three-dimensional carbon fiber composite material for production of the implants; the implants will be produced by a local materials manufacturer in a cooperative agreement. A three-dimensional finite element model was generated of the distal femur of a Labrador-type dog. A second finite element model was then developed by incorporating the prosthesis into the model of the intact distal femur. Finally, tribological studies using pin-on-disk and reciprocating wear tests have been performed on various material combinations, including CFRPs with different fiber orientations on polyetheretherketone (PEEK) and E.

METHODOLOGY—The geometry of the canine femoral component was generated using computer-assisted design (CAD) techniques. The design was based on the same geometry as that used for generation of the finite element model. Patran, on a Sun SparcStation, was used to define the solid model of the prosthesis. Three-dimensional finite element modeling techniques were used to analyze the structural behavior of the canine distal femur with and without the composite prosthesis. The geometry of the finite element model was digitized from direct sections of the femur. The material properties were determined using quantitative computed tomography (QCT) images and custom computer software. Due to the lack of published data on the loads in the canine knee, we assumed that femoral contact loads in the dog were similar to the femoral contact loads in the human, scaled to body

weight, with the contact areas and locations adjusted for the canine anatomy.

A three-dimensional carbon fiber composite material will be used for constructing the femoral component. Carbon fiber laminates were first considered, but these laminates suffer from inadequate out-of-plane strength, and thus a tendency for delamination. This problem is particularly acute for curved shapes, such as the femoral component of a total knee replacement. The three-dimensional composite has much better out-of-plane strength due to the additional fibers running in the third dimension. The matrix material will be a biocompatible polymer (PEEK) or silicon carbide, depending on the mechanical and wear properties resulting from studies in progress.

Two types of tribological tests are used for assessing the wear properties of various material combinations: pin-on-disk, using a fixed pin against a rotating disk, and reciprocating motion, using a cylinder against a stationary flat surface. The wear rates and friction coefficients are measured during the tests. The resulting particles and wear surfaces are evaluated quantitatively using various techniques, including scanning electron microscopy (SEM).

RESULTS—The canine femoral component has anatomic surface shapes for the tibial and patellar articulations. We assumed symmetry of the prosthesis about a sagittal plane through the center of the intercondylar notch, to avoid separate right and left components, and thus simplify manufacture of the prosthesis. For ease of implantation, the inner surface of the component consists of five flat surfaces. These surfaces were located so as to minimize bone resection. A single cylindrical peg was added for fixation and stability of the implant. The peg had a circular cross section with a diameter of 5 mm and a length of 25 mm.

The tribological investigation conducted to date has demonstrated that carbon fiber reinforced PEEK composites yield significantly less wear than LYHMWPE when rubbed against cobalt chromium ally specimens in a reciprocating wear test apparatus.

FUTURE PLANS—The next step of the project will be to complete the design of the tibial component. This component will have one cylindrical peg. The plateau will be 8 mm thick. The distal side of the plateau will be corrugated to enhance fixation using PMMA bone cement. There will be a posterior notch in the plateau to allow the posterior cruciate ligament to be saved during surgery.

The finite element models of the intact distal femur and the femur with the composite prosthesis will be analyzed. Separate analyses will then be performed for cobalt chromium, titanium alloy, and carbon fiber-reinforced composite materials.

The tribological studies will be continued to determine which specific composite material is the most resistant to wear. Three-dimensional carbon fiber reinforced PEEK and silicone carbide specimens will be rubbed against counter faces of the same materials and against cobalt chromium alloy. Couples of cobalt chromium and UHMWPE will serve as a control.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Comparative study of carbon-polymer composite and titanium femoral stems in dogs using computed tomography. Cheal EJ, Grierson AE, Reilly DT, Sledge CB, Spector M. In: Jamison RD, Gilbertson LN, eds. Composite materials for implant applications in the human body: characterization and testing, ASTM STP 1178 Philadelphia: American Society for Testing and Materials, 1993:4-16.

[284] TIBIO-FEMORAL CONTACT STRESS AND STRESS DISTRIBUTION EVALUATION OF TOTAL KNEE REPLACEMENTS

John A. Szivek, PhD
Orthopedic Research Laboratory, Department of Surgery, College of Medicine, University of Arizona, Tucson, AZ 85724

PURPOSE—Polyethylene wear threatens to be the limiting factor in the lifetime of total knee systems. Results using Fuji film to determine the contact stresses in tibial inserts are not in agreement with clinical retrieval studies. Consequently, variables which affect the measurements were examined while

testing six total knee systems. Wear studies currently have been done at room temperature at relatively low loads, and suggest that some components are operating at stress levels which would not result in wear. However, these tests do not accurately represent *in vivo* conditions.

METHODOLOGY—A knee loading fixture was constructed to load a femoral and matching tibial component at a 0°, 15°, and 60° flexion angle on a MTS servohydraulic testing machine. Femoral components were placed onto synthetic fiber-reinforced epoxy "bones" with stiffness characteristics similar to human bone and were aligned to a 5° varus angle. Tibial components were placed horizontally in blocks with the stiffness of the tibial cortical rim.

Components tested were an AMK, MGII, Omnifit, Ortholoc II, PFC, and PCA II. Each knee system was tested at 0°, 15°, and 60° of flexion with loads of 68 and 204 kg. Inserts were heated and tested at 24°C, 37°C, and 55°C. Fuji contact prints were made and imported with a video camera into a Macintosh computer using image analysis software provided by NIH. Areas and moments of inertia were calculated. The ratio of the moments of inertia about the sagittal and lateral planes through the insert represent asymmetry of contact of the contact areas.

RESULTS—Contact areas increased non-linearly with load. Flexion angle did not affect the lateral contact areas but did affect the medial. The highest medial contact areas were noted at the 15° test angle. Comparison of the lateral and medial contact areas indicated that the lateral areas were smaller at 60° flexion for the Omnifit, Ortholoc II, and the PFC but unchanged for the AMK, MG II, and the PCA II.

Contact stresses decreased linearly as temperature increased suggesting that testing should be carried out at physiological temperatures to provide accurate measurements. Flexion angle had less marked effects in the AMK, MG II, Omnifit, and PCA II than in the Ortholoc II and PFC. Contact stresses were 12 to 28 MPa. The fatigue strength for UHMWPe is 10 MPa. The variations in stress with flexion angle and the magnitude of the stress suggest that fatigue will cause all components to wear to a similar extent.

Moment of inertia calculations indicated that implants similar to the PCA II have a circular contact geometry, while those similar to the MG II have an oblong contact geometry. The ratios of the moments which described the contact asymmetry were different for the lateral and medial compartments, and were unaffected by temperature changes. Comparison of asymmetry at 15° flexion to 60° flexion indicated that not all components load the same region of the tibial insert throughout the range of motion of the component. At 15° the lateral compartment contact asymmetry ratios for the components at 204 kg load at 37°C were: 4 for the Ortholoc II, 3 for the PFC, 40 for the AMK, and 2 for the PCA II. Components which bear on the same region throughout the range of motion and have high contact stresses such as the PCA II will show focal wear, while those that showed variations in contact asymmetry are likely to experience more generalized wear.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Tibio-femoral contact stress and stress distribution evaluation of total knee replacements, Szivek JA, Cutignola L, Volz RG. Philadelphia: American Knee Society, 1992.

D. Arthritis

[285] DIAGNOSIS OF CARTILAGE DEGENERATION: QUANTITATIVE SURFACE SPECTROSCOPY

Alan J. Grodzinsky; Eliot H. Frank; Scott I. Berkenblit; David L. Bombard
VA Medical Center, West Roxbury, MA 02132; Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A656-RA)*

PURPOSE—The goal of this project is to develop a new technology for nondestructively detecting certain physical and biochemical changes in cartilage that occur at the early stages of degenerative joint disease (osteoarthritis). Our device consists of an electromechanical probe that is placed on the surface of the cartilage. Injection of a very small electric current by the probe produces a mechanical stress within the tissue that is detected by a sensor; the magnitude and phase of the output stress reflect the tissue composition, integrity, and function. Ultimately, this device is intended for use in a diagnostic instrument capable of detecting focal cartilage degeneration at the time of arthroscopy or during open surgical procedures.

PROGRESS—Over the past two years, we have quantified the ability of the spectroscopic probe to detect changes in tissue properties produced by either chemical modification of the tissue or enzymatic digestion (as a model for cartilage degeneration). In addition, we have quantified the dependence of the mechanical stress on the imposed spatial wavelength and have begun to investigate the ability of multiple-wavelength spectroscopy to spatially localize focal regions of degradation. We are currently incorporating the probe into a device for making measurements on intact joints.

METHODOLOGY—The prototype surface probe is a 4 mm×4 mm multilaminated structure. Small-amplitude sinusoidal currents are applied to the surface of bovine cartilage discs *in vitro* via photoetched silver/silver chloride electrodes; the resulting current-generated stress is measured by a piezoelectric sensor and analyzed by a computer.

One of the early events in osteoarthritis is the loss of highly charged proteoglycan (PG) molecules; the loss of electrical interactions associated with proteoglycans results in decreased compressive stiffness of cartilage and decreased current-generated stress response. We simulate the loss of PGs *in vitro* by neutralization of electrical interactions by titration of tissue pH and by selective enzymatic extraction of charge groups using trypsin. To simulate the nonuniform loss of PGs characteristic of early osteoarthritis, we expose calf cartilage-bone plugs to trypsin such that the enzyme can only diffuse in from the articular surface. These specimens are then tested with probes having long-wavelength and short-wavelength electrode configurations.

RESULTS—Stress amplitude decreased markedly as the pH was lowered from 7, reaching a minimum near the isoelectric pH (the point at which the tissue has zero net charge). Trypsin digestion led to a 70 percent reduction in stress amplitude after 20 hours, as compared to a 20 percent reduction in trypsin-free controls. Thus, surface measurement of current-generated stress appears to be a sensitive indicator of molecular-level degradative changes.

The depth to which current penetrates into the tissue is proportional to the imposed spatial wavelength (defined as twice the electrode spacing). Thus, with widely spaced electrodes, full-tissue penetration is achieved, while with more closely spaced electrodes, current remains confined to the superficial region. Measurements made using the long- and short-wavelength probes showed that the measured stress amplitude was proportional to the imposed wavelength and inversely proportional to

the frequency of the applied current. These results, which are qualitatively consistent with a theoretical model, comprise a spectroscopic signature of normal tissue.

Surface digestion of cartilage with trypsin resulted in progressive loss of PGs, proceeding inward from the surface (as assessed by histological staining and biochemical analysis). A specimen that was digested with trypsin for 2 hours was tested with both the short- and long-wavelength probes. The short-wavelength response (in which current was essentially confined to the degraded region) was less than 10 percent of the long-wavelength response (in which current could penetrate more deeply to the underlying normal tissue), as compared to a ratio of 40 percent in normal tissue. Thus, the marked reduction in the ratio of short- to long-wavelength response distinguishes partially degraded tissue from normal.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Probe, system and method for detecting cartilage degeneration. Frank EH, Salant EP, Grodzinsky AJ, inventors. US Patent 5,246,013 1993.

Quantitative assessment of cartilage degradation via nondestructive surface electromechanical spectroscopy. Berkenblit SI, Frank EH, Grodzinsky AJ. Trans 40th Orthop Res Soc 1994:19:214.

Electrokinetic methods for arthroscopic detection of cartilage degeneration in synovial joints. Berkenblit SI, Frank EH, Bonassar LJ, et al. In: Proceedings of the IEEE Engineering in Medicine and Biology Society 16th International Conference, 1994. In press.

Molecular electromechanics of cartilaginous tissues and polyelectrolyte gels. Berkenblit SI, Quinn TM, Grodzinsky AJ. J Electrostatics. In press.

Nondestructive detection of cartilage degeneration using electromechanical surface spectroscopy. Berkenblit SI, Frank EH, Salant EP, Grodzinsky AJ. J Biomech Eng. In press.

XI. Orthotics

[286] ADJUSTED VS. UNADJUSTED FOOT ORTHOSES IN THE PREVENTION OF FOOT ULCERS IN DIABETICS

Stephen F. Albert, DPM
VA Medical Research Center, Denver, CO 80220

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A607-RC)*

PURPOSE—Fifteen percent of all diabetics develop some type of foot ulcer. The foot is the most frequent site of infection among individuals hospitalized for diabetes and infection, and these infections account for more in-hospital days than any other complication of diabetes. Not uncommonly, foot ulceration leads to infection and/or amputation. Other factors not withstanding, pre-ulcerative and ulcerative foot lesions in diabetics invariably occur at weight-bearing sites with maximum pressure. There is evidence to suggest that custom foot orthoses mitigate such pressures.

In our study, we examined: 1) whether individually adjusted custom foot orthoses (based on in-shoe sensor measurements) reduce the incidence of foot ulcerations and/or pre-ulcerative foot lesions; 2) whether objective measurements confirm that foot orthoses effectively redistribute plantar foot pressure; and 3) whether rigid foot orthoses need adjustment over time.

METHODOLOGY—We randomized 62 ambulatory type I and II diabetic patients, considered at risk for foot ulceration, into one of two groups each of which received extra-depth shoes, rigid orthoses and socks. Utilizing in-shoe plantar foot pressure measurements via the F-Scan system (Tekscan, Boston, MA), only one group received adjustments to their foot orthoses. Adjustments were intended to redistribute and reduce plantar foot pressures. Subjects were followed monthly and received basic diabetic foot care and assessments at each visit.

PROGRESS—Project funding has ended. A few subjects previously and currently enrolled are being followed. No significant differences were noted between the two groups in regard to weight-bearing foot ulcer formation. Objective measurements showed significant redistribution of plantar foot pressures. Details will be presented in an article accepted for publication in the Journal of Foot Surgery. A review of subject F-Scans at 12 months revealed no discemable degradation of foot orthotic function requiring adjustment or replacement.

RESULTS—As stated above, skin ulcers occur on diabetic feet and commonly lead to infection. Although the study did not show significant differences between the two groups at risk, a preliminary review of a subset of the subjects who were at risk for re-ulceration suggests a correlation with reduction of plantar pressures and rate of re-ulceration. This data is currently being analyzed with intent to publish.

The study did show that the F-Scan system was capable of quantifying and verifying redistribution of pedal pressures within shoes.

FUTURE PLANS—Given the magnitude and costs associated with diabetic foot ulcers, infections and amputations, the use of in-shoe foot pressure scanning technology warrants further study to identify and implement enhanced diagnostic and therapeutic strategies for pedal complications of diabetes mellitus.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Diabetic foot pressure studies, comparison study of patient-selected shoes vs. clinician-selected shoes. Albert SF, Christensen L. Lower extremity 1994:1(1):21-7.

[287] COMPUTER-AIDED DESIGN AND COMPUTER-AIDED MANUFACTURING OF ORTHOPEDIC FOOTWEAR

Vern L. Houston, PhD, CPO; Carl P. Mason, MSBE; Edward J. Lorenze, MD; Martin Mussman, DPM, DABPPH; Kenneth P. La Blanc, BA, CPO; Mary Anne Garbarini, MA, PT; Jacqueline Helt, RN; Hans Richard Lehneis, PhD, CPO

New York University Medical Center, New York, NY 10021; Podiatric Medical Service, VA Medical Center, Montrose NY 10548; VA Medical Center, New York, NY 10001

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A674-RA)*

PURPOSE—The objective of this project is to develop a clinically effective and efficient pedorthic computer-aided design and computer-aided manufacturing (CAD/CAM) system that will quantify, automate, and expedite the design and manufacture of custom orthopedic footwear for US veteran pedorthic patients.

METHODOLOGY—To achieve this objective, the following research protocol has been established:

We shall sample 250 representative patients of the 10,000 pedorthic patients whose lasts, patterns, and medical/podiatric records are on file in the NY DVAMC PTC Orthopedic Shoe Service (OSS), digitize the lasts, shoe patterns, (and when available, foot casts), of the 250 sampled patients, together with the stock, library lasts from which their custom orthopedic lasts were fabricated, and compile the data thus obtained with the information available on the patients' medical, podiatric, biomechanical, and orthotics pedorthics conditions and characteristics in a computerized relational database. We shall then develop an intuitive, user friendly, functional, clinically effective, and efficient pedorthic CAD/CAM system satisfying DVA PSAS OSS needs. Under an analysis of the data compiled above, we shall establish last, inlay, and shoe structural component design principles, and derive parametric means for the most common modifications and design features identified among the sampled patients for use as CAD system initial (default) values. Finally, we shall conduct limited clinical tests of the pedorthic CAD/CAM system developed to identify those areas/features that are successful and those that require further research and development.

PROGRESS—Since the project began in April 1993, the custom orthopedic lasts, and the stock library lasts from which they were derived, for 146 patients have been digitized using the NY DVAMC Rehabilitation Engineering Research optical laser digitizer. To date, pairs of shoe upper patterns for 28 of these patients have also been optically digitized. The medical, podiatric, biomechanical, and orthotics pedorthics information available in NY DVAMC PTC OSS files for these patients has been entered into the project computerized relational database.

The Vorum Research LastfitTM CAD system, and the Tekscan, Inc. F Scan plantar pressure measurement system have been procured and thoroughly tested and evaluated. Development has begun on adapting and enhancing these systems to meet DVAMC OSS needs. Initial testing of the project's pedorthic CAD system developments with two veteran research subjects has begun.

FUTURE PLANS—Continued development and enhancement of the project pedorthic CAD system is planned. Research in orthopedic shoe upper and sole CAD pattern design, engineering, and styling, and CAM is also planned. In addition, utilization of the results and knowledge obtained in this project, together with results obtained by the investigators in their other research in tissue mechanical property characterization, measurement of static and dynamic loading, and foot/ankle biomechanics, is planned for development of new, improved, biomechanically based orthopedic footwear designs.

[288] BIOMECHANICAL OPTIMIZATION OF LOWER LIMB ORTHOSES USING DYNAMIC SURFACE POLYELECTROMYOGRAPHY

Rahamim Seliktar, PhD; Alberto Esquenazi, MD; Mukul Talaty; Barbara Hirai
Biomedical Engineering & Science Institute, Drexel University, Philadelphia, PA 19104; Moss Rehabilitation Hospital, Philadelphia, PA 19141

Sponsor: *Post Polio Clinic, Albert Einstein Medical Center; Calhoun Fellowship Endowment of Drexel University, Philadelphia, PA 19104*

PURPOSE—Reduced motor function in the lower limbs may compromise an individual's ability to ambulate. Ability is often enhanced through the use of a passive orthotic device. Orthoses alter the force distribution, provide support and/or restrict motion of the anatomical joints and thereby can make walking more safe and energy efficient if they are properly adjusted. Electromyography (EMG) is a measure of muscle activity, and may be useful to determine an optimal alignment, one where residual motor function is used as efficiently as possible yet undue stress to the joints and unsafe walking is avoided. Prior clinical observations indicate that surface electromyography may be sensitive enough to discriminate between small changes in muscle activity due to different orthotic alignments.

METHODOLOGY—Preliminary experimental work was performed in the Gait & Motion Analysis Laboratory at Moss Rehabilitation Hospital. Four normal subjects were fitted with ankle-foot orthoses; surface EMG was collected for five muscles on each subject in three orthotic alignment conditions and one control condition. EMG and footswitch data were sampled at 1000 Hz; the footswitch was used for stride identification. EMG activity for all the strides (usually $^{1}10$) for a given muscle, a given subject, and a given test condition were rectified, low pass filtered, and averaged to create an ensemble average EMG profile. The profile of a given condition (alignment) could thus be compared to that of another condition, and a visual assessment of muscle activity changes could be made. Statistical analysis of integrated EMGs were used as a more objective criterion for assessing muscle activity changes as alignment varied.

PROGRESS—Ultimately, it is desired to determine whether or not integrated EMG profiles as a measure of muscle activity, heart rate as an estimate of metabolic energy, and patient evaluation indicate the same orthotic alignment to be optimal for a given population. To date, the correlation between alignment variations and statistical changes in muscle activity have been shown in normal subjects. Furthermore mechanically restricted joint motion and the resultant lower limb dynamics change the activation onset and duration of gait related muscles. Thus, demands on muscles that normally exert forces about a joint are changed if that joint does not undergo its usual range of motion. Muscle activity changes observed have agreed with biomechanically predicted changes based on this rationale.

RESULTS—A correlation between surface EMG and orthotic alignment has been documented. Moreover, there is evidence of agreement between the biomechanically predicted changes in muscular activity, as a result of constraining the ankle in an ankle-foot orthosis and the actual muscular activity as obtained from the EMG measurements. One of the test conditions completely prohibited dorsiflexion. Analysis of the ensemble average EMG profile of the soleus muscle showed its phasic activity was reduced in this case as compared to the control run without motion restraint. Both results further suggest the validity of using EMG to fine-tune orthotic alignment.

FUTURE PLANS—Further testing is currently underway on a pathological population to determine whether similar EMG-alignment correlation holds, and whether there is a change in overall energy expenditure for varying orthotic alignment conditions. Coupled with a questionnaire, this information may be used to find an optimal orthotic alignment. A more thorough mathematical biomechanical model which shows the effect of a brace on joint moments is also being developed to verify clinical findings.

[289] MODULAR CUSTOM-FITTING ANKLE-FOOT ORTHOSIS

Stephen Naumann, PhD, PEng; Michael Lee, PhD; John Wedge, MD, FRCS(C); Greg Belbin, CO(C); Mercer Rang, MBBS, FRCS(C); Jonathan Kofman, MASc, PEng; Mendal Slack, BSc(HK), CO(C); Elizabeth Sheil, MASc; Henri Costa, BASc; Branka Maric, MSc, PEng; Steve Ryan, BESc, PEng; Dennis Smith, DSc, PhD, FRSC; Ralph Brink
The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8; Centre for Biomaterials, University of Toronto, Toronto, ON M5S 1A4; The Hospital for Sick Children, Toronto, ON M5G 1X8

Sponsors: *The Ontario Rehabilitation Technology Consortium funded by the Ontario Ministry of Health and The Hospital for Sick Children Foundation*

PURPOSE—The current method of producing custom ankle-foot orthoses involves taking a negative plaster cast of the shank-foot, forming a plaster positive mold, and vacuum-forming a high-temperature thermoplastic sheet over the mold. This method is labor-intensive, generally requiring two client visits before orthosis delivery, and results in high costs. The aim of this project is to develop a modular ankle-foot-orthosis which can be fitted to a client in a single 2-3 hour visit at a lower cost than the present process. A material will be developed which can be formed as a prefabricated blank in the general form of an orthosis that can be custom-formed directly on the client's limb.

PROGRESS—A digitizer for foot-ankle mold shape measurement has been designed and fabricated. Material strains and ground reaction forces have been measured in gait trials of subjects wearing conventional orthoses instrumented with strain gauges. Orthosis deformation patterns to be used in fatigue testing of prototypes have been determined based on the strain/gait data. Mechanical properties of candidate materials are currently under investigation. Flexural and tensile tests have been carried out on a number of different materials. New materials are being modified to have similar mechanical properties to polypropylene. These properties include strength, stiffness, and toughness.

FUTURE PLANS—Prototypes made using the new material will be subjected to mechanical testing. Clinical testing to optimize fitting procedures will then take place followed by clinical evaluation to assess the effect of the new orthosis on ambulation.

[290] ANALYSIS OF A PAEDIATRIC ANKLE-FOOT ORTHOSIS

Kimberley Parker, BASc; Stephen Naumann, PhD, PEng; William L. Cleghorn, PhD, PEng
Human Movement Research Program, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsor: *Natural Sciences and Engineering Research Council*

PURPOSE—Approximately 53,000 ankle-foot orthoses (AFOs) are prescribed for children with neuromuscular disorders in North America annually in order to compensate for the impaired system and maximize functional activities. The current thermoplastic AFO fabrication process is lengthy and labor-intensive requiring at least two visits by the client for fittings resulting in an expensive orthosis. Paediatric orthoses require replacement or adjustments every 6 to 12 months: due to the lengthy fabrication process many of these children spend 25 percent of their usage time in improperly fitted orthoses. There is the need for the development of a modular ankle-foot orthosis (MAFO) that can be prescribed in a single visit at a lower cost.

METHODOLOGY—Specifically this project will deal with two objectives. The first is to determine the mechanical loads on the AFO during activities such as walking, running, and jumping. Initial investigation into the pressure distribution on all surfaces of the orthosis will give the required loading conditions for the finite element analysis. Data collection will be performed at the HMRC in the gait laboratory with at least two individuals

from each of the orthotic needs populations of spina bifida and cerebral palsy.

The second objective is to undertake a finite element analysis of the AFO. This will be done using the computer software package I-DEAS to enable a more efficient design process. The finite element analysis will predict the type, location, and magnitude of stresses and deflections. This analysis will determine the effects of varying AFO geometry, modification of the design in areas of low stress and design constraints in terms of thickness. Implementing different material combinations into the developed model will enable prediction of the required thickness and behavior of the AFO under typical loading conditions which will significantly aid in the development of the MAFO.

FUTURE PLANS—This research project focuses specifically on using the currently available rigid polypropylene AFO as the ideal orthosis for children with neuromuscular disorders such as cerebral palsy and spina bifida. An analysis will be performed to determine the effects of the geometry on the performance and characteristics of the AFO which will further enable evaluation of the behavior of new materials and material combinations used in the MAFO.

RECENT PUBLICATIONS RESULTING FROM THIS WORK

Strain and deformation in ankle-foot-orthoses during gait. Kofman J, Sheil E, Slack M, et al. In: Proceedings of the 2nd World Congress of Biomechanics, Amsterdam, 1994. In press.

[291] ADVANCED CONTRACTURE REDUCTION ORTHOSIS (CRO)

Tom Lunsford; Jack Greenfield; Susan Rouleau; Elizabeth Wyckoff; David Furumasu; Mark Hoffer, MD; Don McNeal, PhD
Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The purpose of this project is to develop a contracture reduction orthosis (CRO) which is effective in reducing contractures and shortening treatment time. The concept is based on the use of a powered orthosis to slowly stretch the contracted tissues until a predetermined resistance (set by the clinician) is met. Stretch is maintained for a preset period, then the actuator backs off to allow the tissues to relax. This is repeated automatically as often as desired. All of the parameters of operation for the CRO are programmed by the clinician. This project is being conducted by the RERC on Technology for Children.

PROGRESS—It was decided to first develop a CRO for knee flexion contractures. Nine patients have been treated for knee contractures. This includes five children with cerebral palsy, one with traumatic brain injury, two with spinal bifida, and one with severe burns. Based on experience gained with these patients, additional improvements have been made to the CRO system. Adjustable plaster splints with polycentric knee joints are being made for each subject to try to maintain gains achieved during treatment sessions. Patients are instructed to wear the splint each night. The CRO has been modified so the splint, with an adjustable knee lock mechanism, becomes the supporting structure for the limb in the CRO. This has reduced the setup time required for each treatment session and ensures a better grasp on the leg for the applied forces.

RESULTS—Results with the CRO have been mixed. Contractures were completely reduced in three of the nine patients, little or no gain was observed in five, and one patient was withdrawn from the program because of surgery unrelated to the contracture. The difference in the two groups seems to be the degree of muscle tone in the treated limb. The three that had successful results, had low to normal tone; the five that were unsuccessful had a high degree of muscle tone.

In all cases, significant gains in range are obtained during the treatment session. The problem is much of this is lost between treatments despite the use of a splint at night. The average gain in range of motion per session in the successful group was 4.0 degrees. Half of that, 2.0 degrees on the average,

was lost between sessions. Even greater gains, 8.9 degrees on the average, were observed in the unsuccessful group, but they lost all of that, 9.1 degrees on the average, prior to the next session.

This problem has been compounded by our inability to treat patients with the CRO on a daily basis. Our original protocol called for daily treatments; the assumption being that all or most patients would be in-patients. This assumption proved to be incorrect, and all patients participating in the program have been out-patients. Because of problems with transportation to the hospital, this has limited treatment sessions to one or two per week. It is not known whether increasing the number of sessions would have made any substantial difference in our results to date other than to perhaps accelerate treatment in those with successful results.

In the last year an upper extremity device has been developed which will work with either a flexion or extension contracture of the elbow. The device consists of a forearm and humeral trough connected by a mechanical elbow joint. The arm troughs are easily changed to accommodate differences in sizes. They are supported on an adjustable stand which can be placed next to the patient's wheelchair. The motor and drive assembly are mounted below the arm troughs with a cable attachment to a pulley located at the elbow. This arrangement allows easy positioning of the patient's arm for treatment. The electronics and pressure sensors are the same as the lower extremity unit.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Advanced contracture reduction orthosis (CRO). Lunsford TR In: Proceedings of the 19th Annual Symposium of the American Academy of Orthotists and Prosthetists; Las Vegas, NV: 1993:5.

[292] LIGHTWEIGHT, COSMETIC, ARTICULATING ANKLE-FOOT ORTHOSIS

Tom Lunsford; Jack Greenfield; Jan Furumasu; David Furumasu; Mark Hoffer, MD; Don McNeal, PhD
Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The purpose of this project is to develop a lightweight, cosmetic, articulating ankle-foot-orthosis (AFO) that restrains dorsiflexion but permits unencumbered plantarflexion. Allowing free plantarflexion from neutral accommodates the loading response and permits a smooth transition from swing to stance without the knee flexion thrust that accompanies a rigid system. Currently there is no acceptable AFO design that meets the needs of children whose calf strength is below normal while anterior compartment strength and proprioception are within normative range. Practitioners must provide either a conventional metal AFO with dual adjustable ankle joints or a totally rigid or totally flexible plastic AFO. Each of these choices presents objectionable qualities. This project is being conducted by the RERC on Technology for Children.

PROGRESS—Static and dynamic tests of a standard rigid AFO and five articulating AFOs have been completed. The static tests documented the resistance to dorsiflexion of each articulating joint compared with a standard rigid AFO. At the suggestion of our research advisory committee, the posterior entry floor reaction AFO was added to the test orthoses. We chose 3/16th inch polypropylene to provide maximum rigidity. This orthosis was compared in static tests to the 1/8th and 3/16 inch polypropylene standard AFOs. Each AFO configuration has been cycled over 1,000,000 times without catastrophic failure in either the joints or the adjacent plastic. An article describing the results of these tests has been accepted for publication.

The one rigid and three articulating AFOs (the Gillette with a posterior restraining strap, the Gaffney with a limit motion stop, and the Rancho with an adjustable planter/dorsiflexion stop) were selected for a clinical study to show whether the articulating AFOs are as capable as the rigid AFO at preventing excessive terminal stance dorsiflexion in children with a weak calf. Additionally, it will show if the Rancho AFO is more capable than the other

two articulating systems at preventing excessive terminal stance dorsiflexion. Finally, a comparison is being made to determine if the articulating AFOs present a less demanding loading response than the rigid AFO.

Instrumented gait analysis has been performed on five subjects with flaccid paralysis of the plantar flexors but strong dorsiflexors. Subjects ranged in age from 5 to 12 years with diagnosis of either incomplete cauda equina lesion or Guillian-Barré. Gait analysis included footswitch stride analysis, surface EMG of the medial and lateral quadriceps and hamstrings, three-dimensional motion analysis, and joint torques measured through ground reaction forces.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Pediatric plastic AFO research. Lunsford TR. In: Proceedings of the 19th Annual Symposium of the American Academy of Orthotists and Prosthetists, Las Vegas, NV: 1993:29.

Viscoelastic properties of plastic pediatric AFOs. Lunsford TR, Ramm T, Miller JA. J Prosthet Orthot 1994:6(1):3-9.

[293] CORRECTIVE HEAD ORTHOSIS FOR THE TREATMENT OF OCCIPITAL PLAGIOCEPHALY

Edward D. Lemaire, MSc; Yvonne Jeffreys, BSc(Eng), CO(C); Enrique C. Ventureyra, MD, FRCS(c), FACS; Michael J. Higgins, MD
The Rehabilitation Centre, Ottawa, ON K1H 8M2; Children's Hospital of Eastern Ontario, Ottawa, ON K1H 8L1

Sponsor: *None listed.*

PURPOSE—During the human growth cycle many infants develop head deformities from premature fusion of isolated skull areas. Since the fused bones limit growth in one region, an infant's head will grow in a non-symmetrical fashion. A corrective/protective head orthosis will be developed to influence realignment of an infant's skull. The headgear will be used by itself to correct small head deformities and used in conjunction with surgery to protect the surgical site and to influence head shaping during recovery.

METHODOLOGY—A custom head orthosis has been designed using the following steps: Obtain a bivalve cast of the infant's head, fill the cast with plaster, modify the positive model by removing plaster at areas of excessive protrusion and adding material at areas of excessive depression, vacuum form a polypropylene shell with a pelite liner over the positive, trim the head orthosis to the client specific trim lines, add attachment and chin straps, finish and fit to the infant. A horizontal alignment pin can be added during the molding process to maintain transverse position.

In some cases a cotton liner was added and/or ventilation holes were drilled through the plastic to deal with perspiration related problems. A snug fit was ensured, with relief for depressed areas and pressure application on the elevated areas without causing persistent redness or swelling. The head gear should not rub the eyes, ears or neck.

RESULTS—Initial clinical use of this device has produced satisfactory results; however, a controlled investigation of the effects of this non-traumatic intervention is required before the success of this device can be outlined.

FUTURE PLANS—A controlled investigation of the shape modification achieved by using a head orthosis on infants with skull deformity will be initiated. This study will quantitatively compare the amount of correction achieved over a one year period for a sample of infants with lambdoid craniosynostosis.

XII. Psychological and Psychosocial Disorders

[294] SEXUALITY ISSUES AMONG WOMEN WITH PHYSICAL DISABILITIES

Margaret A. Nosek, PhD; Diana Rintala, PhD; Mary Ellen Young, PhD; Catherine Foley, PhD; Carol A. Howland; Doris Georgiou, MA, DArch; Jama L. Bennett, MEd
ILRU Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institutes of Health, National Center for Medical Rehabilitation Research*

PURPOSE—Research has been conducted on the physiological aspects of sexuality in women with physical disabilities; however little has been done to examine the psychosocial influence that physical disability has on the development of intimate relationships and the abilities of women with various physical disabilities to pursue behaviors typically taken for granted by women without disabilities, including dating, physical intimacy, marriage, and parenting.

Funded by NIH for three years, this project is designed to examine the broad spectrum of sexuality issues among women with a variety of physical disabilities. The three primary research hypotheses are: 1) there are significant differences in socio-sexual behaviors of women with physical disabilities as compared to women without disabilities; 2) the sexual functioning of women with disabilities is significantly related to age at onset of disability; and 3) psychological factors (including perceived control, self-esteem, and prior sexual exploitation) explain more of the variance in the sexual functioning of women with physical disabilities than do disability factors, social factors, or environmental factors.

PROGRESS—The first phase of this research project is a qualitative study using a semi-structured interview format. Generative questions used in the interviews were drawn from the literature and developed in consultation with a 16-member project development and review team and the consumer advisory committee. Thirty-one women with physical disabilities (including polio, spinal cord injury, traumatic brain injury, arthritis, neuromuscular disorders) were interviewed. Participants were selected to achieve a balance of disability types, ages at onset, current ages, marital status, sexual orientations, and ethnic backgrounds. The two-hour interviews were conducted in the participants' homes by three project staff members who are also women with disabilities, including the principal investigator.

Interviews were tape recorded and transcribed. Using accepted qualitative research analytic techniques, the content of each transcription was coded independently by two staff members. Discrepancies were resolved by the 7-member, core research staff team. Data were coded into 19 basic domains of sexuality, such as sense of self, sex education, family relationships, abuse, dating, marriage, parenting, societal barriers, health issues, and sexual functioning. Themes generated from each of these areas were analyzed in terms of wellness and used to generate a 300-item questionnaire, which was pilot tested on 60 women with disabilities and 60 women without disabilities. These data were then used to further refine the questionnaire, which was sent to 1200 women with disabilities and 1200 women without disabilities. These data are currently being entered into computer storage.

RESULTS—Preliminary analysis revealed 200 themes related to sense of self; sexuality information; relationships; environmental and social barriers; emotional, physical, and sexual abuse; and health and physical sexual functioning. When data were analyzed in accordance with a wellness model, the following characteristics were found among women with disabilities who exhibited positive aspects of sexuality. The woman with a positive self-

concept was found to appreciate her own value, assert her right to make a choice, feel ownership of her body, be able to restrict the limitations resulting from her disability to physical functioning without imposing those limitations onto her sexual self, take action to improve herself and her relationships, be accepting rather than ashamed of her body, make her own decisions about assistive devices, and take action to enhance her attractiveness.

The woman who is best informed about her sexuality has general information about sexuality and is able to apply it to herself, and actively seeks information about how her disability affects her sexuality. The woman who has positive, productive relationships generally feels satisfied with her relationships, is able to communicate effectively with others, feels stability in her relationships, and is able to control the amount and nature of contact with others. The woman who successfully manages barriers is able to recognize psychological, physical, and sexual abuse and exploitation and take action to reduce or eliminate it or its impact, has learned to reduce her vulnerability, understands her disability-related environmental needs and seeks information on how to meet those needs, recognizes her right to live in a barrier-free environment and takes action to achieve it, and confronts societal barriers by using good communication skills to educate her partner, friends, and family. The woman who maintains optimal health and physical sexual functioning by participating in health maintenance activities and engaging in health promoting behaviors, feels congruity between her values, desires, and sexual behaviors, managing her environment to optimize privacy for intimate activities, attaining satisfaction with the frequency and quality of sexual activity, and being able to communicate freely with her partner about her limitations and devices and about what pleases her sexually.

FUTURE PLANS—Data from the survey will be analyzed and disseminated. The results of this study will be used in developing and modifying educational and counseling programs for assisting women with physical disabilities in pursuing a full range of life options.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Qualitative approach to studying sexuality among women with physical disabilities. Howland CA, Nosek MA. Women's Health Forum 1993:3:3.

Sexual abuse of women with physical disabilities: findings from a qualitative study. Nosek MA. In: Monga TN, ed. Sexuality and disability. Philadelphia: Hanley and Belfus. In press.

XIII. Sensory, Cognitive, and Communication Aids

A. Hearing Impairment

[295] COMPUTERIZED ADAPTIVE METHODS FOR SELECTING HEARING AIDS

Donald D. Dirks, PhD; P. Douglas Noffsinger, PhD; Amy S. Martinez
Division of Head and Neck Surgery, UCLA School of Medicine, Los Angeles, CA 90024;
West Los Angeles VA Medical Center, Los Angeles, CA 90073

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C432-2RA)*

PURPOSE—The general purpose of this project is to explore critical variables which govern the choice of speech processing strategies and frequency-gain response characteristics which might be incorporated in hearing amplification systems worn by persons with sensorineural hearing loss. Our laboratory has had a long-standing interest in the use of probe-microphone techniques that can be used to provide objective information regarding the unaided and/or aided real ear measurement of the sound pressure level in an ear canal. In the current studies real ear sound pressure levels measured by a probe-microphone system were compared using three methods for positioning the probe in an ear canal. The techniques compared include 1) an acoustic method that incorporates use of the quarter-wave anti-resonance property of the ear to determine acoustically the location of the probe tube relative to the eardrum in an individual ear; 2) a constant insertion depth method (25-27 mm from the intratragal notch); and 3) the earmold +5 mm method, which places the probe 5 mm beyond the tip of the individual's earmold in the canal, thereby avoiding problems associated with the transition region where sound exits from the bore of the earmold into the larger ear canal.

Although the acoustic method is potentially the most precise and sophisticated of these procedures, even the constant insertion depth or earmold +5 mm procedures theoretically can be used to locate the probe close to the eardrum for adult ear canals of short or average lengths. For long ear canals, however, the constant insertion depth and earmold +5 mm techniques may result in probe locations in the canals which do not adequately measure the real ear sound pressure level at the eardrum itself.

METHODOLOGY—Measurements were obtained at 32 frequencies over a bandwidth from 200 to 6,300 Hz in the unoccluded ears of 17 subjects. The length of the individual ear canals was determined from results obtained with the acoustic method.

RESULTS—The overall results indicated that the sound pressure levels measured by the acoustic method were significantly larger with the long ear canals (>25 mm) at high test frequencies (4.0 to 6.3 kHz). This result was most evident for subjects with long ear canals and primarily at the high test frequencies.

For subjects with short or average length ear canals, the three methods provided essentially equivalent results. The acoustic method, although the most accurate, requires more sophisticated software and is more time-consuming than the other methods. When absolute eardrum sound pressure levels are required, the acoustic method provides the most valid results especially for long ear canals. If,

however, insertion gain (difference between aided and unaided probe measurement) is the assessment of choice the constant insertion depth or earmold +5 mm methods are acceptable clinical procedures.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Preferred frequency-gain response for two and three channel amplification systems. Dirks D, Ahlstrom J, Noffsinger PD. J Rehabil Res Dev 1993:30:305-18.

Effects of probe insertion depth on real ear measurements, otolaryngology. Dirks D, Ahlstrom J, Eisenberg L. Head Neck Surg 1994:110:64-74.

Hearing aids. Dirks D, Ahlstrom J, Eisenberg L. In: Ear diseases, deafness, and dizziness. New York: JP Lippincott. In press.

Intelligibility of speech sounds in amplitude-modulated noise. Bell T, Eisenberg L, Dirks D. J Am Acad Audiol. In press.

Speech intelligibility of normal and hearing-impaired listeners in fluctuating noise. Eisenberg L, Dirks D, Bell T. J Speech and Hear Res. In press.

[296] EVALUATION OF WORD-RECOGNITION PERFORMANCE WITH SENTENCE MATERIALS

Richard H. Wilson, PhD; Ted Bell, PhD; Richard Light, PhD
VA Medical Center, Mountain Home, TN 37684; VA Medical Center, Long Beach, CA 90822

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C690-RA)*

PURPOSE—The purpose of this project is to develop a valid and reliable speech test in a sentence format that is useful for diagnostic and assessment of receptive speech communication problems. The following concepts underlie the speech test being proposed; we propose to employ 1) a sentence format that can be used adaptively, 2) words in sentence frames that provide either high or neutral contextual cues, 3) test words that are differentiated on the basis of phonologic and psycholinguistic characteristics (viz., frequency of usage and phonetic similarities), and 4) the Articulation Index to normalize recognition performance among the various audiometric configurations.

In contrast to previous sentence materials, the proposed project involves target words that vary with respect to word frequency, confusibility, and linguistic context. The proposed sentences will be representative of everyday speech and easy to repeat. The end product will be sets of test materials useful for multi-purpose applications recorded on audio compact disc. These recordings, along with standardized norms of performance for the battery, will be distributed to the audiology clinics throughout the DVA and will be made commercially available.

METHODOLOGY—Selection criteria for target words will be based on the number and nature of the component phonemes, syntactic use, and linguistic properties of the words. Initially, more than 1000 mono- and bi-syllabic words representative of everyday speech (nouns, verbs, adjectives, adverbs, and pronouns) will be selected from the Webster's Pocket Lexicon (19,000 words) and will be sorted sequentially with respect to word frequency and to an index based on the phonetic similarity to other words. All words will be familiar to the listeners as determined by previous studies and will be divided into the following four groups: high- and low-frequency of usage and by high- and low-phonetic distinctiveness. Within each of these four categories, two or three target words will be selected for each of 400 sentences. The sentences will have homogeneous length (9 to 13 syllables) and phonemic content that is representative of language usage. With this sentence format the task of the subject is to repeat the sentence that is presented. Scoring (correct or incorrect) is restricted to the whole word responses to the target words.

PROGRESS—The sentences have been evaluated with subjects with normal hearing under three band pass filter conditions (90-1000 Hz, 90-2000 Hz, and 90-6000 Hz). Thresholds for the sentences were measured using the adaptive procedure described earlier. The threshold data were then subjected to a three filter (1000 Hz vs. 2000 Hz vs. 6000 Hz) by four lexical category (HH vs. HL vs. LH vs. LL) repeated measures analysis of variance (ANOVA).

RESULTS—The analysis revealed that filter frequency had a significant impact on threshold. In particular, thresholds in the 1000 Hz filter condition were significantly higher than thresholds in the other two filter conditions. Thresholds measured in the 2000 Hz and 6000 Hz filter conditions did not differ from each other. There was no interaction between lexical category and filter condition indicating that changing the location of the filter did not influence any one list more than any of the other lists. In addition, the number of trials between reversals in the adaptive procedure was also analyzed. This analysis produced no effect for filter condition or lexical category indicating that the homogeneity of these sentences was maintained across filter conditions. Thus, whereas filtering had a significant impact on how easily subjects understood the sentences, filtering had no impact on the variability within each list or differences in thresholds between lists. This line of testing is currently being extended to subjects with hearing impairment to ensure that the sentences remain equally homogeneous within this subject population.

[297] EVOKED OTOACOUSTIC EMISSIONS FOR OTOTOXIC MONITORING IN ADULTS

George B. Haskell, PhD
Audiology and Speech Pathology Service, VA Medical Center, Iowa City, IA 52246

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C696-RA)*

PURPOSE—Evoked otoacoustic emissions (EOAE) provide an objective measure of cochlear function that is linked to the activity of the outer hair cells. EOAE are being used widely as an auditory screening tool for infants and children, since they tend to extinguish in the presence of hearing loss in excess of 30-40 dB HL. Applications for older adult populations have lagged since early data suggested that emissions declined with age as well as hearing impairment. Our study is designed to establish normative data for EOAE for older adults with some pre-existing hearing loss, and to apply the test as a monitoring protocol for the ototoxic drug CIS Plat. We propose to measure EOAE on 50 control subjects drawn from our clinic caseload, to establish normative data and verify the salience of EOAE in our older population with pre-existing hearing loss. Second, we propose to provide serial measures on 20 patients receiving cisplatin treatment, to determine whether this new protocol could be used in auditory monitoring applications with our population.

METHODOLOGY—Our original plan was to employ two pure tone signals to elicit the cubic difference tone, a technique known as distortion production otoacoustic emissions (DPOAE). Delays in the availability of DPOAE instrumentation and software would have led to a delay in data collection, so we modified our original plan to begin data collection using a somewhat simpler click stimuli to elicit transiently evoked otoacoustic emission (TEOAE). Access to new analysis software has allowed us to extract frequency specific data in 1/6th octave bands from TEOAE, so our original objective of focusing attention on the more vulnerable high frequency region of hearing was not seriously impeded by this change.

PROGRESS—We have collected TEOAE data on 110 patients ranging in age from 40 to 81 years of age. This exceeded our estimated normative data goal. We have also collected complete serial TEOAE control data on 20 nonmedicated patients and on 5 cisplatin patients. The development of a reliable serial monitoring protocol turned out to be more complicated than originally estimated, and this (along with a move from Seattle, WA, to Iowa City, IA, mid-study) has delayed recruitment of cisplatin patients and publication goals.

RESULTS—Results for the normative data portion of our study, based on 110 patients, revealed the following: For those frequencies where hearing was better than 40 dB HL, over 85 percent of our patients revealed reliable TEOAE, independent of age. For those frequencies where thresholds were

greater than 40 dB HL, less than 20 percent of our patients demonstrated reliable TEOAE. There was neither any correlation between age and the absence of expected TEOAE nor any measurable correlation between age and magnitude of TEOAE.

Results for the cisplatin portion of our study are not yet complete. Based on the 20 control subjects, we have evaluated five different parameters of the basic TEOAE response for their stability as serial monitors. An FFT performed on the cross-correlation between baseline and retest is the most promising monitor. One confounding result was the presence of greater than normal test-retest audiometric variability for our five cisplatin patient which has made it difficult to draw conclusions from our TEOAE data.

FUTURE PLANS—We are still developing a cisplatin referral base at Iowa City VA Medical Center, and hope to have additional cisplatin data before the conclusion of the project. The salience of EOAE in our elderly population has been established, but sensitivity of this measure for serial monitoring is still to be verified. We feel that additional data will confirm this application, and lead to additional objective serial monitoring applications to include other ototoxins and noise exposure.

[298] PROGRAMMABLE HEARING AIDS: EVALUATION AND PREDICTION OF BENEFIT

Richard Matthes, EdD; Harry Levitt, PhD; Gabrielle Saunders, PhD; Kathleen Cienkowski, MS
East Orange VA Medical Center, East Orange, NJ 07019; Lexington Center, Research Division, NY 11370

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C664-RA)*

PURPOSE—The VA system currently dispenses over 60,000 conventional hearing aids per year. There are now, however, many models of programmable hearing aids available which incorporate features that conventional hearing aids do not, such as multiple memories for storage of different frequency responses, multichannel compression, and precise frequency shaping. Additionally, manufacturers claim that programmable hearing aids have superior sound quality. However, programmable hearing aids cost considerably more than conventional hearing aids and take substantially more clinic time to fit. One aim of this study is to determine whether programmable hearing aids are sufficiently superior to conventional hearing aids as to justify the additional costs that would be involved if the VA were to dispense them.

Features incorporated into programmable hearing aids are many and varied. No one has determined which particular feature(s) are more or less important than others. The second aim of our study is investigate this. Programmable hearing aids aside, previous research has shown that hearing aid benefit and satisfaction is only partly explained by actual hearing loss. A further aim is to investigate some of the personality, attitude, cognitive, and psychoacoustic factors that might influence hearing aid benefit and satisfaction. From there we hope to develop a predictive protocol for clinical use prior to hearing aid dispensing.

METHODOLOGY—Seventy-two mild-to-moderately hearing impaired subjects between the ages of 55 and 75 are taking part. Each subject wears three hearing aids (two programmable, one conventional) in a total of six conditions, thus spending 18 months in the study. Subjects' performance with each hearing aid is tested at the start and end of each three month period. Subjects also complete a diary and questionnaires to determine their satisfaction with each hearing aid on a monthly basis. Real-ear measures are made for each hearing aid to monitor actual gain received. Additionally, subjects undergo a large battery of psychoacoustic, central/cognitive, personality, and attitude tests to determine factors underlying hearing aid satisfaction in general.

PROGRESS—All subjects have been recruited, 10 of whom have completed the study. All test protocols are running smoothly and subjects have generally been cooperative in the completion of their questionnaires and diaries. Data for many of the

tests have been entered into the computer and preliminary statistical analyses have been carried out.

RESULTS—Statistical analyses to date have been limited to nonhearing aid data since an insufficient number of subjects have completed the study. However, anecdotal evidence suggests the following: 1) one programmable hearing aid has better sound quality than the other two hearing aids; 2) access to two different frequency responses in a hearing aid is useful, more than two programs are not generally utilized; 3) control of a hearing aid with a remote control unit is not favored; and 4) programmable hearing aids are preferred over conventional ones by individuals with relatively less severe hearing losses.

Factor analysis of our 'Attitude Questionnaire' determined six subscales, four of which (Denial of Hearing Loss, Emotional Esteem, Effect of Loss on Socialization, and Perceived Pressure from Significant Others) played a significant role in explaining subject's unaided self-assessed auditory disability and handicap. Auditory thresholds and speech recognition scores, however, did not.

FUTURE PLANS—Evaluation of the hearing aids will continue and statistical analyses will be carried out. The test battery will be developed for predicting hearing aid benefit prior to dispensing. Its validity and reliability will then be assessed.

[299] EFFECT OF PRESENCE VS. ABSENCE OF PROLONGED AMPLIFICATION ON AUDITION

Shlomo Silman, PhD; Carol A. Silverman, PhD; Michele B. Emmer, MS; John Lutolf, MS; Stanley A. Gelfand, PhD
VA Medical Center, East Orange, NJ 07019; Brooklyn College, CUNY, Brooklyn, NY 11210; Hunter College, CUNY, New York, NY 10010; Queens College, CUNY, Flushing, NY 11367.

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C578-2RA)*

PURPOSE—This longitudinal study investigates the effect of presence vs. absence of amplification on various measures of audition in monaurally aided (MA) and binaurally aided (BA) adults with bilateral, sensorineural hearing impairment (BSHI).

METHODOLOGY—BA and MA experimental subjects (Ss) and control, normal-hearing Ss were evaluated annually in years 1 through 4 (Y1-Y4). Measures included pure-tone thresholds, speech-recognition threshold, W-22 suprathreshold speech-recognition score (SSRS), nonsense syllable test (NST) score, acoustic admittance, brainstem auditory evoked potentials, and middle latency responses.

PROGRESS—Of the 103 experimental Ss with BSHI who were seen in Y1, 52 (26 MA and 26 BA) subjects were seen in Y3, and 21 (8 MA and 13 BA) were seen by July of Y4. Of the 85 control Ss who were seen in Y1, 45 were seen in Y3, and 15 were seen by July of Y4.

RESULTS—In the aided ears of the BA and MA Ss, there was no significant difference in the mean W-22 suprathreshold speech-recognition score (SSRS) between Y1 and Y3; there was a nonsignificant trend towards improvement in the aided ears of the MA Ss and the aided left ears of the BA Ss and a nonsignificant trend towards decline in the aided right ears of the BA Ss. In the unaided ears of the MA Ss, the mean W-22 SSRS declined significantly from Y1 to Y3 ($p = 0.000$), consistent with the presence of auditory deprivation from lack of amplification.

There was no significant difference in the mean NST score for the aided ears of the MA Ss between Y1 and Y3 although there was a slight nonsignificant trend towards a decline. As for the W-22s, the mean NST score for the unaided ears of the MA Ss declined significantly from Y1 to Y3 ($p = 0.000$), also consistent with the presence of auditory deprivation from lack of amplification. In the BA group, there was a nonsignificant decline in the mean NST score for the left, aided ear and a significant decline ($p = 0.007$) in the right, aided ear from Y1 to Y3. The mean decline in the NST score from Y1 to Y3 was more than twice as great in the unaided ears of the MA Ss than the aided right ears of the BA Ss.

The bilateral reduction of the mean NST score in the MA and BA Ss may be related to aging, with markedly greater reduction present in the unaided ears of the MA Ss, associated with auditory deprivation. Approximately 95 percent of our MA and BA Ss are more than 50 years of age.

To examine our assumption that the bilateral reduction in the NST score in the BA Ss was related to aging, the control Ss were divided into two groups, ≤ 44 years vs. >44 years of age. There was a bilateral, nonsignificant trend towards decline in mean NST from Y1 to Y3 in the younger adult group, and a significant, bilateral decline in mean NST score from Y1 to Y3 in the older adult group. This finding of bilateral decline from Y1 to Y3 in the older but not younger control Ss supports our assumption that the bilateral decline in NST score in the experimental BA Ss is associated with aging.

No significant changes were obtained for the other measures.

FUTURE PLANS—Further evaluation of the experimental and control Ss will continue over years 5 and 6 to further define and quantify the auditory-deprivation effects.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Effects of prolonged lack of amplification on speech- recognition performance: preliminary findings. Silman S, Silverman CA, Emmer MB, Gelfand SA. J Rehab Res Dev 1993:30(3):326-32.

[300] THE EFFECT OF LACK OF AMPLIFICATION ON PERSONS WITH UNILATERAL HEARING LOSS

Shlomo Silman, PhD; Carol A. Silverman, PhD; Michele B. Emmer, MS; John Lutolf, MS
VA Medical Center, East Orange, NJ 07019; Brooklyn College, CUNY, Brooklyn, NY 11210; Hunter College, CUNY, New York, NY 10010

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C665-RA)*

PURPOSE—This study investigates the effect of presence vs. absence of amplification on various measures of audition in aided and unaided adults with unilateral, sensorineural hearing impairment.

METHODOLOGY—Aided and unaided subjects (Ss) between 25 and 75 years of age with unilateral, sensorineural hearing impairment were evaluated annually in years 1 and 2 (Y1-Y2). Measures included pure-tone thresholds, speech-recognition threshold, W-22 suprathreshold speech-recognition score (SSRS), nonsense syllable test (NST) score, acoustic admittance, brainstem auditory evoked potentials, and middle latency responses.

Of the 80 Ss (38 aided, 42 unaided) who were seen in Y1, 39 (14 aided, 25 unaided) have thus far been seen in Y4. Comparisons were made between the aided ears of the aided, unilaterally sensorineural hearing-impaired Ss and the unaided, hearing-impaired ears of the unilaterally sensorineural hearing-impaired Ss. Thus, "aided ears" refers to the aided, hearing-impaired ears of the aided group, and "unaided ears" refers to the hearing-impaired ears of the unaided group.

PROGRESS—The significant improvement in the aided ears of the unilateral Ss after only 1 year of amplification together with a nonsignificant trend towards improvement in the monaurally aided ears of the bilaterally symmetrical, sensorineural hearing-impaired Ss in the bilateral investigation indicates that recovery with amplification is more striking in unilateral than bilaterally symmetrical, sensorineural hearing-impaired Ss. No significant changes from Y1 to Y2 were observed for the other measures in the aided and unaided unilaterally sensorineural hearing-impaired Ss.

RESULTS—In the unaided ears, the mean W-22 SSRS declined significantly from Y1 to Y2 ($p = 0.005$). In contrast, in the aided ears, the mean W-22 SSRS improved significantly from Y1 to Y2 ($p = 0.01$). For the NST, there was no significant change from Y1 to Y2 in either the unaided or aided ears.

The unaided ears in this unilateral study demonstrated an auditory-deprivation effect in the second year of investigation. The auditory-deprivation effect occurred earlier in this unilateral investigation than in our investigation on subjects with bilaterally symmetrical sensorineural hearing impairment; in the latter investigation, an auditory-deprivation effect did not become evident until the third year of investigation. The findings of a early, significant deprivation effect in the unaided unilateral Ss together with, in the bilateral investigation, a later-occurring deprivation effect in the monaurally aided Ss with bilaterally symmetrical sensorineural hearing impairment suggest the following: interaural asymmetry as well as prolonged lack of amplification is associated with decline in speech recognition.

FUTURE PLANS—Further evaluation of the aided and unaided unilaterally sensorineural hearing impaired Ss will continue through Y3 to further define and quantify the auditory-deprivation and apparent pure-tone asymmetry effects on audition in adults.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Auditory deprivation and recovery in adults with asymmetric sensorineural hearing impairment. Silverman CA, Emmer MB. J Am Acad Audiol 1993:4:338-46.

[301] EARLY DETECTION OF HEARING LOSS FROM OTOTOXIC AGENTS BY HIGH-FREQUENCY AUDITORY EVALUATION

Stephen A. Fausti, PhD; Vernon D. Larson, PhD; P. Douglas Noffsinger, PhD; Cynthia G. Fowler, PhD
VA Medical Center, Portland, OR 97207; VA Medical Center Augusta, GA 30910; VA Medical Center, West Los Angeles, CA 90073; VA Medical Center, Long Beach, CA 90822

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C227-RA)*

PURPOSE—The primary objective of this ongoing four-site study is to determine whether loss of hearing sensitivity due to ototoxicity is detectable in the high-frequency range (9-20 kHz) before the conventional frequency range (0.25-8 kHz). Secondary objectives for this study relate to the ototoxic process (progression, direction, and recovery of threshold change) and to individual patient baseline variables (e.g., age, disease state, pre-existing hearing loss). In addition, data analyses suggests the existence of a limited high-frequency range consisting of five consecutively tested frequencies with threshold for the highest frequency no greater than 100 dB SPL, that is sensitive to initial ototoxicity. This range is specific to each individual's hearing threshold configuration. As a result, this range has been added to the study as another objective which may prove to maintain the integrity of early detection of ototoxicity while significantly shortening the time required to conduct monitoring tests.

METHODOLOGY—Due to the limited number of veteran patients meeting the original hearing threshold criteria, the requirements were altered, for this period, to include baseline thresholds $\leq$100 dB SPL at 10 and 11.2 kHz in at least one ear. Also, younger patients from two additional sites were added as subjects to provide a broader-based population sample. Patients being administered $\geq$4 days of aminoglycoside antibiotics (AMG): amikacin, gentamicin and tobramycin and/or $\geq$1 dose of the chemotherapeutic agent cisplatinum (CDDP) are being monitored for hearing sensitivity prior to, during, and following treatment.

The computer-based audiometer, shown to provide valid and reliable intra- and intersession pure-tone threshold results with normal-hearing individuals, and immittance system is being utilized by all sites for data collection. Because of the large geographic distances of the remote sites from the central site and the extensive data management requirements of a multisite research protocol, computer technology was necessary. A computer software program managing the total research project was custom designed with three main functions: 1) to facilitate peripheral-site data management, 2) to provide electronic transfer of peripheral-site data to the central-site database, and 3) to

consolidate and categorize all data at the central site for analyses.

RESULTS—To date, 15,991 patients have been screened for inclusion in this study. Of this total, 290 patients (517 ears) have met criteria and completed ≥3 tests: 170 AMG subjects (303 ears), 83 CDDP subjects (147 ears), and 37 control-treated subjects (67 ears). Negative (poorer) hearing threshold changes (in ears) were demonstrated in 32.3 percent (N = 98) of those receiving AMG and 71.4 percent (N = 105) CDDP. Of those ears showing hearing changes, initial changes occurred in the high frequencies (≥8 kHz) or in both the high and low frequencies, in 86 percent of the individuals who showed changes. CDDP patients revealed more significant hearing threshold changes. Control subjects revealed minimal change in hearing thresholds (N = 10) throughout testing, demonstrating that ill, hospitalized patients can be tested reliably. Additional data analyses revealed that if only the individualized high-frequency range of hearing determined at baseline would have been monitored, 90.3 percent of initial hearing changes (AMG and CDDP combined) would have been detected.

FUTURE PLANS—Current findings support the use of high-frequency monitoring for patients being administered ototoxic medications. Preliminary data from an alternative protocol, monitoring an individualized frequency range, has demonstrated a high sensitivity to ototoxic change. After further analyses of this individualized range, development of a computer-based, abbreviated monitoring device will be accomplished to shorten the test time and increase patient accessibility without significantly compromising the sensitivity of the monitoring program. The ultimate goal is to prevent communicatively handicapping hearing losses in patients at-risk from potentially ototoxic agents.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

High-frequency audiometric monitoring for early detection of aminoglycoside ototoxicity. Fausti SA, Henry JA, Schaffer HI, et al. J Infect Dis 1992:165:1026-32.

High-frequency monitoring protocol for early detection of cisplatin ototoxicity. Fausti SA, Henry JA, Schaffer HI, et al. Arch Otolaryngol Head Neck Surg 1993:119:661-8.

High-frequency (8-20 kHz) testing techniques and instrumentation for early detection of ototoxicity. Fausti SA, Frey RH, Henry JA, Olson DJ, Schaffer HI. J Rehabil Res Dev 1993:30:333-41.

Serial auditory high-frequency monitoring procedures for early detection of ototoxicity. Fausti SA, Frey RH, Henry JA, Olson DJ, Schaffer HI. Hear J 1993:46:23-8.

Software for managing multi-site auditory research. Fausti SA, Schaffer HI, Henry JA, Frey RH, Olson DJ. Auditory Today 1993:5:22-5.

High-frequency audiometric monitoring strategies for early detection of ototoxicity. Fausti SA, Larson VD, Noffsinger D, et al. Ear Hear 1994:15:232-9.

[302] EVALUATION OF A COPING STRATEGIES PROGRAM IN AURAL REHABILITATION: A PILOT STUDY

Judy Abrahamson, MA, CCC/A; Robert J. Dunlop, PhD, CCC/A
Audiology/Speech Pathology Service, Olin E. Teague Veterans' Center, Temple, TX 76504

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #C92-479AP)*

PURPOSE—The efficacy of a patient-education auditory rehabilitation program, "Living with Hearing Loss," is being evaluated in a 1-year pilot project. This class is designed to teach coping strategies to hearing-impaired veterans and their spouses and provide opportunities to practice skills related to independent management of communication problems which occur even with properly fit hearing aids. It is known that hearing aids do not solve all communication problems and that many veterans have rehabilitation needs after hearing-aid fitting. Group programs appear to be a cost-effective means of meeting many of the auditory rehabilitation needs of hearing-impaired veterans, but their outcome must be carefully evaluated before new rehabilitation programs are implemented.

Two research questions are being addressed: 1) Do veterans who participate in the program report using more effective communication strategies, as measured by the Communication Profile for the

Hearing Impaired (CPHI) than veterans who do not participate? 2) Are the changes or lack of changes in the use of coping strategies reported by veterans socially validated by their wives when wives are requested to respond to CPHI items as they observe their husbands' behavior?

METHODOLOGY—Subjects and their wives were assigned to treatment or deferred treatment groups. In an attempt to examine only the effect of class participation, subjects were limited to retired, first-time hearing-aid users, age 55-75, who were motivated to participate in the class and whose wives would also participate. The CPHI was administered to veterans and their wives on four occasions: week 1, week 5, week 12, and week 24. Subjects in the treatment group and their wives attended the 2-hour class weekly from week 6 to week 11. Group data on the sum of the three Communication Strategies subscales of the CPHI are being compiled and will be used for analysis.

Question 1 will be addressed by applying a repeated measures analysis of variance to test differences in mean scores between the two veteran groups at the four points in time. If treatment is effective, it is predicted that the groups will be similar at weeks 1 and 5, but will differ significantly at weeks 12 and 24. Contrasts to be analyzed are week 1 versus week 5 (for time changes unrelated to treatment); the average of weeks 1 and 5 (pre-treatment) versus week 12 (for immediate changes related to treatment); and the average of weeks 1 and 5 versus week 24 (for longer term changes related to treatment). Question 2 will be addressed in exactly the same way using the wives' responses. In addition, the correlation between the veterans' and their wives' responses will be evaluated at each time period.

PROGRESS—This pilot project is ongoing and data continue to be collected.

RESULTS—None available, as data collection has not been completed.

FUTURE PLANS—If efficacy of treatment is observed, then a study to include a wider range of hearing-impaired veterans will be considered. Class materials will be made available to other VA Medical Centers for use by their audiology programs.

[303] BASIC MECHANISMS AND REHABILITATIVE STRATEGIES FOR PRESBYCUSIS

Brenda M. Ryals, PhD
VA Medical Center, Richmond, VA 23249

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C251-3RA)*

PURPOSE—The specific purpose of this project is to better understand the basic mechanisms of presbycusis. Our goals are 1) to determine central versus peripheral aspects of presbycusis, 2) to determine differences in normal aging of the cochlea as a function of gender, and 3) to determine peripheral influences on maintenance of central processes.

The proportion of veterans over the age of 65 will increase dramatically over the next several years. Hearing loss affects more than 30 percent of this population. Any information, therefore, on basic mechanisms in hearing loss in the elderly will greatly impact patient care in the VA. Further, the proportion of female veterans is on the rise. We must be sensitive to issues which may indicate a different direction of treatment or diagnosis based on gender.

METHODOLOGY—Electrophysiological measures to determine correlates to auditory nerve ganglion cell loss with aging include far-field evoked potential responses recorded from the ear canal. Morphological markers of aging and/or neural changes after regeneration are studied using techniques of light microscopy, transmission and scanning microscopy, digital morphometry and immunohistochemistry.

PROGRESS—We have determined that the histopathological basis for presbycusis in coturnix

quail is similar to that of neural presbycusis in man. We are now studying the electrophysiological correlates of this histopathology. One correlate may be changes in CAP amplitude. We have measured input-output functions from both young and senescent quail and found no significant difference in amplitude as a function of age. There is, however, some evidence for an increased interpeak wave latency. Thus measures of neural synchrony may be better indicators of neural integrity than measures of neural response amplitude.

We have also examined gender related differences in the accumulation of aging pigment in auditory hair cells. We found no significant gender difference in the amount of aging pigment located within the hair cells when measures were taken at the same chronological time. Even though female quail have a shorter life expectancy, there is no more rapid accumulation of lipofuscin in the auditory system.

Finally, we have used the regenerative potential of hair cells within the quail to study the influence of peripheral re-stimulation on central maintenance. Even though all or nearly all hair cells regenerate after trauma, neural degeneration occurs over the following 6 months. When the neural ganglion cells of older quail (without hair cell regeneration) were compared with the ganglion cells of quail with regenerated hair cells, the number of ganglion cells was not different. In other words, aging plus trauma does not result in greater deterioration of ganglion cells than does aging alone. At least three possible explanations exist: 1) there is a minimal number of ganglion cells which are naturally conserved, 2) one population of ganglion cells is more fragile than the other, or 3) ganglion cells can regenerate over time.

RESULTS—Our results have shown that electrophysiological measures of neural synchrony are likely to be better correlated with histopathology than measures of response amplitude. We have also shown that there is no gender based difference in the accumulation of aging pigment in auditory hair cells. Thus, in so far as accumulation of lipofuscin can be said to be a measure of aging, female inner ears do not age more rapidly than male ears. Finally, we have shown an intriguing interaction between the normal loss of neurons through aging and the loss through trauma. It appears that when neurons are lost early in life, there is no additive affect of aging. Clinically, these results have significance for predicting neural degeneration with aging after traumatic hearing loss.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

LM and TEM observations of the homogene cells and tectorial membrane following ototoxicity in the chick basilar papilla. Westbrook EW, Ryals BM. Assoc Res Otol Abstract 1993:16:563.

Ultrastructural changes in the tegmentum vasculosum parallel changes in auditory function after acoustic trauma in quail basilar papilla. Ryals BM, Stalford MD, Becker DG, Lambert PR. Assoc Res Otol Abstract 1993:16:171.

Effect of acoustic overstimulation on the ears of four species of birds. Ryals BM, Dooling RJ, Westbrook EW. Assoc Res Otol Abstract 1994:17:526.

TEM analysis of neural terminals on autoradiographically identified regenerated hair cells. Ryals BM, Westbrook EW. Hear Res 1994:72:81-8.

Effects of acoustic overstimulation on four species of birds. Dooling RJ, Ryals BM. In: Proceedings of the 10th International Symposium on Hearing. In press.

[304] REHABILITATION ENGINEERING RESEARCH CENTER ON HEARING ENHANCEMENT AND ASSISTIVE DEVICES

Matthew H. Bakke; Arthur Boothroyd; Nancy Carr; Edward Cudahy; Judith Harkins; Harry Levitt; Arlene Neuman; Mark Ross; Mark Weiss
The Lexington Center, Inc., New York, NY 11370

Sponsor: *None listed*

PURPOSE—Although hearing aids, text telephones (TTYs), and other assistive devices are widely used, the majority of persons with hearing loss do not make use of technological aids. Costs are high, many technological aids are not as effective as they could be, and many potential consumers are unaware of the benefits that technological aids can provide.

The Rehabilitation Engineering Research Center (RERC) on Hearing Enhancement and Assistive Devices is designed to address these problems in an efficient and productive way. This is done by developing and evaluating improved cost-effective technological aids for the various groups of people with hearing loss according to their needs. Specific projects include the development and evaluation of improved instrumentation for detecting hearing loss at an early age, development and evaluation of improved hearing aids, providing improved access to modern telecommunications, and developing and evaluating specialized technology for community, home and work environments including technology for those who have special needs. All of this work is supported by an active program of dissemination and training to ensure effective utilization of the research results and assistive devices developed by the RERC.

PROGRESS—Highlights of the progress that has been made during the first year of this grant are: 1) Evaluation and improvement of an experimental system for the measurement of hearing using evoked distortion product otacoustic emissions. The system is being evaluated for its potential as a tool for universal hearing screening of infants. 2) A compact disc has been prepared containing noises typical of those encountered by hearing-aid users. The disc contains samples of cafeteria noise, office noise, street noise and apartment noise. 3) An experiment has been performed to evaluate a modified rating technique for predicting hearing-aid benefit in real world environments. Data on the reliability and sensitivity of the ratings have been obtained. The results indicate that the technique has merit, but there are important caveats in terms of interpreting the results. 4) Instrumentation has been developed for simulating automatic frequency response (AFR) hearing aids and an experiment has been initiated to determine the parameters that will maximize intelligibility and overall sound quality of the amplified signals. 5) A fully automated system for the evaluation of hearing aid performance using real speech has been developed. This system shows the effects of automatic gain control and compression as they impact on the audibility of the important acoustic features of the speech signal. 6) Standards are being developed such that all modems will be compatible with both ASCII and Baudot (TTY) code. 7) Several practical needs have been identified which both deaf employees and their managers consider to be particularly important, such as emergency alerting, TTY communication for deaf personnel who have poor literacy skills, and the provision of non-emergency information to deaf workers on the factory floor. Evaluations of innovative solutions to these problems have been inititated. 8) Software has been written at Gallaudet to produce a computer screen display system for remote computer assisted notetaking (CAN) and remote computer assisted real-time transcription (CART).

Dissemination activities have included the publication of papers and articles, and workshops and colloquia in many venues. In addition, the RERC is producing a monthly column written by Mark Ross in the SHHH (Self Help for the Hard of Hearing) journal dealing with technology and hearing loss.

[305] AUDITORY REDUNDANCY OF COMPUTER INFORMATION FOR HEARING-IMPAIRED INDIVIDUALS

Gregg C. Vanderheiden, PhD; Mark Novak, BS, BS, PE
Trace Research and Development Center, University of Wisconsin-Madison, Madison, WI 53705

Sponsor: *National Institute on Disability and Rehabilitation Research; Information Technology Foundation*

PURPOSE—Currently, people with hearing impairments have little or no difficulty in using computers. The use of sound as a standard feature has been minimal, usually no more than a "beep." Software which provides a visual event will accommodate these simple sounds.

However, increasing sophistication of speech technologies has made it easier and more desirable for computer companies to consider incorporating voice output into their products. This would probably take the form of standard voice features in the operating system (such as voice output of error

messages) or available voice features that could be "called" from the operating system by application programs.

PROGRESS—As a first step, a proposal has been made for the incorporation of a ShowSounds flag in standard computer operating systems. Such a flag would appear along with other control settings for the operating system, and would allow the user to signal cooperating software and operating systems that the user cannot hear sounds. Programs and operating systems could then accompany any beeps with some type of visual event on the computer screen. The ShowSounds flag also presents the possibility of closed captioning for computer programs.

METHODOLOGY—The implementation of the recommendations could be carried out in stages. In fact they would need to be, since later stages require built-in text-to-speech capabilities which are not yet a standard part of any computer operating system. The stages would be: 1) ShowSounds flag in the control settings of the operating system; 2) visual events to correspond to beeps triggered by the operating system; 3) closed captions for any voice or complex sound events necessary for use of the operating system; 4) closed captioning tools for use by third party developers; and 5) auto-captioning capability.

In addition, application programs can begin to check for the ShowSounds flag and provide visual cues to any auditory events.

RESULTS—The proposed ShowSounds flag has been moved forward in four ways. First, the Trace Center has had discussions with Apple computer regarding the inclusion of a ShowSounds flag as a part of their standard control panel for sounds in future versions of their operating system. Second, a basic ShowSounds feature was incorporated into several accessibility software packages develop by the Trace Center. This feature creates a visual alert for simple warning beeps, and is part of AccessDOS (for DOS) Windows Access Pack (for Microsoft Windows), and Access X (for XWindows/Unix). Third, the Trace Center has created a set of software application program design guidelines. One of the guidelines deals specifically with the support of a ShowSounds flag by application programs. Several thousand copies of the guideline document have been distributed to application and operating system developers. Fourth, the ShowSounds concept is being incorporated into the Seamless Human Interface Protocol being developed by the Trace Center. This protocol is intended to apply not only to the design of computers but also to the design of public information systems such as automated teller machines and information kiosks.

[306] FEATURE EXTRACTION METHODS FOR A VIDEO TELEPHONE FOR DEAF AND HARD-OF-HEARING PEOPLE

Richard Foulds, PhD; Judith Harkins, PhD; Arthur Joyce, PhD; Lynn Messing, PhD; Scott Galuska, MS; Elizabeth Korres
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Institute on Disability and Rehabilitation Research, U.S. Department of Education; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—In order for people who are deaf to communicate over residential telephone lines using sign language, methods are being developed to significantly compress the information in a video signal in order to meet the severely limited bandwidth requirements of the telephone system. This visual telephone provides an alternative to the TDD for those people who are deaf who prefer to sign.

METHODOLOGY—In order to transmit video information in real-time over residential telephone lines, the video data must be compressed on the order of a 1000:1 ratio. The bulk of this compression is done by performing a feature-extraction on a video image. This feature-extraction method extracts the outlines of the hands, arms, torso, head and facial-features, creating a line-drawing of the signer.

This line-drawing would then be further compressed and transmitted over the telephone lines using a 28.8 Kbaud modem (currently employing V.FAST technology, to be approved in 1994 as the V.34 standard) at a rate of approximately 10 frames per second. These line-drawings are then animated at the receiving end, providing a moving representation of a person signing.

The prototype plug-in PC board implements in hardware the feature-extraction algorithm used to extract the outline of the signer. Arithmetic encoding and decoding to further compress and decompress the transmitted bit-stream is also implemented in hardware on the board. Software has been developed to transmit the bit-stream across the telephone lines, as well as animate the resulting line-drawn images and transmit and display text.

PROGRESS—Further intelligibility studies were performed at Gallaudet University in 1991. In these studies, several pairs of signers were brought in to have unscripted conversations using two "mock" sign language telephone systems. (The systems used were stand alone systems with the monitors swapped.) These experiments were done to judge ease-of-use and other human-factors qualities.

Work over the past two years has been in designing and engineering a single plug-in personal computer board that will compress and encode each frame of the video signal such that the resulting bit-stream may be transmitted over ordinary telephone lines using high performance, state-of-the-art modems. The card design is nearly complete and will be used as a prototype for field testing of the technology.

RESULTS—The results of the Gallaudet experiments were positive. The systems were well received, with the primary comment being the need for a built-in text, or TDD-like, utility to be used to transmit fingerspelled words that may be difficult to understand using this system.

FUTURE PLANS—A demonstration project is being planned to provide several of these boards for use in a real world environment.

[307] NATURAL LANGUAGE PROCESSING PRINCIPLES FOR IMPROVING DEAF WRITING

Kathleen F. McCoy, PhD; Linda Z. Suri, PhD; Chris Pennington, MS
Applied Science and Engineering Laboratories University of Delaware, A.I. duPont Institute, Wilmington, DE 19899

Sponsor: *National Science Foundation, Information, Robotics & Intelligent Systems Division; Nemours Foundation, A.I. duPont Institute, Wilmington, DE*

PURPOSE—The goal of this project is to develop a computer tool to correct the written English of deaf writers. The envisioned program will accept a written document, analyze the document looking for errors, and provide corrective advice when an error is found. Essentially, the system will act as an English tutor that will help deaf individuals improve their English writing skills

METHODOLOGY—The design of this program is based on the belief that English should be viewed as a second language for many deaf people and that errors in the written English of deaf writers arise due to language transfer (LT) coupled with the individual's relative lack of exposure to English. We are designing this program so that it will take advantage of the writer's knowledge of American Sign Language (ASL) in identifying errors and suggesting corrections.

There is considerable linguistic evidence of language transfer between spoken languages. Based on these findings, we believe it is reasonable to expect language transfer from ASL (a visual-gestural language) to English (a spoken language). Our work is motivated by analysis of writing samples based on the research in language transfer. This analysis will lead to a taxonomy of errors.

The system itself will consist of two phases. In the first phase, the system will identify errors. To do this, it relies on a grammar of English which has

been augmented with a set of error rules which capture the errors in our taxonomy. The second phase of processing will generate a correction.

PROGRESS—The majority of the work to date has been devoted to analyzing writing samples from deaf individuals with an ASL background in order to develop the error taxonomy. In addition to this, we have implemented a prototype system that contains an extensive grammar of English which has been augmented with a number of error rules (both syntactic and semantic). The system can use these rules in order to identify a subset of the sentence level errors identified by the sample analysis.

RESULTS—Of major and continuing focus in this project is the correction of errors that result from language transfer at the discourse level. It has been documented that much of the language instruction of the deaf has concentrated on the sentence level and thus deaf students may reach the point where their writing lacks discourse cohesion even though the individual sentences are grammatically correct. Therefore, the correction of discourse level errors should be particularly useful for many deaf writers. Our current work investigates models which can identify such discourse errors. In addition to this, work has begun on the correction phase of processing which must be tailored to the individual user.

[308] SELECTION, FITTING, AND EVALUATION OF HEARING AIDS

D.G. Jamieson; R.C. Seewald; M. Cheesman; L. Cornelisse; I. Kheirallah; S. Moodie; T. Schneider; S. Sinclair
Hearing Health Care Research Unit, Elborn College, University of Western Ontario, London, ON N6G 1H1 Canada

Sponsor: *Ontario Ministry of Health; Ontario Rehabilitation Technology Consortium; University Research Incentive Program; Natural Sciences and Engineering Research Council of Canada; Premier's Council Technology Fund; Etymonic Design Incorporated; Unitron Industries Ltd.; University of Western Ontario*

PURPOSE—The goal of our study is to optimize the benefits which users receive from hearing aids and other personal assistive listening devices (ALDs) by improving the process of selection, evaluation, and fitting.

PROGRESS—Recent research has focused on three themes: 1) development and application of improved procedures for characterizing the electroacoustic performance of hearing aids and ALDs; 2) development and evaluation of improved procedures for selecting and fitting hearing aids for individuals; and 3) evaluation of hearing aid signal processing systems.

The work on electroacoustic measurement has included 1) the development of included the development of dual-channel maximum-length sequence testing procedures, 2) procedures in which bias signals are used to permit hearing aids to be tested under their various operating modes, 3) examination of the effects of hearing aid processing on speech signals and 4) examination of hearing aid processed signals in relation to an individual listener's residual auditory capacity.

The work on hearing aid selection procedures has included the development of a systematic procedure for fitting hearing aids in young children and in adults and the development and verification of a procedure for improving the accuracy of individualized hearing aid fittings, by using real ear measurements in conjunction with hearing aid coupler-based tests in hearing aid prescription and fitting.

Evaluations of hearing aid signal processing systems have included clinical trials to evaluate benefit provided by commercially available hearing aid systems and pre-production studies to evaluate experimental noise reduction signal processing strategies which could be implemented in future hearing aid systems. To expedite this work, we have developed a range of evaluation procedures including computer-based automated speech tests, and self-report measures of hearing aid benefit and satisfaction.

FUTURE PLANS—Work currently underway focuses on ways to improve the precision with which various hearing aid prescriptions can be achieved with commercially available hearing aids, on the refinement of prescriptive fitting strategies through comparative evaluations, on the improvements in listener performance which may be associated with experience in wearing personal hearing aids ("acclimatization") and on the relation between objective (engineering) measures of hearing aid distortion and listeners' subjective perceptions of such distortion.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Clinical evaluation of an automated technique for estimating speech reception thresholds. Jamieson DG, Cheesman MF, Corbin H. J Speech-Lang Pathol Audiology 1994:18:23-8.

Current issues in hearing aid fitting. In: Gagne JP, Tye-Murray N, eds. Research in audiological rehabilitation: Current trends and future directions. Seewald RC. J Acad Rehabil 1994:mono sup:93-112.

The desired sensation level method for fitting children: version 3.0. Seewald RC. Hearing J 1992:45:36-41.

Electroacoustic evaluation of assistive hearing devices. Jamieson DG, Schneider T. IEEE Eng Med Bio 1994:13(2):249-54.

Evaluation of speech enhancement strategies for normal and hearing impaired listeners. Jamieson DG, Brennan RL. In: Proceedings of European Speech Communication Association Conference on Speech Processing Under Adverse Conditions, 1992:155-63.

B. Speech Impairment

[309] A NONLITERAL LANGUAGE TEST AND TRAINING WORKSTATION FOR PATIENTS WITH COMMUNICATIVE DEFICITS: A PILOT STUDY

Diana Van Lancker, PhD; Muriel Goldojarb, MA; Edward Hall, PhD
Department of Research Neurology, USC School of Medicine, Los Angeles, CA 90089; VA Outpatient Clinic, Los Angeles, CA 90012-4051

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #C91-307AP)*

PURPOSE—The goal of this project was to develop a new type of computer workstation for testing and training patients with communicative deficits. This workstation is innovative in two ways: it uses interactive video administered by the computer, and it presents nonliteral, familiar expressions. Our goal was to test a prototype of the Nonliteral Language Test and Training Workstation using patients with language deficits following stroke. Familiar nonliteral expressions, such as speech formulas, idioms, and proverbs were selected because they are commonly used in daily conversation and they are often retained in aphasia. Materials for evaluating and rehabilitating patients in these kinds of expressions are lacking and inadequate.

METHODOLOGY—Stimuli for the test component were selected to overcome shortcomings of the few available nonliteral language tests. The workstation uses dynamic videotaped scenes depicting the meanings of 120 target expressions divided into 30 speech formulas, 30 idioms, 30 proverbs, and 30 matched literal expressions. Three foils are paired with each scene, resulting in 480 test items. Patients respond nonverbally, by pointing to a touchscreen on the computer monitor; scoring is objective and automatic. The training component offers 540 presentations of 90 expressions, each randomly presented with two correct scenes and one incorrect scene, paired with scenes taken from a commercial movie on laserdisc. Patients work at their own pace,

matching the expression presented in written and spoken form to a 15-second scene.

PROGRESS—The developmental phase of the project has come to completion. Two workstations are operational, and 10 stroke patients and 10 normal control subjects have been tested. The data have been analyzed and written up for publication. Revisions in the design of the workstation were made as a result of the pilot work.

RESULTS—Data on patients in the pilot test phase have been analyzed and submitted for publication. Patients with right sided hemiplegia successfully used the touchscreen with the left arm to interact with the computer program. Patients and normal-control subjects completed the workstation test in 2-4 sessions at 1-2 hours per session, and were noted to proceed easily through the items, often seeming to enjoy the task. The patient and normal-control groups differed significantly on idioms and proverbs on initial testing, but not on speech formulas. Preliminary results on the training performance indicated that patients achieved a mean of 85 percent on their first trial, and improved to 99 percent on the second trial. Considering that verbal memory deficits and yes-no confusion often accompanies aphasia, these data from the training sessions seem to reflect a successful training experience. Left-hemisphere damaged patients were observed to improve in all measures following the training experience.

FUTURE PLANS—We are continuing the project by adding two more training modules, two measures of social efficacy of the training experience, and additional quantificational points throughout the training to provide fuller evaluations of training efficacy. The plan is to test a larger group of stroke patients on the Nonliteral Workstation Test as well as standard measures of language and communicative functioning. Patients will be taken through a more extensive training experience using scenes from commercial movies in the sentence/scene matching task. Subjects will be given a post test to evaluate their improvement in recognizing the meanings of nonliteral expressions.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Interactive computer workstation for testing and training nonliteral expressions. Van Lancker D, Hall E, Goldojarb M, Treiman S. American Speech-Language-Hearing Association, Abstract F04-MS74A, 1993:114.

[310] COMPUTER-ASSISTED SPEECH EVALUATION EXPERT SYSTEM

James A. Till, PhD
College of Medicine, University of California, Irvine, Orange, CA 92668; VA Medical Center, Long Beach, CA 90822

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C468-3RA)*

PURPOSE—Diagnostic evaluation of speech requires analysis of speech deviance and speech-related physiological performance. Transfer of laboratory technologies to clinical environments has been slow. Traditional methods are subjective and highly variable. A software/hardware system has been developed for computer-assisted speech evaluation (CASPER). Measures are made of acoustic, aerodynamic, and physiologic signals collected during connected speech, specific diagnostic maneuvers, and user-specified tasks. Speech deviance profiles are obtained and automatically compared to stored normative data.

METHODOLOGY—Programs are written in the C language by professional programmers supervised by the investigator, using algorithms developed and tested by him and a biomedical engineer. Studies of normal and speech disordered subjects have assisted in testing reliability and validity of the protocols under development. Field users of the software continue to provide valuable suggestions for refinement.

PROGRESS—Results have been presented in various scientific forums in this country and in Stockholm, Sweden. CASPER systems have been installed in 20 VA medical centers and 14 private-sector laboratories and clinics. At least two more VA sites are expected to acquire needed equipment within the next few months.

RESULTS—During the last 2 years substantial additions and refinements have been made to the software based on methodological studies and reports from CASPER users. Patient demographic data and clinician comments are stored with the results in a data base. Statistical summary data can be requested for a patient or for a group of patients based on user-specified criteria for group label, gender, age and protocol. Users may enter and edit normative values and critical limits that are used to flag deviant speech or physiological function. The user-specified protocol has been refined to support nearly any custom-designed protocol that results in up to four channels of analog voltage produced by a microphone or physiologic transducers. Full support for calibration allows the user to enter the name of the measured quantity, and voltage levels for both quiescent and reference levels of transducer excitation. Statistics are then reported in calibrated units rather than raw voltages. The analytical tools now include FIR filtering and FFT analysis/display. CASPER protocol data for more than 160 normal speakers and 175 speakers with disordered speech have been gathered thus far.

FUTURE PLANS—During 1994, we will enhance the analytic power of the system. Custom defined wave form discrimination and statistical summary features will be added. We will continue add to the data base for both normal and disordered speakers. Planning for cooperative data collection among existing CASPER sites is underway. Additional funding will be sought to extend the impact of the existing technology by creating a system for real-time biofeedback that can be used during behavioral treatment of speech disorders.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Effects of initial consonant, pneumotachographic mask and oral pressure tube on vocal perturbation, harmonics-to-noise, and intensity measurements. Till JA, Jafari M, Crumley R, Law-Till C. J Voice 1992:6:217-23.

CASPER: computer assisted speech evaluation. Till JA. In: Granstrom B, Hunnicutt S, Spens K, eds. Speech and language technology for disabled persons: Proceedings of an ESCA workshop: ESCA and speech communication and music acoustics, KTH, Stockholm, 1993:125-8.

Interactive effects of local smoothing window size and fundamental frequency on shimmer calculation. Jafari M, Till J, Law-Till C. J Voice 1993:7(3):235-41.

Time-shift, trial, and gender effects on vocal perturbation measures. Jafari M, Till J, Law-Till C. J Voice 1993:7(4):326-36.

[311] CORTICAL AUDITORY EVOKED POTENTIALS AND BEHAVIORAL MEASURES OF APHASIA

Marilyn Selinger, PhD; Thomas E. Prescott, PhD
Denver VA Medical Center, Denver, CO 80220

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C493-R)*

PURPOSE—The purpose of the project is to examine hemispheric processing of language by stable and recovering aphasic patients by using late auditory evoked potientials as direct electrophysiological measurement of hemispheric involvement.

METHODOLOGY—Subjects undergo a behavioral testing battery including the Porch Index of Communicative Abilities; the Boston Diagnostic Aphasia Examination Severity Index; a handedness questionnaire; and a bilateral hearing screening at 500, 1k, and 2k Hz. Evoked potential testing is made up of a right hemisphere task (music), a left hemisphere task (language), and a non-differentiating task (noise). While the subject is actively involved in processing the information in the task, evoked potentials to irrelevant auditory probe tones are used as the measure of hemispheric involvement in the task.

Measurements of electrical activity are bipolar from central midline sites as compared to temporal sites on each side of the scalp. Stable patients will receive this paradigm on two separate occasions, recovering patients will be tested longitudinally at monthly intervals.

PROGRESS—To date, all subjects have been concluded. The findings from the project can be classified into two major areas. First, results from the study can be interpreted as presenting a strong argument for the reliability of the probe-evoked potential measurement. Both size of response and time at which each peak occurs has shown strong test-retest reliability across subjects. In addition, the measured consistency was present for both normal and pathological groups. Finally, one aphasic patient who was a subject in an earlier study 11 years ago was tested. The millisecond (latency) data indicated that the occurrence of this patient's auditory evoked potential peaks were consistent over the 11-year period.

Second, results from the ongoing evoked potential project indicate that 1) patients' recovery process can be monitored by EP techniques, 2) individual neurophysiological response is important to tailoring treatment materials appropriate for each patient, and 3) severity of aphasia appears to define the level of task demand on each patient's processing and, therefore, may define the necessary level of input complexity to bias left hemisphere processing of language.

Presentations based on the methodology and/or findings from this study have been made at the Colorado Speech and Hearing Association Convention, at the American Speech Hearing and Language Association Convention, and at the Clinical Aphasiology Conference.

FUTURE PLANS—Further investigation into the effects of varying language stimuli according to biasing properties and difficulty will be necessary in order to make specific statements about biasing left-hemisphere processing of language. Preliminary work equating various levels of connected language stimuli is currently underway.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Cortical evoked potentials and aphasia: a follow-up case study. Selinger M, Prescott TE. In: Lemme M, ed. Clinical Aphasiology. Austin, TX: Pro-Ed 1993:311-22.

Possible explanation of problem-solving deficits based on resource allocation theory. Selinger M, Walker K, Prescott TE, Davis RE. Aphasiology 1993:7:2.

Preliminary investigations into the effects of changing the attentional target on left hemisphere function in aphasic patients. Selinger M, Prescott TE. In: Lemme M, ed. Clinical Aphasiology. Austin, TX: Pro-Ed. In press.

[312] VERIFICATION OF THE EQUIVALENCY OF LANGUAGE COMPREHENSION MEASURES: A PILOT STUDY

Thomas E. Prescott, PhD; Marilyn Selinger, PhD
Denver VA Medical Center, Denver, CO 80220

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #C92-474AP)*

PURPOSE—This study was designed to verify grade level equivalency between the Stanford Language Comprehension tests and similarly graded scientific subject matter in stable aphasic patients. The specific objectives were 1) to obtain the tests and language materials, 2) to establish stability on each aphasic patient, 3) to establish language comprehension grade ratings using the Stanford Language Comprehension tests, 4) to establish comprehension abilities of scientific subject matter which is graded for educational applications, and 6) to compare the grade level findings obtained from the different language materials.

METHODOLOGY—Twenty-five stable English-speaking aphasic adults with single episode left hemisphere brain damage were tested with the Stanford Listening Comprehension Tests and the selected passages from the scientific curricula. The Stanford listening tests for grades 1.5-9.9 were used

as standardized listening materials. The comparative materials were collected from standardized scientific materials written for students in grades 1-9. The total listening duration at each grade level was between 3 and 3.5 minutes. Following each passage three multiple choice questions were given to the subject.

RESULTS—Pearson r correlations were used to predict grade scores on the scientific materials from the Stanford tests and ranged r from 0.61 to 0.89. The pattern of correlations was highly meaningful (0.80 to 0.89) for 26 of the 40 correlations. The remaining 14 correlations ($r = 0.61$ to 0.79) also fall into a range of moderately to highly meaningful. These results fail to indicate a specific pattern of prediction that is useful in standardizing the scientific language passages.

IMPLICATIONS—Since the standardized passages did not reflect a pattern that would grade the scientific materials, it is felt that there is not appropriate equivalency between the two measures. The results indicated that the Stanford second-grade listening subtests predicted scientific materials recommended for grades 2-9 with essentially equal values. It is now necessary to re-evaluate potential stimuli and grading methods in order to provide appropriate materials for aphasic patients. It is possible that the most efficient means to achieve this goal is to standardize materials on normal and aphasic adults rather than attempting to equivocate materials which are originally written for and standardized on school-aged children. At this point we are not submitting a follow-up proposal on this subject. We need to do some additional background work before designing a new study. However, we must emphasize that we continue to believe that graded listening materials are crucially important for use in measuring and treating auditory comprehension deficits in aphasic adults.

[313] IDEOMOTOR APRAXIA: RECOVERY AND TREATMENT

Leslie Gonzalez Rothi, PhD
VA Medical Center, Gainesville, FL 32602

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C567-RA)*

No report was received for this issue.

[314] AN ANALYSIS OF A TREATMENT FOR APRAXIA OF SPEECH IN ADULTS WITH APHASIA

Julie L. Wambaugh, PhD; Patrick J. Doyle, PhD
VA Medical Center, Pittsburgh, PA 15206

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C692-RA)*

PURPOSE—The primary objective of this project is to conduct an experimental analysis of the effects of a treatment designed to promote improved sound productions in apraxic speakers. Specifically, the effects of training three different sounds sequentially are being examined in terms of 1) acquisition of trained sounds; 2) response generalization (i.e., to untrained exemplars of treated sounds and to untreated sounds); 3) stimulus generalization (i.e., production of treated sounds in oral reading and phrase/sentence repetition); and 4) maintenance of correct sound production.

A secondary objective of this project is to determine whether there are significant differences over time among groups of treated and untreated apraxic speakers and normal speakers on the following aspects of speech production: 1) total number of sound errors; 2) number of phonological processes;

3) speech timing (voice onset time, fricative noise duration, vowel duration, total word and sentence durations); 4) articulatory dynamics; 5) mean length of utterance; and 6) communicative efficiency.

An additional objective is to socially validate treatment effects by having naive listeners determine speech intelligibility through transcribing and rating apraxic subjects' speech samples.

METHODOLOGY—A combination of single-subject and group design is being used to accomplish the preceding project objectives. A series of single-case experimental analyses is being conducted and comparative data are being obtained from untreated apraxic speakers and normal speakers.

Treatment is being applied to each of the treatment subjects individually and in a manner consistent with a multiple baseline design across behaviors and subjects. Treatment consists of a combination of minimal pair contrast and traditional therapy methods (e.g., imitation and phonetic placement). Baseline, treatment, and maintenance probes are being conducted for each individual subject to evaluate production of specific sounds. Additionally, pre- and post-test measures are being obtained from the treatment subjects for comparison to the same measures obtained from the normal and control subjects (obtained at intervals separated by 4 to 5 months).

PROGRESS—Normative speech samples have been collected from a group of 10 non-brain-damaged subjects. These samples have been entered into the Computerized Speech Lab and several analyses are being completed. Preliminary findings indicate that voice onset time measures are stable across testing times. Measures of total sentence duration also appear to be stable across sampling times, whereas measures of total duration of words have varied significantly across times.

RESULTS—Preliminary results indicate that the treatment is effective in promoting improved production of treated sounds in trained and untrained words. That is, positive acquisition and response generalization effects have been observed for all treated subjects. Effects appear to be specific to sounds under treatment, in that generalization effects across sounds have not been noted. Stimulus generalization findings have been mixed, with strong effects seen for some subjects and limited effects seen with others. Maintenance of treatment effects has also varied among subjects

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Treatment for acquired apraxia of speech. Wambaugh JW. Communique 1992:19-28.

Treatment for acquired apraxia of speech: a review of efficacy reports. Wambaugh JW, Doyle PJ. Clin Aphasiology 1994:21:231-43.

Minimal pairs treatment for apraxia of speech. Wambaugh JW, Doyle PJ, Kalinyak MM, West JW. Clin Aphasiology. In press.

Review of acoustic analyses of aphasic and/or apraxic speech. Wambaugh JW, Doyle PJ, Kalinyak MM, West JW. Clin Aphasiology. In press.

[315] EVALUATION OF THE IBM VOICETYPE VOICE RECOGNITION SYSTEM WITH SPEECH-IMPAIRED INDIVIDUALS

Ruth Gannon, MS; Herbert Andrew Leeper, PhD; Nancy Thomas-Stonell, BSc, DSP; Philip Doyle, PhD; Morris Milner, PhD; Ava-Lee Kotler, MSc

Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8; Elborn College, University of Western Ontario, London, ON N6G 1H1

Sponsor: *Ontario Ministry of Colleges and Universities: University Research Incentive Fund; International Business Machines (IBM) Canada Ltd*

PURPOSE—Voice recognition has the potential to allow people who cannot use a standard keyboard to use computer programs such as word processing, spreadsheets, and databases. Unfortunately, many voice recognition systems do not respond accurately when used by people who have speech impairments. The goal of this research project is to evaluate the recognition accuracy of the VoiceType system with six dysarthric speakers and compare the results with those obtained by six normal speakers.

METHODOLOGY—Six subjects (three male, three female) over the age of 13, with dysarthria participated in the project. Subjects were non-hearing impaired, able to follow directions, and spoke English as a first language. There were two subjects for each of three levels of intelligibility: severe (scores between 10-39 percent), moderate (scores between 40-70 percent), and mild (scores between 71-90 percent). Scores were determined from the Computerized Assessment of Intelligibility of Dysarthric Speech (CAIDS).

Each subject was seen for five assessment sessions. Subjects read the word list from the Kent, Weismer, Kent & Rosenbek Test of Intelligibility (1960) and three sentences from the Rainbow Passage. Words were recorded simultaneously by both the computer voice recognition system and a digital audio cassette tape recorder.

Subjects were rank ordered according to voice recognition accuracy, speech intelligibility, and speech consistency. A correlation analysis was performed. Voice recognition accuracy scores were obtained from the fifth training session. This score was selected to allow maximum adaption of the voice recognition system. Speech intelligibility scores were averaged across the five sessions. Speech consistency was calculated using a coefficient of variation (CV = SD/mean) from speech intelligibility and voice recognition accuracy scores.

RESULTS—There was a significantly higher mean VoiceType score for normal speakers compared to dysarthric speakers ($p = 0.008$). Normal speakers scored significantly higher than the mild ($p = 0.03$), moderate ($p = 0.0001$), and severe ($p = 0.03$) dysarthric speakers on the Kent Words. On the Rainbow Sentences, normal speakers scored significantly higher than the moderate (0.009) and severe (0.0003) dysarthric speakers, but not the mild dysarthric speakers. For severe dysarthric speakers, VoiceType accuracy scores equalled or exceeded intelligibility word scores achieved on the CAIDS.

There was a correlation between intelligibility and VoiceType accuracy scores ($r = 0.80$; $p = 0.05$). Those subjects perceived as being more intelligible did better on VoiceType. There was no correlation between perceptual ratings of subjects' overall consistency and VoiceType scores.

Chi-square analyses revealed no significant association between the ability of VoiceType to recognize initial consonants, vowels, or final consonants when the dysarthric speakers were compared to the normal speakers. Vowel recognition was significantly better than the recognition of either initial or final consonants in both groups.

IMPLICATIONS—The results of this study indicate that the more intelligible a speaker, the more success VoiceType will have in recognizing his or her speech. It should be noted, however, that VoiceType is able to recognize speakers across a variety of severity levels. For speaker adaptable systems, consistency of speech production does not appear to significantly affect recognition. These results are promising because they suggest that the frequent inconsistencies in the productions of dysarthric speakers will not limit their use of a voice recognition system.

Further studies need to be conducted to determine how many sessions are required to achieve maximal adaptation of the VoiceType system for dysarthric speakers and whether dysarthric speakers can eventually achieve the same accuracy levels as normal speakers.

[316] REFINEMENT AND EVALUATION OF A COMPUTER-BASED PROGRAM FOR TRAINING SPEECH RATE WITH NEUROLOGICALLY IMPAIRED INDIVIDUALS

Ruth Gannon, MS; Morris Milner, PhD; Nancy Thomas-Stonell, BS, DSP; Patricia Young, MHSc; Russell Galvin, BSc; Edward Stockelbach, BA
Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8;

Sponsor: *Easter Seal Research Institute; International Business Machines (IBM) Canada Ltd*

PURPOSE—The goal of this research was to evaluate the efficacy of "Stepping Stones" for modifying speaking rate in children with dysarthria. Stepping Stones software provides visual and auditory feed-

back of speech using a stepping stone fantasy to teach the concept of pausing. A person naturally alternates movement and pauses when crossing water using stepping stones.

METHODOLOGY—Twelve subjects (5 females, 7 males), ranging in age from 4 to 21 years, were seen for rate modification using Stepping Stones. All subjects had dysarthria due to either developmental or acquired neurological deficits. The 12 subjects were subdivided into 2 subgroups: 5 subjects attempted to increase speaking rate (increase subgroup); 7 subjects attempted to decrease speaking rate (decrease subgroup).

An A-A′-B-C within subject design was employed. The baseline (A-A′) phase was 10 treatment sessions in length. A probe, consisting of sentences, a nursery rhyme, and a picture elicited speech sample, was administered each session throughout the study to provide a measure of speaking rate.

The training phase (A′-B) was equal in length to the baseline phase. A 20 word per minute (wpm) target speech rate range was selected for each client by the speech-language pathologist at the beginning of this phase. Subjects practiced matching sentences at their target speaking rate using the Stepping Stones program. Four weeks after training, a recheck was completed to determine if changes in speech rate were maintained after training.

RESULTS—A repeated measures analysis of variance (ANOVA) revealed that all subjects combined made significant changes towards their speech rate goals during the training phase of the study ($p = 0.001$). There were no significant differences in speech rate between the training and recheck phases, indicating that subjects maintained their new speech rate four weeks after the end of therapy.

Speech rate for the Increase subgroup, was significantly faster during the training phase than baseline for the sentence ($p = 0.0009$) and conversation ($p = 0.02$) conditions of the probe (wpm). Speech rate at recheck (sentences) continued to improve and was found to be significantly faster than training ($p = 0.02$). Post hoc analyses indicated that all three probe conditions (wpm) were significant when the training phase was compared to baseline ($p < 0.05$).

Significant results ($p = 0.01$) were also obtained when subjects' speech rate was analyzed with respect their speech rate goals. During baseline, subjects' rate was, on average, 85 percent of their target range. During the training phase, subjects' rate improved to 100 percent of their target range. The group average at recheck was 101 percent of the target range.

Speech rate for the Decrease subgroup was significantly slower during the training phase than baseline for the sentence ($p = 0.02$) and rhyme ($p = 0.02$) conditions of the probe (wpm). Speech rate at recheck did not differ significantly from the training phase. All three probe conditions were significant when the training phase was compared to baseline ($p < 0.05$).

Significant results ($p = 0.02$) were also obtained when subjects' speech rate was analyzed with respect to their speech rate goals. During baseline, subjects' speaking rate was, on average, 139 percent of their target range. During the training phase, speaking rate decreased to 109 percent of the target range. By recheck, the group average at recheck was 111 percent of the target range.

IMPLICATIONS—Stepping Stones proved effective for modifying speech rate. Speech rate skills were maintained for at least 1 month after therapy. The program proved effective for training speakers to increase or decrease their speech rate, depending on their clinical goals. The large treatment effects obtained from a small number of subjects in this study, demonstrates the potential of computer-based rehabilitation for speech training. Further research should more fully explore the issue of ecological validity, by evaluating rate skills over a longer period of time in home and school settings.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Clinical applications for the SpeechViewer Stepping Stones shareware. Thomas-Stonell, N. IBM SpeechViewer Times 1992:1(3):9-11.

Introducing SpeechViewer Stepping Stones shareware. Thomas-Stonell, N. IBM SpeechViewer Times 1992:1(2):6-7.

[317] CRICOPHARYNGEAL MYOTOMY STUDY

John R. Jacobs, MD; Thomas F. Pajak, PhD; Jeri A. Logemann, PhD
Wayne State University Medical School, Detroit, MI 48201; American College of Radiology, Philadelphia, PA 19107; Northwestern University School of Speech, Evanston, IL 60208.

Sponsor: *National Cancer Institute, National Institutes of Health*

PURPOSE—This study will attempt to answer on a prospective basis whether performance of a cricopharyngeal myotomy improves swallowing. This surgical procedure has been purported to improve dysphagia from a variety of illnesses.

PROGRESS—This multi-institutional, multi-year trial continues to accrue patients. To date, approximately 140 patients have been entered. The subjects for this trial are patients with squamous cell carcinoma involving the supraglottic larynx and the base of tongue. This population is anticipated to suffer with dysphagia following standard treatment. The randomization of the study is between performance of a cricopharyngeal myotomy vs. no myotomy. The primary methodologic tool is videofluoroscopic examination. The study is blinded to investigators.

C. Vision Impairment

[318] USING SELF-MONITORING TO IMPROVE COMMUNICATIVE EFFICIENCY IN APHASIA

Janet L. Whitney, PhD
Miami VA Medical Center, Miami, Florida 33125

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C693-RA)*

PURPOSE—The objectives of this study are to determine the efficacy of self-monitoring treatment for subjects with varying degrees of aphasia to determine social validity of treatment, and to determine the influence of speech, language, cognitive, and demographic variables on treatment effectiveness.

METHODOLOGY—Thirty subjects (10 with mild, 10 with mild-moderate, and 10 with moderate aphasia) will be selected according to proportion of disfluencies and communicative efficiency criteria. They will also be assessed with measures to provide additional information about variables that may influence treatment effectiveness: speech production, word-retrieval, and nonverbal cognitive function. Subjects will also be described in terms of age, education, and occupation. Lesion localization will be determined. The project uses multiple baseline design across subjects and behaviors. Subjects will be exposed to four conditions: baseline, training, independent self-monitoring, and follow-up. The baseline condition serves as the control condition for each subject. Data will be collected continuously in the four conditions.

PROGRESS—Hardware and software for data analysis have been established and all supplies for the first year obtained. Resources and sites for pools of aphasic and normal subjects and volunteer partners have been identified. The investigator has screened and tested a number of aphasic subjects and administered the protocol to several normal subjects. The experience with these subjects has resulted in refinement of the protocol. Early samples of discourse have been analyzed with the language analysis software.

[319] ENVIRONMENTAL INFORMATION NEEDS FOR WAYFINDING BY SPECIAL POPULATIONS

Bruce B. Blasch, PhD; Richard G. Long
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #E-561RA)*

PURPOSE—The purpose of this 3-year project was to determine the most appropriate form and content of wayfinding information for persons with disabilities and older persons.

PROGRESS—The study met its stated goals of obtaining wayfinding data needed by special populations.

METHODOLOGY—In this project, participants were asked to find their way to a destination in an unfamiliar environment. They were permitted to ask questions about the distance and direction they should travel and the direction they needed to turn at choice points along the walk. The type of information they requested along the walk was analyzed to determine the relationship between information content and successful performance in the wayfinding task.

Five groups of 14 participants each participated in this study. They included totally blind persons, partially sighted persons, older adults, people who used wheelchairs, and young people without disabilities. Data were obtained during three wayfinding exercises. One exercise was conducted in an outdoor setting, a second in an indoor environment, and the third in a primarily outdoor setting with an indoor portion. The routes varied in difficulty as a function of number of turns, angle of turns, and length. The outdoor route had eight turns and was approximately 1 mile in length. The indoor route had twelve turns and was about one-fifth mile in length. The mixed route was about one-half mile and had 15 turns.

RESULTS—The data indicate that the frequency of requests for wayfinding and the type of information requested, is related both to the nature of the environment and the nature of the individual's disability. For individuals who were unable to use their vision effectively, for example, the frequency of requests for directions appeared to depend on the regularity of the environment, with more irregular routes yielding more requests. In addition, these groups asked for significantly more categories or kinds of information than the other groups. For example, they, like wheelchair users, requested information about the presence of wheelchair ramps.

Wheelchair users, not surprisingly, frequently requested information about inclines and declines, unusual patterns or breaks in the sidewalk, and the availability of curb cuts. Wheelchair users were similar to blind individuals in the number of categories of information they requested, with one significant exception. They did not tend to request information about the length of the walk.

Older persons without self-reported or obvious disabilities were relatively consistent across environments in the frequency with which they requested wayfinding information. On each of the three routes, for example, slightly less than half of the participants requested information at every turn or choice point. Approximately half the total group requested information about a quarter of the direction set at a time. The older individuals did not request information about ramps, and, with one exception, they requested turns by right/left rather than by cardinal directions.

The control group, made up of young to middle-aged adults without obvious disabilities, tended to request directions at every turn more often than the other groups. Fifty-three percent of persons in this group requested information at every turn in each of the three routes. In contrast to the other groups, only 27, 40, and 33 percent, respectively, requested information at about a quarter of the route at a time. These percentages are lower than for the other groups.

FUTURE PLANS—The technology exists to produce a location/orientation/direction-giving device; however, research is needed to interface the rule base logic or scheme for the user. Based on this study, research is needed to develop a meaningful classification of the environment. This classification could be done on a 1-10 rating scale that could easily indicate the difficulty level of the environment for the functional limitations of the individual.

[320] DESIGN AND TESTING OF AN ELECTRONIC TRAVEL AID FOR BLIND PERSONS

Bruce B. Blasch, PhD; Richard G. Long
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C637-RC)*

PURPOSE—The purpose of this 3-year project was to improve the electronic and mechanical design of an electronic travel aid (ETA), called the Laser Cane, and to investigate the degree to which people with a visual impairment using a Laser Cane could benefit from the device during independent travel.

METHODOLOGY—Part One of this study consisted of the engineering redesign of the Laser Cane (ND-8). Part Two was an evaluation of ND-8 use in natural environments. Survey data about the device was obtained from 60 percent of VA Blind Rehabilitation Center patients receiving training on the ND-8 during 1992 and 1993. All patients had NLP or LPO and none had additional disabilities. Seventy five percent of patients were rated as better than average long cane travelers. The patients that participated in the evaluation were made up of former and present Laser Cane users. The travel ability of individuals using the standard long cane and the newly designed ND-8 was assessed using an established methodology for mobility assessment.

PROGRESS—Improvements were made in the Laser Cane's electronics design, including the use of plug-in integrated circuits to significantly reduce maintenance costs, improve reliability, and provide a more dependable power supply. The ND-8 has also been designed to use standard batteries instead of the custom designed battery used in previous models. Improvements in mechanical design included reduction of the diameter of the cane and relocation of the vibro-tactile outputs to better accommodate people with small hands. The cane was made substantially lighter than the older model, redesigned to make it collapsible, and the lower beam of the three has been eliminated. The ND-8 was then provided to the VA Blind Rehabilitation Centers and patients were trained and tested on this new model.

RESULTS—The valuation verified that the ND-8 Laser Cane reliably detected over 90 percent of the overhanging obstacles on test routes set up at each Blind Rehabilitation Center (mean detection: 7.3 of 8.2 overhangs on route). False alarms for the overhead signal were nonexistent when no object was present either straight ahead or to the side.

As with the up channel, objects were detected with the forward channel with very high reliability. Seventy percent of the patients elected to use the device on the 12-foot setting, and use the forward tone to search for a clear path around obstacles. Patients tended not to contact obstacles with the cane itself, because they used the preview provided by the device to find a clear path around obstacles. In general, patients reported significantly improved travel over use of the long cane alone in negotiating obstacles and overhangs. As expected, little difference was reported in travelers' ability to detect curbs with the Laser Cane as compared the long cane.

For those patients with experience on both models, the ND-8 was judged better because of reduced weight, more stylish appearance, the dramatic reduction of false signals, and the updated technology (e.g., standard batteries). No significant weaknesses were reported for the ND-8 as compared to the ND-7. The benefit of the Laser Cane over the long cane was the preview for obstacles provided by the device. This made obstacle negotiation much

easier and provided the traveler with a more secure feeling. The ND-8 was judged easier to use overall than the ND-7, and had better collapsibility without sacrificing rigidity of joints.

Based on this research, the engineering redesign of the Laser Cane has resulted in a more reliable, ergonomically friendly ETA that is superior to the previous model. One of the major concerns derived from the previous survey was the cost of the Laser Cane. Based on this project, the cost of the Laser Cane was reduced by $1,000 or approximately 1/3. This reduction in price has caused an increased interest in the Laser Cane.

FUTURE PLANS—Future research is needed to determine additional modifications based on canc techniques and patterns of use in natural travel environments. Also, an additional area of research would be to use the software program, RoboCane™ in prescribing the beam length and in determining the most effective ETA for each individual patient.

[321] THE RELATIONSHIP OF AUDITORY SKILLS TO THE MOBILITY OF BLIND INDIVIDUALS

William R. De l'Aune, PhD; Theodore Doll, PhD; Bruce B. Blasch, PhD; Thomas Kuyk, PhD
Atlanta VA Medical Center, Decatur, GA 30033; VA Medical Center, Birmingham, AL 35233

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C430-R)*

PURPOSE—The primary objective of the proposed research was to determine how and to what extent auditory skills contribute to the mobility of persons with low vision and blindness. A secondary objective was to determine how the contribution of audition to mobility differs for special populations, who in addition to having a visual impairment, are elderly, hard of hearing, and/or users of hearing aids.

METHODOLOGY—Older visually impaired subjects were selected from the Southeastern Blind Rehabilitation Center at the VA Medical Center in Birmingham, Alabama. Subjects for the control conditions were drawn from the unit's waiting list. The young visually impaired sample were drawn from the Alabama Institute for the Deaf and Blind in Talladega, Alabama. Young blindfolded, sighted subjects with normal hearing and visual acuity were also tested.

Demographic information was gathered on all subjects, including a profile of their mobility performance. All subjects went through standard clinical vision and audiometric clinical testing. In addition, the subjects were subjected to testing specific auditory tasks central to blind mobility.

To accomplish this specialized psychoacoustic testing at multiple sites, the research project developed portable test equipment. Testing was conducted in an acoustically isolated room with 11 sides, an open ceiling, carpeting on the floor, and 4-inch thick Sonex covering the walls. Ambient noise level and reverberation time for the room were measured, and the Sonex panels were adjusted to minimize reverberation.

Horizontal localization was measured with a counterweighted, boom-mounted loudspeaker capable of being moved silently from directly in front of the seated subject (0° azimuth) to directly behind (180°) with position being recorded directly on the computer through a shaft encoder. The distance from the subject's head to the loudspeaker was 8 feet. The amplitude response of the loudspeaker was measured in octave bands from 20 Hz to 16 kHz, and the loudspeaker was selected so as to provide as flat a response as possible. Experimental subjects responded by means of a pointing device held in their hand.

The remaining tests were conducted through earphones. In the filter test, the subject was presented with two intervals of noise. One interval also contained a signal. The subject was asked to decide whether the signal was present in the first or second interval. Fifty trials of this task were undertaken.

Two tests of temporal resolution, one dichotic and one diotic, were also employed. In these tests the subject also heard two intervals of noise. One of the intervals had a small gap, or interruption in it.

The subject was asked to decide whether the gap was present in the first or second interval. Fifty trials were used in both the dichotic and diotic tests.

PROGRESS—That auditory skills contribute to the mobility of persons with low vision and blindness is not in dispute. The nature and extent of that contribution was the focus of this study. In the course of unraveling the data amassed in this project we hope to answer these questions in considerable detail. At this point, we are able to make two observations based on the data. The first is that visually impaired veterans enter blind rehabilitation programs with formidable auditory skills. The refinement of these skills appears not to be related to the length of time they have been visually impaired, the degree of their visual impairment, or even to the presence of mild to moderate hearing impairment. The second observation is that these skills, perhaps not surprisingly because of their extraordinarily high levels on entry, do not seem to be enhanced through mobility training.

RESULTS—The evaluation of the relationship of auditory skills to mobility performance used a single-subject, multiple baseline approach. The quantity of data produced by this project is enormous and quantitative results will be presented in future as the data analysis unfolds. For the purpose of this report, however, it is believed that data from selected case studies provides the most complete analysis.

[322] DEVELOPMENT OF A COMPUTER MODEL OF MOBILITY COVERAGE FOR THE VISUALLY IMPAIRED

Bruce B. Blasch, PhD; William De l'Aune, PhD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—The purpose of this study was to develop a computer program capable of graphically representing cane coverage in mobility of individuals with severe visual impairment.

METHODOLOGY—The first procedure was to develop a mathematical model of mobility that employs the use of a long cane. The Mobility Coverage Profile and Safety Index (RoboCane®) was accomplished through the programming of mathematical representations for the visually impaired individual's stride length, hand position with a cane, cane sweep width, hand height, shoulder width, foot displacement, foot size, foot splay, heel position, arc offset, tip up, tip maximum height, and cane length. After specifying the relevant measurement parameters involved in the cane technique, developing the mathematical methods for calculating cane coverage, and designing a computer program, it was then necessary to validate the software program. The biomechanics analysis system used for the validation of the RoboCane software included the following: Panasonic Industrial Grade S-VHS Camcorder; Peak Performance Motion Analysis software; Panasonic AG-7300 Computer Controlled Video Player; Matrox Video Frame Grabber Computer Board; Sony Video RGB High Resolution Monitor; and IBM-compatible 386-33 computer system. The Panasonic video camera operating at 60 Hz (pictures per second recording rate) was used for capturing body and cane motions for measurement. The Peak Performance Motion Analysis software utilized the video medium for measuring motion (linear and angular displacement, velocity and acceleration) of the human body and cane in three dimensions. This system operates like a CAD system but it was designed for analyzing the human form as it moves about in space.

RESULTS—The resulting program, RoboCane®, displays a two-dimensional top view of the traveler's foot fall, cane movement pattern, and points where the cane tip touches the ground. A measure of percent protection (the coverage required by the traveler minus the coverage provided by the cane) can be generated from this output. Using Monte Carlo statistical techniques, the software will place user defined obstacles in random positions in the

simulated traveler's path and generate the probability of an unprotected traveler-obstacle collision. This probability in conjunction with the frequency of occurrence of such obstacles in the user's travel environment can be used to generate a safety index for the traveler.

Through adjustment of the input parameters, the mobility professional uses the RoboCane software to design and evaluate techniques and strategies to meet the mobility goals of the client. Increases in aging and multi-impaired clients makes the use of individualized mobility strategies very important. By sharing the results of these analyses with the client, the mobility professional can provide comparative safety information crucial to the client's participation in the rehabilitation process and to his or her informed consent to the rehabilitation plan. By discussing the results with architects and designers, safer and more accessible travel environments can be designed and the mandates of the Americans with Disabilities Act (ADA) can be met.

Based on the results obtained from the use of the RoboCane, mobility specialists around the world have changed the cane techniques that have been taught to visually impaired individuals for the past 50 years. These original techniques were also developed by the VA.

FUTURE PLANS—A 3-year study has been submitted to use the RoboCane software to construct a data base of cane techniques used by blind individuals. This data base will be used to establish norms and to evaluate cane techniques over time. This information will be applied to problems of evaluation, development, and design of mobility techniques, accessibility standards and Electronic Travel Aids (ETAs).

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Computer profile of mobility coverage and a safety index. Blasch B, De l'Aune W. J Visual Impairm Blindn 1992:86(6):249-54.

Development of a computer model of mobility coverage for the visually impaired. De l'Aune W, Blasch B. In: Schoen J, ed. Proceedings of the 1993 Summer Computer Simulation Conference, Boston MA, 1993:1005-10.

RoboCane®. Blasch B, De l'Aune W In: Report from the fourth European Seminar on Education of Orientation and Mobility Instructors, Zeist, The Netherlands, 1993:23-30

[323] REVISION OF THE TEXT: FOUNDATIONS OF ORIENTATION AND MOBILITY

Bruce B. Blasch, PhD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—This is a 1-year project to prepare a revised manuscript of the textbook *Foundations of Orientation and Mobility*. The first edition, edited by Drs. Richard L. Welsh and Bruce B. Blasch, was published in 1980. Developed in an effort to create a comprehensive text for the discipline originally established by the Department of Veterans Affairs in 1947, the book continues to be the only text of its type used in university programs to train mobility specialists for the visually impaired. Used worldwide, it has been translated into Japanese, Spanish, and German.

METHODOLOGY—In order to take into account the advances that have been made over the past 14 years, we first surveyed the professionals. A questionnaire was sent to the instructors of the various O&M programs around the nation. The fecdback received gave critical insight into what those currently teaching in the field of visual impairment and blindness.

Editors Blasch, Wiener, and Welsh have designed the new outline for the second edition and chosen the authors for each chapter. The authors have been given the topics in which to contribute their expertise and have prepared detailed outlines of their chapters for examination by the editors for content, clarity, flow, and redundancy.

Each author has worked closely with either Dr. Blasch or Dr. Wiener, the editors serving as consult-

ant and supervisor to the author during the writing of each chapter. As the chapters are completed, Drs. Blasch, Wiener, and Welsh meet to review the drafts. This assures a thorough review and discussion of the text materials in their entirety and insures consistency of quality throughout. As a result of this process, comments will be sent to the authors for their final revisions.

The manuscript of the entire textbook will then be given to the American Foundation for the Blind (AFB). AFB will work with the editors as well as with textbook architects, photographers, artists, etc. to prepare the final manuscript for publication and dissemination.

FUTURE PLANS—The outcome of this project will result in a second edition of the text. It will be published and distributed by the American Foundation for the Blind, and the VA Rehab R&D Service will share equally in the credits for the preparation and publication of the second edition of this textbook.

[324] FUNCTIONAL INDEPENDENCE MEASURE FOR BLIND ADULTS (FIMBA)

Richard G. Long, PhD; John E. Crews, DPA
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C699-RC)*

PURPOSE—The purpose of this 2-year study was to design and evaluate a set of comprehensive rehabilitation outcome measures for use in VA blind rehabilitation centers. Both self-report measures and clinician rating scales were developed in a series of meetings involving staff of the blind rehabilitation centers and project researchers. Consumers of services also had input into the design of the instruments. Data were gathered at four points: prior to rehabilitation services, at entry to the rehabilitation program, at discharge from the rehabilitation program, and after the client has returned home. The self-report measures permitted collection of a large set of demographic data on veterans. In addition, clients reported their perceived difficulty in performing a set of 23 daily tasks, the frequency with which they perform them, and their satisfaction with task performance. The clinical rating scales involved having clients perform various tasks early in their stay at a center and again just prior to discharge. Clinical ratings were made in low vision, orientation and mobility, manual skills, living skills, and psychosocial adjustment.

METHODOLOGY—The development of FIMBA outcome measures was guided by the theoretical model of the World Health Organization's International Classification of Impairments, Disabilities, and Handicaps. Measures were designed to capture information at the organ, person, and social level. The premise of this research was that at least three types of training-related gains could be documented: gains in veterans' perceptions of their ability to perform routine household tasks safely and independently, gains in observable skills as a result of training, and gains in psychosocial health.

PROGRESS—Prior to this research, little research had been conducted to measure any aspect of rehabilitation outcome of visually impaired individuals. The FIMBA instruments were implemented by a group of VIST coordinators and by VA blind rehabilitation center staff at four centers. Data collection began in February 1993. Many of the instruments have been tested for validity and reliability. Preliminary indications reveal that some instruments present promising validity and reliability results; others will require further refinement. Over 500 subjects have participated in at least some portions of the FIMBA project.

RESULTS—On average, about half the veterans report that the 23 tasks addressed in the Preadmission/Post-Discharge Interview are easier to perform after training than before. Approximately 3 to 15 percent report a maximum gain of three points. Gains in ease of task performance were statistically significant for all tasks. Greatest gains in ease of

task performance were noted for reading mail, reading regular print, identifying a street name, telling time and watching TV. Gains were largest for the low-vision related tasks. These gains presumably reflect the significant impact of device prescription and LV training provided at blind rehabilitation centers.

Statistically and clinically significant gains were also noted for many of the items on the clinical outcome measures in Living Skills and Orientation and Mobility. Analyses are currently underway for other FIMBA clinical components.

FIMBA data will be useful to program managers in designing changes to VA's blind rehabilitation program and in documenting the outcome of program changes. Outcome measures such as FIMBA will likely increase in importance as fiscal constraints and health care reform result in the need to objectively document the impact of rehabilitation services on veterans' quality of life.

FUTURE PLANS—Six regional and national presentations have been made regarding the development of rehabilitation outcomes and the preliminary data analysis of FIMBA. Plans are underway to continue work in development of rehabilitation outcome measures.

[325] DEVELOPMENT OF A SYSTEM TO ASSESS LOCOMOTION OVER LONG DISTANCES: A PILOT STUDY

Richard G. Long, PhD; David Guth, PhD
Atlanta VA Medical Center, Decatur, GA 30033; Western Michigan University, Kalamazoo, MI 49008.

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #C93-601AP)*

PURPOSE—We are working to develop and test a device that will allow researchers to accurately describe the characteristics of visually impaired pedestrians' path of travel while they are walking outdoors or indoors over a distance greater than 15 meters. The absence of such a device severely limits researchers' ability to investigate important problems of large-space mobility in this population. These problems include the ability of pedestrians to successfully detect and avoid objects in the travel path and to maintain a straight line of travel while crossing streets or open areas. Technological developments in laser-based rangefinding devices now make it possible to develop such a device.

METHODOLOGY—The device will measure the path of travel of blind pedestrians using laser-based distance measurement technology coupled with shaft encoder technology. The device will have the capability to continuously track the distance of a traveler from the device with an accuracy of 1/4 in from up to 2,000 ft away. It will detect lateral movement of a traveler with an error of no greater than 6.3 in at 100 yd and 3.15 in at 50 yd. In addition, the device will permit tracking of movement in all directions. Components of the device include an laser-based electronic distance meter that can be aimed a pedestrian, along with a shaft encoder mounted on a heavy duty tripod. A video camera mounted on the laser-based rangefinder completes the system. The subject will wear an omnidirectional reflective target. The sampling rate of the laser-based rangefinder is every 1/2 second after a 4-second initialization period.

PROGRESS—The device has been designed and is currently being built. It will be tested in late 1994.

RESULTS—When the system is operational late in 1994, we expect to be able to generate a plot of the path traveled by a subject. The combined distance and direction data obtained by the system can be readily transformed to a spatial/temporal plot of the subject's route and displayed/manipulated on a computer screen. In addition, the position of the shaft encoder can be calibrated with any cardinal direction, which will allow the plot to show the subject's heading. To test the usefulness of the device, we plan to map out the system's area of coverage and to document the precision of the system. Both distance and angular precision will be assessed. Information provided by the device will be

useful in exploring questions about the ability of blind pedestrians to maintain a desired line of travel or their ability to negotiate objects. The system, for example, should allow us to precisely map a subject's path of travel in response to a given obstacle in the travel path ahead. This information in turn should be valuable in assessing the impact of various interventions to improve mobility performance in this population.

[326] DESIGN AND EVALUATION OF LIQUID CRYSTAL (LC) DARK-ADAPTING EYEGLASSES FOR PERSONS WITH LOW VISION

David A. Ross, MSEE, MEd; Gary L. Mancil, OD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C776-RA)*

PURPOSE—The purpose of this 3-year project is to develop and evaluate liquid crystal (LC) light/dark-adapting eyewear for individuals with low vision. Persons with low vision function best only within a very limited range of ambient lighting. We are working first to develop LC sunglasses that very quickly and precisely control the amount of illumination reaching the user's eyes, and second, to test the usefulness and practicality of these LC sunglasses in actual use by persons with low vision.

METHODOLOGY—Potential LC materials (those with a wide light to dark range) were evaluated for optical quality (transmission range, spectral characteristics, and optical distortion). The two LC materials with the best optical quality and widest light/dark range were chosen for use in the first prototypes, which are to be initially tested for suitability by a small, diverse, population of persons with low vision. Any required changes in design suggested by this population will be implemented and improved prototypes constructed. A final more rigorous testing and analysis will then be performed with a population of 104 subjects comprised of 1) persons with central vision loss from age-related macular degeneration, 2) persons with cloudy ocular media, 3) persons with retinitis pigmentosa, and 4) persons with rod/cone dystrophy. These results will then be published and made available to manufacturers.

PROGRESS—Seven types of LC materials have been evaluated, and one type of twisted nematic material has been chosen for use in subject trials. Control circuitry has been designed and tested, and appropriate frames have been selected. Two different LC materials will be tested: one that effects a transmission range of 64 to 27 percent, and one that effects a transmission range of 35 to 1 percent. Eight pairs (four pairs in each of two head sizes) of LC sunglasses were made for subject testing, which began in July 1994.

RESULTS—The methods described above have been followed in the selection of an LC material. The light/dark range of available materials was found to be less than the optimal range the investigators had desired (namely, a transmission range of 80 to 1 percent). On the high end, the best transmission range was 64 down to 27 percent. On the low end, the best achievable was 35 down to 1 percent. No noticeable visual distortion was evidenced in either case, and ultraviolet and infrared transmissions were attenuated by more than an order of magnitude at the highest transmission levels and by as much as three orders of magnitude at the lowest transmissions levels. Also of concern is the ability to apply this process to plastic lenses. All work to date has been performed with glass lenses.

FUTURE PLANS—A means of widening the transmission range will continue to be investigated, as will a means for directly depositing LC materials directly onto plastic prescription lenses.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Dark adapting liquid crystal glasses for persons with low vision. Abstract. Mancil GL, Ross, DA. Opto Vis Sci (Suppl) 1993:70(12s):130.

[327] ADJUSTABLE POWER LIQUID CRYSTAL LENSES TO ASSIST PERSONS WITH LOW VISION: A PILOT STUDY

David A. Ross, MSEE, MEd; Gary L. Mancil, OD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #C93-608-AP)*

PURPOSE—The purpose of this project is to develop and evaluate adjustable power liquid crystal lenses (APLCLs). The intent is to develop a single 3× magnifying lens comprised of liquid crystal (LC) material. This lens is to be constructed in such a way that the power of the lens can be varied by applying a variable voltage to the LC material. The goal is to be able to linearly increase the power of this lens from 3× to 4.5× via a vernier control.

METHODOLOGY—Potential LC lens materials with large refractive ranges (Δn) were evaluated for optical quality (optical clarity, media bubbles, cloudiness and visual distortion). Each material was encapsulated between the faces of glass slides with spacers to accurately maintain the distance between the faces. Three different thicknesses of each material were evaluated: 50 microns, 100 microns, and 200 microns. The material with the best optical quality at all three thickness was chosen as the material to develop. Then to maximize Δn for this material, solutions of higher viscosity were prepared. An actual lens is then to be constructed of this material and evaluated for optical quality. The lens will consist of the chosen LC material encapsulated between a flat glass sheet and 5× lens (jeweler's loupe), such that the spacing at the edge between the glass and the lens is 200 microns, and the spacing at the center of the lens is 107 microns. The LC material will form a negative lens with predicted variable power ranging from about -2× to about -0.5×, giving an overall predicted range for the combined lens of 3× to 4.5×. The optical quality and power range of this lens will then be measured, and the value of the techniquc evaluated accordingly.

PROGRESS—Thirteen samples of promising LC materials of varying electric-field modulated refractive range (Δn) and varying thickness were tested for optical clarity, media bubbles, cloudiness, and visual distortion. The sample found to be superior in all four tests was an anti-parallel material with a viscosity of 80 C Stokes. This sample had a refractive range (Δn) of 0.28. A clip-on jeweler's loupe is being constructed of this material and will be tested over the next few months.

RESULTS—The methods described above have been followed in the selection of an LC material and in the maximization of Δn for this material. The best optical quality was found in an anti-parallel arrangement of viscosity 40 C Stokes. The viscosity of this material has been increased to 80 C Stokcs, to obtain a Δn of 0.28. A lens is currently being constructed.

FUTURE PLANS—If the jeweler's loupe being constructed proves successful, then techniques for maintaining optical quality in larger lenses will be studied and proposed. Also, methods for obtaining a constant e-field over the varying thickness of thc LC lens will be developed and evaluated for practical use.

[328] DEVELOPMENT AND VALIDATION OF CRITERIA FOR TASK SAFETY IN BLIND MOBILITY

William R. De l'Aune, PhD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C585-RA)*

PURPOSE—There is an increasing trend for the clients of VA Blind Rehabilitation Centers to be elderly and to experience age-related multiple impairments. Evaluation of a client and his or her ability to safely perform an orientation and mobility (O&M) task has become increasingly complex. Clinicians must consider remaining vision, other sensory abilities, cognitive and physical status, and personality variables. These attributes must be evaluated in travel situations ranging from familiar indoor to complex, unfamiliar outdoor. O&M specialists are required to make decisions concerning clients' capabilities without any recourse to a standardized body of professional knowledge.

A conference of O&M experts experienced with multiply handicapped individuals was convened. A complex matrix of O&M tasks, environments, skills, and functional prerequisites (sensory, motor, and cognitive) was generated. While this matrix cannot be validated experimentally, this project utilized published references and O&M expert opinion to refine and validate it as a representation of best professional judgment.

METHODOLOGY—The proposed development project utilized standard knowledge engineering techniques to develop a knowledge base and expert system on task safety in orientation and mobility. The performance of the resulting knowledge base system was evaluated for reliability and validity and then used as a consensus forming tool in a national workshop of experts, which resulted in the further development of the knowledge base. After incorporation of the new and refined knowledge base, the knowledge base system was once again evaluated for reliability and validity.

PROGRESS—The project is completed. A prototype knowledge base was developed on the initial matrix of O&M tasks, environmental characteristics, client skills, and client functional attributes. Pilot testing was performed, followed by reliability and validity testing and analysis of case studies. A database program capable of learning classifications was developed to aid in knowledge acquisition from the experts. A public knowledge database was developed using public literary sources. Private expert knowledge was then integrated with the public knowledge to form a knowledge base of client attributes relating to travel safety. A national meeting of 32 O&M experts was held to evaluate and to refine the client attributes. Statistical analysis and neural network technology was used to obtain importance weightings for the attributes. The client attribute knowledge base was refined based on consensus reached by the panel of experts. The environmental and task attribute knowledge base was expanded and refined, with cross references to the client attribute knowledge base defined.

RESULTS—A complex knowledge base consisting of client variables and environment variables has been created. The client variables define a blind or visually impaired individual's sensory abilities and skills pertaining to orientation and mobility tasks. The environment variables define the functional attributes used to evaluate safety in travelling different environments. Once disseminated, it is anticipated that the knowledge base will serve as a useful tool in the education of future O&M professionals and serve to supplement the expertise of an O&M professional when evaluating a client.

FUTURE PLANS—The knowledge base and KB system will be disseminated to university O&M training programs and to rehabilitation agencies. Periodic updates of the knowledge base will be accomplished through cooperation with Interest Group IX (O&M) of the Association for Education and Rehabilitation of the Visually Impaired (AER). Final validation of the decisions made by the system and its underlying logic and use of the rule base will be evaluated by additional professionals in both rehabilitation and university training programs.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Computer profile of mobility coverage and safety index. Blasch B, De l'Aune W. J Visual Impairm Blindn 1992:86(6):249-54.

Development of a computer model of mobility coverage for the visually impaired. De l'Aune W, Blasch B. In: Proceedings of the 1993 Summer Simulation Conference, San Diego, CA, 1993:1005-10.

RoboCane. Blasch B, De l'Aune W. In: Report from the Fourth European Seminar on Education of Orientation and Mobility Instructors, Zeist, The Netherlands, 1993:23-30.

Risk determination in orientation and mobility services: ethical and professional issues. Banja J. J Visual Impairm Blindn. In press.

[329] THE ENHANCEMENT OF BALANCE TESTING

William De l'Aune, PhD; Richard T. Jackson, PhD; Charles M. Epstein, MD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—We are concerned with enhancing techniques for measuring equilibrium and balance and detecting balance abnormalities in patients. The detection of subtle abnormalities is necessary not only for initial diagnosis but for accurate judgment of the results of rehabilitation programs. We work primarily with dynamic posturography and judgments of subjective visual vertical and horizontal. We wish to make them more accurate clinical tools.

PROGRESS—We use the NeuroCom Equitest dynamic posturography system. Several initial publications by other authors who used this device suggested only moderate sensitivity and specificity for disorders of balance, including diseases of the vestibular system. Our experience with patients was similar. We previously showed that stressing the balance control system with a 55° head extension made the posturography tests more difficult but still easy enough for patients to perform. The early tests on head extension were performed on 20 normal subjects and showed they had more difficulty in two conditions; in both, the support surface moves proportionally to body sway angle (sway referenced feedback). The largest increase in body sway was when the eyes were closed.

We have now extended this control series to 84 normal subjects with special emphasis on subjects older than 60 years. The results are very similar to the results from the 20 earlier subjects. Head extension increases body sway and the chances of falling when performing the more difficult posturography tests. The maneuver is more effective in the elderly than the young. This work is described in a published symposium article and an abstract. We have applied this technique to a group of patients with Meniere's disease to determine if the head extension maneuver increases the sensitivity of the tests. The first group that was tested showed that only 25 percent had abnormal responses in the standard posturography test protocol. However, 86 percent of the remaining patients were clearly abnormal when tested with head extension.

The work with Meniere's patients has been continued and expanded and has been submitted for publication. The results are essentially the same as the earlier work. Head extension is a valuable and simple technique that can be used to significantly improve the sensitivity of posturography testing in patients. In addition to head extension, we are investigating the usefulness of testing a subject's estimation of the vertical and horizontal both with the head erect and 45° in the right and left roll plane. We first established baseline values in 35 normal volunteers. We then tested 28 patients with multiple sclerosis. Only 3 of the 28 produced normal values in the visual alignment tests. Although the visual alignment tests are not specific for multiple sclerosis, the poor performance indicates a disruption of the integration of visual, vestibular, and somatosensory information.

RESULTS—We have shown that we can enhance the sensitivity of posturography tests both by the simple maneuver of 55° head extension and by the calculation of energy use per body weight during

the tests. We have also shown that tests of visual alignment can prove valuable in establishing degrees of abnormality. We are presently using these procedures to assay the effects of strength training on equilibrium in the elderly. We will submit a proposal to use these procedures to test the effects of strength training in multiple sclerosis patients.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Head extension and sway in normal volunteers. Epstein CM, Jackson RT. In: Woollacott M, Horak F, eds. Posture and Gait: Control Mechanisms. Vol. 1. Portland, OR: University of Oregon Books, 1992:171-4.

Oscillating head movement and its effect on posturography. Jackson RT, Park S, Epstein CM. In: Abstracts of the 15th Meeting of the Association for Research in Otolaryngology, 1992:114.

Posturography patterns in Meniere's diseasc. Jackson RT, Epstein CM. In: Woollacott M, Horak F, eds. Posture and Gait: Control Mechanisms. Vol. 1. Portland, OR: University of Oregon Books, 1992:300-3.

Head extension and sway referencing in posturography. Jackson RT, Epstein CM, Boyette JE. In: Abstracts of the 16th Meeting of the Association for Research in Otolaryngology, 1993:18.

Abnormalities in posturography and estimations of visual vertical and horizontal light bar alignment in multiple sclerosis. Jackson RT, Epstein CM, De l'Aune WR, Park K. In: Abstracts of the 17th Meeting of the Association for Research in Otolaryngology, 1994:110.

Abnormalities in posturography and estimations of visual vertical and horizontal in multiple sclerosis. Jackson RT, Epstein CM, De l'Aune WR. Am J Otol. In press.

[330] AN ADAPTIVE CANE FOR SPECIAL ADULT GROUPS: A PILOT STUDY

Rickilyn M. Mancil, MA; Stephanie Manuel, MS
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #C92-482AP)*

PURPOSE—This 1-year pilot study proposed to design an adaptive mobility device (AMD) for visually impaired adults who have multiple impairments or who are elderly. Many of these individuals are unable to use the traditional long cane because it requires strength, coordination, and cognitive abilities they lack. Unlike the long cane, an AMD requires minimal instruction: the user has only to push the device in the direction of travel. The design of the new AMD is based upon devices that have been designed and built by orientation and mobility (O&M) specialists to meet the needs of specific clients. The goal of this study is to develop an effective, durable device designed to meet the needs of special adult populations and designed to have potential for commercial production.

METHODOLOGY—A questionnaire was developed to evaluate AMDs that have been used in the past. Twenty-six O&M specialists who have had previous experience with AMDs completed the questionnaire during an interview conducted by telephone. The results of the interviews have been incorporated into a computer database and statistically analyzed.

The test group will consist of 30 adults who are elderly and visually impaired, 30 adults who are multiply-impaired and visually impaired, and 40 individuals, any age, who have previously used AMDs. O&M specialists have been sent letters requesting the age and height of each client who will participate. Each client will be provided with a prototype AMD to use during the 5-week testing period. The O&M specialist will be required to spend a minimum of 1 hour per week instructing or observing each client. If the specialist feels it is appropriate, the clients can use the AMD under other supervision or without supervision. At the end of the 5-week period, the specialist will complete a questionnaire to assess the effectiveness of the AMD for each client. All questionnaires will be returned and tabulated to determine the positive and negative features of this prototype.

PROGRESS—Notices requesting volunteers for participation in the study were placed in professional newsletters. Volunteers were also recruited through lectures at regional conferences and personal correspondence. Field testing will begin within the next few months.

RESULTS—In general, the O&M specialists felt that the AMDs were bulky, conspicuous, and had a homemade appearance that was socially unacceptable. Devices that rolled on wheels tended to lead the student away from the path of travel, and were noisy to the point of distraction when used indoors. The information obtained from the questionnaire was used to develop the prototype AMD. The prototype is constructed from aluminum tube. It has a sleek, professionally made appearance and will come with interchangeable runners and caster wheels.

FUTURE PLANS—Ideas for further research include curriculum development for adaptive mobility devices, incorporation of the findings of the current project into a newly designed AMD prototype, and measurement of its success against other AMDs on the market or commonly being made and used by O&M specialists.

[331] EVALUATING THE EFFICACY OF A PERIPHERAL VISION EXPANDER SYSTEM: A PILOT STUDY

Rickilyn M. Mancil, MA; Duane R. Geruschat, PhD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #C92-466AP)*

PURPOSE—This 1-year pilot study documented proof of concept regarding a more effective, practical optical device, the Peripheral Vision Expander System (PVES), for independent travel of people with severely restricted visual fields. Using the theoretical model of the PVES patent, central acuity has a 1:1 ratio. An eye movement in any direction provides information in a minified, yet expanded peripheral visual field. This design characteristic is the major design innovation which was evaluated in this pilot study, that of combining normal central acuity with a minified peripheral field. The first generation of the PVES has shown promise for many individuals with significant field loss.

METHODOLOGY—*Creating a Mounting System for the Lens Prototype.* The lenses provided by the inventor were in a hand-held form. For evaluation purposes, a spectacle-type system was required. The prototypes were successfully mounted to a helmet by creating a system of aluminum tubes and counterweights that distributed the lens weight across the head, allowing the lenses to maintain a stable position in front of the eyes. Further fitting adjustments included pantoscopic tilt, vertex and pupillary distance.

Evaluating the System's Optical Characteristics in a Clinical Setting. A standardized battery of clinical vision tests were completed, using best corrected visual acuity with and without the PVES. Specifically, distance acuity in the central and peripheral regions of the device was evaluated. Each participant was screened for best refraction. A comprehensive evaluation of the visual field was conducted and contrast sensitivity was evaluated.

Evaluating the System's Functional Characteristics in the Community. Each participant was required to walk both indoors and outdoors, with and without the system. An indoor shopping mall was selected that included a variety of obstacles. Participants walked from an outdoor, residential neighborhood into a small business environment which involved street crossings. Both routes were divided into two equal sections with participants randomly assigned to complete half the route with the device and half without it. Performance was evaluated on unwanted contacts, stumbles, street crossings, drop-off detection (such as curbs), ability to remain oriented

to the environment while moving, productive walking index, total time, and stride length.

Evaluating the System's Optical Characteristics in a Laboratory Setting. Ray tracings, or mathematical computations of the prototype, were completed by an optical engineer to determine optimum distances and sizes for the lenses and best materials to be used.

PROGRESS—Regarding proof of concept, all 10 participants stated that if modifications of 1:1 ratio in central lens, weight, aesthetics, size, and comfort were incorporated, they would use the lens system. All participants were pleased with the peripheral portion of the lens and the enhanced field it provided.

RESULTS—This project has led us to conclude that 1) adaptation time and instruction are needed prior to walking complex mobility routes, 2) the ring scotoma caused problems which may be addressed through changing the design of the system or offering a variety of central lenses for the system, 3) reducing the weight and size are critical to any practical applications of the system, and 4) consultation with an experienced design and manufacturing team is critical to the development of the next generation of lenses with a 1:1 central lens.

FUTURE PLANS—We plan to develop a prototype that has the 1:1 ratio in central lens, improved aesthetics and comfort, and reduced weight and size. We will compare the performance of this newly designed PVES to that of another popular field enhancement system, a spectacle-mounted reverse telescope.

[332] A NATIONAL SURVEY OF THE IMPACT OF LOW VISION DEVICE USE AMONG VETERANS

Gale R. Watson; Sharon Beck; Joan Stelmack, OD; Joseph Maino, OD; William De l'Aune, PhD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C639-RA)*

PURPOSE—This project investigated veterans' use of low vision devices (LVDs). Subjects were drawn from veterans who attended the Department of Veterans Affairs Blind Rehabilitation Centers (BRC) and Visual Impairment Centers to Optimize Remaining Sight (VICTORS). A telephone interview format was used.

PROGRESS—Staff at each of the seven sites completed forms requesting information from patient records for veterans attending the BRC and VICTORS programs approximately 12 to 24 months before the survey. Telephone surveys were developed and programmed on MacIntosh IIci using Hypercard. A stratified random sampling technique based on age, acuity, and etiology was used to select veterans from the national subject pool. The telephone survey was administered to 200 veterans who had been prescribed 740 devices. A subset of questions was repeated in a reliability check within 5 days for 40 veterans. Fourteen wives were interviewed to ascertain their observances of veterans' use of low vision devices. Fifteen veterans were videotaped using their low vision devices in their homes to validate their responses.

METHODOLOGY—Test-retest reliability correlation was established at 0.9047. Wives' responses resulted in a percent agreement with veterans' telephone interview answers of 86 percent, supporting congruent validity. Expert rating of vetcrans' videotaped use of their low vision devices yielded a congruent validity percent agreement with their answers to the telephone interview of 98.7 percent

Of the 740 prescribed devices, 632 (85.4 percent) were still in use. Demographic variables consisting of age, race, presence of a helper, identity of helper, live-in status of helper, marital status, socialization with friends, shopping for groceries, attendance at clubs, education, employment status, type of residence, and household income were analyzed for possible relationship to the use of

LVDs. Three variables were strongly related to the continued use of LVDs; presence of a helper, the fact that the helper lived in the home with the veteran, and a median income level. Age, level of acuity and type of etiology were not related to continued use of devices for this sample.

Low vision devices were categorized as magnifiers (hand-held or stand), microscopes, hand-held telescopes, mounted telescopes, video magnifiers, and field expansion devices. Subjects were asked whether they used their low vision devices for reading, writing, typing, traveling, watching television, identifying faces, repairs, cooking, lawn and gardening, and grooming/health care.

RESULTS—Of all devices, 49 percent used for reading, 18 percent used for writing, 5 percent used for typing, 19 percent used for travel, 14 percent used for watching television, 9 percent used for identifying faces, 17 percent used for repairing, 13 percent used for cooking, 20 percent used for lawn and gardening, and 9 percent used for grooming/health care.

Video magnifiers were used primarily for reading (97 percent) and writing (76 percent). They were also used for repair (34 percent), cooking (29 percent), typing (16 percent), grooming (14 percent) and lawn and gardening (1 percent). Mounted telescopes were used primarily in watching television (68 percent) but also found useful in lawn and gardening (33 percent), faces (27 percent), travel (21 percent), reading (2 percent), typing (1 percent), and grooming (1 percent).

Hand-held telescopes were used for travel (73 percent) and lawn and gardening (56 percent) with considerable utilization for looking at faces (23 percent). One percent responded that hand-held telescopes were used in reading, typing, TV watching, repairing, cooking, and grooming.

Spectacle mounted microscopes were used primarily for reading (58 percent). Other uses included repair (40 percent), writing (28 percent), cooking (19 percent), grooming (13 percent), typing (13 percent), and lawn and gardening (6 percent).

Magnifiers were used primarily for reading (82 percent) with other uses noted as repair (20 percent), cooking (20 percent), writing (18 percent), lawn and gardening (6 percent), and typing (4 percent). Field expansion devices were used for travel (57 percent) and lawn and gardening (14 percent).

[333] USE OF MICROPHOTODIODE IMPLANTS TO RESTORE RETINAL FUNCTION: A PILOT STUDY

Neal S. Peachey, PhD
Medical Research, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #C93-569AP)*

PURPOSE—The purpose of this project is to determine whether a surgically implanted microphotodiode array (MPA) is capable of mediating vision. Specifically, the silicon-based MPA is placed in the subretinal space of a cat. Visual evoked potentials (VEPs) are recorded from the scalp in response to infrared (IR) and white light. Since the MPA is sensitive to IR light, while the visual system of a cat is not, IR stimulation is used to assess whether the MPA has made functional connections within the retina. If such connections are made, then a reliable VEP signal will be observed in response to IR stimulation. Such an observation would spur the refinement of the implant for the eventual application to humans suffering from retinal diseases such as retinitis pigmentosa and age-related macular degeneration.

METHODOLOGY—Adult cats are initially anesthetized with an injection of ketamine and xylazine and then are brought to a surgical plane with 1.5 percent isoflurane. A scleral incision is made on the temporal side of the right eye. A vitrectomy facilitates movement of the implant within the eye. A small retinal detachment is made near the area centralis. A slit is then placed at the edge of the detached area, to accommodate the implant. The implant is then positioned in the subretinal space, which is allowed to settle to its original position. At this point, the eye is closed and the cat is allowed to wake up. The

left eye is not manipulated, and serves as an unoperated control.

At later time points, VEPs are recorded from anesthetized cats. The recording electrode is placed over the visual cortex and an electrode in the mouth is used as a reference; a needle electrode placed in the middle of the back serves as ground. Responses are recorded first to white light stimulation, to ensure that responses are being reliably recorded from both eyes. IR stimulation is then used, with the implanted and control eye tested separately. The cat is then allowed to wake up and is returned to its home cage until the next testing session.

PROGRESS—To date, an MPA has been placed into the subretinal space of one eye of each of 4 cats. VEPs have been recorded post-surgically to assess their success in mediating visual function.

RESULTS—The first two of the implanted cats were lost during the initial post-surgical recovery period. The latter 2 cats are currently housed in the cat colony and are tested at several-week intervals. In both cases, the retina that was surgically detached has developed into a larger retinal detachment. As a result, the implant has greater freedom to move than is desirable. Evaluation of the retina lying above the implant using an indirect ophthalmoscope indicates that there is no inflammatory response to the implant. VEPs to IR light have been essentially nonexistent, due to the peripheral positioning of the implant: the implants were originally placed near the area centralis, which enjoys the greatest representation of the cortical level. However, implant spikes were recorded, indicating that the implant is responding to light in the expected fashion. We believe that the progressive retinal detachment is the greatest problem and that the initial vitrectomy was too complete so that the vitreous material did not hold the retinal material in place.

FUTURE PLANS—The immediate future plan is to test this idea by using only a partial vitrectromy during the implantation procedure. In addition, we are considering the use of photocoagulation tacks near the detachment border, to prevent the detachment from growing.

[334] CONNECTED SPEECH DEVIATIONS OF APHASIC AND NON-BRAIN-DAMAGED ADULTS

Robert H. Brookshire, PhD
Speech Pathology Section, VA Medical Center, Minneapolis, MN 55417

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C817-RA)*

PURPOSE—During the last decade, there has been increasing recognition that aphasic adults' communicative success in daily life is clinically more important than their adherence to standard language rules and patterns of use. As a consequence, several measures of communicative efficiency have been developed that provide information about how much of what a speaker says is accurate, relevant, and informative. However, they do not quantify other characteristics of aphasic adults' connected speech: failure to provide main concepts, lack of cohesion, failure to include important linguistic elements, or the presence of deviant speech behaviors such as use of inaccurate or vague words or unnecessary repetition. Because such connected speech characteristics may seriously interfere with an individual's communicative success, measurement of these characteristics and assessment of their impact on listeners is an important clinical concern, in terms of deciding who needs treatment, deciding what to treat, and measuring outcome.

The overall objective of the proposed research is to determine which characteristics of aphasic adults' connected speech are likely to have the strongest effects on their communicative success in daily life. Specific objectives are 1) to develop reliable measures of deviant speech behaviors in the connected speech of aphasic adults, 2) to quantify the frequency and nature of deviant speech behaviors exhibited by aphasic adults and by non-brain-damaged adults, and to assess how aphasic adults and non-brain-damaged adults differ with regard to

these behaviors, and 3) to evaluate the extent to which normal listeners' judgments of the quality and adequacy of aphasic and non-brain-damaged adults' connected speech are related to objectively-measured characteristics of the connected speech such as macrostructural integrity, communicative efficiency, and the presence of deviant speech behaviors.

METHODOLOGY—Connected speech samples from non-brain-damaged adults and adults with brain injuries will be transcribed and scored for the presence of several specific behaviors, in addition to the samples' overall communicative efficiency and informativeness. Audiotape recording of non-brain-damaged or brain-damaged speakers will be played to normal judges, who will make subjective judgments about the communicative success of the spcakers and the degree to which the speaker's spcech characteristics cause various subjective reactions in the listeners.

PROGRESS—This is a newly funded projcct, and no data have been analyzed.

IMPLICATIONS—The results of this research promise to affect clinical management of aphasic patients. Sensitive and reliable methods for quantifying the deviant speech behaviors of aphasic adults will provide for data-based decisions about the effectiveness of specific treatment approaches, and enable clinicians to formulate treatment procedures and objectives based upon reliable measures of communicative anomalies. Knowledge of which dcviant speech behaviors have the greatest effects on normal listeners' subjective judgments of communicative success will enable clinicians to focus trcatment on aspects of connected speech that have the greatest potential for improving daily-life communication.

[335] PROMOTING GENERALIZED LANGUAGE USE: AN ANALYSIS OF TREATMENT VARIABLES

Patrick J. Doyle
VA Medical Center, Pittsburgh, PA 15206

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #C330-RA)*

PURPOSE—The objectives of the program are to 1) evaluate the effects of Conversational Skills Training (CST) on the informativeness of aphasic subject's narrative and conversational discourse, 2) determine the extent to which objective measures of informativeness obtained under structured discourse conditions predict subjects' performance on those measures under conversational discourse conditions, and 3) describe the relationship between objective measures and subjective ratings (i.e., direct magnitude estimates) of the informativeness of aphasic subjects' discourse.

METHODOLOGY—Single-subject experimental designs are being utilized to examine the effects of CST on several objective measures of informativeness across a variety of sampling conditions. Descriptive correlational designs were employed to examine the relations between measures of informativeness under conversational and structured sampling conditions, and between objective measures and direct magnitude estimates of informativeness.

RESULTS—Preliminary results of single subject data indicate that the effects of CST on thc informativeness of aphasic subjects' connected discourse are equivocal as measured by correct information units, and accurate and complete main concepts. Clearer effects have been demonstratcd for some subjects on measures of informative minimal discourse units. Comparisons of subjects' performance ($n = 20$) under conversational and structured discourse conditions revealed that subjects produced significantly greater percentages of correct information units under conversational discourse conditions, but that the percentagc of corrcct information units produced during structurcd discourse tasks could be used to predict performance under conversational conditions with a high degrec of accuracy. Correlational analysis of objective

measures and subjective ratings of aphasic subjects' informativeness (n = 25) indicated that objective measures were strongly correlated with perceived informativeness, and that overall severity of aphasia did not fully account for raters' perceptions.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Effects of setting variables on conversational discourse in normal and aphasic adults. Doyle PJ, Thompson CK, Oleyar KS, Wambaugh JL, Jackson AV. Clin Aphasiology 1994:22:135-44.

Relation between objective measures and listeners' judgments of the communicative informativeness of aphasic adults' connected discourse. Doyle PJ, Tsironas D, Goda AJ, Kalinyak M. Clin Aphasiology. In press.

[336] READING REHABILITATION OF GERIATRIC PATIENTS POST EXUDATIVE MACULOPATHY

Joan Stelmack, OD
Central Blind Rehabilitation Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—This study is assessing the effectiveness of a formal instruction program using eccentric viewing training techniques reported in the low vision literature in improving the rate of accurate reading measured with the Minnesota Low Vision Reading Test (MN) developed by Gordon Legge, PhD. The key questions to be answered are: 1) Does training in eccentric viewing improve reading speed of geriatric patients with post-disciform AMD? 2) How much improvement in maximum reading speed can be expected as a result of training in eccentric viewing? 3) Can improvement in reading speed post training be predicted from clinical measures?

METHOD—Thirty-seven geriatric patients with post disciform AMD who are participating in the low vision program at the Central Blind Rehabilitation Center are being recruited for the study. After clinical assessments are completed, the MN is administered to determine the rate of accurate reading without low vision devices. The MN is again administered at the conclusion of eccentric view training. Reading speeds pre- and post-training will be compared.

[337] CAN IMPROVEMENT IN READING RATES IN PATIENTS WITH MACULAR DISEASE BE PREDICTED PRIOR TO VISION REHABILITATION?

T.T. McMahon; M. Hansen; J. Stelmack; P. Oliver; M. Viana
University of Illinois, Chicago, IL; Central Blind Rehabilitation Center, Edward Hines VA Hospital, Hines, IL.

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—As a further study of saccadic eye movements and reading capabilities in individuals with macular disease, a masked clinical study was conducted to determine whether changes in saccadic frequency were correlated to changes in reading rates or number of errors for a reading task.

METHODOLOGY—A measure of eye movement characteristics in the form of a saccadic frequency score (SFS) was utilized. Reading rate measurements, reading error measurements, and eye movement recordings were made in a masked fashion for 12 subjects with macular disease prior to and

following an intense 6-week inpatient vision rehabilitation program.

RESULTS—The mean age was 70.9 yrs. (63-77 yrs). Mean visual acuity was 10/100 (10/40-10/200). Mean reading rates at entry and discharge were 8.5 words/min and 20.9 words/min respectively ($P = 0.02$). Saccade scoring (F/X5) improved from 2.709 to 2.022 ($P = 0.07$). Reading errors improved from 5.60 to 4.00 ($P = 0.03$). Interestingly, data appeared to cluster into two groups, one demonstrating improvement and one not showing improvement. Cluster analysis demonstrated the most powerful association existed between reading rate, saccade scores and reading errors. Membership in the two clusters is consistent prior to and post rehabilitation in all but one case. Clustering is most evident for reading rate and reading errors and less so for saccadic scores. Cluster data suggests that using our test paradigm patients with reading rates less than 10 words/min, more than 2 errors for a short passage, and an F/X5 score of greater than 2.0 are less likely to show improvement in reading with rehabilitation.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Saccadic eye movements as a measure of the effect of low vision rehabilitation on reading rate. McMahon TT, Hansen M, Stelmack J, Oliver P, Viana M. Optom Vis Sci. In press.

[338] VALIDATING A MEASURE OF LOW VISION FUNCTIONAL STATUS

Caroline K. Ross, ScD; Tom Stelmack, OD; Joan Stelmack, OD; Melaine Fraim, MA
VA West Side Medical Center Chicago, IL 60612; Blind Rehabilitation Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *VA Health Service Research and Development Service*

PURPOSE—The purpose of this study is to validate a measure of low vision functional status, the Low Vision Functional Status Evaluation (LVFSE). The LVFSE was designed to be sensitive to functional status of patients who have visual deficits rather than to be reflective of overall functional status.

METHODOLOGY—The measure to be studied has been designed for administration in an inpatient or outpatient low vision rehabilitation setting. Several issues were considered in identifying tasks to be included in the LVFSE. First, tasks likely to be performed during an individual's daily routine which would be limited by visual deficits were included. For example, pouring liquids during mealtime, reading the comics or sorting colored socks were selected tasks. Secondly, the range of tasks included were varied to be sensitive to different types of visual deficits (i.e., acuity, contrast sensitivity, visual field and color recognition). In defining tasks for inclusion in the LVFSE the challenge to visual deficits was maximized (e.g., using a clear glass and pitcher of water against a white background for pouring water). For each task, performance is measured by time to perform, focal distance, examiner rating of task difficulty and performance quality and subject rating of task difficulty. Performance is evaluated under optimal conditions of lighting for each patient.

Subjects enrolled in the study will be male and female individuals with decimal acuities between 0.5 and 0.03. A small number of individuals with normal acuity but visual field losses will also be included. Patients are excluded from the study if they appear to have extreme deficits in cognitive ability so that they cannot follow instruction in the test setting. No other exclusion criteria will be used. Data will be obtained on socio-demographic characteristics, mental status, hearing ability other medical co-morbidities as well as visual functioning and community functioning using the Sickness Impact Profile (SIP).

Inter-rater and test-retest reliability of the LVFSE and the different performance measures are first being evaluated. The reliability of each type of performance measure and the potential to develop a performance index will be evaluated. Then the construct validity of the LVFSE as a measure of low vision functional status will be studied. To do this, performance on the LVFSE will be correlated with

measures of clinical functioning (acuity, contrast sensitivity, visual field) and community functioning. The ability to distinguish between patients with different levels of clinical and community functioning will be used to evaluate discriminant validity.

PROGRESS—Collection of data to evaluate inter-rater and test-retest reliability began in February. To date approximately 15 initial evaluations have been completed.

FUTURE PLANS—Future plans are to determine construct validity, reliability of performance measures, inter-rater and test-retest reliability of the LVFSE.

[339] BRAILLE LITERACY: TRAINING, MENTORING, AND TECHNOLOGICAL SERVICES PROGRAM FOR BLIND ADULTS

Hilda Caton, EdD
Department of Educational and Technical Research, American Printing House for the Blind, Louisville, KY 40206-0085

Sponsor: *None listed*

PURPOSE—The purpose of this joint effort between the American Printing House for the Blind (APH) and the National Federation of the Blind (NFB) is to address NIDRR's "Braille Literacy" priority. Project activities are aimed at blind adults who are considered illiterate because they have not learned to read and write braille and address one of the six national goals for education in the America 2000 initiative. Project activities relate to providing solutions by developing a curriculum guide for reading and writing braille as well as guidelines used by mentors, and an evaluation of braille technology.

METHODOLOGY—APH and NFB have been collaborating in the development and collaboration of the curriculum materials. As braille is too complex to be thoroughly learned in the short period of time a person spends in a rehabilitation center, this program provides training materials that are appropriate for use by mentors who are not professional educators nor rehabilitation workers, but rather blind individuals who use braille themselves. This model enables the students to continue their braille training. Rehabilitation teachers, mentors, and students have been instructed in how to use the program materials and in how to provide feedback to the developers regarding its effectiveness during the field evaluation. A repeated measure design was used in which students were tested on speed and accuracy in both the reading and writing of braille. Tests were administered prior to introductory training, again following the training, and again six months after the students leave the rehabilitation facility. Statistical tests will be run to determine both the magnitude of the changes between testings and its significance for speed and accuracy.

PROGRESS—There are three separate phases of this project. The first is the development of a curriculum guide to teach braille reading and writing to adults. Existing programs were reviewed and evaluated. NFB's blind program consultant's recommendations for the new program included teaching strategies, the introduction of Grade 2 contractions, and the introduction of the slate and stylus and braillewriter. A draft of the new curriculum, *The braille connection: a braille teaching program for blind adults,* was developed and reviewed by the consultants and a second draft was written based on their recommendations. Braille teachers from rehabilitation centers in Minnesota, Colorado, New Mexico, and Louisiana were trained in the use of the curriculum guide and the field evaluation ran from September 1993 through September 1994.

The second phase of the project was designed to ensure that students continue to work towards true proficiency and literacy through the use of a blind mentor. Once students leave the center, there is no follow-up to help the person solidify his/her braille skills and incorporate them into his/her daily life. One of the major purposes of the project is to provide that follow-up. Students were matched with mentors who are proficient braille users and from the student's home communities whenever possible.

The braille connection: mentoring manual was developed to provide guidelines to assist mentors in this endeavor; this manual is currently undergoing a field evaluation.

The third phase involves the evaluation of existing technology and its potential usefulness in enhancing braille literacy. The technology consultants from NFB have compiled their initial assessment of existing computer hardware and various software programs as the *Braille technology evaluation*. This resource will be updated each year of the project: APH will distribute the evaluation in braille and print while NFB will distribute it electronically.

RESULTS—Preliminary results indicate satisfaction with both the curriculum guide and the mentoring manual.

[340] MULTI-MODAL COMPUTER FEEDBACK

Deborah Fels, MHSc, PEng; Mark Chignell, PhD; Morris Milner, PhD, PEng, CCE
Department of Industrial Engineering, The University of Toronto; Rehabilitation Engineering Department, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G1R8

Sponsors: *Ontario Easter Seal Research Institute; IBM Canada Ltd.*

PURPOSE—The graphical user interface (GUI) environment has both enhanced and curtailed access to computers for people with disabilities. Feedback is one of the areas in which the GUI has curtailed access to computers because of the emphasis on visual information displays. The goal of this research is to develop access to computer feedback for people with disabilities that is controlled by the user instead of the software developer.

PROGRESS—A model for providing feedback has been developed using a standardized feedback language that is independent of sensory modalities (i.e., visual, auditory, and tactile). Users can then specify the output device which is most appropriate for them (e.g. VDTs, speech output devices, and braillers) so that feedback can be translated from the standardized system into the modality determined by each different user.

The model separates feedback, such as a system message, from its presentation attributes, such as screen coordinates, color, or pitch. This information can be conveyed through one or more different sensory modalities without losing the context and content of that information. The standardized classification system of feedback (feedback vocabulary) consists of nine standard feedback elements and a method for using them to generate static displays. These elements are: block, menu, message, prompt, position, echo, graphic, symbol, and text. Output device independent context and content of feedback can be represented by combinations of these elements.

RESULTS—Three studies were conducted in order to evaluate the terms and definitions, and the usability of the feedback vocabulary. The results indicate that 1) there are common names and definitions for the feedback elements, 2) users are able to apply the model to existing interfaces, 3) designers are able to create modality independent interfaces using the language, and 4) the output device independent interfaces can be translated into both visual and auditory interfaces.

FUTURE PLANS—This work is one step in the provision of information through multiple modalities. It points the way to multi-modal interfaces where designers are not restricted to the visual modality. In such interfaces people with visual impairments can gain equal and functional access to the application. In the future, we hope to work with software designers to include modality-independent concepts into new software from the onset rather than retrofitting access at a later point.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Interface analysis using a standardized feedback language. Fels D, Shein F, Chignell M, Milner M. In: Proceedings of the 16th Annual RESNA Conference, 1993, Las Vegas, NV. Washington, DC: RESNA Press, 1993:429-31.

[341] MEASURING NEEDS OF ELDERLY PATIENTS FOR LOW VISION DEVICES

J. Stelmack; R. Lowery; L. Pyne; B. Lee; T. Stelmack; A. Rosenbloom
Central Blind Rehabilitation Center, Edward Hines VA Hospital, Hines, IL 60141; West Side VA Medical Center, Chicago, IL 60612; Chicago Lighthouse for the Blind, Chicago, IL 60600

Sponsor: *Illinois Society for Prevention of Blindness*

PURPOSE—The purpose of this study is to create and pilot test a low vision needs assessment for elderly patients which can be used by clinicians and researchers 1) to measure the patient's perception of his/her ability to perform activities of daily living with a large visual component with and without low vision devices, and 2) to determine the importance to the patient of obtaining low vision devices/training to enhance remaining vision.

METHODOLOGY—A set of activities with a large visual component was compiled from the low vision literature with input from patients and low vision specialists. The questionnaire included: self-care, home-care, travel, recreation, reading, and writing. After validation, the activities questionnaire was administered in a face-to-face interview to 138 patients entering the low vision service at the Central Blind Rehabilitation Center, Hines VA Hospital, VICTORS, Chicago West Side VAMC, and Chicago Lighthouse for the Blind. The sample included elderly patients who had previously received low vision services at other facilities and patients who had never received professional low vision services. Respondents indicated their ability to visually perform tasks with and without low vision devices and the importance of obtaining a low vision device to perform specific tasks independently. Patient needs were analyzed using the Rasch Measurement model.

RESULTS—Results indicate that patients entering the low vision service with devices most frequently use them for close and intermediate distance reading tasks. Patients reports of perceived needs of low vision devices most frequently included: close, intermediate, and far distance reading tasks, TV viewing, recognizing people, and finding items.

FUTURE PLANS—Future plans are to analyze data with respect to visual status, physical status, social support and training provided to determine how these factors effect use of remaining vision/low vision devices to perform activities of daily living and perceived needs for low vision services.

[342] REHABILITATION OF VISUALLY IMPAIRED OLDER PERSONS

Cynthia Stuen, DSW; Ruth Fangmeier, DSW; Amy Horowitz, DSW; Betty Bird, EdD; Karen Seidman, MPA; Barbara Silverstone, DSW; Eleanor E. Faye, MD; Ellen Ehrlich, MSW
The Lighthouse Inc., New York, NY 10022

Sponsor: *American Foundation for the Blind, Inc.; Rehabilitation Research and Development Center on Aging, VA Medical Center, Atlanta, GA*

PURPOSE—The purpose of Rehabilitation of Older Visually Impaired Persons is to provide an accumulated fund of knowledge about programs and services for older adults with impaired vision. The primary long-range goal is to enhance the availability, accessibility, and effectiveness of rehabilitation services and technological resources for older persons who are blind or visually impaired in order to maximize functional independence and well-being in later life.

METHODOLOGY—Four specific activities are being conducted: 1) a national survey of programs and services to document the status of service delivery to older persons with impaired vision, describe model programs; 2) a low vision curriculum targeted to

service providers in the health and aging network is to be developed and tested; 3) effective practices utilized in the Older Blind Independent Living Programs are being identified through focus groups; and 4) findings are to be disseminated in accessible formats to service providers, elderly persons with impaired vision and their family members, and other researchers.

RESULTS—As of May 1, 1994, 755 unduplicated completed national survey forms were received. The 755 agencies identified a total of 2118 programs and services provided in the four categories of interest: 1) early identification and prevention strategies; 2) use of optical and electronic devices to maximize residual vision and prevent handicaps; 3) training of visually impaired persons and their families for independent living and mobility; and 4) vocation support strategies to maintain or regain remunerative employment.

These 2118 programs and services and any others identified will be surveyed a second time to identify program models.

An interdisciplinary low vision training curriculum, *Low Vision and Older Adults: Practical Strategies for Service Providers*, was designed for providers in the health and aging network. Three training modules were added to the Lighthouse Low Vision Continuing Education Curriculum.

A series of five focus groups to identify effective practices in the Older Blind Independent Living Programs have been conducted. The first group was part of the meeting of the Region I Rehabilitation Continuing Education Program (RCEP); the second was held in Alexandria, Virginia; the third, prior to the International Conference on Aging and Vision Impairment in Atlanta; the fourth, in Los Angeles hosted by the Center for the Partially Sighted; and the fifth, in Portland, Oregon, hosted by the Oregon Commission for the Blind. The following questions were addressed: 1) What are the critical issues in aging/blindness rehabilitation? 2) Do they differ from state to state, region to region? 3) Do they differ by state or private agencies? 4) How can conflicts be resolved? 5) What should senior policy makers know about these concerns? 6) How can we prioritize critical issues? 7) Where are the holes? A final analysis of the findings will be published in Aging and Vision News, Spring 1995.

FUTURE PLANS—A total of 300 persons will be trained in five sessions. Training programs have been completed in these sites: St. Vincent's Medical Center and Hospital, New York City; The Chicago Lighthouse for People who are Blind or Visually Impaired, Chicago; and in Portland, Oregon. Training sessions are scheduled in Fall, 1994 in Los Angeles and Boston. A random sample of 25 percent of those completing training will be followed for three months to determine attainment of service goals designated at the training.

The results of all program activities will be published as a compendium. The compendium will be disseminated through the combined efforts of The Lighthouse Inc., The Rehabilitation Research and Demonstration Center of the Atlanta Veterans Affairs Medical Center, and The American Foundation for the Blind.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Critical concerns and effective practices among programs for older people who are visually impaired: a preliminary report on the findings of two focus groups. Crews J. Aging Vision News, 1994:6(Sup.2):1-7.

[343] NEW NYSTAGMUS TESTER

Arthur Jampolsky, MD; Anthony Norcia, PhD; John Brabyn, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; National Eye Institute; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The purpose of this research was to develop a new tester for persons with disrupted binocular vision.

PROGRESS—We have developed a novel nystagmus tester for the early detection and quantification of disrupted binocular vision in persons

with strabismus. The new test has several unique features including the ability to generate a sequence of simultaneous left- and right-traveling gratings, the intensity ratio of which can be adjusted to give quantitative readings.

This year, we have performed follow-up testing on this concept on adult amblyopes in order to establish the feasibility of the approach. The initial patient testing indicated that the new nystagmus tester is based on sound conceptual principles and shows promise for clinical applications in preventative rehabilitation.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Comparison of on- and off-axis photorefraction with cycloplegic retinoscopy in infants. Hamer R, Norcia A, Day S, et al. J Pediatr Ophthalmol Strabismus 1992:29:232-9.

[344] PHOTOREFRACTIVE VISION SCREENING RESEARCH

Arthur Jampolsky, MD; Anthony Norcia, PhD; John Brabyn, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; National Eye Institute; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The purpose of this research is to improve early detection methods for visual disorders.

PROGRESS—We have been conducting intensive research into improved methods of early detection of visual disorders in order to prevent blindness and visual impairment from developing.

Our modified Polaroid camera-based photorefractive vision screener has been undergoing a large-scale clinical trial to examine its application for detecting potentially blinding vision impairments in the non-specialist (pediatric) clinic.

The field trial is being conducted in the pediatric clinics of the Kaiser Permanente hospitals in Sacramento and Walnut Creek, in collaboration with Drs. Edward Denz and Leslie Chan. Infants are being screened by pediatricians at the twelve-month immunization visit. Six cameras are in use, each associated with one or two pediatricians.

Over 1,000 subjects have been tested, and a large amount of clinical data has been generated. The information we have gained from this trial to date has allowed us to devise modifications to our previous approach based on real-world experience.

[345] IMPROVED VISUAL EVOKED POTENTIAL RECORDING SYSTEM

Arthur Jampolsky, MD; Anthony Norcia, PhD; John Brabyn, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; National Eye Institute; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The purpose of this research was to develop an improved system for infant vision screening.

PROGRESS—Under funding from NIH and NSF, we have developed a new Macintosh-based Visual Evoked Potential (VEP) recording system. The laboratory of Dr. Norcia of our staff has pioneered various now widely adopted methods of early vision screening using VEPs, and the new system extends this work even further.

Using a sophisticated adaptive filtering technique developed by staff member Yu Tang, the new system is conservatively estimated to give a 6 dB

improvement in signal-to-noise ratio, along with concomitant improvements in flexibility and speed. Vision of infants considered to be at risk for visual impairment can now be objectively measured on the new system with only a few seconds of attention span required. The system can also deal with much more complex stimuli for more sophisticated testing.

The new VEP recording system has already been adopted in ten other outside laboratories, confirming the perception that it represents an extremely valuable advance in infant vision screening and assessment for preventive rehabilitation.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Improving infant evoked response measurement. Norcia A. In: Handbook of infant vision. National Research Council. In press.

Improved processing of the steady-state evoked potential. Tang Y, Norcia A. Encephalog Clin Neurophysiol. In press.

[346] EARLY INTERVENTION: CLINICAL EFFICACY OF ALTERNATE OCCLUSION IN INFANTILE ESOTROPIA

Arthur Jampolsky, MD; Anthony Norcia, PhD; John Brabyn, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; National Eye Institute; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The purpose of this research was to develop a standard practice for pre-operative management of patients with infantile estropia.

PROGRESS—There is currently no standard practice for the pre-operative management of patients with infantile esotropia, a common visual impairment in the pediatric population which, if not properly corrected, can lead to serious visual disability later in life. These infants develop strabismus before 6 months of age and require surgery between 9 months and 2 years of age. Arthur Jampolsky, MD, has advocated the use of full-time, alternate-day occlusion during the period prior to surgery. Other practitioners use patching only to treat clinically apparent amblyopia. In this case the patch is placed part-time over the dominant eye.

In order to test a hypothesis on the efficacy of early intervention for preventative rehabilitation, we recently followed a group of fourteen infants during the course of their pre-operative alternate occlusion therapy. We found that an index of abnormal binocularity, asymmetrical monocular motion VEPs, declined during the course of alternate occlusion. The index declined to a value less than that of untreated infantile esotropes of comparable ages. From this result we concluded that alternate occlusion was causing a significant and presumably positive alteration in an otherwise pathological system. The results suggest that alternate occlusion serves to disrupt an active, competitive interaction between the two eyes, and are suggestive of a beneficial effect of alternate occlusion.

We now plan to design, organize, and initiate recruitment of infants for a randomized, prospective study of alternate occlusion therapy in a large group of infantile esotropia patients recruited from a number of different centers.

[347] EVALUATION OF HEADS-UP DISPLAYS FOR LOW VISION APPLICATIONS

Arthur Jampolsky, MD; John Brabyn, PhD; Gunilla Haegerstrom-Portnoy, OD, PhD; Marilyn Schneck, PhD; August Colenbrander, MD; Daniel Scheinholtz, MD; Albert Alden; Martin Winderl; Hoover Chan, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; National Eye Institute; The Smith-Kettlewell Eye Research Institute; Northern California Society for the Prevention of Blindness; California Department of Motor Vehicles*

PURPOSE—The RERC has been asked by several private firms to supply consulting expertise on various aspects of state-of-the-art heads-up displays, and especially on modifications needed for applications in low vision.

Our staff, including Christopher Tyler, PhD, and John Brabyn, PhD, have advised Spread Spectrum Technologies, Inc. on the relevant features needed for possible low vision applications of their head-mounted display, which utilizes a half-silvered mirror and LCDs to project an image in front of the wearer. Our input acquainted them with possible uses of their system for those with impaired vision, and specific criteria for critical and non-critical parameters which would need to be modified for the low vision user.

Similarly, in collaboration with Drs. Colenbrander and Scheinholtz of our affiliated Low Vision Clinic, we are addressing similar issues relating to a new design from the Human Interface Technology Laboratory, at the Washington Technology Center, University of Washington, Seattle. Their latest system uses a color LCD display in a relatively cosmetic headband package which allows placement of the electronically displayed image in either the upper or lower visual field, leaving the remaining field available for mobility and orientation.

PROGRESS—In collaboration with Drs. Colenbrander and Scheinholtz, we have tested various combinations of this system with different camera inputs and compared the output with more conventional systems such as CCTV reading systems. Dr. Scheinholtz has redesigned the optical system for use by persons with low vision, and submitted the design to the manufacturer.

[348] IMPACT OF VISION IMPAIRMENTS ON EVERYDAY TASKS

Arthur Jampolsky, MD; John Brabyn, PhD; Gunilla Haegerstrom-Portnoy, OD, PhD; Marilyn Schneck, PhD; August Colenbrander, MD; Daniel Scheinholtz, MD; Albert Alden; Martin Winderl; Hoover Chan, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; National Eye Institute; The Smith-Kettlewell Eye Research Institute; Northern California Society for the Prevention of Blindness; California Department of Motor Vehicles*

PURPOSE—We have begun a major study of vision impairment in the elderly covering 1,000 persons over 55. The overall goals of the study are to determine what combination of vision tests best predicts the everyday visual complaints and task performance problems of elderly persons more accurately than the commonly used clinical tests, and to characterize the vision function of the elderly population including the older age groups (75 plus) whose visual characteristics are not well known.

We have obtained additional funding from the National Eye Institute, and in-kind support from the Buck Center for Research on Aging to carry out this study, which addresses the NIDRR goal of improving our understanding of visual impairments and their functional impact on individual's lives, in order to improve rehabilitation strategies.

METHODOLOGY—We will specifically address the following questions: 1) Does performance on the

battery of vision function tests predict subjective visual complaints as reported via questionnaire responses and real-life task performance (driving, reading, low-light walking speed)? 2) Does actual task performance relate to subjectively reported performance via questionnaire? In other words, do people have an accurate sense of their sensory limitations on tasks of daily living?

PROGRESS—Three hundred people ranging in age from 58 to 95 years have been tested to date. Testing will continue throughout the coming year, during which time we anticipate preliminary findings will begin to answer some of the important questions raised above about the impact of visual impairment on daily functioning.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Optic neuritis: small reductions in luminance cause large losses in vision function. Schneck M, Haegerstrom-Portnoy G, Katz B, Brabyn, J. In: Technical digest: non-invasive assessment of the vision system. Optical Society of America, 1993.

Efficient assessment of vision function in optic neuritis. Haegerstrom-Portnoy G Schneck M E, Katz B. J Opt Soc Am. In press.

[349] SKILL CARD: EVALUATION AND TECHNOLOGY TRANSFER

Arthur Jampolsky, MD; John Brabyn, PhD; Gunilla Haegerstrom-Portnoy, OD, PhD; Marilyn Schneck, PhD; August Colenbrander, MD; Daniel Scheinholtz, MD; Albert Alden; Martin Winderl; Hoover Chan, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; National Eye Institute; The Smith-Kettlewell Eye Research Institute; Northern California Society for the Prevention of Blindness; California Department of Motor Vehicles*

PURPOSE—The Smith-Kettlewell Institute Low Luminance (SKILL) Card is a simple-to-administer, inexpensive vision test we have devised in order to provide better clinical assessment of vision under conditions of poor illumination and contrast. These viewing conditions represent a major problem for the elderly and those with various retinal and optic nerve diseases. For example, driving at night or at dusk, reading menus in dimly lit restaurants, and many other tasks become difficult for these patients, even though most of the widely-used clinical vision tests may indicate that their vision is normal. Few objects in our visual world have the high contrast and optimal lighting conditions of these clinical tests. The new SKILL Card can detect, quantify, and monitor the types of vision difficulties mentioned above by simulating poor viewing conditions under normal office lighting. This provides the eye care professional with a convenient test which better correlates with the patient's reported real world vision problems.

The SKILL Card consists of two letter charts, mounted back-to-back and designed to be held at reading distance. Side one of the card is a standard black on white letter chart for assessing visual acuity. On the flip side is a low contrast, low luminance chart consisting of black letters printed on a dark grey background, allowing low luminance to be obtained using normal office lighting. In practice, side one is tested first. The card is then flipped over and side two is tested. The difference between the number of letters that the patient reads on the two sides is the SKILL score.

The resulting test takes only a couple of minutes, and meets our goal of rapid and simple utilization by the busy eye care practitioner.

METHODOLOGY—The SKILL Card is being incorporated in our testing of vision function, vision performance (driving, reading and walking under dim illumination) and subjective visual experience (via questionnaire) in a group of individuals over the age of 55. This study is being conducted at and in conjunction with the Buck Center for Research on Aging in Marin County In an effort to find a better method for assessing vision as it relates to driving performance, the DMV has administered the SKILL Card, as well as three other tests, to over 1700 people at three of its centers.

PROGRESS—We have determined the best method for production and packaging of the SKILL Card,

and 1000 cards have been produced under private funding. Distribution to interested clinicians has begun (approximately 100 cards have been distributed to date). The cards are mounted on foam core for rigid support. Attached to each is a cord for measuring the appropriate 40 cm test distance. Instructions for use and norms are included with each card.

Data have been collected from approximately 80 observers who showed no abnormalities on any vision measure and had no known ocular disease. These data were used to establish age norms and confidence limits for individuals from 15 to 100 years of age. The SKILL score shows a linear increase with age.

We have used the SKILL Card to measure vision in 15 recovering optic neuritis patients, 6 patients with age-related maculopathy and 10 of their family members. The SKILL Card has proven to be extremely sensitive. All of the optic neuritis patients had abnormal SKILL scores. The SKILL scores of the ARM patients were also quite abnormal.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

SKILL card: hidden deficits in 'recovered' optic neuritis. Schneck ME, Haegerstrom-Portnoy G, Brabyn J and Katz B. Invest Ophthalmol Vis Sci 1992:33(S):965.

[350] A STUDY OF DRIVING AND VISUAL IMPAIRMENT

Arthur Jampolsky, MD; John Brabyn, PhD; Gunilla Haegerstrom-Portnoy, OD, PhD; Marilyn Schneck, PhD; August Colenbrander, MD; Daniel Scheinholtz, MD; Albert Alden; Martin Winderl; Hoover Chan, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; National Eye Institute; The Smith-Kettlewell Eye Research Institute; Northern California Society for the Prevention of Blindness; California Department of Motor Vehicles*

PURPOSE—It has proven difficult to establish strong associations between driving performance and standard vision test results, despite the obvious dependence of driving on vision. The topic of driving with impaired vision using visual aids is also a controversial one. For example, the most-often cited study found that total visual field, as well as two measures of night vision (glare recovery and thresholds at low light level), were not predictive of accident rate and that two others (static and dynamic visual acuity) were only weakly associated with accident rates. Nonetheless, visual acuity is still the primary screening measure employed by the California Department of Motor Vehicles (DMV). The failure of vision tests to predict driving performance in the visually impaired is attributable to 1) the failure of the tests to adequately assess the visual impairment and define the visual limitations of the individual, and 2) the failure of the vision measures to tap the visual task demands of driving.

In collaboration with (and with augmented funding from) the DMV, we have been evaluating the ability of a variety of vision measures designed to overcome those two limitations, to allow us to specify which types of visual impairments are of practical significance in causing accidents.

PROGRESS—Each of over 1200 individuals, ranging in age from 24 to 91, was tested using all the measures. Three of the measures were letter charts: the Pelli-Robson Contrast Sensitivity test, the SKILL Card, and the Berkeley Glare Tester. To relate these measures to actual driving performance, driving habit surveys were completed by each participant at the time of testing. Driving performance data (on accidents and moving violations) will be provided by the DMV.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

New low vision devices and tests. Brabyn, J, Jampolsky, A, Haegerstrom-Portnoy, G, et al. In: Proceedings of the 16th Annual RESNA Conference, 1993, Las Vegas, NV. Washington DC: RESNA Press 1993:254-5.

Attentional visual fields: age changes and relation to driving. Brabyn J, Haegerstrom-Portnoy G, Schneck M, Hennessy D. Invest Ophthalmol Vis Sci. In press.

Vision function after fluorescein angiography. Friedman N, Paul O, Jampolsky A, Haegerstrom-Portnoy G. Invest Ophthalmol Vis Sci. In press.

[351] IDENTIFICATION OF DIFFERENTIAL COSTS AND TIME USAGE OF BLIND AND VISUALLY IMPAIRED PERSONS

Lynn W. McBroom, PhD; Corinne Kirchner, PhD; Katherine A. Nelson, PhD
Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762; American Foundation for the Blind, New York, NY 10011

Sponsor: *National Institute on Disability and Rehabilitation Research; Mississippi State University*

PURPOSE—The aim of this project was to answer the following research questions: Are there differential monetary costs and time utilization patterns for persons who are blind or severely visually impaired? In what categories do these different costs occur, and are they associated with particular life styles, life stages, and environments? Are there relationships among the differential expenditures and time-usage patterns associated with blindness and visual impairment and the rehabilitation process?

METHODOLOGY—Telephone interview forms were used to collect information from 227 blind or visually impaired persons and 152 sighted persons (379 total respondents). During the initial telephone contact, respondents were asked questions about their vision loss, health problems, methods of reading, and use of readers. Sighted peers were identified by the visually impaired respondents at this time. During the next four interviews, the 379 respondents were asked about personal care activities and assistance, mobility and transportation, aids and adaptations, education, employment history, household members, type of community, life satisfaction, use of vocational rehabilitation services, and income. Four time diaries were used to solicit information about how that person spent time during the previous 24 hours. Time diaries were balanced by day of the week and season of the year.

RESULTS—Data were coded and analyzed. The results were disseminated through numerous presentations. Results show that visually impaired respondents are involved in a wide variety of activities with little restrictions on their range of activities. Sighted respondents tended to spend more time in child care, obtaining goods and services, attending to self-care activities, and engaging in social activities, while visually impaired respondents spent more time in education and passive activities. When compared with sighted respondents, a college education did not have the same economic payoff for persons who are visually impaired and specifically, for women who are visually impaired.

[352] IDENTIFICATION OF SKILLS, KNOWLEDGE, AND STEPS NECESSARY FOR STUDENTS WITH VISUAL IMPAIREMENTS ENTERING POSTSECONDARY INSTITUTIONS

Lynn W. McBroom, PhD
Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute on Disability and Rehabilitation Research; Mississippi State University*

PURPOSE—The purpose of this project was to identify skills, knowledge, and steps necessary for students with visual impairments to successfully make the transition from high school to postsecondary educational institutions for the purpose of advanced training in order to successfully compete in the job market.

METHODOLOGY—The process of identifying respondents and securing their cooperation continued throughout the telephone interviewing process. Telephone interviews were eventually conducted with 102 college students and mail survey instruments were completed by 65 administrators from postsecondary educational institutions. The data

was coded and entered into a personal computer for analysis. Questionnaire responses were analyzed using frequency analysis, correlation analysis, and a limited use of factor analysis. A separate qualitative analysis of students' responses to two open-ended questions was also conducted. A technical report and an executive summary were written, edited, and printed. The two reports are now available for dissemination. The research is complete.

RESULTS—Students with visually impairments can successfully attend college with their sighted peers if supporting services are available. Based on interviews with students and administrators, this research identified the types of skills and information that students with visual impairments need to know to attend college, the specific steps that should be taken to achieve this goal, and some of the differences in the perceptions of students and administrators.

IMPLICATIONS—Results from this study will be used in a related project identifying skills and knowledge necessary for people with visual impairments beginning jobs after graduating from postsecondary institutions.

[353] IDENTIFICATION OF SKILLS AND KNOWLEDGE NECESSARY FOR PEOPLE WITH VISUAL IMPAIRMENTS BEGINNING JOBS AFTER GRADUATING FROM POSTSECONDARY INSTITUTIONS

Lynn W. McBroom, PhD
Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute on Disability and Rehabilitation Research; Mississippi State University*

PURPOSE—The purpose of this project is to identify skills and knowledge necessary for people with visual impairments to successfully make the transition from postsecondary educational institutions to the workplace. This project builds on work completed in a previous project.

METHODOLOGY—Literature is being reviewed while telephone interviews with respondents continue. Additional respondents are still being identified. A draft instrument to use with employers is being developed.

RESULTS—None, data are still being collected.

IMPLICATIONS—Telephone interviews with employed college graduates will continue. Permission to interview employers will be obtained and those interviews completed by 1995.

[354] A FAX-BASED COMMUNICATION AUGMENTATION SYSTEM FOR THE PRINT-HANDICAPPED

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute; National Easter Seal Research Foundation*

PURPOSE—The initial pilot phase of the Fax Reader Project demonstrated that the concept indeed filled a significant need for the blind and visually impaired population: access to the printed word. This access on demand is realized by having a remote, human reader system comprised of a fax

machine (to send the printed information) and a fax computer display (to receive the printed information for reading by a sighted person).

PROGRESS—The present phase has the aim of extending the user base, exploring new technologies, and pursuing technology transfer. The project continues to emphasize the goal of linking rehabilitation and technology which may generalize to more than a local setting and have a great impact on a population of people with disabilities.

RESULTS—In the pilot phase, analysis of 800 individual transaction records indicated that the total participation of all active users averaged 24 documents per 8-hour service day. That is, the readers received an average of 3 documents per service hour. The fax transmission time for each document averaged 68 seconds, and the time to read each faxed document averaged 163 seconds. Overall, the results were very encouraging, and responses from users of the system indicated strong potential for larger scale use.

In the second phase, we have made significant progress in the implementation of a non-fax media for interactive remote reading systems. The goal here has been to approach as closely as possible the ideal remote reader, one which would function in the same way as a live reader in the same room as the user. Such a system would, for all practical purposes, allow the remote reader to "look over the shoulder" of the blind user. We refer to this concept as virtual presence.

The concept we have been developing employs compressed video technology of very low frame-rate, high-resolution video transmission over ordinary telephone lines. The bi-directional transmission of data allows the remote reader to pan and zoom the remote camera over the document or object of interest to the user. These functions could be accomplished electronically or by voice command from the reader to the user. The increases in speed would provide commensurate reduction in cost of operation for each document read.

We have tested the individual components of the system. The software to link the functions together is currently under development.

We are also investigating ways of augmenting the fax reader service with the option of integrating optical character recognition (OCR) and speech output into the Remote Reader System. Support for this research project has been contributed by the Easter Seal Research Foundation, the Sydney Stern Foundation, Pacific Bell, and Allnet, as well as NIDRR.

[355] ACCESS TO COMPUTER-MUSIC SOFTWARE BY BLIND AND VISION-IMPAIRED MUSICIANS

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—During the past three years we have been surveying the field of computerized music in terms of its accessibility to vision-impaired musicians. We are now considered a national source of information on the various aspects of this issue. Our efforts have also given impetus to networking among musicians already in the field and those just beginning.

PROGRESS—Our collective contacts with some software developers have resulted in more manuals appearing as ASCII files on computer disks. These efforts, and the evolution of computer and synthesizer technology, have provided many more options and rendered this equipment more user-friendly.

We conducted a workshop for special education classes under the direction of Mike Colc at San

Francisco State University, and similar well-attended workshops with other blind musicians, both at the 1993 American Council of the Blind convention in San Francisco, and at an annual music camp operated by the San Francisco Lighthouse.

A related area of great importance to the education of blind musicians is the aggregate of standard MIDI files that contain classical music compositions, both for solo instruments and ensembles. These provide a convenient method of understanding the division of instruments within a musical score. Such files are found on several bulletin boards. We are developing a more systematic approach than presently exists so that the standard repertoire is available.

We have nearly completed a primer for the novice user of computerized music equipment based on a great deal of anecdotal evidence gleaned from the experiences of many blind musicians. It addresses such issues as: 1) how to browse through a music store when shopping for menu-driven equipment; 2) how to gauge the accessibility of a prospective purchase; 3) resources of information concerning computerized music production; and 4) a discussion of the current state of software that converts the synthesizer-playing data into data that generates print or braille music.

[356] DIGITAL SPEECH RECORDER AND PROGRAMMER

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—We have developed a new multipurpose digital speech recording system for use in a number of talking devices for the blind. The device is intended to record speech digitally into computer memory and to program that speech data into EPROM (erasable programmable read-only memory) chips.

This system is compatible with, and is the standard of recording for, Talking Signs. In applications where many copies of a particular sign (e.g., exit) are needed, the EPROM technology is easily mass copied. This system is also appropriate where field recordability is not desirable, in that the exact contents of a sign need to be permanently recorded and must not be changed by untrained personnel. As of this writing, all installed and demonstrated Talking Signs have used this device.

The need for this device, where many commercial speech digitizing systems exist, is based on its use of standard components. All other speech recording systems use specialized speech chips and other components often available from only one source. Since we wish all products we develop to last, and be reproducible, for a number of years, the use of components available from only one source is to be avoided wherever possible. The recorder/programmer described here, along with technology needed to play back speech recorded with it, should be reproducible into the foreseeable future with few or no alterations due to component availability changes.

Another advantage of this system is the simplicity of playback technology. Any microprocessor-controlled system requires only one extra output pin, plus a small audio amplification and filtering board to make its hardware compatible with this system.

PROGRESS—An initial prototype recorder/programmer was completed early in the present reporting period. Initial sound quality did not meet our performance standards, and as further improvements proceeded, a second unit was requested through our privately funded Rehabilitation Engineering Service so that signs could be manufactured and recorded by Talking Signs, Inc.

Therefore, using private funds, a second and very much improved recorder was built. This unit is now in use by Talking Signs. The original prototype unit is used in-house for development of other devices. It is expected that the original prototype will be upgraded with improvements made in the unit built for Talking Signs Corp.

[357] ASSISTIVE DEVICES FOR BLIND DIABETICS

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—Our laboratories have undertaken a study of difficulties experienced by blind and visually impaired people with diabetes. Two problem areas were immediately apparent, resulting in the following developments:

The Smith-Kettlewell Insulin Dipstick. Save for keeping a meticulous log of insulin use and reviewing it frequently, there was previously no good way of assessing how much insulin is left in the glass bottle commonly used for dispensing it; being a delicate protein, insulin must not be shaken to listen to the rattle of the contents, which would otherwise provide a rough guide to the liquid level.

We identified a popular syringe manufacturer, Novolin (a division of Squibb), who makes cartridge-pen type injectors. Two different models allow the dosage to be measured by audible clicks. Being cartridge dispensers, the insulin reservoir is a vial containing a rubber piston which is advanced to dispense the insulin. It was a simple matter to design a measuring stick with tactile markings suitable for locating the rubber piston, and there is no chance for the dipstick to contaminate the insulin.

PROGRESS—*Glucometer Adaptations.* There is a compound problem that makes glucometers hard to use, and the One-Touch II is no exception in addressing it. The blind user has no adequate means to tell when a droplet is formed, nor when it is heavy enough to fall from the puncture site. Positioning the puncture site directly over the window and keeping it there while kneading the finger is very difficult, especially since the One-Touch II has no distinguishing feature adjacent to the window in the test strip to aid in locating it.

The RERC has experimented with various materials in designing an adapter to funnel blood to the test-strip window. Polypropylene was the most promising, since it chemically resists wetting with blood. However, the flow of blood through a funnel is irregular. Furthermore, the consistency of a droplet depends heavily on the sugar level in it. Finally, any possible mixture of the fresh sample with residue would adversely affect the reading, so there is danger that if cleaning were not perfectly done, erroneous readings might put the user at risk.

For now, funneling systems have been abandoned in deference to jigs and fixtures which could serve as guides for proper alignment. The RERC laboratories are attempting to evolve a modification to the lancing device to accommodate a fixture which could then be carried with the finger to location detentes on the glucometer.

The user takes the punctured finger between thumb and finger of the opposite hand and stands the thumb and finger on the marks either side of the window. Centering the guiding hand with the long marks sets the longitudinal position, and locating the differing marks nearest the edges of the strip establishes the proper lateral position.

[358] NEW APPROACH TO SPECIALIZED JOB ADAPTATIONS: KNITTING MACHINE COUNTER EXAMPLE

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—This year, the RERC has been exploring improved approaches to specific vocational instrumentation problems where the usual commercial sensory aids are not applicable. We have

developed a new approach using a commercial single-board microprocessor in conjunction with our in-house-developed speech.

PROGRESS—As a first example, a talking counter was developed for Mrs. Kathy Larson of Williston, North Dakota, who has a home business using a knitting machine. The machine requires that the user read a mechanical counter on the machine to keep track of rows knitted. As no practical means of adapting mechanical counters for use by the visually impaired is available, a talking counter was developed to fill this need.

The counter allows the user to interrogate the number of the last row knitted, as well as to preset memories with row numbers at which some change needs to be made in the pattern. The counter beeps when reaching the row 1 before any preset memory, then announces the row count when the memorized row is reached. The unit has been in service since the end of July 1993. Mrs. Larson is delighted with the device and says it saves her much time and effort.

FUTURE PLANS—It is possible that improvements will be made in the controlling program for this device as other ways are found in which it can help her do her job.

[359] THE AUDIBLE STUD FINDER

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—In 1987, the RERC published the design of an audible modification to the Zircon Stud Sensor (adding a Voltage Controlled Oscillator and a speaker). Communication was made with Zircon, suggesting that they produce such a modified instrument, not only for visually impaired users, but because sighted Smith-Kettlewell staff members felt that the additional feedback was helpful. A commercial audible model has now appeared.

PROGRESS—Identical in appearance to the original Zircon unit, the new instrument is called the Master Mechanic™ Professional Stud Finder with Sound. Its audible output consists of a Mallory Sonalert arranged to sound when the top LED of the column of four (the same visual display as the original instrument) is energized.

The audible indicator being a go/no-go tone which is either on or off, it is not as sensitive an instrument as the RERC-modified one. However, offering the new device to those who have tried the VCO output has led to favorable comments about its performance. The instances for which the commercial stud finder will not give an audible indication are those where only LEDs lower in the column come on in the presence of material in the wall. Where lath and plaster is present in old buildings, there are cases where hearing minor fluctuations in the pitch of the VCO are all that is discernible. However, the new unit will work satisfactorily in most structures. The Sonalert has been shown to be an inexpensive addition: the Master Mechanic unit costs $20.

[360] ROLLING RULER

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—This device is intended to fill the need for the equivalent to a long steel tape measure. Technical problems make the direct adaptation of standard tape measures impractical, yet blind people need a way to measure rooms, furniture, fences, shelves, wire, etc.

Commercial ultrasonic measuring devices with visual displays are available; these devices are impractical for use by the visually impaired for several reasons. Their resolution is quite poor and they must be aimed at a target. There is also the common difficulty involving electrical access to display information where no digital output signal is provided.

PROGRESS—The device currently under development, dubbed the Rooller, uses an optical shaft encoder mounted on a wheel protruding through the bottom of the box. The unit can be placed at one end of anything to be measured, and rolled in a straight line. The push of a button tells the Rooller to speak the distance covered. If a specific distance is to be measured along material to be cut to length, that distance may be programmed into a memory from the built-in 16-key pad. As the Rooller is moved closer to the desired measurement, a variable pitch tone will give the user feedback as the desired measurement is neared. When the exact length is reached, the tone will stop and the measurement will be spoken.

The prototype Rooller is now in the program debugging and development phase, and practical testing is proceeding successfully.

[361] COMPUTER INTERFACING OF DIGITAL MULTIMETERS

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The digital multimeter is a ubiquitous tool for electricians, electronics technicians, and service/technical personnel in many industries. It measures electrical parameters such as voltage, current, and resistance, usually presenting results on a visual display. Over the years, any number of devices of this type have been made to talk for use by the blind. Very few of these have lasted on the market for long, and most have cost $500 or more.

PROGRESS—The talking meter produced by Radio Shack was recently replaced with the Micronta No. 21182 Digital Multimeter with computer interface. This unit bears no resemblance to the previous talking device. It has 32 ranges/scales, measures voltage, current resistance, capacitance and frequency. It can also test transistors and other components. The standard RS232C computer interface is made via a cable plugged into the side of the meter and into the serial port of any IBM-compatible computer. The unit is supplied with a diskette containing example programs which show the entire contents of the meter's display on the computer screen. Our staff adapted the software that came with the meter so that it presents a less cluttered screen. We are exploring several other possible ways to make this unit more useful to blind technicians, such as modifying the software so that the meter may be used in conjunction with a much smaller access device such as a Braille 'n Speak.

[362] THE OEM AUDIBLE CARPENTER'S LEVEL

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The availability of high-quality adapted levels for use by blind artisans has been subject to frequent interruptions, primarily due to limited product life of commercial products on which various designs were based. To make matters worse, specially designed units from Germany and England, evaluated by the RERC, were found to be inadequate, either because of poor damping and/or insufficient tilt sensitivity.

PROGRESS—Since recent development of magneto-resistive semiconductors has led to a new class of inexpensive inclinometers, we decided to design an audible electronic level from scratch. The design is adaptable to a wide variety of tilt sensors, so that very little work will be needed in the future as the sensors themselves become obsolete.

A small round can, cemented in a cutout of the level's beam, is the inclinometer. Made by the Midori company, the inclinometers come in various grades and sensitivities; for approximately $100, a sensor capable of repeatedly sensing tilt within 3 minutes of arc can be obtained (the best the British product referred to above could do was 30 minutes of arc).

In this level, a voltage-controlled oscillator responds to the incline of the instrument's beam; this gives the user feedback about the direction and degree of movement as adjustment is made to the member being aligned. To one side of level, the tone of the oscillator is interrupted approximately 5 times per second so that the tone is pulsating; an opposite incline produces a smooth uninterrupted tone.

Evaluation of the prototype by blind and sighted users has revealed that the unit is easy to use and achieves accuracy exceeding that obtainable with a conventional bubble-type level designed for sighted carpenters. The level is now available through our privately funded Rehabilitation Engineering Service for $225 each.

[363] SPECIAL LIGHT PROBE FOR A MULTI-LINE TELEPHONE

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—An additional new project undertaken this year was the design of a special-purpose light probe for situations where the lights to be detected are unusually small and/or low in intensity. Such a case was encountered by Mr. Donald Belew, a blind employee at the Lawrence Berkeley Laboratories. As part of his duties he was required to operate a 16-line telephone system. This telephone presented the specific problem that its indicator lamps are much too small and dim to be detected with modern photo transistors and photo diodes as used in conventional light probes for blind persons.

PROGRESS—For this application, we developed a design using a cadmium sulfide photo resistor; this type of sensor, while slow compared with modern semiconductors, is extremely sensitive and responds to shorter wavelengths of light than do silicon devices.

The photo resistor was mounted in a 3 cm tube, and a push-button, connected in series with the sensor, was mounted atop the assembly. A blocking oscillator whose bias is affected by the resistance of the sensor gives the user variable-pitch auditory feedback by a rise in frequency as light impinges on

the photo resistor. (The blocking oscillator serves as a current-controlled oscillator.)

Certain earlier instruments, notably Science Products' Audicator, were similar in concept, but improvements including the 3 cm light shield were found to be necessary on more modern telephones in order to resolve closely spaced lamps. The new design is being tested by Mr. Belew, whose initial evaluation is extremely positive.

[364] DESKTOP BROADCASTING

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—Mr. William Loughborough of our staff has been working with two blind entrepreneurs to provide the necessary technical assistance for establishment of an FM radio station in Goldendale, Washington. The radio stations (KYYT-FM, KLCK-AM) are beginning to automate their daily logs so that they can be operated by computer programs. The main advantage of this is that the blind operators will have more time to devote to community interaction and local coverage.

A key requirement is the ability to record repetitive announcements in hard disk files for on-air access via a scheduling program. Most of the software interfaces are graphical and must be modified for use by the blind announcers.

PROGRESS—The operators use a braille embosser to make scripts of commercials and daily log sheets, making these operations simpler than the previous method involving audio tape. The technical changes require replacing tape cartridge players with hard drive files, routine station breaks with indexed files, and satellite music systems with programmable CD players.

FUTURE PLANS—When these steps are complete we will have a model for small town broadcasting that will be of benefit to other blind entrepreneurs wishing to establish similar businesses. A manual covering the necessary steps and technical aspects will be produced. An additional benefit is the facilitation of deurbanization of people with disabilities and consequent enrichment of small communities with what such individuals have to offer.

[365] WIVOX: VOICE OUTPUT FOR WINDOWS

Stephen Farr, DIT, DCT; Fraser Shein, MEng, PEng; Gil Hamann, MASc, PEng
Microcomputer Applications Programme, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsors: *The Ontario Rehabilitation Technology Consortium funded by the Ontario Ministry of Health; IBM Canada Ltd.; IBM Corporation; University Research Incentive Fund of the Ontario Ministry of Colleges and Universities; National Research Council of Canada*

PURPOSE—The purpose of WiVox is to provide auditory feedback of typing when using any Windows application. The intent is to augment the standard visual presentation and enhance interaction by users who are learning to read or who have slight visual impairments. Wivox can also be used as a means to communicate through a computer. It is not a screen reading package.

METHODOLOGY—A simple on-screen menu is provided for specifying the synthesizer and its settings. Default settings for several common syn-

thesizers are included. A word exceptions editor is included to allow the user to specify correct pronunciation of unusual or proper names.

The software text-to-speech features female and male voices, and adjustable rate and pitch. The software includes a powerful feature that analyzes sentences and intelligently pronounces words properly in context (e.g., when similarly spelled words are spoken differently and with an appropriate rhythm of speech).

PROGRESS—The first version of WiVox was released in July 1993 with support for any external speech synthesizer. Since then support for software text-to-speech output through standard sound cards (e.g., SoundBlaster) has been added. WiVox works with WiViK 2, WiViK 2 REP, WiViK 2 Scan, KeyREP, and all regular keyboards. WiVox provides a small on-screen window to turn speech on or off as required. When turned on, WiVox speaks the typed text. Choices may be made for speaking letters, words, partial words (up to the current character), complete sentences, or menus. Any combination of these choices may be selected. WiVox will also speak text highlighted in any window.

FUTURE PLANS—WiVox will be more closely integrated with a computer-based communication system that is being developed based upon WiViK. Research will be undertaken to modify the speech output to reflect different feelings and emotions, and to enhance its naturalness.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Development of a windows-based interface for remote control of appliances. Farr S, Verburg G, Hamann G, et al. In: Proceedings of the 16th RESNA Conference, 1993, Las Vegas, NV. Washington, DC: RESNA Press, 1993:462-3.

[366] A STUDY TO ASSESS THE FEASIBILITY OF CONTRACTING WITH A NOMINEE AGENCY FOR THE BUSINESS ENTERPRISE PROGRAM

J. Elton Moore, EdD, CRC; Brenda Cavenaugh
Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State, MS 39762

Sponsor: *Pennsylvania Bureau of Blindness and Visual Services, Harrisburg, PA 17105-2675*

PURPOSE—The purpose of this study is to determine the most efficient and effective management model for administering the Business Enterprise Program (BEP), Randolph-Sheppard Program for the Blind, Nominee Agency, in the Commonwealth of Pennsylvania. More specifically, the study will determine what consideration should be given to the utilization of a Nominee Agreement allowed under Federal regulations and to what extent would a Nominee Agency enhance the effectiveness and efficiency of the Pennsylvania BEP program.

METHODOLOGY—This study will compare a variety of RSA-15 data elements involving nine state rehabilitation agencies. More specifically, the study will survey four nominee states and four comparison states as well as the Commonwealth of Pennsylvania. Additionally, approximately 60 blind vending facility operators will be interviewed by telephone with regard to what extent vending facility operators in Pennsylvania are satisfied with the current operation of the BEP program and what interest do they exhibit in promoting the adoption of a Nominee Agreement.

PROGRESS—A BEP Vendor Satisfaction Survey has been developed as well as a BEP Program Evaluation Questionnaire for use with approximately 60 blind vending facility operators and nine State Licensing Agency (SLA) Directors. Initial interviews and a site visit have been conducted with the Pennsylvania Bureau of Blindness and Visual Services.

RESULTS—Preliminary data are being collected; it is anticipated that a Final Report will be disseminated in February 1995.

IMPLICATIONS—The results of this study could certainly have implications for state Rehabilitation Agencies throughout the country who provide management services to Randolph-Sheppard Vending Facility Operators with regard to determining whether or not a nominee agency can operate a vending facility program more effectively and efficiently.

[367] ASSESSMENT OF PSYCHOMETRIC TESTS FOR USE BY THE VISUALLY IMPAIRED

Sean Keeley
Royal National Institute for the Blind, Torquay TQ1 2NG England

Sponsor: *The Royal National Institute for the Blind*

PURPOSE—This study investigated the suitability of existing psychometric tests for use by/with visually impaired clients and, if necessary, developed or modified tests for such a client group.

METHODOLOGY—The study was carried out at an employment rehabilitation center in England. Most of the clients were long-term unemployed and often had little or no formal qualifications. The center is concerned with general vocational guidance and assessment, and psychometric tests were considered for use as aids to assessment.

RESULTS—Preliminary investigations showed that most existing tests were highly visual in nature and were often of little use. Large-print versions of tests eased some of the difficulty (few of the clients were totally blind) and some variations in page organization and print sizes were also of help. The timing of tests was also a major difficulty. Because of the need to modify tests (print size, for example), timed tests were not appropriate. Attempts to use times which were adjusted to meet the requirements of a specific client's sight proved unsuccessful because of the huge variations in useful vision. Untimed tests were suggested for use and these have proved much more satisfactory. Many tests were transferred from a written medium to an oral medium (namely tape recordings). These proved successful with clients who had little or no useful sight.

Another primary concern of the study was in areas of vocational interest for visually impaired clients. The areas in which visually impaired people work were analyzed. Experts in the field were also asked which of a long list of jobs were suitable for visually impaired people. This is to ensure that all jobs that were likely, possible, and actual sources of employment were covered. Existing work-interest inventories include items which are not suitable for visually impaired clients. Therefore, two interest inventories were developed: General Level (approximately high-school level education and lower); and Advanced Level (university level education). These instruments take into consideration those areas which are the most likely sources of employment for visually impaired clients and are presently being normed. Educational attainment tests in Math and English were also developed. These tests are vocationally oriented and are suitable for use with an adult population. Existing tests tended to have items which were visual in nature. These tests are also to be normed and have been developed in line with the National Curriculum guidelines for Math and English as recommended by the British Department for Education.

IMPLICATIONS—At present, norms are being developed for visually impaired clients on a whole range of tests. Existing tests are constantly being modified and produced in large-print, braille, and taped formats. A direct comparison of timed and untimed tests is also being carried out. More research is being done into how much extra time is required for timed tests.

[368] TALKING SIGNS® PROJECT

John Brabyn, PhD; Deborah Gilden, PhD; William Crandall, PhD; William Gerrey; Albert Alden; Thomas Fowle; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *The Smith-Kettlewell Eye Research Institute*

PURPOSE—Talking Signs is a remote signage technology developed at Smith-Kettlewell and works much like the infrared remote control of our television sets. However, in this case the speech information stored in the sign is transmitted by an infrared beam to a hand-held receiver that speaks the message to the user.

PROGRESS—We have brought this technology to the attention of public and private entities interested in promoting accessibility to public accommodations by people who are sight impaired through presentations at conferences, design and execution of research studies, and consultations with individuals and agencies. These include presentations and/or exhibits at the RESNA annual convention (Las Vegas), President's Committee on Disabilities (St. Louis), American Council of the Blind Annual Convention (San Francisco), and California Council of the Blind Annual Convention (San Francisco). We have participated in a meeting of public administrators by presenting papers at the American Society of Public Administrators/Cooperative Administrative Support Program Annual Convention, July 17-21, 1993, San Francisco, and directors of state agencies for the blind during the Fall Meeting, National Council of State Agencies for the Blind (San Diego).

A major meeting, hosted at Smith-Kettlewell, was held in April to explore an expanded "Accessible City" demonstration project in San Francisco. Present at the meeting were representatives from many city agencies such as Muni, BART, Parking and Traffic Department, Library, Yerba Buena Center, and others. The San Francisco Lighthouse (now the Resnick Lighthouse) provided a special grant allowing 10 demonstration transmitter-receiver pairs to be fabricated in the RERC laboratories for distribution to agency heads, city planners and transportation personnel. The transmitters were assembled from prefabricated boards from Talking Signs, Inc. The receivers were of our design, originally published for individual builders and experimenters.

We have developed a new approach to Talking Signs programming allowing easy on-site recording of desired sign messages. The speech-recorder integrated circuits from Information Storage Devices (ISD) we utilize in various of our device designs have dropped in price by a factor of 10 (from $70 to $7 in single quantities) in the two years that we have used them. They are now competitive with the RERC's digitized speech storage in EEPROM. Talking Signs, Inc. suggested that, based on their experience in the field, there would be a major advantage in developing a design feeding the output of our RERC-developed field-recordable ISD speech circuit into their Talking Signs transmitter whose radiated power is adjustable.

As Talking Signs negotiates the technology transfer process, the need arises for various research studies to test the use of the system in different real-world situations. This year, we have begun an Easter Seals Research Foundation-sponsored study in collaboration with San Francisco State University to test the system on the university campus setting. Smith-Kettlewell's RERC has also begun a study of enhanced access to a complex public transit station using Talking Signs. This study is being funded by the U.S. Department of Transportation's Project ACTION and is in collaboration with our Bay Area Rapid Transit (BART) and the San Francisco Municipal Railway (Muni) systems.

An independent comparative study of remote signage systems was carried out by Dr. B.L. Bentzen of Boston College with funding contributed by the American Council of the Blind. The resulting report, *Audible signage as a wayfinding aid: comparison of Verbal Landmarks® with Talking Signs®* was extremely favorable to Talking Signs as the most effective remote signage system available for the blind. Copies of the report are available from the ACB, Talking Signs, Inc., or Smith-Kettlewell.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Remote signage and its implications to print-handicapped travelers. Crandall W, Gerrey W, Alden A. In: Proceedings of the 16th Annual RESNA Conference, 1993, Las Vegas, NV. Washington DC: RESNA Press, 1993:251-3.

Talking signs: a remote signage solution for the blind, visually impaired and reading disabled. Brabyn J, Crandall W, Gerrey W. In: Proceedings of the 15th Annual International Conference, IEEE Engineering in Medicine and Biology Society, 1993, San Diego, CA.

[369] ERGONOMIC LOW VISION TELESCOPE GRIP

John Brabyn, PhD; Deborah Gilden, PhD; William Crandall, PhD; William Gerrey; Albert Alden; Thomas Fowle; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *The Smith-Kettlewell Eye Research Institute*

PURPOSE—A low vision aid has been recently developed, a telescope grip allowing one-handed holding and focusing of common low vision telescopes, to fill an identified need.

PROGRESS—This aid has been successfully commercialized by Walters, Inc., and according to feedback from local dispensers is almost always requested as an option by patients purchasing compatible telescopes.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Improving the ergonomics of popular low vision telescopes. Brabyn J, Colenbrander A, Winderl M. J Vis Rehabil 1994:8(1):12-13.

[370] VISION RESEARCH: A NATIONAL PLAN, 1994–1998

Michael P. Davis
National Eye Institute, National Institutes of Health, Bethesda, MD 20892

Sponsor: *National Institutes of Health, Bethesda, MD*

PURPOSE—The National Eye Institute (NEI) and the National Advisory Eye Council have identified several key research areas related to low vision and its rehabilitation. These are 1) development of simple clinical tests to predict performance of everyday tasks to aid in evaluating the outcome of clinical treatment trials, rehabilitation training programs, and new devices; 2) development of simpler technology for measuring field loss, particularly central field loss, and for presenting dynamic stimuli to known retinal locations; 3) investigation of the effects of scotomas, a "blind" spot in the visual field, on visual perception and the plasticity of perception in visual field loss; and 4) development of technologies such as dropoff detection, text navigation, image processing, and route finding aids.

PROGRESS—A number of these areas are currently under investigation. For example, the NEI is supporting research in the development of aids to assist visually impaired individuals with leading full and productive lives. Scientists are investigating the Global Positioning System (GPS) for use by the visually impaired. The GPS navigation systems use data transmitted from satellites to determine the latitude and longitude of the location of the GPS unit. This technology is used by aircraft and ships to plot their positions. If successful, this technology will allow the low vision user to precisely pinpoint his or her location and to make decisions for safe and efficient route planning. Another device under development will utilize an infrared optical ranging module to detect changes in surface texture, allowing the user to respond to obstacles in his or her

path of travel. Such a device would be less awkward and more efficient than the walking cane used by many visually impaired individuals.

In everyday life people read, recognize objects, and perform many other visual tasks to navigate through their environments. Visual impairments can hinder the easy, accurate, rapid, and safe performance of these tasks. Several NEI funded studies are investigating techniques to assist people with low vision in reading various printed material. Magnification is the most important and widely used method for assisting people with low vision. Visual displays and basic properties of vision are being studied by NEI-supported scientists. These studies may provide new technologies to assist the visually impaired.

In addition, researchers are investigating the role of contrast for discerning patterns in the environment. These studies will assist in determining how contrast influences perception of objects and will be useful for the design of visual aids for people with low vision.

[371] VOICE-ENHANCED OVEN: SOFTWARE EMULATION

Geb Verburg, MA; Dennis Ka-Hong Chan; Trong Truong
Research in Cognitive Development (RiCD) Unit, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8 Canada

Sponsor: *None listed*

PURPOSE—We seek to develop a software emulation which will enable researchers to gather data on the most effective design for a voice enhanced oven. The emulation must have great flexibility as many different designs will be tested and analyzed. Specifically, the software must provide the following features: accurate emulation; voice output capabilities; flexibility; and data recording facilities. Background displays that use LEDs (Light-emitting Diodes) and LCDs (Liquid Crystal Displays) are commonly used in computers, banking machines, watches, and other devices; however, such displays are inaccessible to people who are blind or have low vision. The largest manufacturer of household appliances in Canada, Camco, identified this as an important issue in their line of electronically-controlled ovens and approached The Hugh MacMillan Rehabilitation Centre for consultation. To make the ovens accessible, voice feedback will be used; however, no information exists describing the best messages for the oven's voice feedback. Yet, this information is vital to desired oven operation by people with sensory impairments. Thus, a software emulation was developed to gather this information.

PROGRESS—The software emulation was developed using Hypercard, TouchWindow, and MacinTalk. Hypercard is ideal for developing this software for several reasons: object-oriented, easy to use, and flexible. TouchWindow is an input device similar to a mouse: they both locate cursor position on the screen. It is, however, better than a mouse because the user can point and touch instead of move and click. TouchWindow is an important part of the emulation because it allows a better link between the actual operation of the oven and the software. As voice feedback is necessary, MacinTalk turns text into synthesized speech. Using this package, the software emulation was programmed by first organizing a suitable Hypercard structure. By taking a modular approach the Hypercard stack was separated into seven sections (divided according to the seven different features, i.e., BAKE, BROIL, etc., of the oven). Furthermore, each section consisted of two parts: setting and running. This modular organization proved useful because work could be simultaneously developed.

RESULTS—The following were accomplished in this project: emulation of oven settings; voice feedback of both oven screen display and oven buttons; data recording facilities; and tutorial and survey screens. Joint publication of this work is planned with Camco. Testing this software by consumers with and without disabilities is the next step.

[372] INVESTIGATING USE OF THE UNIVERSAL PRODUCT CODE BY VISUALLY IMPAIRED SHOPPERS AND VENDORS

John Brabyn, PhD; William Gerrey; Thomas Fowle; William Crandall, PhD; Albert Alden; Jay Williams; Martin Winderl
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—We have been monitoring developments in machinery, used by high volume vendors, which reads the Universal Product Code (UPC). There is much interest in designing or adapting equipment with which blind shoppers and vendors could identify store goods.

The major obstacle to rendering UPC codes useful to blind persons (without access to the large table-mounted scanners used in supermarkets) is being able to locate the position of the bar code on each specific container in order to read it with an inexpensive scanner.

PROGRESS—Experiments were conducted using audible reflectance indicators which might allow a simple device to be designed providing feedback to the user as to whether or not the UPC has been located. Variations in reflectance, detected by a single sensor, led to frequent confusion between closely spaced lines of small print and the bar code itself. A pair of sensors (with adjustable spacing) was then tried to determine whether coincident leading or trailing edges of standard UPCs could lead to more definite detection. The results of thesc simple approaches were not sufficiently encouraging to warrant further exploration.

The main problem lies in the variety of placement and orientation of the UPC code. The most rapid of the trials tended to be on boxed goods; the UPC is invariably printed on the bottoms of boxcs, and where the bottom can be found tactually, this defines the area to be explored.

FUTURE PLANS—For the next phase of these studies, we believe the ultimately effective aid will be product driven from mainstream industry (particularly with regard to scanners which can automatically locate the UPC code) with modest adaptations to be designed for our specific target population.

D. Deaf-Blind

[373] ELECTRONIC FORMBOARD

Deborah Gilden, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The purpose of this research was to develop educational toys for children with special needs.

PROGRESS—The author has worked during the past year with Toys for Special Children, a manufacturing company in New York, to develop a sophisticated educational tool, the "Formboard with a Brain." This device enables the parent, teacher or therapist to program sequences of inserting and removing any number of the shapes, or groups of shapes. The child's task is to duplicatc this sequence. The child receives a brief reinforcement for every correct insertion and removal within the sequence, followed by a long and more interesting reward upon completion of the entire sequence. The basic short reinforcement is a brief musical phrase; the long reward at the end is any of several

songs. Two other reinforcer options are available: 1) vibration of the actual Formboard for use by deaf and deaf-blind persons, and 2) activation of an interfaced battery-powered toy. Toys for Special Children is now manufacturing and selling the Formboard with a Brain.

[374] AUDITORY ARCADE

Deborah Gilden, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The purpose of this research is to develop an educational tool for visually impaired children.

PROGRESS—The Auditory Arcade is a stand-alone, modular "busy box" for blind children containing a 6502 microprocessor chip and a synthetic speech chip. It was the first computerized talking educational device with manipulable materials ever developed. It presents the user with different types of problems depending on which "Playing Panel" is in place. The Arcade can be used by both blind and sighted children, and presents tasks involving the manipulation of materials, texture matching, and auditory memory span. The system was developed at Smith-Kettlewell, and prototypes have received very positive feedback from users, parents and teachers.

Toys for Special Children has stated they will use our Auditory Arcade specifications to develop a prototype device in 1994. We will then work closely with them to ensure the development of a commercial product which will address some specific educational needs of children who are visually impaired, physically limited, and/or cognitively limited.

[375] TALKING KEYBOARD

Deborah Gilden, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The purpose of this research is to develop an educational game for young blind or sighted children.

PROGRESS—*K is for Kiss Goodnight* is a children's alphabet story by Jill Sardegna. It nicely lends itself to form the basis of an interactive computer game for young blind or sighted children. We have used Sound Blaster on a PC clone to digitize the text in toto, as well as in individual phrases. Pressing any letter results in the computer's reciting the associated phrase; pressing the space bar initiates recitation of the entire story. We are about to re-digitize the story using a voice-over specialist, and design the prototype game software. We will then demonstrate the games to special education professionals and incorporate any appropriate and practical suggestions they offer. At that point we will make the software available for use in selected classrooms and/or organizations and programs for blind children.

In a related project, undertaken in collaboration with Dr. Peter Loubal of Plus Associates International, we have initiated the development of a "Dynamic Single-Tactor Talking Tactile Globe." We anticipate that this device will open the world of geography and other spherical-based subject areas to blind persons.

[376] INVESTIGATING SOME BASIC PARAMETERS OF MULTIFINGER TACTILE PERCEPTION

Deborah Gilden, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The purpose of this research is to develop a new, refreshable Braille display sign.

PROGRESS—Refreshable braille displays of a line or a partial line of computer text provide blind braille readers with valuable computer access. These displays, however, provide much less information than the visual displays used by sighted people, and have other drawbacks as well. A new approach to refreshable braille display design is being developed and evaluated in collaboration with TiNi Alloy Company in San Leandro, California. Instead of fabricating a line of braille, this new system will attempt to provide all the information of a full screen of text, including format, with the use of only one 8-dot cell (i.e., a single character). This will tremendously reduce the cost of the device.

In the TiNi Alloy design, the 8 dots of the braille cell will be teased apart, and each dot relocated to the center of the corresponding key of an 8-key braille keyboard. This tactile feedback keyboard will enable the user to both read and write braille without moving the hands to a new location. This system will also give us a tool to investigate some questions regarding basic tactile perception as it relates to reading braille. This information will be most valuable in future designs of refreshable braille displays.

[377] SURVEY OF DEAF-BLIND TECHNOLOGY NEEDS

Deborah Gilden, PhD; Thomas Fowle; Arthur Jampolsky, MD; Helen Simon, PhD; Carter Collins, PhD; John Brabyn, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The purpose of this research was to acquire information on the technological needs of deaf-blind individuals.

PROGRESS—We have completed our survey of deaf-blind individuals to determine their opinions on technological needs. Thanks to the cooperation of a large number of agencies throughout the United States, we have received 61 completed Deaf-Blind Technology Needs Questionnaires. We have thus exceeded our original goal of acquiring 50 completed questionnaires. The following is a brief summary of the survey results. More details appear in our Annual Report of Progress, available from the RERC.

Sensory Loss. Of the 61 respondents, 32 reported having useful vision, 26 reported having no vision, and 3 did not answer the question. Regarding useful hearing, 32 reported having some, 27 responded they had none, and 2 did not answer this question.

Technology Used. Only 4 respondents reported that they use absolutely no technology at all. The remainder listed between one and over a dozen devices, ranging in sophistication from a large print watch to specialized computer technology.

Technology Desired from Current Market. Twenty-five individuals stated that there was no special technology that they know of that they would like to own.

Problems which Technology Might Address. To the question of whether they had any problems that a new device might help with, 29 individuals responded positively.

Computer Use. Forty-six respondents said that they do not use a computer, and 15 said that they do.

IMPLICATIONS—This survey gives us a firmer, more valid grasp of what deaf-blind people encounter as problems and of what technology they believe could assist them, the results hold no great surprises. Probably the most important findings, however, are that the two biggest problems require a system change: 1) getting the word out to deaf-blind individuals (and those professionals who work with them) as to what is already available for them on the commercial market of special interest to that population, and 2) getting those devices into the hands of the people who need them.

[378] DEXTER: THE FINGERSPELLING MECHANICAL HAND FOR DEAF-BLIND PERSONS

Deborah Gilden, PhD; Thomas Fowle; Arthur Jampolsky, MD; Helen Simon, PhD; Carter Collins, PhD; John Brabyn, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—This project addresses the need for a mechanical hand capable of performing the fingerspelling code used for communication with persons who are deaf and blind.

PROGRESS—During the past year, Upstart Robots of San Francisco has obtained a Phase I SBIR grant, with Smith-Kettlewell as consultant, to develop a Dexter III prototype with a view toward ultimate commercial production. To date Dexter III can form all 26 letters of the alphabet in a way which appears to the researchers' visual observations to be good simulations of the human hand shapes, or close enough to not be confused with any other letters. Wrist flexion has been incorporated into the new prototype to allow formation of letters G, H, and P, as well as formation of the "dynamic" letters, J and Z. Letters now transition smoothly, without needing to move to a neutral position between letter pairs. Letter presentation is currently infinitely variable up to a maximum speed of about 1/sec.

Five deaf-blind tactile fingerspelling readers have been helping us test variations of Dexter III. Results have been incorporated into a Phase II Small Business Innovative Research grant in collaboration with Upstart Robots.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Touching reality: a robotic fingerspelling hand for deaf-blind persons. Gilden D, Smallridge B. In: Proceedings of the Conference on Virtual Reality and Persons with Disabilities; 1993 June 17-18; California State University-Northridge, Millbrae, CA.

[379] VIBRATING MEDICATION REMINDER FOR THE DEAF-BLIND

Deborah Gilden, PhD; Thomas Fowle; Arthur Jampolsky, MD; Helen Simon, PhD; Carter Collins, PhD; John Brabyn, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—Independence and self-reliance are difficult problem areas for people who are both deaf and blind. They are issues which have potentially devastating practical and psychosocial ramifications. Dependency not only has a negative effect on a deaf-blind person's self-esteem, but may also cause major disruption among family members' lifestyles and schedules. This is especially true of dependence related to certain aspects of health care. The simple need to know when to take medication sometimes wreaks havoc within a deaf-blind person's family, as it requires an able-bodied person to be in regular physical proximity to the patient.

Questions 9, 9a, and 9b on Dr. Deborah Gilden's Deaf-Blind Technology Needs Questionnaire deal with the deaf-blind population's perceived

need for a medication reminder which could be used without vision or hearing. Of the 61 respondents, 41 indicated they take medication. Eighteen (nearly half) of those individuals indicated they would like a vibrating reminder.

PROGRESS—We have been working with Mr. David Herrmann, a graduate of the San Francisco State University Department of Design and Industry, on the development of a prototype vibrating medication reminder which could be used independently by deaf-blind people. As a result, Mr. Herrmann completed the fabrication of a functioning prototype which served as a class project.

The prototype, a plastic box 4-3/4 in x 2-1/2 in x 1-1/2 in, displays two clock faces, one above the other. One face is the equivalent of a braille clock. That is, it has tactile markings to indicate the numbers, and the two clock hands may be felt. The other face has a two-position switch at each number location. Moving a switch away from the center automatically sets the unit to vibrate at that time. (An AM-PM switch was not incorporated.) This prototype received tremendously favorable comments from all three blind staff members of The Smith-Kettlewell Rehabilitation Engineering Research Center, who pointed out that hearing blind persons would also find a vibrotactile reminder valuable.

FUTURE PLANS—We have initiated discussions with Mr. Herrmann on collaborating to develop a second-generation prototype of this device.

[380] THE SMITH-KETTLEWELL VIBRATORY BATTERY TESTER FOR THE DEAF-BLIND

Deborah Gilden, PhD; Thomas Fowle; Arthur Jampolsky, MD; Helen Simon, PhD; Carter Collins, PhD; John Brabyn, PhD
The Smith-Kettlewell Eye Research Institute, San Francisco, CA 94115

Sponsor: *National Institute on Disability and Rehabilitation Research; The Smith-Kettlewell Eye Research Institute*

PURPOSE—The purpose of this research was to develop a hearing-aid battery tester for the blind.

PROGRESS—Responding to a joint request from the Arizona State Department of Rehabilitation and an on-staff audiologist at the Arizona State School for the Deaf and Blind, a hearing-aid battery tester was developed for blind hearing-aid wearers. A visual button battery tester made by Activair (a division of Mallory) was adapted by adding a vibrotactile output.

The prototype accommodates two tactile transducers; this was done as an experiment to see which type is most satisfactory. There was room on the circuit board to mount a Star Micronics CMB-12 buzzer, whose cantilever armature causes the housing to vibrate quite noticeably. The alternative output is a 200 Hz power oscillator fed to a small loudspeaker whose cone can be touched.

Comments from the person who received our first unit were favorable. Because of its portability, and since indications from the on-board buzzer were deemed sufficient, the loudspeaker was deemed to be superfluous.

The privately funded Rehabilitation Engineering Service of Smith-Kettlewell is making the device available individually for $125 each.

[381] WARNING DEVICE ALLOWS SWIMMERS WHO ARE DEAF-BLIND TO SWIM INDEPENDENTLY

Linda Gurd; Bruce McClure; Patti Longmuir; Phil Weaver
Variety Village, Scarborough, ON M1N 2G2 Canada; The Hugh Macmillan Rehabilitation Centre, Toronto, ON M4G 1R8 Canada; Ontario College of Art, Design Programme, Toronto, ON M5T 1W1 Canada

Sponsor: *Variety: The Children's Charity*

PURPOSE—Swimming is a popular recreational activity among individuals who are deaf and blind since it requires a minimal amount of interaction with other participants and/or the environment. Presently, deaf-blind individuals must be accompanied while swimming to ensure that they are not injured by collisions with other swimmers or the walls of the pool. Due to the limited availability of staff/volunteers, deaf-blind individuals are often unable to participate in community recreation programs. In order to enable deaf-blind individuals to participate independently in aquatics programs, a warning device was developed to signal the swimmer as he approaches the wall of the pool.

METHODOLOGY—Lane ropes can be used effectively to prevent a deaf-blind swimmer from colliding with the sides of the pool, or other swimmers. However, a warning device was required to warn swimmers as they approach the end walls of the pool. Warning devices currently available rely on visual or auditory cues which cannot be perceived by deaf-blind individuals. Initially, plastic streamers were suspended from a rope above the surface of the pool. The streamers would touch the arms and head of the swimmer to indicate that he was 5 meters (approximately 3 or 4 swimming strokes depending on individual ability) from the wall of the pool. This design was found to be an effective warning device; however, many swimmers found that the streamers wrapped around their arms and therefore interfered with their swimming stroke.

The second prototype utilized a spray of water rather than the plastic streamers. When the spray utilized recirculated pool water, the warning device was 80 percent effective. When cold tap water was used for the spray, the device was 100 percent effective but uncomfortable for the swimmers to use for extended periods of time. Further modifications to the spray nozzle have increased the pressure of the spray with recirculated pool water.

FUTURE PLANS—Additional work on this project is required to ensure the effectiveness of the warning device and its compatibility with the circulation systems of most community swimming pools.

XIV. Spinal Cord Injury and Related Neurological Disorders

A. General

[382] MANAGEMENT OF THE MUSCULOSKELETAL COMPLICATIONS OF SPINAL CORD INJURY

Leonard J. Deftos, MD; Jacqueline G. Parthemore, MD; Kevin D. Gerhart, MD; Estralita Martin, PhD; Susan Szollar, MD
San Diego VA Medical Center, San Diego, CA 92161

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B576-2RA)*

PURPOSE—The specific purpose of this research is the development of clinical assessment procedures that can be in the diagnosis and management of the musculosketal complications of patients with spinal cord disease and injury. The goal of the project is to provide a panel of biochemical and immunochemical tests that can be applied along with other modalities to the clinical evaluation of the spinal cord patient. These purposes and goals relate to the mission of the VA Rehabilitation R&D program, because musculoskeletal complications are common clinical events in the patient with spinal cord injury and disease. More specifically, this project is designed to develop and apply newly discovered, bone cell-specific serum markers to clinical studies of museuloskeletal assessment in patients with trauma and illness involving the spinal cord.

PROGRESS—We have achieved our goals or made substantial progress toward them. This project was reinstituted in January 1994. We have developed new procedures for the measurements of bone alkaline phosphatase and bone Gla protein, and we have made substantial progress toward the development of procedures for the measurement of bone acid phosphatase. We have extant assays for the calcemic hormones. In addition, we have developed protocols that can be implemented for clinical application of these procedures to spinal cord patients.

METHODOLOGY—The methods we have developed and used are immunochemically based. They are generically immunoassays for the respective bone proteins. However, in addition to standard immunoassays, they also include new immunoassay formats that allow the precise identification in serum of the bone proteins under study, such as bone alkaline phosphatase (BAP), and new skeletal markers, such as Gla protein (BGP, osteocalcin) and its derived peptides.

RESULTS—Our results are summarized in the publications that we cite. In brief, they indicate that we have developed working assays for bone alkaline phosphatase and bone Gla protein, and that we have developed key reagents for other measurements. Thus, we have achieved the essential goals of the first phase of our project and are ready to proceed to clinical studies.

FUTURE PLANS—Our future plans, upon renewal of our application, are to apply these procedures to clinical studies of patients with spinal cord injury and disease.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

2-Site assays of bone gla protein (Osteocalcin) demonstrate immunochemical heterogeneity of the intact molecule. Deftos LJ, Wolfert RL, Hill CS, Burton DW. Clin Chem 1992:38:2318-21.

Two-site immunoradiometric assay for intact salmon calcitonin. Deftos LJ. Clin Chem 1992:38:2284-6.

Associations and dissociations between gla protein (BGP) and alkaline phosphatase (AP) in skeletal metabolism. Parthemore JG, DW Burton, LJ Deftos. J Orthop Res 1993:11:671-6.

Markers of bone turnover in primary hyperparathyroidism. Deftos LJ. In: Bilezikian JP, Levine MA, Marcus R, ed. Parathyroids. New York: Raven Press Ltd., 1994:485-92.

[383] SPINAL CORD INJURY-INDUCED BONE LOSS

Guy A. Howard, PhD; Parmender P. Mehta, PhD; Vicky R. Holets, PhD; Esther L. Hill, PhD
VA Medical Center, Miami, FL 33125; Department of Medicine, University of Miami, School of Medicine, Miami, FL 33101

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B684-RA)*

PURPOSE—Both the central and peripheral nervous systems are altered after spinal trauma; hence, our hypothesis is that changes in neuropeptides, neurotransmitters, and cytokines found in nerves supplying bone are involved in the osteoporosis which develops following spinal cord injury (SCI). We propose to gain an understanding of how these alterations affect bone metabolism after SCI, since 45,000 veterans suffered SCI, are paralyzed, and are treated in the VA system annually. The significance of the research lies in the potential for discovering the neural mechanism(s) involved in bone loss following SCI. These results could lead to a therapy to prevent the pathogenic loss of bone in newly injured veterans, or aid in the recovery of bone in chronic SCI veterans. Such treatment would result in enhanced rehabilitation, independence and productivity in SCI veterans.

METHODOLOGY—The studies are being done using a rat model in which the animals are well maintained, and in which the bone loss is both dramatic and progressive over time. Histomorphometry, mechanical testing, radioimmunoassays, and molecular biology techniques are being used to characterize bone loss following SCI. This will allow us to determine changes in neuropeptide distribution and levels in bone and periosteum over time. Specifically we have focused on calcitonin gene-related peptide (CGRP), substance P (SP), vasoactive intestinal peptide (VIP), neuropeptide Y (NPY), and interleukin-1 (IL-1), since these substances are known to be contained in nerve fibers in bone and are implicated *in vitro* as modulators of bone metabolism. Immunohistochemistry, receptor binding assays, and autoradiographic methods will be used to evaluate receptor changes.

PROGRESS—During the past 2 years we have been defining the model, and to date have histomorphometrically evaluated the effects of SCI on the bone at various times post lesion, as the animals age. Methods have been developed to evaluate the neuropeptide content and their mRNAs in bone and periosteum. We have established a bone cell model in which to evaluate the effect of various neuropeptides on mRNA levels of proteins involved in cell-cell communication via gap junctions which we have shown to be present and functionally regulated in bone cells.

RESULTS—Characterization of the effects of SCI on bone metabolism at the histomorphometric level has been completed. Older animals lost approximately 60 percent of their trabecular bone compared to nonlesioned animals. This bone loss results in considerable loss of mechanical strength in the femurs of lesioned animals. Immunohistochemical and retrograde tracing studies of nerves associated with bone demonstrated that sensory nerves containing neuropeptides which affect bone cell metabolism are particularly dense in the periosteum and pene-

trate the bone surface. Whole mounts of periosteum from tibiae of lesioned animals has demonstrated the presence of CGRP, VIP, and NPY. We have just begun our RIA work, having established a reliable method to prepare the periosteum for RIA of the various neuropeptides and cytokines to be evaluated. VIP, but not SP is capable of acutely up-regulating the mRNA for the predominant gap junction protein in osteoblasts. VIP also regulates functional cell-cell communication in osteoblasts as shown by single cell injections.

FUTURE PLANS—During the coming year we will finish the RIA studies on the periosteum to determine the amount of each neuropeptide. We will continue our comparative studies with periosteal bone cells of lesioned and nonlesioned animals for the effects of neuropeptides on mRNA levels and functional status of cell-cell communication and gap junctions. We are beginning studies to identify any post-SCI changes in bone cell receptors for these neuropeptides.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Hormonal regulation of intereellular eommunication: parathyroid hormone inereases eonnexin 43 gene exprcssion and gap junctional communication in osteoblastic cells. Schiller PC, Mehta PP, Roos BA, Howard GA. Mol Endoerinol 1992:6:1433-40.

Neuropeptides modulate gene exprcssion in bone metabolism. Bendix MV, Schiller PC, Howard GA, Roos BA. J Bone Miner Res 1992:7(suppl 1):S208.

Opposing differential regulation of osteoblastie mRNAs by ealcitonin gene-related peptide and parathyroid hormonc. Burns DM, Howard GA, Roos BA. J Bone Miner Res 1992:7(Suppl 1):S126.

PTH regulation of inter- and intracellular channels and junctions in osteoblasts. Howard GA, Schiller PC, Drivdahl RH, Roos BA. In: Cohn DV, Gennari C, Tashjian Jr AH, eds. Calcium regulating hormones and bone metabolism, Amsterdam: Elsevier Sci Pub, 1992:212-17.

Changes in bone in a model of spinal cord injury. Hill EL, Martin BR, Gunther E, Morcy-Holton E, Holets VR. J Orthop Res 1993:11:537-47.

Similar regulation of bone eell eommunieation by parathyroid hormone and the neuropeptide vasoaetive intestinal peptide. Howard GA, Schiller PC, Bendix M, Mehta PP, Roos BA. In: Program & Abstracts, The Endocrine Soeiety 75th Annual Meeting, 1993:325.

[384] WHEELCHAIR EXERCISE AND DIGITAL ECHOCARDIOGRAPHY FOR THE DETECTION OF HEART DISEASE

W. Edwin Langbein, PhD; Lonnie C. Edwards III, MD; Kevin Maki, MS; Eric K. Louie, MD; Ming H. Hwang, MD; Bernard A. Nemchausky, MD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #716-RA)*

PURPOSE—The purpose of this research is to establish a cost-effective and clinically useful noninvasive diagnostic procedure for detection of coronary artery disease (CAD) in persons with lower limb disabilities. This investigation will compare the sensitivity, specificity, and predictive valuc of wheelchair ergometry (WCE), with and without exercise, to digital two-dimensional echocardiography (EX + ECHO) for the detection of coronary artery lesions in patients with lower limb disabilities.

PROGRESS—To date, EX + ECHO data has been collected on 138 subjects (134 males, 4 females) 29-79 yr of age (63.1 ± 11 yr). Coronary angiographic follow-up has been completed on 12 paticnts.

METHODOLOGY—The subject sample will be composed of three patient categories: 1) patients who undergo angiography following the EX + ECHO, these test results will be used primarily to establish sensitivity and specificity; 2) patients who have had angiography prior to EX + ECHO with and without significant CAD, these test rcsults will be used primarily to establish sensitivity and specificity; 3) patients who do not undergo angiography following EX + ECHO and will bc followed for a period of 9 months to establish predictive value of a positive or negative EX + ECHO.

Cardiologists blinded to patient status will independently review EX + ECHO studics, ECG

data, and angiographic films. The WCE exercise test protocol will be 2-min stages with 30-sec pauses between stages. Exercise will begin at 6 W with 6 W increases in subsequent stages. In addition, we have designed and constructed a new prototype imaging table that will permit us to perform the echocardiographic imaging with the wheelchair restricted patient in the left lateral reclined position (optimal imaging position) within 20 sec of the end of exercise. The following information will be collected: 1) blood lipid analysis; 2) symptom limited maximal graded exercise WCE test with metabolic measurements, resting and peak exercise echocardiography; 3) spirometry; and 4) individual demographic data.

RESULTS—The peak mean ± one standard deviation measures for heart rate (HR), systolic and diastolic blood pressure, double product, percentage of age predicted maximal HR, metabolic equivalents (MET) were for the 138 subjects were 134 ± 28, 170 ± 26, 85 ± 16, 22497 ± 5378, 85 ± 14, 4.5 ± 1.3, respectively.

Twelve patients who had coronary angiographic follow-up achieved similar cardiac workloads. CAD was defined as ≥ 50 percent luminal diameter narrowing of any major epicardial vessel. CAD was present in 11 patients: single vessel CAD ($n = 4$), 2 vessel CAD ($n = 5$), 3 vessel CAD ($n = 2$), no CAD ($n = 1$). An abnormal exercise ECG was defined as ≥ 1mm horizontal or down sloping ST depression occurring 80 msec after the J point. One ECG was non-diagnostic due to LBBB. An abnormal digital echocardiography study was defined as the presence of a stress induced wall motion abnormality (WMA) or worsening of a resting WMA. A blind review of the echo studies, ECG's and angiograms was conducted by independent investigators. Diagnostic accuracy in patients with documented CAD was 83 percent and 58 percent for EX + ECHO and exercise ECG, respectively. We believe that as more data is collected and analyzed the results will demonstrate that for patients unable to undergo treadmill or bicycle exercise, the EX + ECHO test is a clinically useful technique to detect CAD in patients with lower limb disabilities.

FUTURE PLANS—At the end of 2 years the feasibility of expanding this research to include a minimum of two additional VA Medical Centers will be evaluated.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Wheelchair ergometry for the detection of coronary artery disease in persons with lower limb disabilities. Langbein WE, Edwards LC, Hwang MH, Maki KC, Sibley P. Med Sci Sports Exerc 1992:24:S33.

Initial clinical evaluation of a wheelchair ergometer for diagnostic exercise testing. Langbein WE, Maki KC, Edwards LC, Hwang MH, Sibley P, Fehr L. J Rehabil Res Dev. 1994:31(4). In press.

[385] URINARY BLADDER STIMULATION FOLLOWING SPINAL CORD INJURY

James S. Walter, PhD; John S. Wheeler, MD; Wuying Cai, MD; Robert B. Dunn, PhD; Paul Zaszczurynski, BS; Robert D. Wurster, PhD; Lisa Riedy, PhD

Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141;
Loyola Medical Center, Department of Urology and Physiology, Maywood, IL 60153

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B441-2RZ)*

PURPOSE—The purpose of this pilot project was to further develop neuroprosthetic devices for the lower urinary tract. This is important because after spinal cord injury, control of bladder function is usually lost. This project's goal was to learn more about the mechanisms of bladder dysfunction following spinal trauma both incontinence and voiding and to use this knowledge to develop ways to stimulate the bladder.

PROGRESS—Direct bladder stimulation was evaluated before spinal cord injury in six male cats. Animals were instrumented under anesthesia with eight 'woven eye' type electrodes consisting of

multistranded 316LVM stainless steel wire wound into an eye at the electrode tip and sutured into the serosa of the bladder wall. Electrodes were implanted anterior to the trigone and on the dome. Additional instrumentation consisted of two suprapubic bladder catheters for recording bladder pressure and bladder filling, and a peritoneal balloon for recording abdominal pressure. EMG recording electrodes were implanted in the pelvic floor and leg quadriceps.

Responses to direct bladder stimulation were recorded during a four week period in tethered animals without anesthesia. All of the cats responded to direct bladder stimulation using a single 3 s stimulation period, at 40 pps, 1 ms pulse duration and a stimulating current from 7.5 to 20 mA. The maximum voiding rates were from 0.5 to 1 ml/s with a total voided volume of 6 to 14 ml, peak detrusor pressures were from 40 to 70 cm H_2O and minimal residual volume from 4 to 8 ml. Discomfort was noted in the these intact animals at higher stimulating currents which were not continued.

Stimulation was evaluated after SCI in the two animals studied. Voiding with stimulation was observed after one and three weeks in the two animals. Maximum voiding rates after SCI were similar to before SCI, and the volume voided was 4 to 10 ml at peak detrusor pressures from 40 to 50 cm H_2O. Based on the pelvic floor EMG, high urethral resistance appeared to be due to the spinal cord injury, not to the stimulation. The only adverse effect of stimulation was slight abdominal movement.

IMPLICATIONS—We believe that direct bladder stimulation offers an alternative method of promoting voiding following SCI. Potential advantages or new directions in direct bladder stimulation are 1) the pudendal nerve in the pelvic floor may not be directly stimulated; 2) the large surface area 'woven eye' electrode may be an improvement in electrode design; and 3) we are currently developing a suture electrode that can be sutured into the serosa of the bladder wall. However, problems related to clinical trials of direct bladder stimulation include 1) SCI patients must be continent and their high urethral resistance must be managed, and 2) acute evaluation procedures must be developed that will show which patients will benefit from direct bladder stimulation. If these issues can be addressed, and this is the area of our current research, direct bladder stimulation may become more widely available to the SCI patient.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Comparison of direct bladder and sacral nerve stimulation in spinal cats. Walter JS, Sidarous R, Robinson CJ, Wheeler JS, Wurster RD. J Rehabil Res Dev 1992:29:13-22.

Evaluation of direct bladder stimulation with stainless steel woven eye electrodes. Walter JS, Wheeler JS, Cogan SF, et al. J Urol 1993:150:1990-6.

Inhibiting the hyperreflexic bladder with electrical stimulation in a spinal animal model. Walter JS, Wheeler JS, Robinson CJ, Wurster RD. Neurourol Urodynamics 1993:12:241-53.

Observations of a dynamic bulbocavernosus reflex (DBC) in the SCI cat and humans. Walter JS, Wheeler JS. J Am Paraplegia Soc 1993:16(1):59.

[386] ADVANCED TECHNOLOGY NEURAL INFORMATION SENSORS FOR PROSTHETIC CONTROL BY QUADRIPLEGICS

David J. Edell, PhD; Amico Bignami, MD; Bruce C. Larson; Lisa P. Devaney; James R. Mann; Terry O. Herndon
West Roxbury VA Medical Center, West Roxbury, MA 02132

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B706-RA)*

PURPOSE—The objective of this research is to develop technology capable of transducing neural information from the motor cortex. The eventual application is to use such a system for chronic implantation in quadriplegics for control of FES systems. One main difficulty with implementation of chronic neural interface technology in the brain is motion of the brain relative to the skull, necessitating some telemetry system. The specific aim of the current research is to develop the integrated circuit telemetry techniques and implant structure that will provide a mechanically stable neural interface for many years. The key question to be addressed by this proposal is: what would be a reasonable design

for a neural information sensor that could be chronically implanted in humans as part of a system for rehabilitation of the SCI patient?

PROGRESS—An electrically-isolated, low-noise recording system was constructed and used to record from a brain implant. Noise performance was below that of the biological noise. Brain recordings are continuing. A low noise test system for characterization of integrated circuit transistors was designed and constructed and is currently being evaluated. This system will be used to provide information on noise performance of subthreshold devices important for the design of a low power electronic implant. A test chip with differential amplifiers and transistor arrays for noise/geometry evaluations was designed and submitted to MOSIS for fabrication.

RESULTS—The noise level of the recording amplifier was less than 1 μV RMS for a 10 kHz bandwidth. Input bias current was less than 1 pA. Recordings from a cortical electrode array implanted several years ago in a rabbit showed neural potentials on the order of 100 μV. The noise floor of the low noise transistor characterization system was limited by the thermal noise of a single feedback resistor used for detecting the drain current. Several different commercial low noise operational amplifiers were evaluated for the input stage. All so far exhibit significant flicker noise below a few hundred hertz. Several peaks in the frequency response were traced to computer induced noise. More aggressive shielding and isolation of the power supply substantially reduced the problem.

FUTURE PLANS—Noise levels will be further characterized for all instrumentation. Programming will be developed to subtract out the base amplifier noise from the device-amplifier noise. Correction for band-limiting effects of the test device will also be made in software. This should allow measurement of noise spectra from test devices that are lower noise than our instrumentation. More efficient and reproducible techniques for producing ultrasharp, smooth structures with tightly controlled shapes will be investigated throughout the proposed research. A custom micromanipulator with fine axial alignment capability will be constructed and used for all future implants.

[387] DEVICE FOR TREATMENT OF PERIPHERAL NERVE INJURY

Ioannis V. Yannas, PhD
VA Medical Center, West Roxbury, MA 02132; Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B687-RA)*

PURPOSE—The objective of this study is to modify the current design of a prosthesis that induces regeneration and functional recovery in the transected rat sciatic nerve so that it is suitable for clinical studies. The current design consists of a type I collagen-glycosaminoglycan matrix, an analog of extracellular matrix (ECM), with known pore diameter and degradation rate, which is ensheathed in a silicone tube. Better control of the regeneration process may provide improved functional performance in patients with peripheral nerve injuries, thus improving the quality of life for veterans.

PROGRESS—The focus of the research this year has been on the replacement of the silicone tube currently used to ensheath the ECM analog in nerve regeneration experiments with a biodegradable collagen tube. The collagen tube will eliminate the need for follow-up surgery after nerve regeneration. The protocol for production of the collagen-glycosaminoglycan matrix in a silicone tube has been followed with slight modifications to produce collagen-glycosaminoglycan matrix ensheathed in porous and nonporous collagen tubes. The focus of the studies has been to determine the effect of the collagen tube on the regeneration process. The studies in progress involve graft implantation in the rat sciatic nerve across a 10 mm gap. Surgery has been performed on 35 rats (one implantation in the sciatic nerve per rat) for 6-week studies. The implanted prostheses include five of each of the three types of tubes empty, five matrix filled porous

collagen tubes, five matrix filled nonporous collagen tubes, five matrix filled silicone tubes, and five autografts. At the time of sacrifice, the nerves will be removed, fixed, and embedded for sectioning. Histology studies will be done on the sections.

METHODOLOGY—The new prosthesis has been studied by several techniques including SEM and moisture content assay. SEM studies have been performed on the collagen tubes containing matrix. The matrix pore size is 5 μm as determined by SEM, and the pore distribution is predominantly longitudinal. The nerve prosthesis is comprised of a matrix which was produced by freeze-drying a collagen-chondroitin 6-sulfate suspension inside of a porous or nonporous collagen tube. The animal studies consist of the introduction of two surgically cut nerve endings 5 mm into a 20 mm tube, leaving 10 mm of matrix between the ends. Sacrifices involve the perfusion of the rat and removal of the sciatic nerve. Standard fixation, embedding, and sectioning procedures are used. Sections will be stained with hemotoxylin and eosin, Masson's trichrome, anti-αactin, and osmium tetroxide.

RESULTS—The early results show that it is possible to obtain a collagen-glycosaminoglycan matrix ensheathed in a nonporous or porous collagen tube with similar pore sizes and degradation rate when compared to those previously used with silicone tubes. Surgical implantation of the nonporous and porous collagen tubes has been successful. Only four rats have been sacrificed early due to autotomy. As the study is still in progress, comparison of the different tubes and their effect on regeneration is not possible.

FUTURE PLANS—These studies will continue and we expect to obtain histological results for the various controls and types of tubes. A digitized analysis of the myelinated axons in the regenerated nerve and TEM studies will also be performed. Conclusions will be made on the effect of the nonporous and porous collagen tubes on the regenerative process when compared to previous data on the silicone tubes. With this data, studies will continue to determine an optimum pore size and degradation rate for the new prosthesis.

[388] PROKINETIC AGENTS FOR CONSTIPATION IN SPINAL-CORD INJURED (SCI) PATIENTS: A PILOT STUDY

Walter E. Longo, MD; Monica Bruckner, MS; Anthony M. Vernava, MD; Kathy S. Virgo, PhD; Frank E. Johnson, MD

Department of Surgery, St. Louis University School of Medicine, St. Louis, MO; John Cochran VA Medical Center, St. Louis, MO 63110-0250

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B93-585AP)*

PURPOSE—Maintenance of gut function is one of the most important quality-of-life issues facing SCI patients today. Chronic constipation is the most common gastrointestinal complication in these patients. Bowel care occupies much of the SCI patient's day. The objectives of this study are 1) to determine the degree to which abnormalities in both colonic transit and pelvic floor motor function contribute to refractory constipation in patients with quadriplegia and paraplegia and 2) to determine whether prokinetic agents improve colonic transit, pelvic floor function, and quality of life (relief of chronic constipation)

METHODOLOGY—Initial studies on this topic have begun. Patients are recruited from our VA Spinal Cord Unit. Details of spinal cord injury, current bowel regimen, and quality of life are assessed by questionnaire. Patients are invited to participate in a study using the prokinetic agents cisapride and erythromycin to alleviate constipation. Initially colonic transit studies are obtained using radio-opaque markers and serial abdominal X-rays. Evaluation of the pelvic floor is done using anorectal manometry physiology.

After baseline studies, patients receive cisapride 20 mg po q.i.d. for 1 month. If, at the end of 1

month, functional and physiological results are improved, patients continue on cisapride alternating monthly with an identical- appearing placebo for 6 months. Clinical and physiological assessment is reassessed at 5 and 6 months. In patients with no improvement on cisapride, erythromycin 500 mg po q.i.d. is given for 1 month. If clinical and physiological improvement occurs, patients alternate between erythromycin and an identical-appearing placebo for 6 months with testing repeated at 5 and 6 months. If neither drug is beneficial, both drugs are used, with similar testing and controls. If both drugs together are not beneficial, the study is terminated for that patient.

PROGRESS—Since March 1994, 18 patients have agreed to participate. Ten patients have undergone physiological studies; 9 have received cisapride. Most have significant delay in progression of markers through the colon. Resting anal pressures have been within normal physiological limits, but squeeze pressures are markedly reduced. All patients have tolerated cisapride well, but it is premature to assess long-term results.

FUTURE PLANS—Following the completion of this 1-year pilot study, a 3-year proposal evaluating other prokinetic agents such as serotonin agonists and dopamine antagonists in spinal cord patients will be submitted. We plan to evaluate receptor mediated phenomena *in vitro* as well as using from smooth muscle cells harvested from the colon of spinal cord injured patients evaluating the effect of prokinetic agents on neuropeptide released.

[389] IMPROVING EXERCISE PERFORMANCE OF QUADRIPLEGICS

Stephen F. Figoni, PhD; Satyendra C. Gupta, MD; Roger M. Glaser, PhD; Mary M. Rodgers, PhD; Agaram G. Suryaprasad, MD; Watson D. Parker, Jr., MO
VA Medical Center, Dayton, OH 45428; Institute for Rehabilitation Research and Medicine, Wright State University, Dayton, OH 45435

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B587-RA)*

PURPOSE—The goal of this project is to develop and evaluate an arm + leg (hybrid) exercise system for spinal cord injured (SCI) quadriplegics. The design of this system aims to maximize active muscle mass and aerobic metabolism and facilitate central and peripheral circulation. Arm-cranking is used to drive the leg-cycling motion, while a computer controls the electrical stimulation (ES) of appropriate leg muscle groups during the crank cycle to enable leg cycling. Phase I consisted of modification of the current prototype voluntary-arm + ES-leg cycle ergometer to permit operation in either the upright sitting or reclined/recumbent posture. Phases II and III, respectively, consist of evaluation of acute and chronic physiologic responses of quadriplegics during exercise testing and training with this system. Changes in fitness gained in the reclined posture, over and above that gained in the upright posture, will be determined.

The data derived from this project should contribute toward optimizing methods for exercise testing and training of quadriplegics so that they can achieve substantially higher cardiopulmonary fitness levels.

PROGRESS—*Phase I.* To date, the hybrid exercise system has been built, and techniques and protocols have been devised for exercise testing and training of SCI quadriplegics. Major structural modifications have involved rotation of the system on a fulcrum located at the ergometer's rear end, allowing up to 40° reclination, and thus relative elevation of the leg cranks to heart level to enhance venous return. To further increase active muscle mass and enhance venous return via the skeletal muscle venous pump, ES of gastric-soleus and tibialis anterior muscle groups of the lower legs was added to traditional ES of quadriceps, hamstring, and gluteal muscle groups. At present, ES intensity is manually controlled and can be increased up to 250 mA. Digital displays show in near-real time the cycling cadence, ES current, total power output, power outputs at each crank, and heart rate via cardiotachometer. Maximal current outputs to each muscle group can

be limited to less than 250 mA if sensory tolerance dictates. The computer processes signals from strain gauges on the left and right arm and leg cranks, and on the flywheel, to calculate power inputs from each limb and total power output measured at the flywheel, respectively. Post-exercise data processing prints out these five argometric variables as well as ES current, cycling cadence, elapsed time, and heart rate. Each line of data represents the average of ten consecutive crank cycles at the target cadence of 50 rpm.

Phase II. To date, 14 SCI quadriplegic subjects have undergone assessment of acute physiologic responses during graded exercise testing in both postures with arm cranking alone, ES leg cycling alone, and hybrid exercise. In general, the results demonstrated superior peak arm and hybrid exercise performance (power output, oxygen uptake, and cardiac output) in the reclined posture compared with upright. The results also clearly documented chronic exercise hypotension in quadriplegics, especially during/after hybrid exercise without protective compressive garments or vascular supports.

Phase III. This exercise training phase has not yet been completed. There are nine quadriplegic subjects who still remain involved in reclined-hybrid exercise training. In general, subjects show substantial increases in peak arm-crank power output, oxygen uptake, and cardiac output after 15 weeks of upright hybrid exercise training.

FUTURE PLANS—Research is needed to improve further the exercise tolerance of SCI quadriplegics to enhance their health, fitness, and rehabilitation outcome.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Computer-controlled hybrid exercise systems for SCI individuals. Ezenwa BN, Gigonni SF, Glaser RM, et al. In: Proceedings of the 15th Annual RESNA Conference, 1992, Toronto, ON. Washington, DC: RESNA Press, 1992:477-9.

Exercise responses and quadriplegia. Figoni SF. Med Sci Sports Exerc 1993 25(4):433-41.

Physiology of aerobic exercise: effects of physical disability. Figoni SF. In: Miller P, ed. Fitness programming and physical disability. Champaign, IL: Human Kinetics. In press.

Adapted principles of conditioning for development of physical fitness. Figoni SF, Lockette KF, Surburg PR. In: Miller P, ed. Fitness programming and physical disability. Champaign, IL: Human Kinetics. In press.

Effects of posture an arm exercise performance and cardiovascular responses of persons with quadriplegia. Figoni SF, Glaser RM, Gupta SC, Suryaprasad AG. Med Sci Sports Exerc. In press.

[390] OBJECTIVE ASSESSMENT OF SPASTICITY IN SPINAL CORD INJURY

Arthur M. Sherwood, PE, PhD; Janusz Markowski, MD; Michael Priebe, MD
Baylor College of Medicine, Houston, TX 77030

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B705-RA)*

PURPOSE—We propose to develop methods for quantitative measurement of spasticity in lower limbs of SCI subjects. This measurement is based upon the amount of activity generated during various maneuvers recorded electromyographically, in comparison with clinically used scales of spasticity (tendon reflex, plantar reflex, clonus, Ashworth and Penn spasm frequency scales).

METHODOLOGY—Surface EMG (electromyographic) electrodes are placed over major muscle groups of the lower limbs bilaterally (quadriceps, adductors, hamstrings, anterior tibial, and triceps surae muscle groups). Standardized maneuvers including reinforcement and voluntary efforts, passive limb movement and reflex elicitation are undertaken with continuous digitization of amplified EMG, position and event mark data. The envelope of activity is calculated from the full bandwidth data using an RMS algorithm, and the area under the envelope or integrated EMG (iEMG) calculated for each maneuver. Clinical and iEMG results are stored in a database for subsequent analysis.

PROGRESS—Begun in April 1993, a laboratory has been established and equipped, and data acquisition begun. To date, more than 120 data sets on more

than 45 SCI subjects and 5 healthy subjects have been collected.

RESULTS—The subjects studied demonstrated a variety of features of altered motor control. The most representative single clinical index appeared to be the Ashworth scale. Scores on the Ashworth index ranged from 0 to 4, with a median of 2 (mode 1). Similarly, subjects showed the full range of responses for the other indices used (taps 0 to 4, median and mode of 3; clonus 0 to 3, median and mode of 0; plantar reflexes 0 to 4, median and mode of 2).

In repeated (baseline) studies in 23 subjects, there was an average change of 12 percent and 21 percent for clinical and self-report scores respectively (percentage of maximum possible) and 5 percent for iEMG values (percentage of maximum observed iEMG value).

We evaluated the correlation of the various measures of spasticity obtained clinically in 85 studies, and found relatively little correlation among these measures, indicating that each scale measures a different aspect of altered motor control in these subjects. The only scores to correlate above 0.3 were plantar reflexes and taps (0.54), clonus and taps (0.66), and spasm frequency and pain (0.5).

We then examined iEMG values obtained from various components of the BMCA study across the group of subjects. We found the best correlation ($r = 0.66$) between the passive movement index which is the sum of the iEMG from bilateral hip and knee movement, and ankle movement with the total Ashworth score (right plus left scores for hip and knee movement). Individual limb correlations were almost as high (0.62 and 0.58). The iEMG from the right and left anterior tibial muscles correlated strongly with the plantar reflexes respectively (0.51 and 0.49).

The data collected to date are supportive of the importance of the iEMG values as an index of spasticity or altered motor control. The data were compared directly in spite of the known difficulties regarding interpretation of the absolute value of surface EMG amplitudes.

The initial findings suggest that for purposes of quantitating spasticity, it would not be necessary to conduct the entire protocol as currently constituted. The other elements provide information related to the severity of the lesion and patterns of motor control.

Many issues remain to be resolved. The validity and appropriateness of the clinical measures themselves are open to question. The current methods of combining clinical scores and iEMG scores are far from ideal. Nevertheless, we are optimistic that the present study will successfully resolve these issues and demonstrate the utility of this approach.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Characterization of upper motor neuron dysfunction: motor control profile. Sherwood AM. In: Proceedings of the 15th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1993, San Diego, CA; 1993:15:1227.

EMG as a measure of motor control in man: toward a basis for quantification. Sherwood AM, Eaton WJ, McKay WB, Kharas NF. In: Proceedings of the 10th International Congress of ISEK, 1994, Charleston SC. In press.

[391] DC FIELD EFFECTS ON AXONAL TRANSPORT IN THE CORTICOSPINAL TRACT FOLLOWING SPINAL CORD INJURY

Jerry A. McLane, PhD; Talat Khan, PhD

Rehabilitation Research & Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141.

Sponsor: *VA Rehabilitation Research and Development Center (Core Funds)*

PURPOSE—Unlike axons of peripheral nerves, injured axons of the adult spinal cord seldom undergo a functional regeneration. Recent studies have shown that a direct current field at the injury site enhances neurite outgrowth, and stimulates directed neurite growth. Spinal cord injury in adult rats temporarily increases the level of slow axonal transport to the higher level normally seen in young rats. The present study was designed to test the hypothesis that electrical stimulation increases

neurite regrowth by enhancing this period of increased axonal transport following spinal cord injury.

METHODOLOGY—Adult rats received a dorsal spinal cord hemisection at the T8 level. Miniature stimulators were implanted at the time of surgery with platinum disk electrodes placed extradurally proximal (anode) and distal (cathode) to the injury. Electrodes were spaced one centimeter apart. The stimulators provided a constant 15 μA of DC current. These animals received daily postoperative care.

Axonal transport in the corticospinal tract was labeled with 35S-methionine one week, five weeks, or fourteen weeks later by injecting 200 μCi of radioisotope unilaterally into the sensorimotor cortex. One week (fast transport) or three weeks (slow transport) after the isotope injection the animals were perfused with 10 percent formalin, the entire spinal cord was dissected, and the radioactivity in each 5 mm segment of the spinal cord determined by scintillation counting.

PROGRESS—We found the amount of radiolabel delivered by slow axonal transport to average 25 percent higher in the spinal cords of animals treated with electric fields. The spinal cord segment containing the injury site in the animals treated with the electric field for one week contained significantly more (154 percent) label relative to sham animals (no electrical field). This increased label at the injury site disappeared in animals treated for five or fourteen weeks.

Fast axonal transport was not altered at any time point, and therefore likely did not contribute to the increase observed in the slow transport. These data suggest that electric fields increase the slow transport of materials within the corticospinal tract, and temporarily prevent axonal die back and/or stimulate neuronal sprouting near the injury site.

FUTURE PLANS—Further studies are in progress to determine whether the normal components of slow axonal transport are altered by the electrical fields. Additionally, autoradiographic and immunocytochemical studies will be undertaken to compare the extent of neurite sprouting at the injury site in injured spinal cords with and without electrical field treatment.

[392] EFFECT OF SERINE PROTEASE INHIBITORS ON NEURITE OUTGROWTH

Jerry A. McLane, PhD; Talat Khan, PhD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141; SIBIA, La Jolla, CA 92037

Sponsor: *VA Rehabilitation Research and Development Center (Core Funds)*

PURPOSE—Protease nexin-1 (PN-1) is thought to play an important role in the normal regulation of neuronal contacts between cells by inhibiting endogenous proteases. This balance between protease and inhibitor would be lost when vascular thrombin floods into an injury site. If this flood of thrombin activity could be neutralized then regenerative processes would be enhanced.

The purpose of this study was to address the following questions: 1) How does thrombin and its inhibitors affect outgrowth of neurites from neuroblastoma cells as well as spinal cord, cortex, and DRG explants? 2) Does the tissue donor age alter the thrombin and PN-1 effects on neurite outgrowth?

METHODOLOGY—N2a neuroblastoma cells were grown on acid washed glass coverslips in MEM media containing 0.5 percent fetal bovine serum. Cells were exposed to various levels of thrombin, PN-1, hirudin, or combinations of this protease and inhibitors for 24 hours. At the end of the treatment period the cells were fixed to the coverslips with 4 percent paraformaldehyde dissolved in Hank's balanced salt solution and mounted for light microscopy. Neurite production of the cells was evaluated

using phase contrast microscopy at a final magnification of 100X. Three fields from each of three slides for each condition were scored for total cells and neurite production. A cell was scored positive if it had at least one process as long as the cell diameter.

Embryonic (E15) and neonatal (1, 14, 21 days) rat cortex, spinal cord and dorsal root ganglia (DRG) were cultured on laminin coated coverslips in DMEM/F12 media supplemented with 10 percent FBS in a 5 percent CO_2 atmosphere. Under these conditions many fibroblast-like cells migrated out of the explants and were viable for at least two weeks.

RESULTS—The experiments with neuroblastoma cells confirmed some of the reported effects of thrombin and one of its inhibitors, hirudin, on process production. Increasing concentrations of thrombin had little effect on process outgrowth unless relatively high levels (1000 ng/ml) were included in the media. Neurite formation was likely already inhibited by the thrombin endogenously in the fetal bovine serum used to make the media. When hirudin was added the production of neurites was dramatically increased in cultures with no added thrombin as well as in cultures with 10 ng/ml purified thrombin added. Addition of 100 ng/ml of thrombin to the media containing hirudin prevented the stimulation of outgrowth. PN-1 alone was unable to stimulate neurite outgrowth. PN-1 required the presence of active thrombin in the culture media in order to enhance the production of neurites in this cell line.

PROGRESS—Embryonic explants produced neurites over a period of 3-7 days. High concentrations of thrombin added to culture media prevented attachment of most explants. Addition of 1 U/ml of thrombin reduced the number and length of processes, but did not affect the migration of non-neuronal cells out of the explants. Addition of excess PN-1 to the cultures did not reverse the thrombin effects. The media contained low levels of protease activity, coming from the FBS, which was not totally inhibited by PN-1. Explants from neonatal rats were less likely to produce neurites, and the presence of PN-1 had no effect. We observed that while addition of PN-1 to explant cultures containing no added thrombin did not noticeably affect neurite production and length, it enhances the migration of non-neuronal cells from the explant. Conversely, a high concentration of thrombin was required to inhibit this cell migration. This suggests that thrombin or another serine protease may be involved in the migration mechanisms.

[393] CARBOHYDRATE METABOLISM AND CARDIOVASCULAR RISK FACTORS IN PERSONS WITH SPINAL CORD INJURY

Kevin Maki, MS; Mahmood Sam, MD; Bernard A. Nemchausky, MD; W. Edwin Langbein, PhD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—Several investigators have reported that persons with chronic SCI often show disturbances of glucose and lipid metabolism which may increase their risk of developing atherosclerotic cardiovascular disease (CVD) and non-insulin-dependent diabetes mellitus (NIDDM). A limited number of studies have reported increased morbidity and/or mortality from CVD in persons with SCI. Moreover, a recent cross sectional study of 100 veterans with SCI found impaired glucose tolerance or frank NIDDM in 46 percent of persons with paraplegia and 68 percent of those with quadriplegia. Thus, research to assess the determinants of glucose tolerance and CVD risk is needed in persons with SCI so that potential targets for intervention may be identified. This will aid in the design of strategies aimed toward the prevention of NIDDM and CVD in this group.

The present investigation has been designed to compare parameters of carbohydrate metabolism and selected cardiovascular risk factors in persons with and without SCI who are matched as closely as possible for sex, age and activity level. The specific goal of the study is to determine whether persons with SCI display abnormalities of carbohydrate and

lipid metabolism after correction for abdominal circumference as a proxy for total and abdominal adiposity.

PROGRESS—A full grant proposal has been submitted for review by the Paralyzed Veterans of America Spinal Cord Research Foundation. We are currently collecting pilot data while awaiting a response from the funding agency.

METHODOLOGY—Carbohydrate metabolism will be studied using the minimal model method. This requires a frequently sampled intravenous glucose tolerance test (FSIGTT) modified to include injection of insulin or tolbutamide 20 min after glucose injection. Glucose and insulin concentrations from the 180 min FSIGTT are entered into the MINMOD (© RN Bergman) computer program which generates an index of insulin sensitivity (Si) and an index of glucose effectiveness (insulin-independent glucose disappearance or Sg). A fasting lipid profile and various anthropometric measurements will also be collected.

RESULTS—Eighteen FSIGTTs have been completed; 10 on men with SCI and eight on control subjects. No between group differences were found in the glucose tolerance value or lipoprotein lipids. More than 50 percent of the variance in Si ($P<0.01$) could be explained by abdominal circumference. After taking this variable into account, only 3 percent of the variance in Si ($P>0.10$) could be explained by the SCI status (present vs. absent). Unexpectedly, a significantly increased Sg (52 percent, $P<0.01$) was noted in the SCI group. These associations support the hypothesis that increased adiposity contributes to the adverse metabolic changes commonly found in persons with SCI.

FUTURE PLANS—It is anticipated that the information obtained from this and other studies currently underway in our laboratory will provide information necessary for the design and testing of rehabilitative strategies aimed at reducing long-term NIDDM and CVD risk in this population.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Comparison between bioelectrical impedance and near infrared interactance for assessing body composition in persons with spinal cord injury. Maki KC, Briones ER, Langbein WE, et al. J Am Coll Nutr (Abstract) 1993:12:616.

Insulin sensitivity and serum lipids in lean men with SCI (abstr). Maki KC, Sam M, Nemchausky BA, Langbein WE, Orebaugh C. J Am Paraplegia Soc (Abstract) In press.

[394] EFFECT OF SUPPORTED STANDING AND UPPER BODY EXERCISE ON LOWER EXTREMITY SPASTICITY IN PERSONS WITH SPINAL CORD INJURY

Linda S. Fehr, MS; Morris A. Fisher, MD; W. Edwin Langbein, PhD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—The purpose of this research is threefold: 1) to demonstrate that supported standing and/or aerobic upper body exercise (UBX) significantly alter signs of the upper motor neuron syndrome (UMNS), particularly lower extremity tone and reflexes, in patients with spinal cord injury (SCI); 2) to analyze neurophysiological measures indicative of altered motor neuron pool excitability and/or presynaptic inhibition and define the relationship between these measures and changes in signs of the UMNS following UBX or standing; and 3) to use electrophysiological measurements to explain the pathophysiology of specific aspects of UMNS.

PROGRESS—Electrogoniometers for the pendulum drop test (PDT) were interfaced to an IBM-compatible computer which calibrates and samples electrogoniometers and calculates normalized relaxation index (R2n). Protocols and computer software for measurement of ankle compliance were developed. A wheelchair ergometer was built and cali-

brated; exercise test protocols were developed (Rehabilitation R&D grant B398-RZ).

Based on 1991 preliminary evidence, an experimental protocol was developed and applied to three SCI and two neurologically intact (NI) subjects.

METHODOLOGY—To measure peak UBX aerobic capacity, subjects complete maximal wheelchair ergometry (WCE) exercise tests. Subjects complete (random order) three experimental procedures: 1) to test the effect of moderate aerobic UBX on signs of the UMNS, subjects engage in 20 minutes of submaximal WCE exercise; 2) to examine the effect of low intensity activity on signs of the UMNS, subjects engage in 30 minutes of supported standing; 3) to isolate the effects of low and moderate physical activity on tone and reflexes from changes which occur in response to normal activity and to the testing procedure itself, a timeout (control condition) is included.

Measurements of tone and reflexes (PDT, ankle compliance, neurophysiological recordings) are followed immediately by one of the experimental conditions. To examine the temporal pattern of changes in tone and reflexes following the experimental condition, all measurements are repeated immediately following the activity or timeout and at 90 minute intervals for 3 hours.

PDT-electrogoniometers are strapped laterally to each knee. The legs are alternately lifted to a horizontal position, dropped, and allowed to swing freely about the knee. R2n (normalized ratio of the angular deflections of the limb in each direction from its final resting position) is computed. Ankle compliance perturbations are applied to the foot via a torque motor while a computer measures displacement, acceleration and torque. The stiffness coefficient is estimated from the linear second order model ($t = Jq + Bq + Kq$).

H/M ratios and F-waves are used to assess motoneuron pool excitability. Stimulation is applied to the tibial nerve. The suppressive effect of vibration on the H reflex is measured.

RESULTS—Pilot data suggest that exercise is associated with decreases in tone and physiological changes at the segmental spinal cord level which can last for at least three hours.

Based on mean R2n, all SCI subjects experienced the same or greater improvement in tone immediately following UBX as they did following timeout. Improvements in tone 1-3 hours later for 2 subjects were substantially greater with exercise than without it (42-67 percent vs. 7-15 percent). Tone was diminished in NI subjects immediately post exercise; R2n values for one remained more or less elevated over the testing period. Based on "initial drop R2n," improvement among SCI subjects following exercise was consistently and substantially greater than after timeout (33-104 percent vs. $\leq$22 percent).

In one SCI subject, ankle stiffness normalized immediately post exercise and remained so for most of the session. In another, substantial normalization of stiffness appeared with a delay of about 2 hours.

All 3 SCI subjects exhibited substantial reductions in the H/M ratio (22-27 percent) immediately following UBX. Reductions $\geq$15 percent persisted for at least 2 hours. No reductions of that magnitude were observed following timeout. Exercise had no definite influence on the suppressive effect of vibration in the SCI subjects but increased it in the NI subjects, consistent with increased presynaptic inhibition.

In 4 of 5 subjects, pre-exercise F-waves could not be elicited or were present with abnormally low persistence. After exercise, at least some F-waves could be identified, consistent with decreasing patterns of recurrent inhibition.

FUTURE PLANS—Merit review proposal B94-744A has been submitted in support of a 2-year study.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Physiologic analyses of lower extremity muscle tone with upper extremity exercise. Fisher MA, Fehr L, Langbein WE, Itkin A, Sibley P. In: Proceedings of the AAEM Annual Scientific Meeting, 1994.

[395] SODIUM PUMP EXPRESSION IN SPINAL CORD TRAUMA: A PILOT STUDY

Scott Sayers, PhD; Talat Khan, PhD; George J. Siegel, MD; Michael Dauzvardis, PhD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—Trauma to the spinal cord produces complex biochemical and physiologic changes including edema, altered cellular permeability, blood-brain barrier changes, and alterations in other functions dependent on cation transport. (Na,K)-ATPase is the membrane-bound enzyme that produces active cation transport, and is responsible for maintenance of the resting membrane potential. The aim of the proposed project is to test the hypothesis that impact trauma to the spinal cord produces altered cation transport function manifested by altered expression of specific (Na, K)-ATPase catalytic subunit isoforms. Better understanding of the cellular changes that lead to degenerative changes after trauma will help in the development of methods to prevent these changes and aid in restoring function.

METHODOLOGY—The spinal cords of 5 anesthetized young adult rats were rapidly harvested and divided into five sections each; Section 1 (C1-C8), Section 2 (T1-T4), Section 3 (T5-T8), Section 4 (T9-T13), and Section 5 (L1-L5). Total RNA from each section was isolated, the RNA was slot-blotted onto membranes, and hybridized with ^{32}P-labeled riboprobe transcribed from the cDNA clone which codes for the alpha 1 isoform of (Na,K)-ATPase. The membranes were washed, subjected to autoradiography, the autoradiographs were scanned, linear regression lines were plotted, and the slopes of the lines were compared.

Additional rats of the same age were anesthetized and perfused intracardially. The spinal cords were removed, divided into five sections, and then 10μm thick transverse sections were cut from sections 1, 3 and 5. These sections were hybridized with ^{35}S-labeled riboprobe, washed, dipped in Kodak NTB-2 emulsion, and then subjected to autoradiography.

PROGRESS—(Na,K)-ATPase alpha 1 isoform mRNA levels were measured from five levels of the rat spinal cord in order to obtain baseline data on normal spinal cord.

RESULTS—The amount of total RNA/g of tissue varied in the five different spinal cord sections. After normalizing for the total μg of RNA, the alpha 1 mRNA levels were also found to vary. Assigning a value of 1 to the slope obtained from Section 1, Section 2 was 2.6 times higher, Section 3 was 4.5 times higher, Section 4 was 2.6 times higher, and Section 5 was 1.7 times higher. Our results show that alpha 1 mRNA levels are highest in the mid-thoracic level (T5-T8).

Our autoradiographic results obtained from *in situ* hybridization studies showed that alpha 1 isoform mRNA was diffusely abundant in glial and central canal ependymal cells, while labeled neurons were localized exclusively in laterally located anterior horn neurons in cervical, thoracic and lumbar segments and in ventromedial neurons in mid-thoracic spinal cord. Dorsal root ganglia neurons were also extensively labeled at all segments.

Alpha 1 isoform mRNA was also found in the microvasculature of the spinal cord. Our preliminary results show that most of the capillaries in the spinal cord gray and white matter were labeled. Due to the limitation of resolution of the microscope, it is very difficult to distinguish whether labeling is in the endothelium, pericyte or astrocytic end-feet around the microvessels.

FUTURE PLANS—Presently, the physiological significance of the three different isoforms of the (Na,K)-ATPase alpha subunits are not known. It may be possible that each isoform is specially adapted for a specific regulatory function in different cell types. Our next objective is to measure alpha 1, alpha 2, and alpha 3 mRNA levels in the spinal cord of contused rats at various time periods after injury and to correlate these changes with the progression of primary and secondary pathologic changes.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Regional distribution of alpha 1 subunit isoform of (Na,K)-ATPase in the rat spinal cord. Sayers S, Shahid R, Dauzvardis M, et al. Abstr Soc Neurosci 1992:18:1334.

Localization of alpha 1 isoform of (Na,K)-ATPase in spinal cord microvasculature by *in situ* hybridization. Sayers ST, Khan T, Siegel GJ, Chauhan NB, Dauzvardis MF. Abstr Soc Neurosci 1993:19:899.

Distribution of alpha 1 subunit isoform of (Na,K)-ATPase in rat spinal cord. Sayers ST, Khan T, Shahid R, Dauzvardis MF, Siegel GJ. Neurochem Res 1994:19:597-602.

[396] UNDERSTANDING LEISURE BEHAVIOR OF PEOPLE WITH SPINAL CORD INJURY

Douglas A. Kleiber, PhD; John Dattilo, PhD
Department of Recreation and Leisure Studies, The University of Georgia, Athens, GA 30602

Sponser: *American Association of Spinal Cord Injury Psychologists and Social Workers*

PURPOSE—In spite of the fact that leisure plays a significant role in the lives of all people, remarkably little is known about the leisure behavior of people with spinal cord injury (SCI). There is a need for research examining the ways in which people with SCI successfully or unsuccessfully achieve a meaningful leisure lifestyle. To address this need, the following research questions will be addressed by this project: 1) how does SCI affect leisure behavior? 2) how do people with SCI adjust to leisure? 3) how do changes in leisure experience (pre to post trauma) effect the rehabilitation process? 4) how has the therapeutic recreation intervention process influenced people with SCI to experience leisure? and 5) how do people who have received therapeutic recreation services experience leisure in the community?

METHODOLOGY—To effectively answer these questions, the following objectives were established: 1) conduct first phase systematic data collection within the inpatient setting through participant observations and in-depth interviewing to answer research questions #1-4; 2) conduct second phase systematic data collection after informants are discharged, and execute participant observations and in-depth interviews within the community setting to answer research question #5; and 3) develop documents and presentations summarizing research findings.

To achieve these goals, the project staff will employ a qualitative case study method. Using various qualitative methods (e.g., participant observation, in-depth interviewing), investigators will effectively capture what respondents say in their own words with regard to their level of emotion, the way in which they have organized their world, their thoughts about what is happening, their experiences, and their basic perceptions. The rationale for using qualitative methods in this project is that they are very effective in revealing previously unknown phenomena.

In this project, investigators will employ participant observations, in-depth interviews, and document analysis. In the first phase, the Project Director (PD) will assume a participant-as-observer role at the Shepherd Spinal Center (SSC) and at various recreation programs occurring outside of SSC (e.g., movies, dinners, swimming). Further, the PD will record data continuously via field notes, using a small notebook to reflect actions, interactions, and dialogues occurring before, during, and after activities. In addition, informal interviews, through casual conversation with informants, will be made to collect data. The PD will gather and analyze official documents (i.e., clinical record, program sheets, progress notes) and unofficial documents (letters, notes, diaries, photo-albums, music records). In-depth interviewing will be conducted with informants selected through theoretical and negative case sampling.

Several main concepts generated from the participant observation will be explored with the informants prior to being discharged. With the participant's permission, interviews will be tape recorded for later transcription. The second phase will focus on the time period after informants are discharged as they re-enter their communities. Semi-

structured interviews will occur with some informants (selected from a theoretical sampling) to examine leisure experiences in the community. Participant observation will occur whenever necessary. Data will be analyzed using the Constant Comparative Method. All project staff will be involved in the process of analyzing data. Results of the investigation will be disseminated.

[397] RETURN TO PRODUCTIVITY, ON YOUR MARK, PROJECT INCUBATOR, BRIDGE: FOUR EMPLOYMENT DEMONSTRATION PROJECTS

Ann Temkin, MA, ACSW; Maribeth Abrams, MS, CRC; Sally Atwell, MS, LPC, CRC; Karen Dorrough, NMEd; Charlotte Gunter, MHS; Cheryl Simpson, BS; Frances Whitaker, MS, CRC
Clinical Research, Shepherd Spinal Center, Atlanta, GA 30309

Sponsor: *Dole Foundation; Woodward Foundation; Metropolitan Atlanta Community Foundation; Mauldin Foundation; Georgia Pacific Company; Atlanta Foundation; Nordson Corporation*

PURPOSE—The following programs are all offered through Career Planning and Placement, the vocational services program of Shepherd Spinal Center. All programs are founded on the relational model: people and resources coming together for mutual benefit.

Return to Productivity is a mini course which teaches problem solving and goal setting skills to persons with spinal cord injury (SCI) who desire employment. Originally developed for inpatients in 1989, this course is now available to persons living in the community with spinal cord injury.

On Your Mark is a workshop for employers and unemployed and employed persons with SCI which has been offered annually since 1990. The workshop creates an informal setting in which employers, successfully employed, and job seekers meet each others as persons. The workshop has contributed both directly and in various indirect ways to the employment of persons with SCI in the competitive job market.

Project Incubator is an innovative program of paid internships for persons with SCI who are qualified for careers in the competitive labor market but lack the work experience generally necessary for hiring. Internships are in the individual's chosen field and in a setting comparable to that in which he/she would prefers to become employed. Approximately 18 months into the program, 51 persons attended the initial informational meeting; the poster presents the employment status of these persons.

Project Bridge is designed specifically to meet the needs of middle aged persons with SCI. The project was developed because the employment statistics among this population are lower than among younger person with SCI, because persons over 40 have seldom participated in intensive employment programs, either because their injury predated these programs, or because they elected not to participate. New ways of reaching these persons are being developed with the invaluable assistance of an Advisory Board of productive persons who represent the same age group and injury levels.

[398] QUANTIFICATION OF SPASTICITY BY PENDULUM TEST AND EMG ACTIVITY ANALYSIS

Maurizio Ferrarin, PhD; Carlo Frigo; Giuseppe Abello, DrEng; Antonio Pedotti
Centro di Bioingegneria, Fnd. Pro Juventute IRCCS, Politecnico di Milano, Milano, Italy

Sponsor: *Italian Ministry for University and Scientific Research; Italian National Research Council*

PURPOSE—The aim of this study is to develop an automatic procedure for quantifying spasticity of knee joint muscles, to apply it to healthy subject and paraplegic patients and to compare results with data

coming from clinical and neurophysiological tests performed on the same patients. One application will be the assessment of the modification induced by electrical stimulation (ES) on spasticity level of Spinal Cord Injury (SCI) patients.

METHODOLOGY—A combined kinematic and EMG analysis has been implemented using respectively an ELITE system and an Electromyograph. Passive markers are glued on reference points on the lower limb to detect angular displacement of knee joint during passive pendular movement and simultaneously surface EMG signals are recorded from rectus femoris, biceps femoris and semimembranous muscles. A dedicated software has been implemented to compute the relaxation index (RI) and the angular velocity threshold (AVT) of stretch reflex both in extensor and flexor muscles. Moreover the length of muscle during pendular movement is estimated through a muscolo-skeletal modelization allowing more parameters to be computed (LRI-length relaxation index and LVT-lengthening velocity threshold). These parameters are computed for all trials of an experimental session (10 trials for each leg). Trends, graphs, and average values (with standard deviation) are also computed for each parameter.

RESULTS—Control acquisition has been performed on 5 healthy subjects and results show high repeatability and good correlation with data taken from literature. The procedure has been applied also on 4 paraplegic patients with complete lesion at thoracic level. Despite differences due to individual characteristics, the results are consistent with clinical and neurophysiological evaluations of proprioceptive responses (H and M threshold, H/M ratio, H vibratory inhibition). Particularly interesting is the high level of correlation between the biomechanical index (RI, LRI) and the EMGbased index (AVT, LVT). Once the spasticity level has been quantified, it is possible to follow the modifications induced by pharmacological treatment and/or ES treatment, as in SCI patients under our analysis.

FUTURE PLANS—We plan to go further in data acquisition on healthy subjects (to have more consistent reference values) and on different kinds of pathology involving spastic behaviour (hemiplegia, cerebral palsy, etc.). Furthermore, we are going to consider more complex data elaborations such as the dynamic evaluation of joint moment and power, to correlate them with EMG activity.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Assessment of spasticity by an integrated system for the analysis of pendular motion and EMG activity. Ferrarin M, Frigo C, Osio M, et al. In: Proceedings of the XIII International Congress of EEG and Clinical Neurophysiology; Vancouver, Canada, 1993; Electroenchephalogr Clin Neurophysiol 1993:87(2):S66.

[399] THE DEVELOPMENT OF AN INSTRUMENT TO PREDICT COMPLIANCE WITH SELF-CARE BEHAVIORS IN A SPINAL CORD-INJURED POPULATION USING THE THEORY OF REASONED ACTION

Gail Drescher, MA, BS, RRT
National Rehabilitation Hospital, Washington, DC 20010

Sponsor: *National Rehabilitation Hospital, Washington, DC 20010; University of Maryland at College Park, College Park, MD 20740*

PURPOSE—This research used the Theory of Planned Behavior (TPB) to begin the process of predicting adherence with self-care behavior in a spinal cord injured population. The purpose of this research was to develop a reliable and valid instrument to measure the model's constructs.

METHODOLOGY—Three samples of paraplegic and quadriplegic subjects were recruited to participate. The first sample (n = 31) was given an open-ended elicitation questionnaire by telcphone to determine their salient beliefs about bladder and skin care. These beliefs were used to develop a

closed-ended questionnaire. This draft was then given to two expert panels: one to determine content validity (n = 8), and the other to determine theory construct and psychometric appropriateness (n = 3). Due to excessive length, the resulting draft of the questionnaire only contained questions about skin care. This draft was pilot tested by a second group of subjects (n = 5) in person for readability and acceptability. The final draft was completed by a third sample (n = 26) to obtain measures of reliability and the predictive ability of the model's constructs.

PROGRESS—A final draft of the closed-ended questionnaire for pressure relief performance was completed.

RESULTS—The questionnaire had a reliability coefficient of 0.89, and subscale coefficients ranged from 0.67 to 0.87. Step-wise regression analyses were performed for each intention item. Behavior beliefs accounted for 16 percent of the variance in intentions to perform pressure reliefs; attitudes accounted for 30 percent of the variance in turning in bed; and outcomes and perceived behavioral control accounted for 43 percent of the variance in using special equipment. Thus, these initial analyses indicate the questionnaire is a reliable and valid instrument for measuring intentions to perform skin care.

FUTURE PLANS—Data will be collected to obtain reliability and validity measures on the bladder care questionnaire. All research will be submitted for publication when complete.

[400] IMMUNE RESPONSES TO PNEUMOCOCCAL VACCINE IN SPINAL CORD INJURY

K.B. Waites, MD
University of Alabama at Birmingham, Birmingham, AL 35233

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Pulmonary complications, with pneumonia being the most frequent, are a major cause of both morbidity and mortality in persons with spinal cord injury (SCI). Both bacterial and viral immunizations have been recommended to prevent infectious pulmonary complications in patients with neuromuscular disorders producing mechanical dysfunctions of the respiratory system. Although patients with SCI, particularly those with quadriplegia and high paraplegia, have been shown to be at increased risk for the development of serious pulmonary complications, including pneumonia, we are unaware of any studies documenting the efficacy of either bacterial or viral immunizations to reduce the incidence of pulmonary complications in the population with SCI.

Objectives of this study are to document changes in immunologically-related laboratory values of patients vaccinated at varying intervals after spinal cord injury; and to compare the incidence in a series of patients with SCI vaccinated at varying times following injury.

METHODOLOGY—This study entails random assignment of SCI patients into one of 4 groups following their entry into the University of Alabama at Birmingham (UAB) Hospital care system. Groups 1 and 2 will receive the vaccine or placebo at 17 days (± 24 hours) of injury. Groups 3 and 4 will receive the vaccine or placebo at 4-6 months post injury. The groups for which a patient is eligible to be randomized as a subject (to receive vaccine) or control (to receive placebo) are determined according to the time at which the patient is admitted to the UAB Hospital or Spain Rehabilitation Center. Following enrollment, blood samples are collected on four separate occasions: the first at the time of vaccination or administration of placebo, the second one month later, the third two months post vaccination, and the fourth at one year following enrollment.

Laboratory tests performed at each blood sampling interval include: anti-pneumococcal antibody titers to four major representative serotypes, quantitative immunoglobulins, complete blood count with

differential leukocyte count, liver profile, total serum protein and albumin. Subjects and controls are monitored during their initial hospitalization for the occurrence of respiratory or other systemic complications of pneumococcal disease. Appropriate microbiological and/or immunological diagnostic procedures are implemented whenever possible to determine whether or not such complications are indeed due to infection with Streptococcus pneumoniae.

PROGRESS—*Changes in Plan.* Recent developments in the acute care of persons with SCI made it necessary to alter the study design and eliminate the group immunized immediately post injury. SCI patients are currently getting short term high dose steroids very soon after injury in an attempt to improve neurological outcome. Steroid presence negates the immunogenicity of the pneumococcal vaccine unless at least two weeks elapse prior to immunization. Therefore, there will be no groups vaccinated at 72 hours. Groups 1 and 2 will receive vaccine/placebo at 17 days and Groups 3 and 4 will receive vaccine/placebo at 6 months postinjury.

Preliminary Data. Data collection instruments and accompanying syllabus have been completed and are in use. Subject identification, enrollment, administration of vaccine or placebo, follow-up and collection of blood samples are underway. As of December 1993, 104 eligible persons have been asked to participate. Of these, 61 have been enrolled and 43 refused.

FUTURE PLANS—Plans are to continue enrollment and follow-up at the present rate. Antibody levels will be determined in batches with all four samples from each person assayed at the same time after collection of the 12-month specimen. All laboratory data and pulmonary complications are being recorded and entered into the computer database. Preliminary antibody determinations and analysis of laboratory and clinical data will be conducted after 50 persons have completed the study to discern whether significant trends are present or whether protocol changes are necessary.

Enrollment will continue until December 1994. Follow-up data collection will continue until December 1995. The final six months will be used to perform antibody and bactericidal assays, analyze results and disseminate findings.

[401] NATURAL HISTORY AND CLINICAL COURSE OF URINARY TRACT COMPLICATIONS IN PATIENTS WITH SPINAL CORD DYSFUNCTION

Samuel L. Stover, MD; L.K. Lloyd, MD
University of Alabama at Birmingham, Birmingham, AL 35233

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Analyzing a spectrum of urologic data acquired from a large number of persons with spinal cord injury (SCI) will help clinicians understand the natural history of the urinary tract and its complications following SCI, thus helping clinicians select those prevention and management methods capable of assuring the most positive progress.

The objectives of this study include 1) documenting the natural history and clinical course of urinary tract complications among persons with SCI, 2) answering specific research questions addressing the effects of various bladder drainage management methods, various bacterial pathogens, and various demographic factors, and 3) developing, refining, and offering for extramural acquisition a transportable urologic complication data collection protocol and its associated database.

METHODOLOGY—Data are collected prospectively for each patient admitted to the UAB-Spinal Cord Injury Care System (UAB-SCICS) at admission, discharge, and annually thereafter. In addition data have been collected retrospectively from chart reviews on 596 patients between January 1970 and April 1979. Since 1979, persons who were enrolled retrospectively have been followed prospectively along with the more recently injured persons. Persons constituting the prospective study group (n = 1402) were injured and admitted between May 1979 and December 1993. The latter group will

continue to grow in size as the project continues. Overall, 1,986 persons have been entered into the project database, although not every record has been retained. Data from 269 persons in the retrospective study group and 253 persons in the prospective study group have been purged from the database because of inadequate follow-up information. Nonetheless, complete data have been collected on 327 persons from the retrospective study group and 1,150 persons from the prospective group, yielding a total of 1,477 persons with usable data in the database.

RESULTS—This database is frequently used to provide data for other research projects within the scope of this RRTC. The project has directly or indirectly led to the publication of one book, 10 book chapters, 10 peer-reviewed journal articles, three other publications in Proceedings, and 11 other abstracts in leading medical journals. There have been 24 presentations at scientific meetings of professional societies and organizations.

The database is now available on computer software and contains quality control computer programs that cross-check the data for out of range entries and internal consistency. This will increase opportunities to compare data among users since variable definitions and methods of collection will be the same.

FUTURE PLANS—This project will continue during the next five years. Research questions which may be addressed during the next project year include: 1) What are the effects of various bladder drainage management methods on long-term renal function in persons with SCI? 2) How do the various methods of bladder drainage management either prevent or lead to urologic complications? 3) How does the level and extent of SCI affect the development of urologic complications?

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Bladder management in women. Jackson AB. In: Stover SL, Lloyd LK, eds. Neurogenic bladder. Phys Med Rehabil Clinics North Am 1993:321-328.

Epidemiology and risk factors for urinary tract infection following spinal cord injury. Waites KB, Canupp KC, DeVivo MJ. Arch Phys Med Rehabil 1993:74(7):691-695.

Long-term follow-up of neurogenic bladder. Lloyd LK. In: Stover SL, Lloyd LK, eds. Neurogenic bladder. Phys Med Rehabil Clinics North Am 1993:391-409.

Neurogenic bladder. Stover SL, Lloyd LK, eds. Phys Med Rehabil Clinics of North Am. Vol. 4. Philadelphia: Saunders, 1993.

[402] COLLABORATION BETWEEN MEDICAL REHABILITATION PROGRAMS AND INDEPENDENT LIVING CENTERS IN FACILITATING INDEPENDENT LIVING BY PERSONS WITH RECENTLY INCURRED SPINAL CORD INJURY

Margaret A. Nosek, PhD; C. Don Rossi, MS
ILRU Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—During the period immediately after discharge from a medical rehabilitation program, health maintenance and independent living skills taught during hospitalization must be put into practice, and adjustment problems must be resolved that could not be prepared for adequately during hospitalization. Yet knowledgeable assistance is difficult to obtain on a timely, affordable basis during the post-discharge period. Independent living centers (ILC) can provide vital services in facilitating transition of the individual with a recently incurred spinal cord injury from hospital-based rehabilitation to an independent, productive, life in the community. Differences in program philosophy and style of service delivery, however, may make it difficult for medical rehabilitation programs and independent living services to work together effectively. This project is designed to develop, implement, and systematically evaluate a cooperative re-entry program involving a medical rehabilitation program and an ILC for facilitating the post-hospitalization life adjustment of persons

with recently incurred, ventilator-dependent spinal cord injury.

PROGRESS—Thirty subjects with quadriplegia have been selected from a database of ventilator users kept at the Institute for Rehabilitation and Research (TIRR), while another 30 who do not use ventilators have been selected from a spinal cord injury registry to serve as matched controls. They are being interviewed about issues they faced re-entering the community after hospitalization for rehabilitation and the extent two which HCIL assisted them with that process.

FUTURE PLANS—Data from the interviews will be analyzed and the results will be used to create a coordinated, comprehensive discharge program between TIRR and HCIL incorporating factors that persons with spinal cord injury found to be the most useful in re-entering the community with severe disability.

[403] ADAPTIVE NOISE CANCELLATION APPLIED TO SPINAL CORD MONITORING

D.F. Lovely
Institute of Biomedical Engineering, University of New Brunswick, Fredericton, NB E3B 5A3

Sponsor: *Natural Science and Engineering Research Council*

PURPOSE—During surgery on the spine, a system for monitoring spinal integrity is becoming increasingly important to prevent subsequent neurological complications. This research is targeted toward the development of a non-invasive system which monitors spinal somatosensory evoked potentials (SSEPs) during the surgical procedure. However, this technique is limited by the high level of background noise associated with the measurement.

PROGRESS—Initially, it was thought that the non-white nature of the noise contaminating the surface recorded SEP signals was due to myoelectric (ME) activity. Consequently, attempts were made to employ adaptive noise cancellation techniques to improve the signal to noise ratio.

RESULTS—In practice this proved difficult due to both crosstalk between primary and reference channels and the limited ME correlation. After further study into the noise components present in a surface recorded signal, it was found that ECG activity is more prevalent than ME. Consequently, attention is now being focused on ECG cancellation.

FUTURE PLANS—At present work is underway to remove ECG contamination from surface recorded SEP signals using adaptive noise cancelling. This is being implemented with a TMS320C25 digital signal processor.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Reduction of myoelectric noise in surface recorded spinal somatosensory evoked potentials by adaptive noise cancelling. Harrison SAB, Lovely DF. In: Proceedings of the 19th Canadian Medical & Biological Engineering Conference (CMBEC), 1993, Ottawa, ON.

[404] KEYREP: KEYBOARD RATE ENHANCEMENT PACKAGE

Tom Nantais, BASc; Fraser Shein, MEng, PEng; Gil Hamann, MASc, PEng; Morris Milner, PhD, PEng, CCE
Microcomputer Applications Programme, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsors: *The Ontario Rehabilitation Technology Consortium funded by the Ontario Ministry of Health; IBM Canada Ltd; IBM Corporation; University Research Incentive Fund of the Ontario Ministry of Colleges and Universities; National Research Council of Canada*

PURPOSE—The purpose of the KeyREP is to increase typing efficiency of users of keyboard users of Windows 3.1. Typing is relatively slow when using a single finger or stylus to type. Although

macro keys may be defined, large user vocabularies make it impractical to include entire vocabularies as macro keys.

METHODOLOGY—Predicted words are displayed in a floating window. Words are selected and entered into the current application by typing a number key.

PROGRESS—KeyREP (Version 1.0), released in July 1993, offers rate enhancement for regular keyboard users of Windows 3.1. It provides the same powerful word prediction and abbreviation-expansion features in WiViK 2 REP. KeyREP works with any computer keyboard and any Windows application.

Both KeyREP and WiViK 2 REP handle punctuation intelligently. Spaces are automatically added after predicted words. Punctuation characters selected after predicted words are positioned correctly and a space is automatically added when appropriate. In addition, following a period, question mark, or exclamation mark, the next letter typed is capitalized to begin the next sentence.

RECENT PUBLICATION RESULTING FROM THIS RESEARCH

Predictive selection technique for single-digit typists. Nantais T, Shein F, Treviranus J. IEEE Trans Rehabil Eng. In press.

[405] CARDIORESPIRATORY RESPONSES TO EXERCISE TESTING IN ACUTE SPINAL CORD INDIVIDUALS

Sarah A. Morrison, PT; Sandee L. Melton, PT
Shepherd Spinal Center, Physical Therapy Department, Atlanta, GA 30309

Sponsor: *U.S. Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—The purpose of this longitudinal study was to evaluate cardiorespiratory responses to a maximal ergometer exercise test using a discontinuous, progressive protocol.

METHODOLOGY—Subjects were 110 acute hospitalized spinal cord injured individuals (approximate age = 29), with injury levels of C6 and below. A two-way ANOVA with repeated measures was performed comparing quadriplegics and paraplegics with variables across 3 tests: 1) within 2-4 weeks of admission (ADM), 2) at discharge (DC) and 3) 8 weeks after discharge (8 wk).

RESULTS—Significant differences ($\rho < 0.05$) in heart rate (HR) response, peak oxygen uptake (VO_2), peak blood pressure (BP) and wheelchair (WC) propulsion were found between ADM and DC. In general, changes seen at DC were maintained through the 8 wk. Peak VO_2 was significantly different at DC (12.8 ml/kg/min) than at ADM (10.2 ml/kg/min) with no significant difference between DC and 8 wk. At comparable workloads, quadriplegics reached submaximal HR of 133 bpm initially, decreasing to 107 bpm at DC and increasing to 109 at 8 wk. Paraplegics showed an initial submaximal HR response of 149 bpm, 139 bpm at DC and 127 bpm at 8 wk. Peak blood pressure showed significant changes between ADM and DC and between DC and 8 wk.

There appeared to be greater variability of blood pressure between test periods with the quadriplegics than the paraplegics, possibly due to the compromise to their autonomic nervous system. Improvements across all groups were seen in their WC push time over a constant distance at DC ($F = 19.3$, $P = 0.000$), with the activity being perceived as easier by DC. No significant change was noted between DC and 8 wk.

IMPLICATIONS—These and other findings on fitness and functional parameters have significant implication on the importance of spinal cord injury rehabilitation in improving fitness levels. Based on a relatively large group of patients, these results suggest that activities of daily living may help to maintain the cardiorespiratory capacity achieved during acute rehabilitation.

[406] SPINAL CORD INJURY OCCURRING IN PATIENTS WITH ANKYLOSING SPONDYLITIS: A MULTICENTER STUDY

David F. Apple, Jr., MD; Carol Anson, PhD
Clinical Research Department, Shepherd Spinal Center, Atlanta, GA 30309

Sponsor: *U.S. Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—Ankylosing spondylitis (AS), also known as Marie-Strumpell's disease, is the third most common form of chronic arthritis in the United States. Spine involvement is characterized by a progressive inflammatory process which ultimately leads to calcification of the longitudinal ligaments and the disc spaces. As the disease process matures and the patient ages, the spine is very susceptible to fracture, even with minor trauma, particularly in the cervical region. To assess the appropriate management of patients with fractures due to spondylitic spines, a study was developed involving eight of the model spinal cord injury systems.

METHODOLOGY—The study evaluated 59 patients, 22 managed operatively, and 37 non-operatively. The two groups were compared on neurologic outcome, complications, mortality and length of stay.

RESULTS—The results indicated that patients in the non-operative group had a signifi-cantly shorter length of stay, and, therefore, a significantly lower cost of care. Surgical patients spent much more time in acute care (80 vs. 35 days), suggesting that surgery and the associated recovery time may increase both acute and total length of stay by several weeks. No other differences between operative and non-operative groups were identified in regard to other outcome variables. Results of descriptive analyses of patient characteristics and treatment choices have significant implications for practitioners. Most importantly, the results indicate that until research in the area can demonstrate clear advantages to new techniques in operative management, a non-surgical approach appears to be in the best interests of most patients.

[407] HAND GRIP ASSISTIVE DEVICE ALLOWS QUADRIPLEGICS TO PLAY TENNIS

Jennifer Colborne; Ivan Samila; Patti Longmuir
Variety Village, Scarborough, ON M1N 2G2 Canada; One Step Beyond, Richmond Hill, ON L4C 4C3 Canada

Sponsor: *Variety: The Children's Charity*

PURPOSE—Wheelchair tennis is an exciting, fast-growing sport for both amateurs and professionals. Individuals with limited hand grip function (e.g., quadriplegia) are able to play tennis using a custom-made orthotic. However, the cost of the orthotic is prohibitive for many individuals, particularly beginners who are unsure whether the sport is of interest to them. The individual orthotics are also unsuited for use by community fitness facilities which may have several different individuals using the same rackets. Therefore, an assistive device was sought which would securely connect the tennis racket to the hand of the player but which could be used by a variety of individuals and produced at a reasonable cost.

METHODOLOGY—Initially, a leather glove was designed which was connected to the racket with Velcro. Individual placement of the fingers and thumb were important for racket control. Although this design was initially successful, the Velcro did not maintain a sufficiently strong connection between the glove and racket handle to prevent the racket from twisting in the palm of the hand when the ball was hit off of the center of the racket head. The design was altered so that the glove was permanently attached to the racket handle.

RESULTS—Evaluations indicated that players with C6-7 quadriplegia could put the glove on independently. The grip provided was sufficient for accurate

forehand and backhand control, and was maintained throughout a full lesson or game. Information regarding the tennis grip design is now being disseminated to ensure that individuals with limited hand grip function are able to effectively participate in wheelchair tennis.

[408] WHEELCHAIR PERFORMANCE CAPACITY AND PHYSICAL STRAIN IN SPINAL CORD INJURED SUBJECTS

L.H.V. van der Woude; T.W.J. Janssen; A. Dallmeijer; R.H. Rozendal; A.P. Hollander; H. van As; E. Angenot
Vrije Universiteit, Faculty of Human Movement Sciences 1081BT Amsterdam; The Netherlands Rehabilitation Center Amsterdam, Amsterdam, The Netherlands

Sponsor: *STipT Technology Programme; Linido Bv*

PURPOSE—Performance capacity and physical strain of ADL in spinal cord injured (SCI) wheelchair confined subjects are evaluated with systematic and repeated standardized wheelchair exercise and functional tests to study the evolution in capacity and the relation between stress and strain in ADL. Thus, the long-term consequences of a wheelchair confined lifestyle on the cardio-respiratory as well as the musculo-skeletal systems are systematically studied.

METHODOLOGY—Both subjects with a recent (intra-murally treated) as well as subjects with a long-standing SCI are studied in a cross-sectional and a longitudinal research design. Each session maximum performance capacity is determined on a computer-controlled wheelchair ergometer in terms of aerobic capacity, anaerobic sprint performance and isometric strength. The strain of standardized ADL is evaluated in different wheelchair-related ADL tasks with the percentage of Heart Rate Reserve (%HRR), as measured with a simple SportTester. Risk factors for cardio-vascular disease (blood pressure, cholesterol, etc.) are determined. Different physical and personal characteristics are inventoried by questionnaires.

RESULTS—The results on extramurally treated subjects with a long-standing SCI indicate a close inverse association between physical strain in ADL and indicators of maximum performance capacity. The three indicators for maximum performance capacity appeared highly associated. An expected reduction in performance capacity over a period of three years was not found. Even a slight tendency of improvement of performance was seen in maximum power output. Also in this longitudinal perspective a significant inverse association between changes in performance capacity and the strain during ADL was found. Important indicators for change in performance capacity were hours of sports activity and frequency of hospitalization and disease.

FUTURE PLANS—Effects of quad rugby training among a group of trained and recently started athletes with cervical lesions will be evaluated in an intervention study. A control group is also measured at the start and end of the study.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Isometric strength, sprint power and aerobic power in spinal cord injured subjects. Janssen TWJ, van Oers CAJM, Hollander AP, Veeger HEJ, van der Woude LHV. Med Sci Sport Exerc 1993:25(7):863-70.

Maximal wheelchair exercise responses in spinal cord injured subjects: comparison of a discontinuous and continuous protocol. Rasche W, Hollander AP, Janssen TWJ, van Oers CAJM, van der Woude LHV. Eur J Appl Physiol 1993:66:328-31.

Anaerobic power output and propulsion technique in spinal cord injured subjects during wheelchair ergometry. Dallmeijer A, Kappe Y, Veeger HEJ, van der Woude LHV. J Rehabil Res Dev. In press.

Physical strain in daily life of wheelchairs with spinal cord injuries. Janssen TWJ, van Oers CAJM, van der Woude LHV, Hollander AP. Med Sci Sports Exerc. In press.

Reliability of heart rate responses to non-steady state activities in daily living in men with spinal cord injuries. Janssen TWJ, van Oers CAJM, van der Woude LHV, Hollander AP. Scan J Reh Med. In press.

[409] 3-D OPTICAL ANALYSIS OF CHEST WALL MOTION

G. Ferrigno; P. Carnevali; A. Aliverti; F. Molteni; G. Beulcke; A. Pedotti
Centro di Bioingegneria, Politecnico di Milano, Dipartimento di Bioingegneria, Fondazione Pro Juventute IRCCS, Milano Italy

Sponsor: *None listed*

PURPOSE—The work is aimed to the noninvasive, nonionising analysis of the chest wall motion in order to infer the motor strategy used by healthy and pathological subjects for breathing. This goal is of primary importance in the evaluation of respiratory diseases of primary and secondary nature and for the assessment of therapeutic treatments and of the objective improvements of the patients.

METHODOLOGY—Analysis has been carried out by the ELITE system for motion analysis by using small passive markers fixed to chest wall landmarks. Initially two experimental set-ups have been designed for standing or sitting and supine positions. After clinical application, a set-up with the subject laying on one side has been added. The time course of the 3D coordinates of the landmarks so obtained have been used to compute the volume of a geometric model fitted to the chest wall. The volume changes have been split into contributions of the upper thorax, the mid thorax and the abdomen, thus allowing the inference of the status of the different active and passive components of the respiratory system.

PROGRESS—During the last 2 years the accuracy and reproducibility of the method has been assessed on a control group of healthy subjects leading to very promising results. Tests on paradigmatic pathologic subjects have been carried out showing the applicability of the method in almost all the respiratory diseases. In particular in the last year an intensive work has been performed on pathological subjects also in clinical environment.

RESULTS—The last 2 years of research have led to the validation of the method and to the extensive application on selected pathologic subjects. These latter results have shown the power of the method in identifying new information, not yet available today with the conventional techniques, on the motor strategy and on the status of active and passive components of the respiratory system. The preliminary analysis of tetraplegic subjects (neuromuscular diseases and medullar lesions) has shown the possibility to objectively quantify the effects of the muscular groups still active, while subjects affected by ankylosing spondylitis have shown a typical abnormality in volume distribution due to the reduction of the rib-cage compliance. The effects of assisted ventilation and of rehabilitation have also been assessed on many tetraplegic and neuromuscular subjects.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Evaluation of chest volumes during respiration. Ferrigno G, Carnevali P, Molteni F, Pedotti A. In: Bracale M, Denoth F, eds. Proceedings of Medicon '92, VI Mediterranean Conference on Medical and Biological Engineering, 1992:361-4.

3D Kinematic analysis of respiratory movements: a new approach of evaluation. Molteni F, Ferrigno G, Carnevali P, Aliverti A. In: Proceedings of 4th International Conference on Home Mechanical Ventilation, Lion, 1993:18

Thoraco-abdominal coordination in respiration. Carnevali P, Aliverti A, Ferrigno G, Molteni F. In: Beneken JEW; Faust UR, eds. Proceedings of 2nd European Conference on Engineering and Medicine; Stuttgart, 1993:158.

3-D kinematic analysis of respiratory movements. Ferrigno G, Molteni F, Carnevali P, Aliverti A. In: Proceedings of the XIV Congress of International Society of Biomechanics, 1993:412-3.

3-D optical analysis of chest wall motion. Ferrigno G, Carnevali P, Molteni F, Aliverti A, Beulcke G, Pedotti A. J Appl Physiol. In press.

B. Treatment and Rehabilitation

[410] FUNCTIONAL ELECTRICAL STIMULATION OF SPINAL CORD INJURY PATIENTS

A.M. Erika Scremin, MD; Karen L. Perell, MS; Deborah L. Mutton, MA; Oscar U. Scremin, MD, PhD; Livia Kurta, PT; Kari Matsumoto, BS; Robert J. Gregor, PhD; Brian J. Whipp, PhD; Charles Kunkel, MD; K.K. Firoozbakhsh, PhD; T.G. Cagle, PhD; Michael Scott, MD

Physical Medicine & Rehabilitation Service, VA Medical Center, West Los Angeles, CA 90073; University of California, Los Angeles, CA 90024; Department of Health and Performance Sciences, The Georgia Institute of Technology, Altanta, GA 30332; St. George's Hospital Medical School, University of London, London; Physical Medicine & Rehabilitation Service, VA medical Center, Albuquerque, NM 87108; and University of New Mexico, Albuquerque, NM 87131; Spinal Cord Injury Service, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B603-RA)*

PURPOSE—The potential benefits from functional electrical stimulation-induced ergometry of lower extremities (FESIELE) for paraplegic or quadriplegic patients are enhanced functional capabilities of patients, improved cardiovascular fitness and decreased blood cholesterol levels, decreased spasticity, increased bone mineralization with decreased risk of osteopenic bone fractures, prevention of joint contractures, and improvement of peripheral adaptations to exercise including increased muscle mass, energetics, and blood flow. The purpose of this project is to study the effects of FESIELE on spastic paraplegic and quadriplegic subjects who have complete spinal cord injury with the ultimate aim of determining the therapeutic benefits and associated risks of this novel form of rehabilitative therapy.

PROGRESS—Subjects participate in a 48-session training protocol on a computerized REGYS ergometer powered by the lower extremity muscles which are activated by cutaneous electrodes. A total of 13 subjects have participated in various phases of the project.

RESULTS—*Spasticity.* Studies assessing the degree of spasticity utilizing an isokinetic dynamometer (Kincom H-500) which measures the resistance to passive movement have been conducted. Data from 10 normal, 12 spastic, and 6 flaccid subjects demonstrated significant differences between normal and spastic and spastic and flaccid subjects when maximum peak during flexion was analyzed. Further studies into the time course of the effect of FESIELE on the spasticity of eight spastic patients immediately after, 2 hours after, and the next day following FESIELE suggest only immediate decreases in spasticity, not lasting more than 2 hours. Further assessment of FESIELE effects on spasticity using H-reflex measurements are also being quantified.

Bone Density. Studies to understand the usefulness of FESIELE on osteopenia secondary to SCI have begun. Loads normal and orthogonal to the pedal surface are measured and joint reaction forces calculated during FESIELE in SCI subjects using bicycle pedals instrumented with standard foil strain gauges. Changes in seat position to reduce high tensile forces are being explored. Dual Photon Absorptiometry (DPA) studies are underway to assess bone density before and after training.

Muscle Mass. Computerized tomographic studies before and after training to assess muscle mass changes in the thigh (stimulation applied to muscles) and in the shank (no stimulation to muscles) are underway in 13 subjects.

Metabolic Studies. Results from measurements of VO_2 kinetics were performed on seven subjects during a 10 minute session of FESIELE indicate the time constant of VO_2 is significantly longer in paralyzed subjects than has ever been reported for sedentary controls or elderly subjects. In addition, while there appears to be a ceiling effect on the improvement of their maximal aerobic capacity (peak VO_2), subjects have shown significant improvement in their recovery VO_2 kinetics indicating that this may be a more sensitive marker for fitness

and endurance capacity. Blood work regarding the lipid composition show that these subjects tend to have normal levels of cholesterol but very low levels of HDL and high ratios of CHOL/HDL suggesting that paralysis and lack of aerobic exercise increases the risk of heart disease. Creatinine kinase (CK) level results show that during FES leg training (quadriceps muscle FES only) and during Phase I (FESIELE less than 30 minutes/session) CK values were at the high end of the normal range (nl = 40–280) while during Phase II-III (FESIELE 30 minutes/session for 24 sessions) CK values were above the normal range. Further research is needed with additional subjects and trials to make a more definitive conclusion.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Pedal reaction forces during FES induced cycling ergometry (abstract). Gregor R, Scremin AME, Perell KL, Franco J, Kaplan S. In: Proceedings of the American Paraplegia Society Annual Meeting, 1992, Las Vegas, NV.

Quantitative technique for quantitative measurement of spasticity. Firoozbakhsh KK, Kunkel C, Scremin AME, Monein MS. In: Proceedings of the American Paraplegia Society Annual Meeting, 1992, Las Vegas, NV.

Kinetics of oxygen uptake in subjects with complete motor/sensory spinal cord lesions during leg exercise induced by functional electrical stimulation. Scremin AME, Mutton D, Kunkel C, Cagle G, Whipp B. In: Proceedings of the American Paraplegia Society Annual Meeting, 1993, Las Vegas, NV.

Peak and submaximal physiologic responses to FES induced cycle ergometry training. Scremin AME, Hooker S, Mutton D, Kunkel C, Cagle TG. Arch Phys Med & Rehab 1993:74:1237.

Quantification of muscle tone in spinal cord injury patients. Perell KL, Scremin AME, Woodrow R, Firoozbakhsh KK, Kunkel C. Arch Phys Med Rehabil 1993:74:1271.

Technique for quantitative measurement of spasticity. Firoozbakhsh KK, Scremin AME, Kunkel C, Monein M, Hayden M. Am J Phys Med & Rehab 1993:72:379-85.

[411] MANAGEMENT OF INCONTINENCE IN SCI PATIENTS WITH PENILE NERVE STIMULATION

John S. Wheeler, MD; James S. Walter, PhD; Paul Zaszczurynski, BS; Patricia Sibley, RN
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141;
Loyola Medical Center, Department of Urology, Maywood, IL 60153

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B689-RA)*

PURPOSE—Abnormal micturition with urinary incontinence, especially associated with detrusor hyperreflexia, is still a major problem in patients with spinal cord injury (SCI) and a major risk factor for upper urinary tract pathology. Current methods of treating such problems include intermittent catheterization with systemic or intravesical anticholinergic medication. However, these treatments may have significant side effects or may not be entirely effective. This project's goal was to evaluate the efficacy of dorsal penile nerve stimulation for bladder inhibition and incontinence management with a home use device.

METHODOLOGY—Prior to entrance in the study, potential subjects completed an informed consent and a two-week incontinence evaluation. Subjects with greater than 8 incontinence episodes per week were scheduled for an evaluation in the GU clinic at Hines. Patients with suprasacral injuries and one person with Multiple Sclerosis were enrolled. They underwent baseline cystometry (CMG) evaluation which recorded filling bladder pressure and capacity, bladder contractile activity, and sphincter electromyographic (EMG) activity. A cardiac monitor was used during the study. Stimulation was provided by a small battery-powered stimulator (Con-stim, Life Tech. Inc.) and surface electrodes (Unipatch Inc.). Stimulating frequencies of 5 Hz were used and had a maximum of 50mA. In order to evaluate the effects of stimulation the bladder was repeatedly filled and emptied (CMG). The sequence consisted of alternating between CMG with and without stimulation. The procedures took

2 to 3 hours and no adverse side effects of stimulation were noted other than one incidence of headache which was relieved by discontinuing the procedure.

PROGRESS—At completion of the acute studies, subjects were given the home stimulator, supplies and complete instructions for use. Follow-up telephone calls were made to the subjects. They continued their incontinence log during this period. Stimulation began at threshold parameters and was increased after one to two weeks based on results. After 6 weeks evaluation, subjects wishing to continue the at-home stimulation were given the equipment to do so.

RESULTS—Nine patients were evaluated for home stimulation treatment. One subject (C6,7, complete) successfully completed the study and was pleased with the results. His bladder filling volume increased from 180 ml to 300 ml, and his incontinence episodes stopped. He continued the stimulation technique for over eight weeks and then, because it was cumbersome, stopped it to return to school. The most effective stimulating parameters for him were 5 Hz with 250 μs pulse duration and a current of 40 mA. A second patient (C7,8, incomplete) had similar positive results.

One group of 3 subjects also had urinary incontinence. The level and extent of their injury suggested a hyperreflexic bladder, however, CMG's on these subjects demonstrated areflexic bladders and stress type incontinence. They were dropped from the program.

A second group of 3 subjects withdrew before adequate evaluation of the protocol. One subject had Multiple Sclerosis and a second (C5,6) had an incomplete cervical injury. Both of these patients had sufficient sensation to be aware of the stimulation. They began home stimulation at sub-threshold levels which they felt were tolerable. They continued the program for 2 and 3 days respectively but withdrew because of continued incontinence and their dislike of the stimulation. One subject (T5,6 complete) withdrew because of a medical problem unrelated to the project. A final subject (T-5,6, complete) was not improved even after making a good effort.

IMPLICATIONS—The encouraging results in two patients warrants further evaluation. This study is being continued as a pilot program through the Rehabilitation Research and Development Technology Transfer Service.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Management of incontinence in SCI patients with penile nerve nerve stimulation. Wheeler JS, Walter JS, Sibley P. In: Proceedings of the American Paraplegia Society 39th Annual Meeting 1993:6.

Observations of a dynamic bulbocavernosus reflex (DBC) in the SCI cat and humans. Walter JS, Wheeler JS. J Am Paraplegia Soc 1993:16(1):59.

Dynamic bulbocavernosus reflex (DBC): Dyssynergia evaluation following SCI. Walter JS, Wheeler JS. J Am Paraplegia Soc. In press.

Management of incontinent SCI patients with penile stimulation: Preliminary results. Wheeler JS, Walter JS, Sibley P. J Am Paraplegia Soc. In press.

[412] NEUROPROSTHESTIC CONTROL OF BLADDER AND BOWEL IN SCI PATIENTS: A PILOT STUDY

Donald R. Bodner, MD; John G. Banwell, MD
VA Medical Center, Cleveland, OH 44106

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B91-299AP)*

No report was received for this issue.

[413] EFFECT OF EXERCISE ON UPPER EXTREMITY RECOVERY FOLLOWING QUADRIPLEGIA

James W. Little, MD
VA Medical Center, Seattle, WA 98108

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B320-3RA)*

No report was received for this issue.

[414] THIN-FILM PERIPHERAL NERVE ELECTRODE

Stuart Cogan, ScD; James S. Walter, PhD; Meegan McCaffrey; Wuying Cai, MD; Jerry McLane, PhD; Charles Robinson, PhD; Paul Zaszczurynski; Michael Turner
EIC Laboratories, Norwood, MA. 02062; Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—The purpose of this project is to develop a cuff electrode capable of selective, graded, and stable activation of hand muscles for restoration of grasp in an animal model. The cuff electrode is comprised of a multielectrode circumneural cuff interfaced to a multichannel implantable stimulator and associated control algorithms.

METHODOLOGY—Electrodes are being fabricated by vacuum depositing Pt-Ir films on thin sheets of fluorocarbon polymer and photolithographic patterning and etching to form the leads and charge injection sites. The patterned substrate is then selectively covered with a second polymer layer. Four charge injection sites in a 'round about' geometry, similar to that being investigated for phrenic nerve stimulation, are being evaluated.

PROGRESS—*In vivo* studies of implanted circumneural electrodes have been conducted in the three cats. The methodology involved implanting the electrodes on the sciatic nerve for six weeks. Mechanical effects of the cuff on the nerve were assessed without using electrical stimulation. Following tissue fixation, the degree of edema, fibrous tissue encapsulation and general pathology of the nerve were documented as well as a histological evaluation. Postmortem observations of the cuffs revealed that one cuff had come off of the nerve and was covered with a thick connective sheath. The remaining two cuffs were on the nerves and had a thin connective sheath on them. Histological studies with light and electron microscopy indicated no injury to the nerve at the level of the cuff.

FUTURE PLANS—Electrodes will be interfaced with a multichannel implantable stimulator, and stimulation algorithms will be developed for selectivity and graded activation of muscle groups similar to those used in human grasp using an animal model with digit dexterity. EMG measurements will be correlated with tension and functional measurements.

The cuff electrode will be used to record peripheral nerve sensory topography and correlate this activity with dermatomal distribution in the somatosensory cortex. The cuff will then be used to depolarize regions within the nerve in an attempt to excite the same region of the cortex. The use of a steering current should allow more precise activation of the cortex.

[415] APPLICATION OF THE NURSING MINIMUM DATA SET TO SPINAL CORD INJURY CARE

Margaret Ross Kraft RN, MS; Barbara J. Lang, RN, MS
Nursing Service, VA Medical Center, Hines, IL, 60141

Sponsor: *American Association of Spinal Cord Injury Nurses*

PURPOSE—The contributions of nursing to cost-effective spinal cord injury care and positive patient outcomes must be demonstrated with objective data. Information technology and the computerization of nursing data permits documentation, retrieval, and analysis of nursing practice information that can be used to describe and evaluate nursing care, investigate the quality and outcomes of care, support resource allocation, and stimulate nursing practice research. Participation of a VA SCI Nursing Service as an ALPHA site in the development of the VA Decentralized Hospital Computer Program (DHCP) Nursing Package (proposed by Werley and others, 1988), has resulted in the development of a computerized SCI nursing database that offers the opportunity to study actual nursing practice within the VA spinal cord injury population. Inclusion of all elements of the Nursing Minimum Data Set (NMDS) in the VA computer package will permit a test of the utility of the NMDS in data collection.

METHODOLOGY—Analysis of this VA SCI nursing database is conceptualized as a two-stage process. Stage I, represented in this proposal, will use quantitative methods to identify the nursing diagnoses, associated defining characteristics, and nursing interventions in this database. Incidence and prevalence rates will be reported with frequency rankings for both nursing diagnoses and nursing interventions. Stage II of this study, proposed for Year Two, will address statistical analysis of possible relationships between nursing diagnoses and interventions, patient demographics, acuity, length of stay, and patient outcomes.

RESULTS—Based on our experiences in the analysis of data in the pilot study, we recognize the need for a more powerful statistical package for data review. Currently we are discussing the application of SAS which is now available in a limited basis on a study site mainframe. We are also exploring the capability of the DHCP Fileman functionality to generate data reports from mainframe data, using a PC for data manipulation to speed up the process. We believe that total database analysis may result in the identification of statistically significant relationships not evident in the smaller population of the study group. One of the NMDS elements found to be consistently missing in the data was the final evaluation of patient outcomes. We learned that although care plans were kept up to date during an episode of care, nursing staff failed to update patient status "on-line" at the time of discharge. A review of five charts from study patients indicated that discharge status was present in the paper record progress notes, but had not been updated in the computerized patient care plan database. This information was shared with the clinical nurse administrators (head nurses) on the study units who are responsible for assuring that documentation standards are met, and additional work with staff has reviewed the need to complete the discharge evaluation. A random review of more recent care plans shows some improvement in this area. The relationship of nursing diagnoses, care plans, and staffing methodology is an issue not included in the scope of the pilot study, but should be addressed in further studies.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

SCI nursing. Kraft MR, Lang BJ. In: Proceedings of International Nursing Informatics conference, Amsterdam: Elsevier, 1994.

[416] CATHETER CLEANING FOR RE-USE IN INTERMITTENT CATHETERIZATION

Diane J. Lavalle RN, MSN; Nathalie LaPierre RN, BScN; Penny Henwood RN, BScN; Jayne Pivik Hons, BA; Susan V. Springthorpe, MSc; Syed A. Sataar PhD
The Rehabilitation Center, Ottawa, ON K1H 8M2

Sponsor: *American Association of Spinal Cord Injury Nurses*

PURPOSE—Intermittent catheterization, the passage of a catheter into the bladder and its removal after the drainage of urine, has become a common method of emptying a neurogenic bladder, one whose function is altered due to impairment of the nervous system. With changes, such as de-institutionalization and improved life expectancy, a growing number of people with neurological disabilities using intermittent catheterization are now living in the community and are involved in school, work, and recreational activities. Catheter cleaning and re-use has been recommended for over twenty years and is widely practiced in the community. Numerous catheter cleaning methods are being recommended by agencies, although very few have been validated with research. The need for more studies on cleaning techniques for re-use has been identified (Health Services Directorate, Canada, 1985; Moore, 1991). Research on catheter cleaning methods is needed before implementing changes in policies and procedures.

METHODOLOGY—The objectives of this study are 1) to compare, in laboratory, the ability of hydrogen peroxide 3 percent USP, Sunlight liquid dishwashing detergent, and tap water, to remove Pseudomonas aeruginosa from plastic urinary catheters, and 2) to determine the effect on bacterial colony count when storing cleaned catheters for 24 hours in two types of containers; paper or plastic bags.

It is predicted that, after contamination with Pseudomonas aeruginosa, there will be no difference in the bacterial colony count between catheters cleaned with hydrogen peroxide and those cleaned with dishwashing detergent, the effect of water being unknown. Given no difference in the bacterial colony count after cleaning, it is also predicted that any difference in bacterial colony count after 24 hours will be less in those stored in a paper versus a plastic bag.

A total of 352 sterile catheters will be contaminated and a colony count will be verified on 40 catheters. Experiment 1: N = 156 catheters, where 52 will be cleaned in hydrogen peroxide, 52 in detergent, and 52 in tap water. Bacterial count will be done. Experiment 2: N = 156 catheters, where 52 will be cleaned in hydrogen peroxide, 52 in detergent, and 52 in tap water. Twenty-six catheters from each group will be stored in either a paper or plastic bag for 24 hours. Bacterial count will be done.

The data will be analyzed using a one-way analysis of variance (ANOVA) for the first hypothesis. For the second hypothesis, the interactive effect of storage (paper vs. plastic) and cleaning solution (hydrogen peroxide vs. detergent vs. water) will be examined using a two-way ANOVA.

[417] PROPOSAL FOR A SURVEY OF ATTENDANT CARE ARRANGEMENTS FOR INDIGENT SCI INDIVIDUALS IN LOUISIANA

Susan Hitzman, BCSW; John F. Berry, MD; Gregory W. Stewart, MD
Louisiana State University Medical Center, New Orleans, LA 70140

Sponsor: *American Association of Spinal Cord Injury Psychologists and Social Workers*

PURPOSE—Spinal cord injuries resulting in quadriplegia above the C7 level do not allow individuals to return to fully independent living in the majority of cases. Thus, some level of attendant care is required for most higher level quadriplegics. For patients with financial resources, health insurance coverage, insurance settlements, or strong family support, attendant care is usually not a problem. However,

for the indigent spinal cord injured person with no financial resources and a weak or nonexistent family support system, attendant care can be a serious problem. In some cases, individuals who would otherwise be able to return to their communities with limited attendant care require nursing home placement. In other cases, individuals may return home with inadequate assistance, resulting in preventable medical and social problcms.

METHODOLOGY—The proposed study will investigate the attendant care arrangements of indigent higher-level quadriplegic patients, with measurement of such variables as attendant care training, general educational level, relationship, availability, reliability, time in the home, and services provided. A representative sampling of the caretakers of C7 and higher level quadriplegics followed in the spinal cord injury clinic of the Louisiana Rehabilitation Institute will be surveyed and the results collated, analyzed, and reported. Planned further studies will correlate the findings of this study with the incidence of medical and social problems in this population and will attempt to remediate identified problems with attendant procurement, training, and other interventions suggested by thc findings of the proposed study.

IMPLICATIONS—We believe that the identification of the primary caregiver needs to occur early in the rehabilitation stay and this person needs to be brought in for training. The vast majority of attendants receive their training while the client is on the rehabilitation unit. In the indigent population this caregiver is usually a family member. Great efforts should also be taken to identify a secondary caregiver during this early stage of rehabilitation, especially since very few clients have secondary attendants. This would allow for adequate training of the secondary attendant and establish respite for thc primary attendant. Transporation is a significant problem in at least 40 percent of the time that medical care is needed, even with the availability of adapted transportation as in the metropolitan New Orleans area. The availability and problcms with transportation services is in need of continued assessment in the larger community. This is an ongoing project of the Committee for the Prevention of Secondary Disabilities of thc Louisiana Advisory Council on Disability Prevention. Dr. Stewart is a member of this Committee.

The caregivers are not being paid and should have an alternate means of support, both financially and emotionally. They are providing a cost saving function for the health care community. Without their attendant care, the client would likely be placed in a nursing home whcre thc cost to the government currently exceeds $1800 per month. The attendant's ability to provide timely services may have a direct relationship to their level of stress. Respite care is needed, but limited to what the families can pull together, since the community does not offer any services to this population. The available home health care through Medicaid is limited, and they are encouraged to use this when the medical need is critical. This leads into thc concern for the overall health of the client and their caregiver. We should look closer as to the reasons persons are lost to follow-up for medical care. The closer monitoring of this patient population could lead to more information as to their community/family/ personal issues which may prevent their receiving the needed care. The identification of the issues could lead to implementation or advocacy for needed intervention strategies. The reason could be positive in that they found a provider closer to their home community that they find more accessiblc. Yet, it could be negative in that they have not been able to obtain the needed medical carc due to transportation or some other unknown problem, and will not receive care until their condition becomes critical. Future research should includc studies on this same SCI population who live in nursing homes. lt would be of benefit to determinc the reason for their admission to that facility, for example what was lacking for them to be cared for in the home.

[418] ASSESSMENT OF POST-TRAUMATIC STRESS DISORDER IN SPINAL CORD INJURY

Cynthia L. Radnitz, PhD
Mount Sinai Medical Center, New York, NY 10029

Sponsor: *American Association of Spinal Cord Injury Psychologists and Social Workers*

PURPOSE—Although traumatic incidents are generally responsible for spinal cord injuries, very little is known about Post-Traumatic Stress Disorder (PTSD) in the SCI population. The present study has several objectives relevant to this question, including: 1) establishing prevalence rates for PTSD, 2) assessing the relationship between length of time since injury and onset of PTSD, 3) determining whether loss of consciousness and alcohol or drug intake during the injury are related to the onset of PTSD, 4) gathering co-morbidity data, and 5) determining the impact of SCI on the development of PTSD in a sample of SCIs who recently were in motor vehicle accidents (MVAs).

METHODOLOGY—Subjects will be approached and asked to participate in the study. Those who consent will be given both structured interviews and questionnaires.

[419] CONSUMER PERCEPTION OF RESOURCES NEEDED FOR LONG-TERM RECOVERY FROM SPINAL CORD INJURY

Denise G. Tate, PhD; Evan H. Cohen, PhD
Department of Physical Medicine and Rehabilitation, University of Michigan, Ann Arbor, MI 48109-1248

Sponsor: *American Association of Spinal Cord Injury Psychologists and Social Workers*

PURPOSE—Today's climate of health care cost containment and rationing presents unique challenges to persons with spinal cord injuries (SCI) and their caregivers. In order to influence health care policy, SCI persons and health services researchers will need to develop an empirical consensus about what resources outside of the hospital are necessary for positive long-term adjustments. The proposed study examines the perceptions of SCI persons concerning what assistive services and equipment they need, receive, and utilize as a means of improving prediction and understanding of long-term rehabilitation outcomes. The study's primary objectives are 1) to assess the extent to which the receipt of assistive services and equipment rated as necessary by SCI persons will enhance prediction and explanation of long-term psychological and functional outcomes, and 2) to contrast positive and negative rehabilitation outcomes in terms of associated experiences of SCI persons who have/have not secured and utilized these resources, the priorities they assign to resources, and their socio-demographic characteristics.

METHODOLOGY—The first objective will be addressed by means of new multiple regression and partial correlation analyses performed on an existing data set collected from 145 SCI persons being followed by the University of Michigan Medical Center's Model Spinal Cord Injury Systems program and the NIDRR-funded study of Insurance Benefits Coverage and Independent Living Outcomes. The second objective will be met by conducting new interviews on subsamples of at least 30 SCI persons from "positive" and "negative" outcome groups, respectively. Each group will exhibit unique patterns of distributions with respect to outcomes, such as depression and handicap experienced in the environment after injury.

IMPLICATIONS—Results will be used to lend persons with SCI an empirical voice in the arena of health care policy decisions. Results will also be used to better equip health services researchers with measures that capture predictive aspects of the experiences that persons with SCI have in trying to access independent living resources.

[420] FACTORS AFFECTING EMPLOYMENT STATUS AMONG PERSONS WITH SPINAL CORD INJURY

Ann Temkin, MA, ACSW; Charlotte Gunter, MS
Department of Clinical Research, Shepherd Spinal Center, Inc., Atlanta GA, 30309

Sponsor: *American Association of Spinal Cord Injury Psychologists and Social Workers*

PURPOSE—This study follows a pilot study conducted at the Shepherd Spinal Center in 1992 where forty-four persons with spinal cord injury (SCI) were interviewed in an attempt to gain insight into factors affecting their employment history. The findings of this intentionally subjective study suggest that the individual's creative ability, need for stimulation, and subjective perceptions about his/her need to work may exert significant influence on whether he/she actually obtains and maintains employment. There is now a need to define these variables and measure them objectively. Furthermore, although extensive demographic and historical information was obtained about the subjects, certain data will be gathered which has not been uniformly collected to date. The ultimate goal of these studies is to make the delivery of vocational services more effective.

METHODOLOGY—The present study will have seventy-five participants. The original subjects will be contacted and asked to participate in the present study. Since these persons were eager to participate in the pilot, and because we have ongoing contact with this population and will offer a small stipend, we anticipate that most participants will recommit. Additional subjects will then be recruited to bring the number to 75. This will be done in such a way that persons with different levels of injury and employment status will be appropriately represented. Subjects will be classified as follows: Group A (employed for the preceding 2 years), Group B (both employed and unemployed during the preceding 2 years), and Group C (unemployed for the preceding 2 years). Participants will be tested using four instruments: 1) an instrument developed for this study measuring perceived Need to Work, 2) a Myers-Briggs Type Indicator, Form G, 3) Lifetime Creativity Scales (LCS), as a measure of creativity, and 4) Sensation Seeking Scale (SSS V) as a measure of need for stimulation/susceptibility to boredom. Certain demographic and historical information presently not complete will also be collected. Descriptive statistics will be produced for all variables in the study.

Assuming that groups are similar in terms of demographic characteristics, analysis of variance will be used to test for differences. However, in the 1992 study age was significantly different across the employment status groups. If this pattern is repeated in the current sample, group comparisons will then be made using analysis of covariance. The working hypotheses are that those employed for two years will test significantly higher on the Need to Work, Lifetime Creativity Scales, and Sensation Seeking Scales, and that there will be significant differences between the three groups on the Myers-Briggs Type Indicator.

[421] TREATMENT OF VESICOSPHINCTER DYSSYNERGIA USING THE UROLUME PROSTHETIC STENT: EFFECT ON THE MAXIMUM URETHRAL PRESSURE GRADIENT

Bruce G. Green, MD; James K. Bennett, MD; Jenelle Foote, MD; Mikel Gray, PhD, CURN
Urology Department, Shepherd Spinal Center, Atlanta, GA 30309

Sponsor: *American Medical Systems and Pfizer Hospital Products Group*

PURPOSE—The research project was undertaken to determine if the Urolume prosthetic stent has an effect on the maximum urethral pressure gradient (MUPG). The MUPG is a quantitation of the outflow resistance at the level of the external sphincter, and identifies those spinal injured persons

managed by reflex voiding who represent an increased risk for upper urinary tract distress. Traditionally, sphincterotomy has been the mainstay of treatment of vesicosphincter dyssynergia. More recently, the use of internal stents across the sphincteric junction have been proposed as an alternative and less morbid procedure than sphincterotomy.

PROGRESS—Over the past 18 months, we have treated 20 subjects with the AMS Urolume Wall Stent. All patients underwent preoperative videourodynamics with calculation of the MUPG using a triple lumen catheter allowing simultaneous measurement of intravesical and urethral pressures during micturition. The average preoperative MUPG was 53 cm H_2O and the postoperative dropped 21 cm H_2O. Other urodynamic parameters measured were maximum detrusor pressure, capacity, compliance, and post void residual urine. Complications included bladder neck dyssynergia, hematuria, and recurrent obstruction necessitating additional stent placement.

[422] MUSIC MAKING IN REHABILITATION FOR PERSONS WITH SPINAL CORD INJURIES

Roger Knox, PhD; Brenda Lee, BScOT(C); Tom Nantais, BASc
Lyndhurst, The Spinal Cord Centre

Sponsor: *Lyndhurst Spinal Cord Centre Seed Fund; Rick Hansen Man in Motion Legacy Fund*

PURPOSE—The study evaluated effects of upper extremity exercise for quadriplegic (SCI) clients involving performance of music using specially designed inputs to an electronic synthesizer.

METHODOLOGY—The study ($n=6$) employed two treatment blocks of five weeks: A) the control condition, upper extremity therapy of rote exercise without music, and B) the experimental condition, upper extremity therapy where subjects produce music. In a within-subject crossover design, subjects were divided into two groups of three, one proceeding through treatment blocks in AB and the other in BA order.

Maximal hand grasp and maximal isometric strength in flexion and extension planes of wrist and elbow joints were tested. Respiratory function of subjects using the puff device was also tested.

PROGRESS—The study employed a system that allows SCI patients to perform electronic music using exercise devices. Three devices were designed for hand grasp, wrist flexion/extension, and elbow flexion/extension. Each device is attached to a potentiometer that fed into a microcomputer to control a synthesizer through the Musical Instrument Digital Interface (MIDI). Songs chosen by clients were arranged assigning the three input devices to the melody, bass and chords. A sip-and-puff switch was used along with the exercise device by the melody performer.

RESULTS—All five subjects who completed the study attended more frequently in music than in rote exercise conditions. Mean attendance in music conditions was 91.4 percent and in rote conditions 82.0 percent; the difference has statistical and practical significance (9.4 percent; SD 6.5, $t=3.23$, $p<0.03$). The implication of motivation from music-making was supported by clinical observations and exit interviews.

Hand grasp exercising subjects achieved gains, but without significant differentiation between conditions. Also, no significant changes were found among elbow or wrist exercising subjects in either condition, but the manual muscle testing procedure has a relatively low sensitivity. The two subjects using the sip-and-puff device improved respiratory function (measured for Maximum Voluntary Ventilation and Forced Vital Capacity) more in the music condition. In the rote exercise condition where puff switches were not used, one subject actually declined.

While the original goal was improved upper extremity strength, the areas of attendance and respiratory function provided the best results. The music activity might have generated more upper extremity exercise benefit had the sessions been

open-ended rather than time-limited. Observations suggested that fine targeting required by the music system may have improved quality of upper extremity movement, which was not measured. Based on this study, the areas of better motivation in rehabilitation, improved respiratory function, and quality of upper extremity movement are most promising. Pilot study results have led to implementation of this activity into the regular occupational therapy program at Lyndhurst.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

A system for creating computer music as an occupational therapy activity. Nantais T, Lee B, Davies J, Knox R. In: Proceedings of the 16th Annual RESNA Conference, 1993, Las Vegas, NV. Washington, DC: RESNA Press, 1993:420-2.

[423] INTRATHECAL BACLOFEN FOR TREATMENT OF INTRACTABLE SPINAL SPASTICITY

Donald P. Leslie, MD; Namoi Abel, MD; Richard A. Smith, MD
Shepherd Spinal Center, Atlanta, GA 30309

Sponsor: *Medtronic, Inc.*

PURPOSE—The purpose of this research is to assess the safety and efficacy of intrathecal baclofen for the treatment of intractable spasticity. Although intrathecal baclofen is safe and effective, some patients appear to require increasingly higher doses over time.

METHODOLOGY—Thirty-three patients with severe chronic spasticity of spinal cord origin underwent bolus test dosing of intrathecal baclofen administered by lumbar puncture. All patients were either refractory to oral baclofen at a dose of 120 mg/day or side effects were unacceptable at a lower dose. All 33 patients responded with significant decrease in tone and spasticity. Thirty patients underwent implantation of a programmable pump and intrathecal catheter for purposes of delivering baclofen directly to the spinal cord. The first 6 patients entered a multicenter randomized double-blind, placebo-controlled screening protocol in September 1989. The remainder entered an open trial study which began in June 1990. Rigidity (tone) was assessed on the Ashworth scale (rated 1-5) and spontaneous spasms on a spasm scale (rated 0-4). Rigidity was decreased from a mean pre-bolus Ashworth score of 3.8 to a mean post-bolus score of 1.2 for a minimum of 4 hours.

RESULTS—Patients have been followed for a mean of 16 months (range 2-34 months) in an outpatient clinic. Ashworth scores and spasm scores have remained reduced to an acceptable level (<3) with periodic increase in dosage in all but 2 patients. Of interest is the fact that these 2 patients are currently on <1500 mcg/day with Ashworth scores of 3-4 and spasm scores of 3. One patient whose tone and spasticity was adequately reduced voluntarily withdrew from the study.

There has been one patient death which was attributed to underlying disease. There were no deaths due to intrathecal baclofen or the pump and catheter delivery systems. There were 2 serious medication complications. One patient received an overdose of medication during a CT myelogram and required ventilatory support for 36 hours. Another patient experienced hypotension following bolus screening which precluded implantation. There was 1 pump malfunction and 5 catheter malfunctions which all resulted in a decrease in medication delivery and required replacement. There were not other post-operative complications with the exception of one patient who developed a cerebrospinal fluid seroma.

PROGRESS—In June 1992, Medtronic received FDA approval for intrathecal baclofen. Five of the 23 patients who were tested prior to FDA approval have continued under research surveillance. The last 10 implantations have not been considered research subjects. However, the same patient selection crite-

ria have been used, the same bolus test dosing has been done prior to implantation, and the patients will continue to be followed as the research subjects prior to FDA approval were.

[424] REHABILITATION RESEARCH AND TRAINING CENTER: COMPLICATIONS OF SPINAL CORD INJURY

David Green, MD, PhD; David Chen, MD
Northwestern Memorial Hospital, Chicago, IL 60611; Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research RRTC: Complications of Spinal Cord Injury*

PURPOSE—The goal of this research is to prevent thromboembolism in patients with spinal cord injury.

PROGRESS—In a series of studies, low molecular weight heparin (LMWH) was found to have greater safety and efficacy than unfractionated (standard) heparin in preventing thromboembolism in spinal cord injured patients with complete motor paralysis. To date, 68 such patients have been treated with LMWH; 40 of these subjects were evaluable, the others having been transferred or discharged prior to the defined treatment period. There have been six deep vein thromboses (two proximal), one pulmonary embolus, and one minor bleeding event. The percentage of patients event-free 8 weeks following injury was 84.4 percent. Subsequently, LMWH was discontinued and 33 subjects followed without prophylaxis for an additional 4 weeks; 2 of these patients had thrombotic events. We conclude that LMWH represents a significant improvement in thromboprophylaxis for most patients with spinal cord injury, and that eight weeks of treatment is probably adequate for most individuals.

FUTURE PLANS—The patients investigated in previous studies had uncomplicated spinal cord injuries, that is, they were excluded from treatment if they had rib or long bone fractures or other injuries. Since bleeding with LMWH was very uncommon (only one episode in 68 treated patients), this agent may be safe for all spinal cord injured subjects. In future work, LMWH will be compared with compression boots in unselected patients with spinal cord injury.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Deep vein thrombosis in spinal cord injury. Green D, ed. Chest 1992:102:633S-67S.

Effect of lower limb paralysis on the recanalization of deep vein thrombosis. Lim AC, Roth EJ, Green D. Arch Phys Med Rehabil 1992:73:331-3.

Prophylaxis of thromboembolism in spinal cord-injured patients. Green D. Chest 1992:102:649S-51S.

Fatal pulmonary embolism in spinal cord injury. Green D, Twardowski P, Wei R, Rademaker AW. Chest 1994:105:853-5.

Low molecular weight heparin: a critical analysis of clinical trials. Green D, Hirsh J, Heit J, et al. Pharmacol Reviews 1994:46:89-109.

Prevention of thromboembolism in spinal cord injury: role of low molecular weight heparin. Green D, Chen D, Chmiel JS, et al. Arch Phys Med Rehabil 1994:75:290-2.

[425] ADJUSTMENT OF SPINAL CORD INJURED WHO ARE VICTIMS OF INTENTIONAL VS. UNINTENTIONAL INJURIES

Ruby L. Wesley, PhD, RN, CRRN
Nursing Services, Rehabilitation Institute of Michigan, Detroit, MI 48201

Sponsor: *National Institute of Disability Rehabilitation Research Merit Scholar Fellow, Wayne State University General Faculty Research Award, and Sigma Theta Tau International Nursing Honor Society.*

PURPOSE—The purpose of this study was to examine the adjustment processes that the spinal cord injured who are victims of intentional (gunshot wounds, stabs, and assaults) versus unintentional

(motor vehicle accidents, sporting accidents, and falls) injuries are enduring.

METHODOLOGY—This qualitative research study utilized the focus group methodology to examine the processes of adjustment. Each focus group had 9 to 12 members at any given session. The researcher was able to obtain the assistance of co-leaders who were also spinal cord injured either intentionally or unintentionally. The sessions were two hours in length and six weeks in duration. The topics of adjustment which were addressed were: health care management, vocational rehabilitation/employment, interpersonal relationships/sexuality, and adjustment issues.

RESULTS—The analysis indicated that the themes of lifestyle, spirituality, and empowerment are important requirements for adjustment. The two groups differed in their adjustment related to the theme of lifestyle. This difference in adjustment has implications for health professionals in rehabilitation and the patient's therapies.

There were five patterns of behavior which were derived from the themes which were indicative of adjustment. This study has major implications that are important for rehabilitation health professionals and nurses, including issues related to: value clarification, role development, cultural/lifestyle, sexuality, and substance abuse.

IMPLICATIONS—Future work will be directed toward development and implementation of an intervention study for spinal cord injured who are victims of intentional injuries. This cohort has unique needs that have not been systematically addressed in the rehabilitation program.

[426] BACLOFEN PUMP: FUNCTIONAL AND NEUROPSYCHOLOGICAL IMPACT

J.M. Meythaler, MD
University of Alabama at Birmingham, Birmingham, AL 35233

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The development of severe upper motor neuron spasticity is among the most common secondary medical complications for persons with spinal cord injury (SCI). This spasticity is often severe enough to affect the ability to independently perform routine activities of daily living, thereby causing many individuals to remain homebound, in acute care hospitals, or in nursing facilities. Mass reflex spasticity often contributes to the development of pressure sores and joint contractures requiring hospital admissions for treatment.

Oral baclofen (Lioresal) has proven to be a relatively effective agent for treating upper motor neuron spasticity due to spinal pathology. Among persons with severe spasticity resulting from wither multiple sclerosis, cerebral palsy, or SCI in whom use of oral baclofen has proven ineffective, recent research has focused on the administration of baclofen intrathecally by means of a subcutaneously placed pump with a drug reservoir. This delivery system consequently bypasses the blood-brain barrier and delivers baclofen directly into the cerebrospinal fluid surrounding the spinal cord. Intrathecal delivery of baclofen concentrates the medication in the lower lumbar area of the spinal cord cerebrospinal fluid at a much higher level than attainable via the oral route. Other than anecdotal evidence and case reports of reduced muscle tone and spasticity, there is a paucity of reliable information regarding the actual benefits, complications, and costs associated with continuous infusion of intrathecal baclofen. The purpose of this study is to examine the effects of intrathecal baclofen on cognition and the ability to conduct routine activities of daily living independently. Incidence of any medical complications will also be determined. The cost-effectiveness of treating spasticity with intrathecal baclofen will also be addressed.

The objectives of this study are 1) to determine the degree to which spasticity is reduced following administration of intrathecal baclofen, 2) to determine whether intrathecal baclofen administration significantly improves the ability of individuals to function independently in activities of daily living,

mobility transfers, and bowel and bladder care, 3) to determine whether the level of cognitive awareness changes after administration of intrathecal baclofen, 4) to assess the cost-effectiveness of intrathecal baclofen administration, and 5) to document systemic side effects that occur secondary to intrathecal baclofen administration.

METHODOLOGY—A randomized prospective follow-up study will be conducted. Potential participants will be randomly assigned to one of two groups: (a) a problem-solving skills training group (treatment) or (b) no treatment (control). Participants will be persons with SCI who are receiving either conservative or surgical treatment for skin breakdown at Spain Rehabilitation Center. Those who participate in the intervention will engage in focused, psycoeducational sessions that will meet every other day for a total of eight sessions. Data will be collected on 6 dimensions: 1) personal responsibility for health care and maintenance, 2) psychosocial impairment secondary to SCI, 3) personal appraisal of problem solving skills, 4) demonstrated abilities in solving a problem specific to skin care, 5) demonstrated compliance with therapeutic regimen to conduct periodic pressure reliefs, and 6) prevalence of skin breakdown. It is anticipated that a total of 68 persons (34 per treatment group) will participate in this study. This is a larger sample than other published studies of problem-solving interventions have used.

PROGRESS—Patients are presently being enrolled in this study.

[427] LONGITUDINAL ANALYSIS OF WELL-BEING IN PERSONS WITH SPINAL CORD INJURY AND THEIR CAREGIVERS

J.S. Richards, PhD
University of Alabama at Birmingham, Birmingham, AL 35233-7330

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Much of the research in spinal cord injury (SCI) has been focused on acute medical aspects of SCI, with relatively little emphasis being placed on follow-up concerns, particularly quality of life issues. Recent work has suggested that there is a strong relationship between both physical health and emotional well being of the person with SCI and the existence of an effective social support system. There is very little information, however, on the impact of care demands on the caregiver who also most typically is the major source of social support. The purpose of this project is to investigate on a longitudinal basis, the relationship between the physical and emotional care needs of the person with SCI and the physical and emotional health of the caregiver at several intervals postinjury.

Objectives for this project include 1) the development of descriptive data reflecting changes in caregiver physical and emotional health over the first year postdischarge; 2) the examination of the relationship between factors of well-being in persons with SCI and their caregivers, measured at preselected times postinjury; 3) the determination of the association between physical and psychosocial characteristics of the person with SCI and feelings-of-burden variables in caregiver(s) at preselected times postinjury; 4) the determination of the interrelationships between feelings of well-being of the person with SCI and his caregiver(s) in different cohorts over time; and 5) the determination of the interrelationships between physical and psychosocial characteristics of the person with SCI and the feeling of burden in the caregiver over time.

METHODOLOGY—This is a longitudinal study consisting of four waves of data. A sample size of 100 SCI/caregiver pairs has been targeted. Individuals who identify themselves as most likely to be the primary caregiver are approached regarding participating in the study. The caregivers are administered four structured interviews: one in person during the rehabilitation phase prior to discharge, and three by mail at 1 month, 6 months and 1 year postdischarge. The predischarge measures serve as a baseline of caregiver mental and physical health, as well as an indicator of "anticipated" burden of care.

To date, 47 caregivers have been enrolled in the project. Nine of those 47 missed the in-hospital

questionnaire. To date 27 caregivers have completed all 4 phases. Twenty-four other caregivers in addition to the 47 listed above were approached about participating in the project but were inappropriate and/or refused participation.

PRELIMINARY RESULTS—89 percent of the caregiving sample is female, 66 percent have a high school education or better, and 51 percent were employed outside the home at the time of injury. With regard to relationship to the person with SCI, 57 percent are spouses, 37 percent are parents, and 5 percent are children. Of the persons with SCI, 95 percent are male and 57 percent have a high school education or greater. Fifty-two percent of the persons with SCI have a cervical injury, while the remaining 48 percent have paraplegia.

Preliminary analysis of hospitalization data reveals the caregivers are experiencing an elevated amount of negative affect secondary to the stress of having a family member hospitalized with SCI. Decreasing instrumental support is also apparent over the first year post discharge.

FUTURE PLANS—Subjects will continued to be enrolled through May 1995, with follow-up completed by the end of May 1996.

[428] A CLINICALLY DERIVED PROTOCOL FOR CHANGING CONDOM CATHETERS IN MALES WITH SPINAL CORD INJURY

Joan Stelling, MSN
University of Alabama at Birmingham, Birmingham, AL 35233

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—While meticulous hygiene and observation of the condom catheter and penis is consistently advocated, a disagreement exists on how often the condom catheter needs to be routinely changed. Recommendations range from changing it twice a day to changing it every few days. In fact, several of the most highly regarded nursing texts make no recommendation on how frequently it should be changed. Failure to reach a consensus on this issue is undoubtedly the result of the lack of any meaningful data upon which to base this clinically important decision.

The objectives of this randomized controlled clinical trial are 1) to determine the incidence of urinary tract and penile skin complications for male patients with spinal cord injury (SCI) whose condom catheters are changed daily, every other day, or every third day, and 2) to develop a protocol for routine changing of those catheters.

METHODOLOGY—The study population will include all male patients with SCI admitted to our hospital who use only condom catheter urinary collection devices, are asymptomatic for urinary tract infection for at least 48 hours, and are free from other urinary tract and penile skin complications at the time of entry into the study.

Subjects will be randomly assigned to one of three groups, patients whose condom catheters are changed 1) every day (Group I), 2) every other day (Group II), and every third day (Group III). Routine inspection of the penile skin will occur whenever the catheter is changed regardless of study group assignment. The duration of the study will be 30 days for each patient. A single brand of condom catheter has been selected and will be used for all study subjects. Patients having numerous accidents related to an improperly fitting catheter will be dropped from the study. At the conclusion of the study, a protocol will be developed for routine changing of these catheters.

Subjects are also obtained from the outpatient clinic. These patients are given an oral questionnaire by the clinic nurse. They are placed in either Group I or Group II, and the type of catheter used and complications are determined.

RESULTS—Due to the small sample size of inpatients in the study, inpatient data were not used for tabulating results. Of the 113 subjects participating in the study, 80 subjects changed their condom catheters every day and 33 changed their condom catheters every other day. The most commonly identified penile skin complication was redness;

excoriation, ulcers and swelling were also reported skin complications. Of the penile skin complications noted, there was no statistical difference found between the every day and every other day groups.

The most common urinary tract complication reported was urinary tract infection, followed by bladder stones and renal stones. There was no difference found between the every day and every other day groups. Neither group reported experiencing orchitis, epididymitis, ureterectasis, penoscrotal abscess, penoscrotal fistula, vesicourethral reflux, or pyelocaliectasis.

IMPLICATIONS—Since no difference was found in the incidence of penile skin and urinary complications in males with SCI who changed their condom catheters every day or every other day, it is recommended that selected patients can change their condom catheters every other day. Patients selected to change the condom catheter on an every other day basis should follow the guidelines of proper selection and fit of the condom catheter, daily penile skin inspection and daily hygiene.

A new procedure for condom catheter change at UAB's Spain Rehabilitation Center has been developed using the research results.

[429] PROBLEM-SOLVING SKILLS TRAINING IN THE TREATMENT OF PRESSURE ULCERS IN PERSONS WITH SPINAL CORD INJURY

Timothy B. Elliot, PhD
University of Alabama at Birmingham, Birmingham, AL 35233

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—People with spinal cord injuries (SCI) may experience a variety of psychosocial problems following injury. It has yet to be determined if persons with SCI can learn effective problem solving skills, and use these skills to improve their rehabilitation outcomes. This proposal describes a pilot project to develop a problem solving intervention directed at preventing secondary complications following SCI, specifically the incidence of repeat pressure ulcers in those who have already undergone surgery for pressure ulcer repair. The project will employ an intervention that helps individuals acquire effective problem solving skills and goal-setting techniques by teaching them to anticipate, plan, choose, execute, and monitor effective problem solving efforts.

The objectives of this study are twofold: first, we test the effectiveness of a problem solving skills training intervention for pressure ulcer prevention on the following criterion measures: 1) degree of self-perceived responsibility for health care and maintenance; 2) degree of psychosocial impairment secondary to disability; 3) general problem solving skill; 4) demonstrated ability to solve problems specific to skin care and maintenance; 5) demonstrated compliance with pressure relief maneuvers; and 6) prevalence of skin re-breakdown following discharge. Second, we develop and disseminate materials documenting the effectiveness of this intervention and methods for its implementation in other agencies by a variety of professionals.

METHODOLOGY—A randomized prospective follow-up study will be conducted. Potential participants will be randomly assigned to either a problem solving skills training group (treatment) or a no treatment (control) group. Participants will be persons with SCI who are receiving either conservative or surgical treatment for skin breakdown at Spain Rehabilitation Center. Those who participate in the intervention will engage in focused, psychoeducational sessions that will meet every other day for a total of eight sessions.

Data will be collected on six dimensions: 1) personal responsibility for health care and maintenance, 2) psychosocial impairment secondary to SCI, 3) personal appraisal of problem solving skills, 4) demonstrated abilities in solving a problem specific to skin care, 5) demonstrated compliance with therapeutic regimen to conduct periodic pressure relief, and 6) prevalence of skin breakdown. It is anticipated that a total of 68 persons (34 per group) will participate in this study. This is a larger

sample size than other published studies of problem solving interventions have used.

PROGRESS—Patients are being enrolled.

FUTURE PLANS—Patients will continue to be enrolled and intervention groups formed.

[430] PATHOLOGIC EFFECTS OF RECURRENT BACTERIURIA IN PATIENTS WITH SPINAL CORD DYSFUNCTION

K.B. Waites, MD
University of Alabama at Birmingham, Birmingham, AL 35233

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Urinary tract infections (UTIs) are a serious source of morbidity for spinal cord injury (SCI) patients. Recurrent hospitalizations and out-patient services required for treatment of acute and chronic UTIs are extremely expensive and may impede both the rehabilitation process and vocational pursuits. In addition, UTIs may lead to grave urologic complications and, in some cases, eventual renal failure. There is a need to prevent these infections and their sequelae. This would improve the overall rehabilitation potential and quality of life for SCI patients.

Original objectives of this study were to determine 1) the incidence of clinically significant urinary tract complications coincident with the major bacterial species; 2) whether aggressive treatment of most pathogenic organisms results in fewer long-term secondary urinary tract complications; 3) whether patients with certain human leukocyte antigen (HLA) combinations are at unusually high or low risk for developing long-term secondary urinary tract complications; 4) whether the phagocytic activity of human leukocytes correlates with the incidence of clinically significant UTIs and long-term secondary complications; and 5) the prevalence of Mycoplasma hominis and Ureaplasma urealyticum in lower and upper urinary tract and the association of these organisms with various pathologic conditions, with particular emphasis on upper urinary tract disease and calculi.

METHODOLOGY—Records of SCI patients examined in the out-patient clinics at Spain Rehabilitation Center were evaluated to determine the presence of UTI, the species of organisms involved and type(s) of urologic complications which occurred over time.

A group of patients (subjects), who are chronically infected and have diminished renal function on two successive annual urologic examinations and a separate group (controls) who have consistently sterile urine or whose sole complicating diagnosis is bacteriuria, have been identified from our patient database. Forty-two total patients from these two groups have had tests performed at the time of their annual urologic evaluation to determine the phagocytic abilities of their peripheral blood neutrophils, and for the determination of HLA haplotypes. The prevalence of mycoplasma in urine specimens from SCI patients was also determined.

RESULTS—Neutrophil phagocytic and serum opsonic activities against uropathogenic Escherichia coli and Enterococcus fecalis were studied in 17 persons with SCI who had diminished renal function and 25 persons with SCI who had normal renal function. Phagocytic and opsonic activities of neurologically intact persons were also comparatively studied as an additional control group. No differences in efficiency of opsonization or phagocytosis were detected when persons with SCI and impaired renal function were compared with persons with SCI who had normal renal function or neurologically intact controls.

HLA antigens were determined on leukocytes from 48 patients thus far in an attempt to determine whether an association exists between a particular HLA haplotype and predisposition to urologic complications following SCI. Preliminary findings did not show any such association. However, the larger-than-anticipated patient numbers required to prove such an association, should it exist, will necessitate a multicenter study.

We performed a prospective pilot study to determine the frequency with which genital mycoplasmas occur in urine collected by catheterization in males with SCI. U. urealyticum was isolated from the urine of 7/119 (5.9 percent) of recently injured in-patients and 6/102 (5.9 percent) out-patients who were >1 year post injury. Documentation of the presence and persistence of these organisms in bladder urine collected by catheterization represents the first study of this type in men, although the clinical significance of these findings in this or any population has not yet been determined.

FUTURE PLANS—The study has been completed.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Prevalence of ureaplasma urealyticum in urines collected by catheterization from men following spinal cord injury. Waites KB, Canupp KC. In: Proceedings of the American Society for Microbiology 92nd General Meeting, 1992, New Orleans, LA, Abstract G-4.

Epidemiology and risk factors for urinary tract infection following spinal cord injury. Waites KB, Canupp KC, DeVivo MH. Arch Phys Med Rehabil 1993:74:691-5.

Eradication of urinary tract infection following spinal cord injury. Waites KB, Canupp KC, DeVivo MH. Paraplegia 1993:31:645-52.

Phagocytosis of urinary pathogens in persons with spinal cord injury. Waites KB, Canupp KC, DeVivo MJ. Arch Phys Med Rehabil. In press.

[431] ULTRASOUND FOR URINARY TRACT SURVEILLANCE OF PERSONS WITH SPINAL CORD INJURY

L.K. Lloyd, MD
University of Alabama at Birmingham, Birmingham, AL 35233

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Patients with SCI require long-term surveillance to detect and treat urinary tract dysfunction. Because such dysfunction is often asymptomatic, continued screening of patients who appear to be doing well is important. Screening of the urinary tract requires an examination that is sensitive, specific, easily performed, well-tolerated by the patient and cost-effective. The renal ultrasound examination (RUSE) is less invasive than either excretory urography (EXU) or comprehensive renal scintigraphy (CRSP) and, therefore, might further increase the likelihood of patients returning for routine annual evaluations. The RUSE eliminates the risk of ionizing radiation, can be performed in considerably less time than CRSP, and costs substantially less to perform.

Objectives of this project are to determine 1) the sensitivity and specificity of the RUSE compared to CRSP for detecting upper urinary tract abnormalities of persons with SCI, 2) the sensitivity and specificity of the RUSE compared to EXU for detecting upper urinary tract abnormalities of persons with SCI, and 3) the role of the RUSE in the long-term urologic follow-up of persons with SCI.

METHODOLOGY—Standardized data collection instruments and a syllabus have been developed. At this RRTC, CRSP is routinely performed on all patients with SCI who have neurogenic bladders prior to first definitive discharge and annually thereafter.

The RUSE will be performed on a random sample of 10 percent of patients scheduled for routine CRSP. The RUSE will be performed using an ACCUSAN 128 Real Time ultrasound scanner utilizing 3.5 and 5.0 MHz transducers. Renal size, parenchymal thickness, presence, size, and location of calculi; presence, size, location, and character of renal masses; presence and severity of hydronephrosis; size of ureters (normal or enlarged); bladder volume and anterior wall thickness; presence of other abnormalities; and the overall quality of the examination will be recorded. Overall, at least 100 patients will receive both the RUSE and CRSP within four weeks of each other during the five year project time frame. Most will receive both the RUSE and CRSP within two weeks of each other.

EXU is routinely performed only once per person just prior to the first definitive discharge from the rehabilitation hospital. The RUSE will be

performed on a random sample of 25 percent of persons scheduled for EXU. Overall, at least 100 persons will receive both the RUSE and EXU within 2 weeks of each other during the 5 year project time frame. Most will receive the RUSE and EXU on the same day.

RESULTS—A total of 46 patients have been entered into the study. Twenty-five patients have received CRSP, RUSE and EXU all within a two week period. Seven patients received RUSE and EXU within four weeks of CRSP. A total of seven patients who received RUSE and EXU within a two week period received CRSP more than four weeks prior to these. One patient underwent EXU and RUSE and data for CRSP was unavailable due to technical problems. Five patients have received CRSP and RUSE within the two week time frame, but have not received EXU.

Divided by groups the totals are as follows: 30 received CRSP/RUSE within 2 weeks; 7 received CRSP/RUSE within 4 weeks; 39 received EXU/RUSE within 2 weeks. There have been no formal reviews of the data collected to date. Twenty-three informal reviews have been done; however, there have been no conclusions drawn at this time.

FUTURE PLANS—Data collections will continue for three years and formal reviews will be done at the conclusion of the project.

[432] NATURAL HISTORY AND CLINICAL COURSE OF SKIN COMPLICATIONS (EXCLUDING PRESSURE ULCERS) IN PERSONS WITH SPINAL CORD INJURY

Samuel L. Stover, MD; Anna-Margaret Hale, CRRN; Allison B. Buell
University of Alabama at Birmingham, Birmingham, AL 35233

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Persons with spinal cord injury (SCI) frequently develop an array of potentially serious skin complications in addition to the more dramatic pressure ulcer typically associated with spinal paralysis. Examples include superficial and deep bacterial and/or fungal infections, furuncles, abscesses, dermal fibrosis, paronychia and a host of related changes affecting the nail plate, bed, and wall.

The objectives of this study are 1) to establish a clinically useful method to document the occurrence, etiology, definitive characteristics, management, and treatment outcome(s) of all nonpressure ulcer skin lesions occurring in a series of patients with SCI, 2) to determine the nature of the relationship(s), if any, between nonpressure ulcer skin lesions in patients with SCI and specific characteristics of the spinal injury itself (e.g., neurologic level and extent of lesion, time post-injury, etc.), and 3) to develop, print, and distribute a clinically oriented, teaching/training monograph devoted to the photographic documentation and description of nonpressure ulcer skin lesions in patients with SCI.

METHODOLOGY—A prospective study was done at the time of 679 annual SCI clinic visits, at which time a clinical nurse specialist in SCI examined skin and nails for changes or other lesions. Questions about diagnoses were verified with the attending physician. Fingernails and tocnails were examined for hypertrophy, discoloration, and ridging. Photographs were made of skin lesions and nails for future comparisons.

Clinical skin thickening was graded on a 0-4 scale by pinching the skin of the lower lateral thigh between the thumb and index finger. Grade 0 indicated normal skin, and grade 4 indicated severe, almost woody induration of the skin. Only grade 2 or greater were considered a definite change. Autonomic dysreflexia was graded by patient history on a scale of 0-3 according to the severity of the symptoms reported. Study patients were divided into four groups by level of injury. Group I) C1-C8, Group II) T1-T6, Group III) T7-T11, and Group IV) T12 and below.

All persons were grouped according to neurologic level of injury, time since injury, and grade of autonomic dysreflexia.

RESULTS—The most commonly identified skin lesions included chronic acne vulgaris, seborrheic dermatitis, intertrigo with or without moniliasis, contact dermatitis, tinea cruris, tinea pedis, paronychia, folliculitis, furuncles, cellulitis, and generalized dryness and scaling.

Since nail discoloration and ridging occurred infrequently without hypertrophy, and hypertrophy was a more identifiable lesion, only hypertrophy was used for this report. The percentage of persons with nail hypertrophy in each of the 4 patient groups was almost identical, ranging from 12.3 percent in cervical injuries to 6.0 percent in neurologic levels at T12 or below.

Skin thickening of grade 2 or greater was dependent on the level of injury. Skin thickening was seen in 57.9 percent of group I; 31.6 percent of group II; 23.6 percent of group III; and 16.0 percent of group IV. Skin thickening was also seen more frequently during the first 4-5 years after injury and then remains relatively constant. Skin thickening was present in only 21.7 percent of persons without symptoms of autonomic dysreflexia, but was present in 80.0 percent when autonomic dysreflexia was severe.

IMPLICATIONS—Increased attention is needed to learn more about the nonpressure ulcer skin complications. Because dermal collagen is increased most commonly in cervical spinal cord injuries, it suggests that a loss of autonomic nervous system control may have some influence over dermal collagen biosynthesis and influence skin complications.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Skin complications other than pressure ulcers following spinal cord injury (Abstract). Stover SL, Hale AM, Buell AB. J Am Paraplegia Soc 1993:16:115.

Skin complications other than pressure ulcers following spinal cord injury. Stover SL, Hale AM, Buell AB. Arch Phys Med Rehabil. In press.

[433] FUNCTIONAL ASSESSMENT OF THE PERFORMANCE CAPACITY OF THE WHEELCHAIR-USER COMBINATION DURING REHABILITATION

L.H.V. van der Woude; R.H. Rozendal; H.E.J. Veeger; R. Goossens; C.J. Snijders; C. Pons; M. Soede
Vrije Universiteit, Faculty of Human Movement Sciences, 1081 BT Amsterdam, The Netherlands; Institute for Rehabilitation Research, Hoensbroek, The Netherlands; Hoensbroek Rehabilitation Centre, Hoensbroek, The Netherlands; Department of Biomedical Physics and Technology, Erasmus University, Rotterdam, The Netherlands

Sponsor: *Dutch Innovation Research Programme/Assistive Devices for the Disabled*

PURPOSE—A protocol for the functional evaluation of the wheelchair-user combination during the course of rehabilitation was evaluated in the Hoensbroek Rehabilitation Centre. The functional work capacity and performance of the wheelchair-user combination under daily conditions in a group of male spinal cord injured (SCI) subjects were evaluated each month. The results of the tests were evaluated with respect to the course of the rehabilitation process. The value of the protocol with respect to the functional capacity of the wheelchair-user combination, as evaluated in a series of standardized daily activities, was determined. With the exercise tests it appears possible to evaluate the individual progress in rehabilitation and to support a more accurate provision of the wheelchair in terms of functional demands.

METHODOLOGY—Exercise tests are performed on a wheelchair ergometer and daily wheelchair tasks are evaluated on a standardised wheelchair track. Heart rate and ECG are monitored in conjunction with power output and energy cost. Both a sprint protocol and an aerobic maximum exercise test are conducted on the ergometer. The cardiorespiratory stress of several tasks on the wheelchair track is evaluated similarly. For the exercise tests a stationary transportable computer-controlled wheelchair ergometer has been developed in cooperation with Sopur wheelchair manufacturers. It allows standardized exercise testing in conjunction with the study of overall torque and power production.

RESULTS—Seventeen male SCI subjects were subjected to several repeated measurements. The results

of the tests tended to agree with the functional load of the subjects during the wheelchair activities, proving to some extent the validity of the exercise tests. The trend in the individual results of the exercise tests showed a recognizable trend with the progress of rehabilitation. A peak in performance generally was seen some time before the rehabilitation process was concluded. This seems to agree with the fact that patients were waiting for their homes to be adapted, before they finally could leave the rehabilitation centre.

FUTURE PLANS—A follow up study will focuss upon the development of performancc capacity and propulsion technique during and after the conclusion of the rehabilitation process in conjunction with risk factors for cardiovascular disease and aspects of training and efficiency.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Ergonomics of manual wheelchair propulsion: state of the art. Van der Woude LHV, Meijs PJM, Van der Grinten BA, De Boer Y. Amsterdam: Edizioni Pro Juventute, IOS Press, 1993.

Technical requirements of wheelchair exercise testing in rehabilitation field research. Meijs PJM, Michiels KJ, Van der Woude LHV, Veenbaas R, Rozendal RH. In: Ergonomics of Manual Wheelchair Propulsion. Amsterdam: Edizioni Pro Juventute, IOS Press, 1993:61-71.

Physical stress and strain active in wheelchair propulsion: overview of a research programme. Van der Woude LHV, Janssen TWJ, Meijs PJM, Veeger HEJ, Rozendal RH. J Rehabil Sci 1994:7(1):18-25.

[434] PSYCHOSOCIAL ADJUSTMENT OF SPINAL CORD INJURED WHO ARE VICTIMS OF GUNSHOT WOUNDS

Ruby L. Wesley, PhD, RN, CRRN
Nursing Services, Rehabilitation Institute of Michigan, Detroit, MI 48201

Sponsor: *Wayne State University, Minority Faculty Research Award, Women of Wayne Mini Research Award, Rehabilitation Institute of Michigan intramural grant award.*

PURPOSE—This study examines the psychosocial adjustment of spinal cord injured who are victims of violence. In particular the issue of posttraumatic stress disorder was identified as a factor which could affect adjustment. Van der Kolk states that all victims of trauma experience a response that is fairly consistent, no matter what the traumatic experiencc is. However, program development for the spinal cord injured who are victims of violence has not addressed their unique needs from this perspective.

METHODOLOGY—This study examined 51 persons with spinal cord injuries by gunshot wound in the southeastern Michigan region who were 6 months to 5 years post injury. Home visits were made to obtain quantitative data utilizing a semi-structured interview format.

The Wesley Model of Adjustment was developed. The instruments used to mcasure thc constructs of the model are: Posttraumatic Stress Disorder, Brief Symptom Inventory, Meaning in Life Scale, Psychosocial Adjustment to Illness Scale, Ways of Coping Checklist, Social Support, and Reintegration to Normal Living Scale.

RESULTS—Reliability cstimates for internal consistency of the instruments ranged from $r = 0.75$-0.94. The Wesley Model of Adjustment was appropriate for examining the adjustment process. Utilization of the instruments in this study resulted in an explained variance of 32 percent of what is occurring in thc adjustment process; with the present DSM III diagnostic categories, 33.3 percent (17 cases) had posttraumatic stress disordcr; the over 24 years old group had poorer scores of adjustment but a morc positive perception of life than the younger group; the longer the time clapsed since injury, the poorer was the reintegration to normal living score.

IMPLICATIONS—This study identificd that many of the spinal cord injured who arc victims of violence suffer from posttraumatic stress disordcr; programmatic issues related to rehabilitation are being addressed. Additionally, based on the results from this study, the researcher was ablc to have a follow-up study to examine the adjustment process using the focus group methodology for groups of spinal cord injured (intentional vs. unintentional categories based on the Centers for Disease

Control classification). It is the intention of the researcher to develop an intervention study for rehabilitation of spinal cord injured who are victims of violence.

C. Spinal Cord Regeneration

[435] APPLICATION OF ELECTRIC FIELDS TO ENHANCE RECOVERY FOLLOWING SPINAL CORD INJURY

Talat Khan, PhD; Joel B. Myklebust, PhD; Michael Dauzvardis, PhD; Scott Sayers, PhD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141;
Zablocki VA Medical Center, Milwaukee, WI 53295

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #423-2RA)*

PURPOSE—The purpose of this study is to evaluate the effect of electrical stimulation on the injured spinal cord. The goals of this project are to determine whether applied electric fields are more effective in improving functional recovery when injury to the spinal cord is moderate or severe. Recent studies have suggested that the application of small electric fields to injured spinal cord may result in long-term improvements. If these promising results materialize in future studies, the benefit to disabled veterans will be significant.

PROGRESS—The first phase of the study, in which we compared severe contusion injury to moderate contusion injury of the spinal cord, has been completed. Three control groups of animals were studied. Group one sustained a moderate contusion injury (n = 5), group two sustained a severe contusion injury (n = 11), and group three sustained a severe contusion injury with the implantation of non-functional stimulators (n = 5).

METHODOLOGY—Cats weighing 2-2.5 kg were anesthetized with an intramuscular injection of ketamine and xylazine. A laminectomy was performed at T8-T10, and the spinal cord was subjected to a contusion injury at the T9 level. An impact force of 75 newtons was delivered for a moderate contusion injury, and 90 newtons for a severe contusion injury. Animals received daily postoperative care in accord with American Association for Accreditation of Laboratory Animal Care guidelines. All animals were behaviorally and electrophysiologically tested for a 6-month period.

RESULTS—Both severely contused groups (without and with nonfunctional stimulators) displayed similar behavioral findings. After 6 months of testing, these animals showed no visible weight bearing, limited placing reflexes, and hyperreflexive and hyperspastic hindlimb activity. Only 5 out of 16 animals demonstrated vocalization following a mild tail pinch. Moderately contused cats were however capable of limited ambulation, were less spastic and hyperreflexive, and consistently responsive to tail stimulation.

Somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs) were recorded from cats at various intervals after both severe and moderate contusion injuries. In 10 cats which sustained severe contusion injury, SSEPs were recorded in the spinal cord above the lesion site 4 months after injury. Approximately 5 months post-injury, SSEPs were also present in the motor cortex. In 4 out of the 10 cats, at 5 months post-injury, MEPs were also present. In 6 cats which sustained moderate contusion injuries, SSEPs were recorded in the spinal cord above the lesion after approximately 1 month, and in the motor cortex after approximately 2 months. MEPs were also present 2 months post-injury. Cat gait analysis was accomplished using Motion Analysis software on the Sun Sparc Workstation. The movements of retro-reflective markers were digitized, and the angular excursions of the joints were calculated. Based upon

this data, the joint angle profiles, the angular velocities, phase plane plots, and interjoint coordination profiles were computed. The kinematic parameters, the angular excursions, and the peak latencies were tabulated along with the velocities for comparison between groups. The progressive development of interjoint condition was tracked. We are in the process of analyzing the data from cats which sustained severe and moderate contusion injuries.

FUTURE PLANS—We will conduct complete electrical stimulation studies on cats with moderate and severe injuries and continue electrophysiological, behavioral, gait, and histological evaluations.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Electric field distribution within normal cat spinal cord. Khan T, Myklebust JB, Swiontek T. J Neurotrauma. In press.

[436] PREPARATION OF GENETICALLY MODIFIED BDNF AND NT-3 SECRETING FIBROBLASTS AND EVALUATION OF THEIR CAPACITY TO ENHANCE REGROWTH OF INJURED SPINAL CORD FIBERS

Scott T. Sayers, PhD; Talat Khan, PhD; Michael Dauzvardis, PhD
Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL 60141

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Core Funds)*

PURPOSE—Current studies have suggested that regeneration can be encouraged in the damaged mammalian spinal cord by providing trophic factors, and by introducing substrates which provide a favorable attachment surface and also directionality to regrowing axons. Studies in our laboratory have shown that carbon filaments fulfill this criteria, as they act as a scaffold and give directionality to regrowing injured spinal cord axons.

Neurotrophins are proteins which are essential for the survival, target innervation, and function of different populations of neurons. Nerve growth factor (NGF), brain-derived neurotrophic factor (BDNF), and neurotrophin-3 (NT-3) all belong to the same family. The neurotrophins have great potential as pharmacological agents, however, their use for the treatment of spinal cord injury has not been evaluated at present. Recently, through the use of genetic engineering technology, various cell lines can be infected with replicative incompetent retrovirus-based vectors containing the cDNA for NGF, BDNF, or NT-3. Once infected, these cells will then continuously deliver these growth factors.

The primary goal of the present study is to infect fibroblasts with a retrovirus-based vector into which the cDNA for BDNF or NT-3 has been inserted. Once the fibroblasts have been infected, they will be evaluated *in vitro* for the production of these two neurotrophins. The secondary goal of this study is to culture BDNF and NT-3-secreting fibroblasts on carbon filaments, and then to implant them into the lesion sites of spinal cord contused rats. The animals receiving these implants will be electrophysiologically, behaviorally, and histologically evaluated to determine their effect on the regrowth of injured spinal cord axons.

The use of fibroblasts, which have been genetically modified to secrete BDNF or NT-3, have great potential as a means of gene therapy for the treatment of spinal cord injury. This technology, once evaluated in an animal model, can be directly applied to the treatment of human spinal cord injury.

METHODOLOGY—Fibroblasts will be infected with retrovirus-based vectors into which the cDNA for BDNF or NT-3 has been inserted. Virus will be generated from the plasmid forms of the retroviral vectors by transient transfection of PA317 amphotropic retrovirus packaging cells. The resulting virus will then be used for infection of rat fibroblast cells.

Total RNA will be isolated from the BDNF and NT-3-secreting fibroblasts and mRNA levels for these two neurotrophic factors will be evaluated by slot and Northern blots. Levels of BDNF and NT-3 secreted by the fibroblasts will also be measured using a bioassay based on the fact that each

neurotrophic factor is capable of promoting the survival of select populations of PNS and CNS neurons.

BDNF secreting, NT-3 secreting, or regular nonsecreting fibroblasts will be cultured on carbon filaments and then subsequently implanted into the contused rat spinal cord. Electrophysiological evaluations will be performed biweekly and behavioral evaluations will be performed weekly on all animals. At the end of the eight week survival period, all animals will be sacrificed and histological evaluations will be performed.

PROGRESS—At the present time, the BDNF retroviral vector has been constructed and the NT-3 retroviral vector is in the process of being constructed. PA317 amphotropic retrovirus packaging cells have been transfected with BDNF retroviral vector and BDNF retrovirus has been harvested. Fibroblasts have been infected with the BDNF retrovirus and stable BDNF-secreting colonies are being selected.

[437] ION CHANNEL EXPRESSION IN ASTROCYTES

Stephen G. Waxman, MD, PhD
VA Medical Center, West Haven, CT 06516; Department of Neurology, Yale Medical School, New Haven, CT 06520

Sponsor: *Paralyzed Veterans of America/Eastern PVA Center for Neuroscience and Regeneration Research, Spinal Cord Research Foundation*

PURPOSE—Research programs in our Center utilize a variety of cellular and molecular techniques to focus on the pathophysiology of neuronal injury, and recovery of function, in the brain and spinal cord. Disease targets of our research include spinal cord injury, multiple sclerosis, and white matter stroke.

PROGRESS—Astrocytes are specialized glial cells that outnumber neurons within the brain and spinal cord by ten to one. Classically, astrocytes have been considered as "scarring" cells that inhibit regeneration and remyelination following various injuries to the brain and spinal cord. However, there are a variety of reasons for thinking that astrocytes may play more positive roles, possibly promoting recovery of conduction in demyelinated axons. This potential role may be important, both as a mechanism underlying remissions in multiple sclerosis, and as a possible approach to the development of new therapeutic strategies for nonpenetrating spinal cord injury, where our laboratory, along with several others, has demonstrated demyelination.

Earlier work from our laboratory demonstrated that, following chronic demyelination in the brain and spinal cord, some fibers acquire the capability to conduct action potentials supported by sodium channels which are present in higher-than-normal densities in areas denuded of myelin. Our studies demonstrated that sodium channels are inserted in the demyelinated axon membrane at sites of abutment by astrocytes. This led to the hypothesis, that astrocytes might play a role in the reorganization of the demyelinated axon membrane, encouraging the acquisition of clusters of sodium channels. In fact, it has been speculated that astrocytes might function as subsidiary sites for the synthesis of sodium channels which are transferred to nearby axons in the brain and spinal cord.

RESULTS—We have now used a variety of methods to demonstrate that astrocytes, within the brain and spinal cord, express sodium channels. We have used patch clamp methods to characterize the sodium channels that are present in astrocytes. Notably, some astrocytes express sodium channels with physiological properties very close to those of neuronal sodium channels. Moreover, our studies have demonstrated that, under some conditions, astrocytes can synthesize large numbers of sodium channels. In addition, our experiments have demonstrated that production of sodium channels by astrocytes is subject to modulation, via neuronal factors. The neuronal modulation of astrocyte sodium channel expression is highly complex, and depends on the type of neuron involved, as well as the type of astrocyte. Interestingly, spinal cord astrocytes have the capability to produce uniquely high densities of

sodium channels in the absence of neurons, consistent with an up-regulation of sodium channel synthesis in these cells following spinal cord injury.

We have also used molecular biological techniques including *in situ* hybridization and polymerase chain reaction (PCR) to identify the messages (mRNAs) for sodium channels that are present in astrocytes, to study the expression of sodium channel MRNA in astrocytes. These techniques demonstrate that astrocytes produce the MRNA for rat brain sodium channels, which had previously been considered as neuronal sodium channels. We are attempting to clone unique glial-specific ion channels.

All of these lines of evidence are converging and demonstrating that astrocytes have the capability to produce sodium channels similar to those that are present in neurons.

FUTURE PLANS—We are now beginning to study astrocytes derived from the injured spinal cord. We hope that these studies will provide a better understanding of the glial scar, and of the role of astrocytes in recovery from demyelination. Hopefully, these studies will lead to the development of new, more effective therapeutic strategies for multiple sclerosis and spinal cord injury.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Expression of voltage-activated ion channels by astrocytes and oligodendrocytes in the hippocampal slice. Sontheimer H, Waxman SG. J Neurophysiol 1993:70:1863-73.

Ion channels in spinal cord astrocytes *in vitro*: 111. modulation of channel expression by co-culture with neurons and neuron-conditioned medium. Thio CL, Waxman SG, Sontheimer H. J Neurophysiol 1993:69:819-31.

Expression of rat brain voltage-sensitive NA + channel mrnas in astrocytes. Oh Y, Black JA, Waxman SG. Mol Brain Res 1994:23:57-65.

[438] PHYSIOLOGICAL EFFECTS OF GLIAL CELL TRANSPLANTATION IN THE MYELIN-DEFICIENT SPINAL CORD

Stephen G. Waxman, MD, PhD
VA Medical Center, West Haven, CT 06516; Department of Neurology, Yale Medical School, New Haven, CT 06520

Sponsor: *Paralyzed Veterans of America/Eastern PVA Center for Neuroscience and Regeneration Research, Spinal Cord Research Foundation*

PURPOSE—Research programs in our Center utilize a variety of cellular and molecular techniques to focus on the pathophysiology of neuronal injury, and recovery of function, in the brain and spinal cord. Disease targets of our research include spinal cord injury, multiple sclerosis, and white matter stroke.

PROGRESS—Over the past three years, we have carried out studies to examine the physiological effect of transplantation of myelin forming cells in the myelin-deficient spinal cord. These studies have been carried out in our Center by a team that includes Professor J.D. Kocsis and David Utzschneider (an MD, PhD student at Yale) in addition to myself, in collaboration with Drs. Ian Duncan and David Archer at University of Wisconsin.

In these studies, we have used electrophysiological methods to study the effects of myelin formation by transplanting glial cells in the myelin-deficient spinal cord. Previous studies had demonstrated that exogenous, transplanted glial cells can produce morphologically intact myelin in the myelin-deficient nervous system, but no studies had been carried out to study the functional effects of myelin formation by exogenous cells. This is a crucial question, since computer simulations and biophysical studies had demonstrated that myelin formation, per se, might not necessarily improve conduction in myelin-deficient axon; in fact, some patterns of myelin formation by exogenous cells might even be expected to interfere with conduction. In these studies, both field potential recordings and intracellular recordings were used.

RESULTS—These experiments have demonstrated that myelination by exogenous, transplanted glial cells, in the myelin-deficient spinal cord, leads to a striking increase (nearly 4-fold) in axonal conduction velocity. Axonal conduction velocities approach normal values as a result of transplantation of glial cells and subsequent myelination. Moreover, our studies demonstrate that, in the transplanted spinal cord, action potentials can propagate from myelin-deficient regions into zones where myelination has occurred and, conversely, from myelinated regions into myelin-deficient zones. These studies provide, for the first time, a demonstration of enhanced function in myelin-deficient axons as the result of cell transplantation.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Transplantation of glial cells enhances action potential conduction of amyelinated spinal cord axons in the myelin deficient rat. Utzschneider DA, Archer DR, Kocsis JD, Waxman SG, Duncan ID. Proc Natl Acad Sci 1994:91:53-57.

Delayed depolarization and slow sodium currents in cutaneous afferents. Honmou O, Utzschneider DA, Rizzo MA, Waxman SG, et al. J Neurophysiol. In press.

[439] STUDIES ON SECONDARY INJURY IN ANOXIC WHITE MATTER

Stephen G. Waxman, MD, PhD
VA Medical Center, West Haven, CT 06516; Department of Neurology, Yale Medical School, New Haven, CT 06520

Sponsor: *Paralyzed Veterans of America/Eastern PVA Center for Neuroscience and Regeneration Research, Spinal Cord Research Foundation*

PURPOSE—Research programs in our Center utilize a variety of cellular and molecular techniques to focus on the pathophysiology of neuronal injury, and recovery of function, in the brain and spinal cord. Disease targets of our research include spinal cord injury, multiple sclerosis, and white matter stroke.

PROGRESS—Considerable research has focused, over the past several years, on mechanisms of secondary injury, whereby cells die, days to hours following a pathologic insult, in response to self-destructive metabolic events in gray matter (which contain synapses) of the brain and spinal cord. Given our interest in spinal cord injury, however, we wished to understand the mechanisms underlying secondary injury in white matter (which contains myelinated axons and associated glial cells, but not synapses). Thus, Professor Bruce Ransom and I, together with Drs. Peter Stys (visiting Assistant Professor) and Robert Fern (Postdoctoral Fellow) have carried out studies to examine the pathophysiology of anoxic injury in a model white matter tract, the rat optic nerve. Over the past several years, these studies have demonstrated that anoxic injury in the rat optic nerve is critically dependent on influx of calcium. This calcium influx is mediated by reverse operation of the sodium-calcium exchanger, a specialized molecule that exchanges sodium ions for calcium ions. This reverse exchange is triggered by influx of sodium via voltage-sensitive sodium channels.

RESULTS—Over the past year, our studies have demonstrated that the influx of sodium, in the anoxic optic nerve, is largely mediated via a unique group of sodium channels (i.e. persistent, or non-inactivating, sodium channels). In simple terms, these sodium channels do not inactivate (or close) when subjected to sustained depolarization. As a result, they mediate a large influx of sodium in the anoxic optic nerve.

Having demonstrated the contribution of persistent sodium conductance to calcium-mediated injury in the optic nerve, we have more recently studied normal optic nerve axons. Our experiments,

using grease-gap recording methods which permit uniquely sensitive measurement of membrane potential, have clearly demonstrated the presence of persistent sodium channels in the optic nerve.

We are currently following up on these exciting findings, and are continuing to dissect the molecular mechanisms that are involved in calcium-mediated injury in white matter.

FUTURE PLANS—Our goal in these studies is the development of therapeutic strategies that would limit neuronal death following various pathologic injuries to white matter. Hopefully, these therapeutic strategies will be applicable to both spinal cord injury and white matter stroke.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Ionic mechanisms of anoxic injury in mammalian CNS white matter: role of Na+ channels and Na+-Ca^{2}+ exchanger. Stys PK, Waxman SG, Ransom BR. J Neurosci 1992:12:430-9.

Ultrastructural concomitants of anoxic injury and early post-anoxic recovery in rat optic nerve. Waxman SG, Black JA, Stys PK, Ransom BR. Brain Res 1992:574:105-19.

Molecular dissection of the myelinated axon. Waxman SG, Ritchie JM. Ann Neurol 1993:33:121-36.

Protection of the axonal cytoskeleton in anoxic optic nerve by decreased extracellular calcium. Waxman SG, Black JA, Ransom BR, Stys PK. Brain Res 1993:614:137-45.

Sodium channel mRNAs in cultured spinal cord astrocytes: *in situ* hybridization in identified cell types. Black JA, Yokoyama S, Waxman SG et al. Mol Brain Res. In press.

[440] MOLECULAR ORGANIZATION AND PHARMACOLOGY OF MAMMALIAN AXONS

Stephen G. Waxman, MD, PhD
VA Medical Center, West Haven, CT 06516; Department of Neurology, Yale Medical School, New Haven, CT 06520

Sponsor: *Paralyzed Veterans of America/Eastern PVA Center for Neuroscience and Regeneration Research, Spinal Cord Research Foundation*

PURPOSE—Research programs in our Center utilize a variety of cellular and molecular techniques to focus on the pathophysiology of neuronal injury, and recovery of function, in the brain and spinal cord. Disease targets of our research include spinal cord injury, multiple sclerosis, and white matter stroke.

PROGRESS—We are examining the ionic mechanisms underlying action potential conduction in mammalian axons. Our work has demonstrated, in this regard, that 'fast' potassium channels, sensitive to drugs such as 4-aminopyridine (4-AP), are present in the axon membrane under the myelin. Following damage to the myelin, the 'fast' potassium channels are unmasked so that they interfere with conduction.

Our early experiments suggested that, by blocking the unmasked potassium channels with drugs, it might be possible to improve conduction in demyelinated axons. Our laboratory, together with several others, subsequently showed that applying 4-AP to demyelinated fibers, it is possible to improve the safety factor. This was followed by clinical trials which showed transient improvements in symptomatic status in multiple sclerosis patients treated with 4-AP. However, the clinical usefulness of 4-AP is limited by side effects which include paresthesias (pins and needles tingling).

RESULTS—Recently, we have carried out studies in which we have examined the basis for these side effects. Our studies have demonstrated that they are due to repetitive impulse activity, generated by slowly inactivating sodium channels in cutaneous sensory axons. Our experiments showed, however, that slowly inactivating sodium channels are not, however, present in muscle afferent axons. This explains why abnormal motor activity is much less common than tingling and paresthesias in patients treated with 4-AP and related drugs.

Our studies are the first to demonstrate a molecular differentiation of cutaneous sensory axons, compared to muscle afferent fibers.

FUTURE PLANS—We are continuing our molecular dissection of these various types of axons, with the goal of better understanding their ion channel organization. Hopefully, as we better understand the ion channel organization of these various classes of fibers, we can develop pharmacologic approaches that will permit therapeutic manipulation conduction in these axons, without producing unacceptable side effects.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Molecular dissection of the myelinated axon. Waxman SG, Ritchie JM. Ann Neurol 1993:33:121-36.

[441] TRANSPLANTS OF ENSHEATHING GLIA FROM ADULT OLFACTORY BULB FACILITATE AXON REGENERATION IN THE CNS

Manuel Nieto-Sampedro, PhD; Paola Bovolenta, PhD; Almudena Ramón-Cueto, Lda; Isabel Fernaud Espinosa, Lda;
Neural Plasticity Group, Cajal Institute of Neurosciences, CSIC, Madrid, Spain

Sponsor: The Spanish Research and Development National Plan, Grants FAR 89-0683 and SAF-212/92; the Madrid Autonomous Community, Grant A 0132/92 and Boehringer Ingelheim España, S.A.

PURPOSE—We believe that neural plasticity is the result of glia-neuron interactions and that understanding these interactions will permit functional repair of damaged CNS.

METHODOLOGY—Olfactory axons are the only fibers capable of navigating towards their targets in an adult CNS environment. We hypothetized that they could do it thanks to the properties of ensheathing cells, a special kind of glia, unique to the olfactory system. Ensheathing glia were cultured from adult olfactory bulb, immunohistochemically characterized and shown that they could enfold axons *in vitro*. Immunopurified cells, transplanted in the rhizotomized rat spinal cord, permitted the ingrowth and navigation in the cord of regenerating sensory axons. In the immediate future, we will explore the possible generalization of this intervention to other CNS fiber systems, to permit regeneration of pure central axons, such as optic nerve or corticospinal fibers.

PROGRESS—*Purification of Neurite Outgrowth Inhibitors from Reactive Glia.* Distinct temporal patterns of glial reactivity were observed in astrocytes and microglia after anisomorphic (stab wound) and isomorphic (intraventricular kainic acid) injuries. Isomorphic gliotic tissue contained the greatest neurite outgrowth inhibitory activity. With the help of an *in vitro* glial scar model, the inhibitory molecules were partially purified and characterized. They are heparan-sulfate/chondroitin-sulfate proteoglycans, of molecular weight about 250 kDalton and core protein of 48 kDalton, probably located in reactive microglial cells. Definitive studies on their cellular location and function depend on the preparation, now in progress, of specific monoclonal antibodies against them.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Anatomical, physiological and behavioral effects of chronic MK-801 administration to adult and developing rats. Nieto-Sampedro M, Bailon C, Rivas F, Moreno MT. In: Cuello AC, ed. Neuronal cell death and repair. New York: Elsevier, 1993:89-104.

Differences between reactive astrocytes and cultured astrocytes treated with dibutiryl-cyclic AMP. Wandosell F, Bovolenta P, Nieto-Sampedro M. J Neuropathol Exper Neurol 1993:52:205-15.

Differential activation of microglia and astrocytes in aniso- and iso-morphic gliotic tissue. Fernaud-Espinosa I, Nieto-Sampedro M, Bovolenta, P. Glia 1993:8:277-91.

In vitro enfolding of olfactory neurites by p75 NGF receptor positive ensheathing cells from adult rat olfactory bulb. Ramon-Cueto A, Perez J, Nieto-Sampedro M. Eur J Neurosci 1993:5:1172-80.

Regeneration of damaged dorsal root axons into the spinal cords is promoted by ensheathing glia from adult rat olfactory bulb. Ramon-Cueto A, Nieto-Sampedro M. Eur J Neurosci sup 1993:6:288.

Regeneration into the spinal cord of transected dorsal root axons is promoted by ensheathing glia transplants. Ramon-Cueto A, Nieto-Sampedro M. Exp Neurol. In press.

XV. Wheelchairs and Powered Vehicles

A. General

[442] DEVELOPMENT AND TESTING OF CLINICAL WORKSTATION FOR THE REDUCTION OF WHEELCHAIR PROPULSION INJURIES

Rory A. Cooper, PhD; W. Edwin Langbein, PhD; Rick N. Robertson, PhD; David P. VanSickle, MS; Greg Ensminger, BS; Steve J. Albright, BS; Ken J. Stewart, BS; Sean Shimada, BS; Mike L. Boninger, MD
Departments of Rehabilitation Science and Technology, Bioengineering Schools of Health and Rehabilitation Science, Engineering, and Medicine, and Orthopedic Surgery, University of Pittsburgh, Pittsburgh, PA 15261; Human Engineering Research Laboratories, VA Medical Center, Pittsburgh, PA 15206; Rehabilitation Research and Development Center, Edward Hines Jr. VA Hospital, Hines, IL, 60141; Department of Health and Physical Education, and Biomedical Engineering, Biomechanics and Human Engineering Laboratories, California State University, Sacramento, CA, 95819-6073

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B686-RA)*

PURPOSE—The purpose of this research is to develop instrumentation to study the kinetics, and net joint moments/forces during wheelchair propulsion. With this instrumentation, the biomechanics of wheelchair propulsion can be analyzed in greater depth. The goal of this project is to aid in manual wheelchair prescription and design so the risk of repetitive strain injury to the upper extremities is minimized while maximal function for activities of daily living is maintained. The clinical workstation is also used to assess upper extremity injury and medical interventions.

METHODOLOGY—The clinical workstation for the reduction of wheelchair propulsion injuries consists of a computer controlled wheelchair dynamometer which controls/measures speed and torque, a six degree-of-freedom force/torque sensing SMART^{wheel}, and a three camera video bases motion analysis system. We have begun to integrate surface EMG into the system. All of the components of the system are synchronized through a master computer. We used several different protocols to assess wheelchair propulsion biomechanics. Metabolic data is collected during each test.

PROGRESS—We have constructed four SMART^{wheel} systems, and have developed data acquisition (kinetic and kinematics) software, numerically efficient net joint moment/force algorithms and software, data analysis and display software, and a microcontroller-based DOS computer interface. Two of the clinical workstations are being used and evaluated in clinical sites and two are being used in research laboratories. Modifications have been made in the mechanical hardware to improve sensitivity, linearity, and reliability. The SMART^{wheel} electronics have been refined to interface directly to the serial port of a computer and are more reliable. We have also done some preliminary work on developing a real-time video image processing system to interface with the clinical workstation.

RESULTS—Data collected from 30 subjects indicates that real-time feedback of kinetic, kinematics, and multimodal data may be critical to effective assessment and intervention to control potentially injurious stroke kinetics and kinematics. We have identified biomechanical markers associated with experience, economy, efficiency, and risk of injury. Our results suggest that useful information related

to manual wheelchair propulsion is obtained in the kinematics and kinetic data, and when combined to estimate joint moments/forces more powerful assessments can be made.

FUTURE PLANS—Over the last 3 years we have been able to affect changes in the selection of wheelchairs, and medical treatment of shoulder injuries. Currently, the system does not provide information in real-time, which we believe is critical to successful clinical applications of the system. We intend to continue refining the electronics of the SMART^{wheel} (e.g., decrease the size, include wireless infrared communication, add on-wheel memory, and reduce power consumption). We envision integrating an improved digital SMART^{wheel}, real-time image processing, and EMG. In addition, software and mathematical models require further development. Models with more realistic anatomical constraints need to be integrated into the workstation. From the perspective of a researcher, the current system provides a considerable amount of useful information, but this information may be overwhelming to the clinician. Methods for analyzing and presenting data in a format that is efficient and meaningful to clinicians must be developed.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Kinetic characteristics of wheelchair propulsion utilizing the SMART^{wheel}. Robertson RN, Cooper RA. In: Proceedings of the 17th Annual Meeting of the American Society of Biomechanics, 1993:202-3.

Recursive back propagation algorithm for computing net muscle moments and net joint forces. Cooper RA, Robertson RN, VanSickle DP. In: Proceedings of the 16th Annual RESNA Conference, 1993, Las Vegas, NV. Washington, DC: RESNA Press, 1993:277-9.

SMART^{wheel}: development and testing of a system for measuring manual wheelchair propulsion dynamics. Asato KT, Cooper RA, Robertson RN, Ster JR. IEEE Trans on Biomed Eng 1993:40:1320-4.

Smoothing of wheelchair propulsion kinematic data. Cooper RA, Robertson RN, VanSickle DP. In: Proceedings of the 15th Annual Conference IEEE Engineering in Medicine and Biology Society, 1993, San Diego, CA, 1296-7.

Wheelchair injury clinical workstation: method for determining a characteristic stroke. Cooper RA, Robertson RN, VanSickle DP, Langbein WE, Fehr L. In: Proceedings of the 15th Annual Conference of the IEEE Engineering in Medicine and Biology Society, 1993, San Diego, CA, 1294-5.

Upper extremity net joint forces and moments during wheelchair propulsion. Robertson RN, Cooper RA, Ensminger GJ, Stewart KJ. In: Proceedings of the 17th Annual RESNA Conference, 1994, Nashville, TN. Washington, DC: RESNA Press. In press.

[443] SCI RESPONSES TO WHEELCHAIR PROPULSION DURING FATIGUE: A PILOT STUDY

Mary M. Rodgers, PT, PhD; G. William Gayle, PhD; Stephen F. Figoni, RKT, PhD; Masuo Kobayashi, PhD; Roger M. Glaser, PhD; Satyendra C. Gupta, MD

VA Medical Center, Dayton, OH 45428; Institute for Rehabilitation Research and Medicine, Wright State University Research Center, Dayton, OH 45420; Dept. of Health & Physical Education, Wright State University, Dayton, OH 45435

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B90-87AP)*

PURPOSE—The goal of this one-year pilot project was to evaluate the responses of nonathletic spinal cord injured (SCI) wheelchair users to wheelchair propulsion during fatigue. Two objectives to accomplish this goal were: 1) to examine how the physical characteristics of SCI wheelchair users relate to upper extremity stresses, and 2) how wheelchair propulsion biomechanics change with fatigue during wheelchair locomotion.

METHODOLOGY—Twenty male paraplegics were videotaped during wheelchair propulsion for two tests conducted on separate days: 1) a test to determine peak physiologic responses, and, 2) a test to determine biomechanical changes with fatigue. A stationary, instrumented wheelchair positioned on a roller with adjustable frictional resistance was used for data collection. Heart rate and oxygen uptake (VO_2) were monitored continuously during each test

using a metabolic cart and ECG. Force was detected via strain gauges in the wheelchair handrim support brackets and force data were collected via computer. Reflective markers locations (wheelchair hub, wheel rim, hip, shoulder, elbow, wrist, and fifth metacarpophalangeal joint) were computer digitized from videotape to provide three-dimensional (3D) displacement data. Videotaped movements were analyzed using a computerized 3D motion analysis system.

PROGRESS—Upon completion of this project, a total of 20 nonathletic male paraplegic subjects participated. Computer software was developed to enable the three-dimensional analysis of joint reaction forces and moments during wheelchair propulsion. Average subject age was 36 ($\pm$8.1) years and average time since injury was 10.5 ($\pm$11.4) years. All participants were paraplegic, with injury levels ranging from T4 to L4 (10 complete and 10 incomplete SCI). All subjects were medically screened and measured for anthropometric and isokinetic upper extremity strength.

RESULTS—Test results showed average peak VO_2 was 1530.1$\pm$462.8 mL/min, at 50 percent load 815.9$\pm$242.2 mL/min, and at 75 percent load 1158.9$\pm$369.9 mL/min. Heart rate was 114.2$\pm$18.3 bpm and 147.3$\pm$31.2 bpm for 50 percent and 75 percent loads, respectively. Correlational analysis of peak handrim force with upper extremity strength measurements revealed significant relationships with concentric shoulder flexion ($r=0.65$), eccentric/concentric elbow flexion ($r=0.53$), and eccentric/concentric elbow extension torques ($r=0.71$). No significant relationships were found between handrim force and anthropometric measurements. Significant kinematic/kinetic changes with fatigue were found in the peak handrim force, ulnar/radial deviation, and trunk angles. Highest calculated joint reaction forces occurred in the wrist joint in the tangential (mediolateral) direction. Highest calculated joint moments and power were located at the shoulder joint.

FUTURE PLANS—Results from this pilot study indicated that wheelchair propulsion may predispose certain joints (i.e., the wrist) to musculoskeletal overuse problems, whereas other joints (i.e., the shoulder) may be more susceptible to musculotendinous types of overuse injury. Findings appear consistent with the incidence of injury in the SCI wheelchair-using population in general. Continuation of this work will focus upon further evaluation of wheelchair propulsion biomechanics in the elderly and in individuals with different disabilities. We expect that the understanding of wheelchair propulsion biomechanics will result in more effective measures for prevention of injuries in wheelchair users.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Kinematic and kinetic responses to wheelchair propulsion during fatigue in SCI individuals: a pilot study. Rodgers MM, Gayle GW, Figoni SF, et al. In: Proceedings of the RESNA International '92 Conference, 1992, Toronto, ON. Washington, DC: RESNA Press, 1992:202-4.

Multibody dynamics for biomechanical systems. Lieh J, Rodgers MM, Tummarakota S, Schrag DR. Advances in Bioengineering ASME Winter Annual Meeting, 1992:22:597-600.

Multidisciplinary data acquisition and analysis of wheelchair ergometry. Kobayashi M, Rodgers MM, Figoni SF, et al. J Biomech 1992:25:768.

Three-dimensional dynamic analysis of joint reaction forces and moments during wheelchair propulsion. Rodgers MM, Tummarakota S, Lieh J, Schrag DR. In: Draganich L, Wells R, Bechtold J, eds. Proceedings of the Second North American Congress on Biomechanics, Chicago, IL, 1992:457-8.

Biomechanics of wheelchair propulsion during fatigue. Rodgers MM, Gayle GW, Figoni SF, Kobayashi M, Glaser RM. Arch Phys Med Rehabil 1994:75:85-93.

[444] WHEELCHAIR PROPULSION PERFORMANCE IN YOUNG, MIDDLE-AGED, AND ELDERLY

Mary M. Rodgers, PT, PhD; G. William Gayle, PhD; Stephen F. Figoni, RKT, PhD; Roger M. Glaser, PhD; Satyendra C. Gupta, MD; Watson D. Parker, MD

VA Medical Center, Dayton, OH 45428; Institute for Rehabilitation Research and Medicine, Wright State University Research Center, Dayton, OH 45420; Dept. of Health & Physical Education, Wright State University, Dayton, OH 45435

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B764-RA)*

PURPOSE—Results from a pilot study of wheelchair propulsion (Project #B90-87AP) suggested some age-related trends in wheelchair propulsion, and that certain interventions (i.e., therapeutic exercises which stretch or strengthen certain muscle groups) might prevent specific types of overuse injuries. The purpose of this three-year continuation research program is twofold: 1) to investigate how wheelchair performance compares among three different age groups of disabled (lower-limb impaired) wheelchair users; and 2) to test a specific exercise intervention for its effectiveness in reducing potentially injury-producing biomechanical characteristics and excessive physiologic stresses.

METHODOLOGY—Sixty wheelchair users in three age groups of n = 20 (20-39, 40-59, and 60-79 years) will participate in this study. Body measurements, muscle strength, neuromuscular assessments, and wheelchair propulsion testing will be performed before and following exercise training. The first wheelchair graded exercise test will include incremental increases in wheelchair handrim resistance to determine peak physiologic responses. The second test will be a prolonged fatigue test consisting of wheelchair propulsion exercise at 75 percent peak oxygen consumption (VO_2) until volitional fatigue is achieved. Handrim force, wheel velocity, heart rate (HR) and VO_2 will be monitored during each data collection session. Upper-extremity and trunk movement will be videotaped using a 3D motion analysis system to obtain kinematic data. Telemetered electromyography using surface electrodes will be used to document upper-extremity muscle activity patterns during testing. Shoulder, elbow, and wrist-joint kinetics (joint moments and joint reaction forces) will be calculated from the motion and handrim force data. After initial testing, each subject will participate in a specific intervention program of therapeutic exercise (stretching/strengthening and aerobic training) three times weekly for six weeks. Wheelchair tests will be repeated at the end of the training program to determine changes in stresses.

PROGRESS—During the initial 11 months of this project, the wheelchair ergometer has been designed, constructed, calibrated, and tested. This ergometer includes handrim transducers on each side which detect forces in three-dimensions, precise power output (PO) measurement using a flywheel friction system, and a wheelchair seat which can be adjusted for width and height to accommodate individuals of different sizes. The three dimensional (3D) motion analysis system was modified to allow simultaneous collection of kinematic data from both left and right sides during wheelchair propulsion. Computer software developed to enable the 3D analysis of joint reaction forces and moments during wheelchair propulsion was modified to accommodate the new ergometer system and to allow analysis of both right and left sides. A total of 19 subjects have been medically screened. Twelve subjects (11 paraplegics and 1 amputee, 2 females and 10 males) have undergone pre-exercise testing (anthropometric, isokinetic upper extremity strength, and wheelchair testing measurements). Three subjects are in the first group to complete the exercise training and are currently being post-tested.

RESULTS—Initial peak wheelchair testing (n = 5, age 48 ± 15, height 181 ± 10 cm, weight 82 ± 27 kg) has been completed. Peak VO_2 was 1.1 ± 0.4 l/min, 75 percent VO_2 was 0.8 ± 0.3l/min, peak HR was 143 ± 6 bpm. Seventy-five percent HR was 107 ± 5 bpm, peak load was 1650 ± 379 gm, and 75 percent load was 970 ± 311 gm. Example fatigue wheelchair testing (n = 1) resulted in the following fresh/

fatigued condition changes: 9.5 N increase in tangential force, 18 N increase in radial force, no change in medial/lateral force, and a 1 Nm increase in all three moments.

FUTURE PLANS—Testing and exercise training will continue until the desired sample size is reached (n = 60). Determination of age-related characteristics which are related to high joint stresses, and evaluation of potential injury-reducing interventions is expected to provide the necessary foundation for optimizing wheelchair function.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Biomechanics of wheelchair propulsion during fatigue. Rodgers MM, Gayle GW, Figoni SF, Kobayashi M, Glaser RM. Arch Phys Med Rehabil 1994:75:85-93.

[445] TOWARD THE DESIGN OF A NEW BOWEL CARE/SHOWER CHAIR: A PILOT STUDY

Pascal Malassigné, MID, IDSA; Audrey L. Nelson, RN, PhD; Thomas L. Amerson, PhD; Richard Saltzstein, MD; Joseph E. Binard, MD
Research Service, Spinal Cord Injury Center, Clement J. Zablocki VA Medical Center, Milwaukee, WI 53295; Nursing Service, James. A. Haley VA Medical Center, Tampa FL 33612; US Naval Medical Research Institute, Bethesda, MD 20814

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B91-245-AP)*

PURPOSE—This study involved evaluation of three commonly used bowel care/shower chairs at the Milwaukee and Tampa VA SCI Centers.

METHODOLOGY—The chairs were evaluated with respect to patient transfer and mobility, accessibility for bowel care and showering, static stability, and evaluation of seat pressure. Videotaping, photography, and administration of questionnaires were used during the evaluation.

RESULTS—Traum-Aid chair. The following deficiencies were noted: 1) the chair cannot be properly rolled over a toilet, 2) the seat is too small to hold patients properly, 3) the foam cushioning is too thin and the seam on its surface can cause pressure sores, 4) the support bar, under the seat, blocks hand access for digital stimulation, 5) the arm rests are too narrow and too high for proper use, 6) the footstraps held by bolts, cut the unprotected feet of users, 7) the brakes cannot be activated by patients, and 8) too much of the body surface is covered by the chair, limiting access for showering.

Lumex chair. The following deficiencies were noted: 1) the chair cannot be properly rolled over a toilet, 2) the seat is too small to hold patients, 3) the cushioning of the seat does not wrap around the support board, leaving the wood exposed predisposing patients to cuts or pressure sores, 4) the armrests are not padded, too high, and too narrow, 5) the foot-rests are difficult to adjust and their footstraps are held by bolts that cut unprotected feet of users, 6) the backrest of the chair is not adjustable, and 7) the brake handles, located above the wheels, cut or bruise the patient's hands and are inoperable when the tire pressure is low predisposing the patients to serious injuries due to falls.

E&J chair. The following deficiencies were noted: 1) the chair cannot be properly rolled over a toilet, 2) the armrests are not padded and are not adjustable, 3) the footrests are adjustable but do not have the heel-straps needed to prevent foot injury due to spasms, 4) the brakes have the tendency to fail, resulting in falls and injuries during transfers, 5) the wheel rim's area for hand placement is too narrow for quadriplegics to hold and push independently, 6) the chair is unstable and has a tendency to tip over during transfer or transport, and 7) accessibility for digital stimulation is poor.

FUTURE PLANS—This study indicated that there were severe design deficiencies in these chairs. They were found to be unsafe, inconvenient, and ineffective for bowel elimination and showering. The

results of this study were incorporated in a VA Rehabilitation R&D research proposal to design new bowel care-shower chairs. With the approval of this proposal, design and development work is expected to begin in october 1994.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Descriptive study of bowel care practices and equipment in spinal cord injury. Nelson A, Malassigne P, Amerson T, Binard J, Saltzstein R. SCI Nurs 1993:10(2).

Evaluation of three bowel care/shower chairs. Malassigne P, Nelson A, Amerson T, Binard J, Saltzstein R. In: Proceedings of 16th Annual RESNA Conference, 1993, Las Vegan, NV. Washington, DC: RESNA Press, 1993:271-3.

Toward the design of a new bowel care chair for spinal cord injury. Malassigne P, Nelson A, Amerson T, Binard J, Saltzstein R. SCI Nurs 1993:10(3).

Comparison of seat pressures on three bowel care/shower chairs in spinal cord injury. Nelson A, Malassigne P, Murray J. SCI Nurs 1994:11(3).

Determination of static stability on bowel care/shower chairs. Malassigne P, Nelson A., Amerson T. In: Proceedings of 17th Annual RESNA Conference, 1994, Nashville, TN. Washington, DC: RESNA Press. In press.

[446] ERGONOMICS OF MANUAL WHEELCHAIR PROPULSION

L.H.V. van der Woude; H.E.J. Veeger; R.H.Rozendal
Vrije Universiteit, Faculty of Human Movement Sciences, 1081 BT Amsterdam, The Netherlands

Sponsor: *Innovation Research Programme/Assistive Devices for the Disabled*

PURPOSE—Manual wheelchair propulsion is studied with a combined physiological and biomechanical approach. The general aim is to improve the mobility of wheelchair users, as far as the wheelchair-user combination is concerned. Important areas of research are currently the factors influencing the wheelchair-user interaction in terms of functional load and mechanical efficiency, and the factors influencing the work capacity and power output (among others: functionality and propulsion technique) of the wheelchair user as the 'motor' in wheelchair mobility.

METHODOLOGY—Wheelchair propulsion is being studied during standardized aerobic exercise and sprint tests on a motor driven treadmill and during simulated conditions on a computer controlled wheelchair ergometer. During the treadmill tests (studies on prototype-evaluation, performance capacity, propulsion technique) physiology is combined with 3-D kinematics and electromyography. On the wheelchair ergometer an additional 3-D reconstruction of the movement pattern of arms and trunk is combined with measures of force and power production, electromyography of upper arm and trunk muscles, and overall physiology. An inverse dynamics segment model of the upper extremity and shoulder regime is used to interprete cardio-respiratory phenomena and measures of efficiency from a biomechanical and anatomical perspective. A model of shoulder complex allows simulation of static and dynamic activity of shoulder muscles during wheelchair propulsion. The model also allows the calculation of joint forces and muscle forces and torque.

PROGRESS—Linear speed of the hand during the push phase has a major impact on energy cost, efficiency, and technique. The effectiveness of force production onto the hand rim reduces with increased linear hand velocity (i.e., mechanical advantage). Also a negative twisting torque produced by the hand onto the surface of the rim is seen during wheelchair propulsion and increases with rim velocity, as do the negative deflections at start and end of the push phase. Another critical phenomenon is the medio-lateral force component perpendicular to the plane of the rim. It seems an ineffective force component, but is probably a necessary aspect of technique to ensure sufficient friction between hand and rim. Moreover, the major pectoral muscle is a prime mover of the shoulder but has an adducting and endo-rotating effect on the arm, leading to a medio-lateral force of hand on the rim. Results on 68 wheelchair athletes show a clear association between technique parameters, performance capacity, and the functionality of the subject. This leads

to highly significant correlations between power output and technique parameters at the individual level. At a group level this relationship was more obscure indicating that different technique factors vary among groups of disabled athletes in their relation with performance.

FUTURE PLANS—Fitting guidelines will be evaluated for groups of disabled subjects during the process of rehabilitation. Different forms of arm work will be studied with respect to mechanical effectiveness of force production among different groups of disabled subjects and in different modes of arm work.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Biomechanical aspects of wheelchair propulsion. Veeger HEJ. Academic Thesis, Vrije Universiteit, Amsterdam, 1992.

Computerized wheelchair ergometer: a comparison study. Veeger HEJ, Van der Woude LHV, Rozendal RH. Scan J Rehabil Med 1992:24:17-23.

Differences in performance between trained and untrained subjects during a 30 sec. sprint test in a wheelchair ergometer. Veeger HEJ, Lute EMC, Roeleveld K, Van der Woude LHV, Eur J Appl Physiol 1992:64:158-64.

Ergonomics of manual wheelchair propulsion: state of the art. Van der Woude LHV, Meijs PJM, Van der Grinten BA, De Boer Y. Amsterdam: Edizioni Pro Juventute, IOS Press, 1993

Physiological evaluation of a newly designed lever mechanism for wheelchairs. Van der Woude LHV, Veeger HEJ, Rozendal RH. J Med Eng Tech 1993:17(6):232-40.

Peak power production in wheelchair propulsion. Van der Woude LHV, Drex HD, Veeger HEJ, Clin J Sport Med 1994:4:14-24.

[447] ASSESSMENT OF DEFICIENCIES IN ASSISTIVE TECHNOLOGY FOR PERSONAL TRANSPORTATION SYSTEMS

C. Greg Shaw, MS; Stephen Sprigle, PhD; John G. Thacker, PhD
University of Virginia Rehabilitation Engineering Center for Personal Licensed Transportation for Disabled Persons, Automobile Safety Laboratory, Charlottesville, VA 22902

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The purpose of this project was to determine, by means of a survey, the perceptions of assistive transportation technology from the perspective of persons with disabilities, driver evaluations and trainers, and equipment vendors and installers. This information will be used to guide research efforts in developing improved methods and/or equipment used in the evaluation of disabled drivers, the modification of vehicles for persons with disabilities and the development of standards for transportation-related assistive technology.

PROGRESS—Three separate surveys aimed at driver evaluators/trainers, vehicle modifiers, and consumers, respectively, were developed to assess the current state of personal transportation of people with disabilities. A survey of driving evaluators/trainers was conducted to determine the methodologies, equipment, and criteria utilized in determining the driving potential for individuals with disabilities. The survey of adaptive driving vendors was conducted to collect information on equipment, installation, servicing, and funding issues. The consumer survey was targeted at drivers and passengers of personal vehicles that had been modified for a person entering the vehicle in his or her wheelchair. This survey identified problems associated with obtaining and using adaptive transportation equipment and determined the desires and needs of equipment users.

FUTURE PLANS—A paper summarizing the results of the surveys has been submitted to the Occupational Therapy Research Journal for publication.

[448] METHODOLOGY FOR EVALUATING EQUIPMENT USED WHEN ASSESSING INDIVIDUALS' NEEDS FOR VEHICLE MODIFICATION AND ADAPTIVE EQUIPMENT

C. Greg Shaw, MS; Walter D. Pilkey, PhD; John G. Thacker, PhD
University of Virginia Rehabilitation Engineering Center for Personal Licensed Transportation for Disabled Persons, Automobile Safety Laboratory, Charlottesville, VA 22902

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The purpose of this project is to identify equipment or techniques that are currently being used during driver evaluations, to assess the utility of commonly used driver simulators and other devices, and to develop recommendations for the use of driver evaluation equipment.

PROGRESS—A literature search and telephone survey of expert driver evaluators has been conducted to determine the current state-of-the-art in driving evaluation and how driving assessment devices were being used as part of the evaluation protocol. The equipment identified is generally one of two types. The simpler devices measure one driving parameter such as brake reaction time. The most complex devices, which are driving simulators, attempt to measure a number of parameters such as visual tracking, steering accuracy, and accident avoidance. The literature and survey suggest that devices, while useful in some situations and some populations, are generally inadequate for assessing whether an individual is able to drive. The surveyed individuals stressed the importance of an on-road evaluation in an actual vehicle and questioned the cost and time effectiveness of the presently available driving simulators. Moreover, some questioned whether any simulator could accurately create a realistic driving environment that includes vestibular input.

FUTURE PLANS—The results of this project will be reviewed by the survey participants and a report will be written. A paper summarizing the report will be written for presentation at a national conference and for publication in trade journal.

[449] TESTING PROCEDURES FOR WHEELCHAIR LIFTS

John G. Thacker
University of Virginia Rehabilitation Engineering Center for Personal Licensed Transportation for Disabled Persons, Automobile Safety Laboratory, Charlottesville, VA 22902

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The objective of this project is to determine the reliability of wheelchair lifts under normal and extreme operating conditions by establishing standard test equipment and protocols. In addition, contraindications of the various types of lifts are being compiled.

PROGRESS—The project began with the proposed wheelchair lift performance standard developed by the Society of Automotive Engineers (SAE). Seven wheelchair lifts were identified that encompass the various designs currently sold. The test procedures developed consisted of four series of tests which included receiving inspection test, a visual inspection test, specification requirements, and a series stress test. Many protocol changes were suggested to the SAE Committee and rational statements were written for each test. Mechanical problems were identified on several of the lifts which have been or are being corrected by the manufacturers. A related project surveyed all wheelchair manufacturers for dimensional information as well as wheelchair lift manufacturers to determine which groups of wheelchairs would not fit on which group of lifts.

[450] TESTING PROCEDURES FOR WHEELCHAIR SACRAMENT SYSTEMS

C. Greg Shaw, MS; Walter D. Pilkey, PhD; John G. Thacker
University of Virginia Rehabilitation Engineering Center for Personal Licensed Transportation for Disabled Persons, Automobile Safety Laboratory, Charlottesville, VA 22902

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—This project's goal is to develop a dynamic (crash) testing procedure for wheelchair tiedowns and occupant restraint systems. We anticipate that these procedures will be adopted as a major component of the national and international WTORS performance standards that are currently under development.

PROGRESS—During the course of working with the Society of Automotive Engineers (SAE) Adaptive Devices Committee and the International Standards Organization (ISO) wheelchair restraints task groups since 1991, we have developed a test protocol and a test wheelchair capable of producing repeatable and reproducible crash test results. This effort involved the design and coordination of a multi-lab, multinational comparison test.

FUTURE PLANS—Additional crash testing of the test wheelchair with a variety of commercially available WTORS's is required to complete the project

[451] EVALUATION OF STRUCTURAL INTEGRITY AND DYNAMIC STABILITY OF MODIFIED VANS

Walter D. Pilkey, PhD; C. Greg Shaw, MS; John G. Thacker, PhD
University of Virginia Rehabilitation Engineering Center for Personal Licensed Transportation for Disabled Persons, Automobile Safety Laboratory, Charlottesville, VA 22902

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—It would be impractical to destructively test a sample of each vehicle modified for the physically challenged because of high diversity and low production. The objectives of this project are to develop criteria for evaluating the structural modification to passenger vehicles to ensure that they meet the needs for use and safety of disabled individuals, to quantify the stability of vehicles which have undergone modifications that affect the handling of OEM (Original Equipment Manufacturer) vehicles, and to give guidelines for permissible vehicle modifications.

PROGRESS—In cooperation with an SAE committee, van structural modification standards have been proposed. The Static Stability Factor (SSF), which has been proposed as a criterion for rollover propensity and directional stability, was measured using static measurement techniques for four Ford E150 vans, of which three have been subjected to different modifications. Based on the measurement and estimated inertial properties of the vans, the Vehicle Dynamic Analysis Non-Linear simulation package has been used to simulate the directional or handling stability of these vans. It has been found that a raised roof modification degrades both directional stability and maneuver-induced rollover stability more than a lower floor modification. To study tripped rollover, a new criterion, the Minimum Lateral Impulse (MLI) needed to just overturn a vehicle, has been proposed. The MLI has been formulated as a constrained optimization problem to be solved by mathematical programming. Unlike the static stability criteria such as SSF, MLI shows that an increase in rolling mass moment of inertia has a positive effect on the tripped rollover stability of vehicles. For modified vans, the most important factors are roof height, modified roof weight, the

height of lowered floor, and the weight and position of added frames, wheelchair lift, and extra equipment.

FUTURE PLANS—Computer models will be used to conduct parametric sensitivity studies on the directional stability and rollover propensity for modified vans. Correlation studies of the computer simulations and stability criteria with accident statistics data will be performed. Guidelines for the modification of vehicles will be prepared.

[452] WHEELCHAIR RESEARCH AT THE UNIVERSITY OF PITTSBURGH RERC

Douglas Hobson, PhD; Clifford Brubaker, PhD
Department of Rehabilitation Science and Technology, School of Health and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, PA 15240

Sponsor: *National Institute on Disability and Rehabilitation Research, Department of Education, Washington, DC 20202*

PURPOSE—We are engaged in research, training, and information dissemination in three interrelated areas of wheelchair technology: 1) improved electromechanical components and control concepts for powered wheelchairs, 2) new concepts and clinical measurement tools related to pressure management, seating posture and specialized seating in general, and 3) new concepts for enhancing occupant independence and safety when wheelchairs are used as seats in motor vehicles, both private and public.

METHODOLOGY—Fourteen research tasks have been identified within the three focus areas, each with an assigned task leader. Graduate students work with research staff. Consumers and local service providers serve as research collaborators and work directly in focus group sessions and on the research projects. Partnerships have been formed with two external contractors. Westinghouse Corporation has been contracted through its Science and Technology Center to provide computer optimization, battery technology, advanced materials, and controller technology support in wheelchair technology. Ken Digges and Associates provides computer simulation and standards research support related to wheelchair transportation safety. Project staff are directly involved in seating research and standards development activities in wheelchairs and wheelchair tiedown and occupant restraint systems.

PROGRESS—The 5-year support for the RERC began August 1, 1993. Staff and students have been identified and all planned start-up activities have been initiated. Laboratory space and related equipment has been acquired. Three focus group sessions, involving consumers and service providers, have been conducted in an effort to clarify research goals and form ongoing collaborative partnerships.

FUTURE PLANS—The second year of the project began on August 1, 1994. Detailed information on specific tasks may be obtained by contacting the Center. Broader communication is planned through the publication of a Center brochure and Newsletter, commencing in October 1994. The program will host the International Seating Symposium in February 1995 in Pittsburgh. A call for papers for the symposium has been widely distributed. Two paper presentations and an exhibit are scheduled for the 1994 RESNA annual conference.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Technology identification for non-invasive spinal/pelvic alignment monitoring system for individuals seated in personal wheeled mobility devices. Malagodi M, Hobson D. In: Proceedings of the 17th Annual RESNA Conference, 1994, Nashville, TN. Washington, DC: RESNA Press. In press.

B. Powered Controllers

[453] RESEARCH IN CURVILINEAR SYNCHRONOUS MOTORS FOR POWER WHEELCHAIRS

Kent R. Davey, PhD; David A. Ross, MSEE
Georgia Institute of Technology, Atlanta, GA 30332-0250; Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B338-4R)*

PURPOSE—The purpose of this project was to research, design, and test a Curvilinear Synchronous Motor (CSM) for power wheelchairs. The goal was a space-saving, in-wheel motor which was rugged, highly efficient, and fully capable of producing the torque required to meet the performance criteria set forth in Wheelchair III and IV and in the International Standards Organization (ISO) recommended standards.

METHODOLOGY—Mathematical modeling techniques were employed in the design of each of the seven prototypes that were built and tested, one at each major decision step, to verify model accuracy and physical viability. As each prototype was constructed and tested, the limitations and associated problems of each were analyzed and used to further refine the mathematical modeling techniques. Also, as the work progressed, it became evident that no single mathematical model could be employed to optimize the multitude of variables involved within the time span of the project. As these limitations to computer modeling were realized, a hierarchical methodology was developed. Once a specific geometry was chosen, specific variables were sequentially optimized about certain reasonable operating points. By employing this method reiteratively, values were determined that optimized the chosen geometry. As particular design geometries were optimized and compared, the results often indicated the possibility of employing design geometries previously not considered.

PROGRESS—The CSM began as a space-saving in-wheel direct-drive design that incorporated newly developed high-energy density magnets to realize large torques at high efficiency. This project was completed March 1993, with the testing of Prototype VII and the drawing up of recommended design plans for a more realistic scaled-down version of Prototype VII.

A major setback occurred during the last 2 years of the project when Prototype V, which was to have been the final prototype, evidenced an unpredicted and unworkable amount of cogging torque. To account for this, a completely new computer model had to be employed to take into account nonlinear magnetic effects. Employing this new software, two major breakthroughs occurred, each of which resulted in innovative design geometries. Prototype VI (designed and constructed with existing materials) incorporated these two new geometries. It realized a 60 percent increase in drive torque with no increase in power demand, and exhibited very low cogging torque.

The final design (Prototype VII) was thus based on these new geometries. It was built into the rim of a standard 16-inch wheel of a power chair and employed the best high-energy magnets and steel laminations available.

RESULTS—Prototype VII was constructed as a cylindrical ring that fit snugly into the rim of a standard 16-inch power chair wheel. It has a 3-inch axial width, a 2.5-inch radial depth and weighs 48 pounds. Maximum stall torque was in excess of 105 foot•pounds (the point at which the measuring apparatus coupling broke loose). Prototype VII is very efficient: it consumes only 35 W of power while producing 37 foot•pounds of torque (the torque goal). Some cogging torque (an average of 3.8 foot•pounds) was exhibited by Prototype VII, but drive circuitry had been designed to counter these torques, eliminating any noticeable noise or vibration.

A design more suited to actual wheelchair performance standards has been recommended. Investigators predict it should weigh 23 pounds, produce at least 40 foot•pounds of torque while consuming approximately 90 W of power and exhibit less than 1.8 foot•pounds of average cogging torque.

[454] THE NAVCHAIR CONTROL SYSTEM FOR AUTOMATIC ASSISTIVE WHEELCHAIR NAVIGATION

Simon P. Levine, PhD
VA Medical Center, Ann Arbor, MI 48105

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B630-DA)*

PURPOSE—Technology developed for autonomous navigation in mobile robots is being transferred to a powered wheelchair. The purpose of this new system, called NavChair, is to assist a user with marginal or insufficient ability to operate a power chair safely and effectively. NavChair consists of a commercial powered wheelchair which has been enhanced to sense its environment. In operation, the user drives the chair in the normal way. Commands from the user joystick go first to the onboard NavChair computer where they are evaluated in terms of what the system knows about surrounding obstacles and the mode of operation (obstacle avoidance, wall following, etc.). Control commands from the user which will not cause the chair to collide with nearby objects and are within the scope of the current mode are passed on to the wheelchair drive controller unchanged. Commands which do cause conflict are modified in real time to avoid the obstacles or maintain the mode function. This includes both altering steering direction and reducing forward speed.

METHODOLOGY—A number of design modifications were identified to further improve the performance of the NavChair system during this past year. These include enhancement of the obstacle avoidance software by treating the wheelchair as a rectangular object instead of a circular source, and the addition of specialized operational modes for closely approaching objects and going through doorways, in addition to those for obstacle avoidance and wall following. In this regard a new navigation method, called MVFH, was developed which allows allocation of influence between the user and the obstacle avoidance routine to achieve these goals.

Also developed in the last year were new methods of shared-control for the NavChair system, including the development of a stimulus-response feedback loop using autoregressive modeling techniques to classify user behavior and intention, and determine the most appropriate mode of operation.

PROGRESS—In 3 years, the NavChair project has been very successful in meeting the work plan as proposed. we have built the prototype system hardware, developed the software, calibrated the prototype subsystems, evaluated and modified the ultrasonic sensor ranging system, and operationally tested the system in laboratory and real world environments.

RESULTS—The new MVFH navigation routine has demonstrated improvements over the previous methods in open environment and hallways as measured by speed and smoothness and in door passage as measured by success in passing through significantly narrower doors than was previously possible. The stimulus-response feedback technique has demonstrated an ability to differentiate between driving in an open room vs. a hallway with 80 to 94 percent accuracy. This accuracy approaches 100 percent as data is accumulated over time.

[455] COGNITIVE READINESS FOR POWERED WHEELCHAIR MOBILITY

Donita Tefft; Jan Furumasu; Paula Guerette, PhD; Fabiola Moy; Don McNeal, PhD; Mark Hoffer, MD
Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Independent powered mobility allows young children with physical disabilities to participate more fully in play, educational, and community situations. However, few resources are available to therapists to assist in the decision to recommend a powered wheelchair to a young child. Information gained from this project will be used to assist professionals in determining cognitive readiness for powered wheelchair mobility, as well as to describe a program of mobility skills necessary for functional operation of a powered wheelchair. The project seeks to identify the cognitive developmental skills and temperament factors that influence readiness for powered wheelchair mobility in young children with physical disabilities from ages 18 to 36 months. All participants are children who have severely limited independent mobility, yet demonstrate age-appropriate cognitive abilities. This project is being conducted by the RERC on Technology for Children.

PROGRESS—To evaluate cognitive developmental skills, an assessment battery has been compiled with tasks grouped into five Piagetian-based scales. A child's stage of developmental thinking within each cognitive scale (cause-effect, object permanence, problem solving, spatial relations, symbolic play) is determined from performance on the assessment battery. The battery also includes a measurement of "temperament", which includes factors such as persistence and adaptability in new situations.

The powered wheelchair mobility program introduces and evaluates powered wheelchair mobility skills through exploratory play with the wheelchair. Tasks representing 35 mobility skills are organized into basic skills and integration of these basic skills into functional settings. The child's ability to maneuver the powered wheelchair through the tasks is scored according to the amount of hands-on assistance and/or verbal cueing required to operate the wheelchair safely.

To date, 16 children have been evaluated with the assessment battery and mobility program. For children who scored below 3.0 on powered mobility and required hands-on assistance for safety, a powered mobility toy would be recommended. This provides them with the opportunity to practice self-produced locomotion without risk of injuring themselves or others. For children who received an average score above 3.0, powered wheelchair mobility would be considered. Additional training of the child, parents, and teachers would be recommended to improve recognition of potentially unsafe settings.

Preliminary findings indicate strong relationships between performance on the cognitive development scales of spatial relations, symbolic play, and cause-effect and the powered mobility score. Independent samples t-test with subjects grouped by high or low mobility scores (above and below 3.0) indicate that there is a significant difference between the groups within the cognitive developmental scales of spatial relations and symbolic play.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Cognitive readiness for powered mobility in the young child. Tefft D, Furumasu J, Guerette P. In: Proceedings of the 16th Annual RESNA Conference, 1993, Las Vegas, NV. Washington DC: RESNA Press, 1993:339-40.

Cognitive readiness for powered mobility in the young child. Tefft D, Furumasu J, Guerette P. In: Proceedings of the Ninth International Seating Symposium, 1993, Memphis, TN, 277-82.

Ready, set, go: young children and powered mobility. Tefft D, Furumasu J, Guerette P. In: Childhood Powered Mobility, Third Edition, E. Trefler, ed., Arlington, VA: RESNA Press. In press.

[456] DETERMINING THE APPROPRIATENESS OF INTEGRATED CONTROL OF ASSISTIVE DEVICES

Paula Guerette, PhD; Kevin Caves; Richard Nakai; Eunice Sumi; Don McNeal, MD; Mark Hoffer, MD
Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Integrated controls allow the user to control more than one assistive device through a single, "universal" input device. Typically, this is the device chosen to control the powered wheelchair. Since the technology providing the capability to integrate is relatively new, there is little information available to suggest when the use of integrated controls is appropriate. The purpose of this project is to identify the factors which support integrating control of multiple assistive devices and those which suggest that control be distributed across multiple input devices. To determine when integrated controls are appropriate, a retrospective review of client charts from all individuals who have been evaluated at the Center for Applied Rehabilitation Technology (CART) at the Rancho Los Amigos Medical Center has been conducted. This project is being conducted by the RERC on Technology for Children.

METHODOLOGY—The purpose of the retrospective review is to identify the factors that were of primary importance in the decision whether or not to recommend systems with integrated controls. A total of 230 CART client charts have been reviewed. Since the majority of commercially available integrated controllers operate through the wheelchair input device, only those individuals who received recommendations for powered mobility and at least one other assistive device were considered. Sixty-five individuals fit the study criteria and were entered into the retrospective review. For each individual, background information was recorded on type of disability, age at onset, goals, available access sites, current system, and configuration of current input devices. In addition, discussions were held with CART therapists to determine the reasons why a particular system configuration (i.e., integrated versus distributed) was recommended, and whether or not a system with a different configuration of input devices may have been clinically feasible. In many cases, multiple reasons were cited for recommending a particular system configuration.

RESULTS—Of the 65 individuals entered into the retrospective review, a total of 54 (83 percent) were recommended systems with multiple, distributed controls. Performance factors such as speed, accuracy, and degree of ease using separate, distributed controls were the primary reasons cited for not recommending a single, integrated input device. Functional abilities such as cognitive limitations and visual/perceptual limitations were cited in ten cases, and funding issues were reported for seven individuals (a system with integrated controls can cost up to $3500 more than one with separate controls). Another factor that was noted as important for several individuals was the location from which assistive devices were to be accessed. These individuals wished to use equipment such as a computer, communication device or ECU from a location other than from their powered wheelchair (e.g., from a bed, couch, or chair). Thus, it was not practical to integrate control to the wheelchair input device. Technical limitations of integrated controllers, which had been hypothesized to preclude therapists from recommending systems with integrated controls, were found to be a factor for only four individuals in the sample.

The remaining 11 individuals in the retrospective review received recommendations for systems with a single, integrated control. This small sample size makes generalizations difficult. However, of these eleven, four were found to have a single, reliable access site and thus, integrated controls offered them greater opportunity to control assistive devices. Performance factors such as speed and ease of use were also reported by therapists as being of primary importance for four of the eleven individuals.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Modified Nintendo controller: an application of integrated controls. Caves KM. In: Proceedings of RESNA International '92, 1992, Toronto, ON. Washington, DC: RESNA Press, 1992:551-2.

To integrate or not? findings from a performance study and a retrospective review. Guerette P, Nakai R, Sumi E. In: Proceedings of the 16th Annual RESNA Conference, 1993, Las Vegas, NV. Washington DC: RESNA Press, 1993:327-9.

Integrated control of multiple assistive devices: a retrospective review. Guerette P, Sumi E. Assist Technol 1994:6(1):67-76.

[457] ROBOTIC WORKSTATION WITH OPTOELECTRONIC CONTROL

Dimiter Hr. Stefanov, PhD
Institute of Mechanics, Sofia-1113, Bulgaria

Sponsor: National Department of Science and Research, Bulgaria

PURPOSE—The goal of this project is to check experimentally the principles of control of a robotic workstation for severely physically disabled persons. Our efforts are oriented to human-machine interface simplification and to the increase of user participation in concrete manipulation tasks. The robotic workstation allows the increase of functional user indepcndence in accomplishing daily living tasks. There is another goal, the development of the manipulator, a cost-effective robotic system to assist individuals in handling objects in their environment. The manipulator should be appropriate not only in the labs, but also in a domestic environment. It is not intended to perform global movements.

METHODOLOGY—The robotic workstation contains a manipulator with four degrees of freedom and a gripper, an anthropomorphic kinematic structure similar to the human arm and hand. This design makes it easier for the operator to accept the manipulator, as its motion and operating commands resemble the human ones. The manipulator drive units contain geared permanent magnet DC motors located within the arm.

Three kinds of user motion control the manipulator: the turning of the head to the left or right is converted into one proportional signal; a second proportional signal is formed by nodding the head up and down; a third independent signal (digital) is created by the motion of the user's eyelids.

The human-machine interface is based on the infrared optosensors located on a spectacles frame. On the inside of the frame two diffused reflection photocouplers convert eyelid movement into electrical signals. On the outside of the frame are installed four LEDs, divided by optical partitions. LED signals are received by a photodetector, installed on the manipulator near the gripper. The received signals depend on mutual attitude between the user's head and the detector. The difference of the signal amplitudes defines control commands for gripper position.

Three electrical information signals are generated by the head and eyelid movements. Each control device has two functional positions. The user can chose every one of them. By each of this positions the user controls three manipulator degrees of freedom. By the first position the elbow and both shoulder joints are controlled. By the second one the gripper opening/closing, wrist rotation and shoulder flexion are controlled.

The robotic workstation has been under development for several years.

PROGRESS—Last year the control algorithm was changed. Presently the control device allows slow speed gripper rotation when the gripper is near the user's face (to permit, for example, sipping from a cup).

Now, another functional position is available. This position can be chosen by the level of optoelectronic signals between LEDs and a photodetector. In this position all manipulator joints are fixed except the slow gripper rotation controlled by eyelid movements.

RESULTS—Test trials were carried out with a control group of ten healthy people. The user can easily control such tasks as pouring liquid from a bottle into a cup, buttoning, turning book pages, etc. The user can easily operate up to three degrees of freedom simultaneously; he directly commands the position and velocity of the gripper. Joint driver commands are generated automatically by the control device.

FUTURE PLANS—The future development of the device is oriented to the perfection of human-machine interface and manipulator design.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Robotic workstation for severely disabled persons. Stefanov D. In: Proceedings of SPRANN '94, IMACS International Symposium on Signals, Processing, Robotics and Neural Networks, 1994 April 25-27, Lille, France.

Patent: Method for anthropomorphic mechanical construction control and control device based on the method. Stefanov D, Prentshev N. Bulgarian patent 29738.

[458] POWERED WHEELCHAIR CONTROLLER WITH DYNAMIC STABILITY CHECKING

Dimiter Hr. Stefanov, PhD
Institute of Mechanics, Sofia 1113, Bulgaria

Sponsor: *National Department of Science and Research, Bulgaria.*

PURPOSE—The present-day control devices for powered wheelchairs possess high computing capabilities. Often a considerable part of these capabilities remains unused. This enables the construction of control systems with better characteristics without considerable hardware expense. It is important for the control process to calculate the dynamic parameters of the whole human-wheelchair system and to determine the effect of operator's commands on the wheelchair stability before command execution.

The main goals of this approach are to attain an increase of the transport stability and smooth motion, to make the use of the batteries more economic, and to decrease the user's participation in the control process.

METHODOLOGY—A powered wheelchair with two driving wheels and two self-directing wheels has been analyzed, and analytical criteria for retaining equilibrium during the motion have been defined. The criteria express the connection between the geometrical, kinematical and dynamic parameters of the common person-wheelchair system and the value of the wheelchair dynamic stability. The criteria form restrictions about the angular velocities of the driving wheels. Keeping within these restrictions assures the stability of the motion.

Three criteria of stability have been chosen. The first of them is based on the data about the current angular speeds of the driving wheels and about user's command signals. The second of these criteria processes the information of the wheelchair seat reaction forces and it targets the influence of the mass and the position of the operator. The third criterion is more precise, focusing on the spatial information of the wheelchair base concerning horizontal plane.

The parameter combination form a multidimensional field which can be pre-programmed into the memory of the wheelchair's control device. The controller analyses the current user's commands about the angular velocities of the wheels before its execution. It compares the commands with the memorized data. The wheelchair's control device carries out only the commands that would not

disturb the stability of the common person-wheelchair system. Commands that might threaten stability are transmitted to the speed controller in a modified form; for example, the request for a desired radius of curve might be preserved but the speed of the wheelchair automatically reduced.

PROGRESS—A control device based on the first criterion has been tested. It operates on an analog mode of information processing.

FUTURE PLANS—A single chip microprocessor control device is being developed. Some requirements for the memorizing of large data array have been taken into consideration as far as the structure is concerned.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Powered wheelchair control based on the dynamical criteria of stability. Stefanov D, Boiadziev G. Second World Congress on Biomechanics, July 10-15, Amsterdam, The Netherlands, 1994.

Patent: Control Device for a wheelchair with two driving wheels, Stefanov D, Boiadziev G, Bulgarian Patent No 88186/89.

[459] SMART WHEELCHAIR MODULES

Mark Lightfoot; Troy Hare; Geb Verburg, MA
CATE, Ryerson Polytechnical University; Research in Cognitive Development (RiCD) Unit, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsor: *None listed*

PURPOSE—This project developed initial prototypes of two intelligent wheelchair control modules. The modules were designed to be attached to existing wheelchairs. The two modules were a Wall-Following module and an Obstacle Avoidance module. Both modules incorporate sensors and are based on a 6805 microprocessor.

METHODOLOGY—The current project uses two types of wheelchairs: the Miniature Powered Vehicle (MPV), a go-cart-like children's wheelchair prototype developed at the Hugh MacMillan Rehabilitation Centre and an Invacare chair with a MCC Mark II controller. The Wall-Following Module allows a person to drive straight through corridors or past buildings without collisions. It is expected to make driving a wheelchair easier for a person who has difficulties controlling the wheelchair.

PROGRESS—The prototype module that was designed experienced considerable difficulty keeping a steady path. The poor performance was attributed to the nature of the sensor. It was decided not to take this prototype further but to develop a second prototype using a different sensor technology.

The Obstacle Avoidance Module is capable of identifying obstacles in front, to the left, to the right, and behind the wheelchair. The module used four Polaroid sensors, one for each direction. Each sensor provided feedback to the joystick which controlled the wheelchair. As soon as the sensor picked up an obstacle in its 'field of view' the corresponding joystick direction was disabled so that the chair could only move away from the obstacle. The sensitivity (i.e., distance) of the sensors can be adjusted.

C. Seating Systems

[460] DESIGN OF A VIDEOFLUOROSCOPY CHAIR FOR SCI AND OTHER DISABLED PATIENTS: A PILOT STUDY

Pascal Malassigné, MID, IDSA; Marilyn Corlew, PhD; Terilyn Nitschke, MS; Marilyn Berman, PhD; Inge Thomas, PhD; Thomas L. Amerson, PhD;
Research Service, Audiology and Speech Pathology Service, Clement J. Zablocki VA Medical Center, Milwaukee, WI 53295; Audiology and Speech Pathology Service, Atlanta VA Medical Center, Decatur, GA 30033; Milwaukee Institute of Art & Design, Milwaukee, WI 53200

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B92-419AP)*

PURPOSE—The first phase of the study involved the evaluation of one Hausted videofluoroscopic imaging chair at the Atlanta and Milwaukee VAMC for a period of 12 months. This evaluation was necessary to determine if the actual performance of the Hausted videofluoroscopy chair did corresponds to the established criteria developed by the investigators for the design of an ideal videofluoroscopy chair. A videofluoroscopy chair is used in conjunction with a fluoro x-ray table for the evaluation of dysphagia (swallowing disorder) using the Modified Barium Swallow roentgenography procedure.

METHODOLOGY—In addition to the clinical evaluation of the chairs at the VAMC's with patients, radiologists, and speech pathologists, the investigators developed a questionnaire to assess the various features and usage of the Hausted chair in comparison with other chairs used for swallowing studies. Questions concerning transferring (from a gurney, stretcher or a wheelchair), transportation of patients seated in the chair and their positioning, and use of the chair and its various features were included.

PROGRESS—The questionnaire was sent to the members of the Dysphasia group of the American Speech Language Hearing Association and to the all VA Speech Pathologists. At this time, the results of the questionnaire are not ready for inclusion in this report but will be included in a separate publication.

FUTURE PLANS—The evaluation of the Hausted chair has been completed and the investigators have presented their recommendations to the VA Rehabilitation R&D Service, VACO, as to the need to modify the Hausted chair in collaboration with the manufacturer.

During the last phase of this project it is proposed to work in collaboration with the Hausted Co. on the following aspects of the chair: 1) development of a push bar to properly steer the vic chair, 2) development of a wheelchair accessible version that will match wheelchair height with cushion ranging from 50 to 55 cm (20 to 22 in), 3) development of a slanted seat to hold patient properly, 4) development of a cover behind the backrest to conceal the structure/exposed parts and perhaps include a tray for patient chart and a pushbar to steer the chair, 5) development of an extended lock guard mechanism to prevent that the backrest be released accidentally when attendants are assisting in patient transfers, 6) development of a larger and longer brake pedals to provide more leverage, and 7) relocation of the chair swivel locking mechanism for easier use.

[461] QUALITY IMPLICATIONS OF INFORMATION CAPTURE, TRANSFER, AND USE IN A CROSS-DISCIPLINE REHABILITATION ENGINEERING TEAM

Gilbert D. Logan, BEng, MSc. Grad Dip Bus Admin; David F. Radcliffe, BE, MEngSc, PhD
Royal Brisbane Hospital, Brisbane, Australia Q 4029; University of Queensland, St. Lucia Q 4072 Australia

Sponsor: *Brisbane North Regional Health Authority*

PURPOSE—The purpose of this project is to develop an understanding of information capture, transfer, and use by and within a cross-discipline rehabilitation engineering team providing special seating. We consider that the capture, transfer, and use of information of various types by the team members in design and manufacture of seating is critical to the successful outcome of the rehabilitation engineering effort for the client. From a strength of understanding we plan to develop key strategies and tools to support communication and information management by cross-discipline, rehabilitation engineering teams.

METHODOLOGY—Activities of the team (including client assessment, discussion and goal/decision-making, design, and manufacture of custom seating) is recorded by non-intrusive video camera and microphone systems. Videotapes are analyzed to determine what information was presented during assessment and how it was interpreted and used by team members and the team as a whole during down-stream processes. Client files, equipment designs, manufacturing data, and client device supply fit-outs are examined to compare/contrast the apparent information usage with the total information that is available. Visual information, particularly detail that is important to the seat design, but is difficult to depict/describe orally or in writing (client movements, mimicry by team members), is being examined for its importance in the design process.

Transcripts of the videotape are being analyzed on a hypertext database and also by qualitative data analysis software (NUDIST) to determine elements implicated in quality of the process and the outcome for the client (in terms of the inputs). Graphics and video clips are being incorporated into the database.

The operation of the "seating clinic" is being modified to incorporate improvements suggested by the analysis undertaken. This cycle of analysis leading to changes in practice will be repeated a number of cycles in keeping with the principles of action research.

PROGRESS—A number of videotapes have been transcribed and are being analyzed by the hypertext and NUDIST software. The first cycle is in progress, reflecting changes in documentation aimed at improving the capture of data during client assessment and having it available during design and manufacture and other downstream stages.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Emergence: learning and interaction in a cross-discipline design environment. Radcliffe DF, Slattery PJ. Design Theory Methodol 1992:42:123-30.

Video as a change agent in a cross-discipline design team. Radcliffe DF, Slattery PJ. International Conference on Engineering Design, ICED '93, 1993, The Hague, Netherlands.

[462] CLINICAL ANALYSIS OF A CAD/CAM SYSTEM FOR CUSTOM SEATING

Edward D. Lemaire, MSc; David Upton, BSc; Joe Paialunga, BSc(OT)
The Rehabilitation Centre, Ottawa ON K1H 8M2 Canada

Sponsor: *Otto Bock Orthopedic Industry of Canada Ltd., Winnipeg, Manitoba, Canada; Labatt's Relay Research Fund, Institute for Rehabilitation Research and Development, Ottawa, ON, Canada*

PURPOSE—At the present time, limited information is available on custom seating and no clinical research is available involving seating CAD/CAM systems. The Otto Bock Shape System (OBSS) is the first CAD/CAM system which promotes itself as being ready for clinical use. A pilot project which assesses clinician and patient satisfaction with seats produced using this procedure is essential for informed evaluation of CAD/CAM for custom seating. This study will clinically evaluate a seating CAD/CAM system (OBSS) in terms of patient satisfaction, clinician satisfaction, and manufacturing efficiency.

PROGRESS—Data collection has been completed and compilation of the final report is in progress.

METHODOLOGY—Twenty subjects were recruited through the Special Seating section at The Rehabilitation Centre (Ottawa) and the Centre de Readaptation Lucie-Bruneau (Montreal) and were fit with a CAD/CAM produced custom contoured seat. A clinician questionnaire and a patient questionnaire were used to assess satisfaction with the resulting wheelchair seat and to record patient specific information (degree of disability, etc.). One questionnaire was completed for each seat. The patient questions were administered by mail three months after the device was dispensed and inquired about seat comfort, satisfaction with the seat, and general comments.

The questionnaire data will be analyzed using descriptive statistics. The patient and clinician responses will be compared based on gender, age, disability, and level of disability. The manufacturing and fitting times associated with the CAD/CAM approach will be compared to conventional manufacturing and fitting times. If the CAD/CAM produced seats are at least equal in function with conventionally produced seats, the manufacturing superiority of the CAD/CAM approach would indicate continued use of the CAD/CAM system for custom seating.

RESULTS—A midterm report from a sample of eight seats showed a substantial decrease in hands-on fabrication time through the use of central fabrication facilities. No difference was found between CAD/CAM and conventional methods in terms of initial fitting or final fitting times. All seats were dispensed without having to repeat the CAD/CAM process; however, manual modifications were required on three seats. Clinical satisfaction with the seats were at or above four on a scale of five. All but one client response to seat comfort, overall seat satisfaction, and general comments were good or excellent. One client rated seat comfort as fair.

Central fabrication time averaged 28 days; however, the fabrication time lag is now within 15 days. A series of software recommendations made in the mid-term report have been addressed and included in the January 1994 release of the OBSS program.

FUTURE PLANS—Since all test seats have now been dispensed and the majority of the client questionnaires have been received, the final data will be analyzed and evaluated before the end of 1994.

[463] CONSUMER INVOLVEMENT IN CHILDREN'S SEATING DESIGN

Steve Ryan, BESc, PEng; Patricia Rigby, MHSc, OT(C); Wes From, MASc; Jonathan Kofman, MASc, P.Eng; Danielle Thompson; Emily Walczak; Morris Milner, PhD, PEng, CCE
Rehabilitation Engineering Department, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8 Canada

Sponsor: *Rotary Club of Toronto (Leaside), The Ontario Rehabilitation Technology Consortium funded by Ontario Ministry of Health, Special Health Systems Limited*

PURPOSE—The aim of this project is to develop and evaluate the performance of an adjustable, contoured wheelchair seat. The seat design proposed is unique because it can be easily fitted by a seating clinic, adjusted by the parent, and later altered to allow for growth. It will be specifically developed for young children with cerebral palsy from 6 to 12 years of age.

PROGRESS—To learn how we should design the new seat, we asked consumers and clinicians for their opinions. Initially, we polled 33 seating therapists from across Canada and the United States to learn what they thought of commercially-available seats. We also asked them to tell us about features we should include in the design. To find out what young consumers thought, we organized seating "experience" sessions with more than 80 school children with cerebral palsy. We wanted to know what seat colours and shapes they liked, what they thought of different upholstery textures, and how they liked sitting on different seat cushions and using different types of lap belts. We also had 81 parents respond to a self-reporting mail-out survey to obtain their thoughts on seating systems.

Based on the perspectives we received from parents, service providers, children and through earlier experimental work, we developed early concept models and drawings of the proposed seating system. We are now proceeding with the next phase of development. Focus group sessions with consumers are being used to develop and evaluate design concepts. Since consumers reported that commercial seating systems are generally unreliable, we also devised a life testing program. Based on recognized standards for wheelchairs, we are designing test rigs and developing modified test procedures to predict the long-term performance of our prototypes.

FUTURE PLANS—We will continue to involve consumers throughout the development process through both focus group activities and clinical trials. With Special Health Systems Limited as industry partner on the project, we are working toward developing a commercial version of the system.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Clinical views of modular seating systems. Rigby P, Ryan S. In: Proceedings of the Canadian Seating and Mobility Conference, 1993, Toronto, ON.

Toward obtaining useful consumer feedback from young children with physical disabilities. Ryan S, Rigby P, From W, Kofman J. In: Proceedings of the RESNA 16th Annual Conference, 1993, Las Vegas, NV. Washington DC: RESNA Press, 1993.

Toward understanding consumer concerns about transporting children with physical disabilities in the family car. Ryan S, Rigby P, Sommerfreund J, Young M, Milner M. In: Proceedings of the RESNA 16th Annual Conference, 1993, Las Vegas, NV. Washington DC: RESNA Press, 1993:89-91.

[464] CUSTOM CAR SEATS FOR SCHOOL-AGED CHILDREN

Steve Ryan, BESc, PEng; Patricia Rigby, MHSc, OT(C); Wes From, MASc; Karen Yip; Murray Rice; Morris Milner, PhD, PEng, CCE
Rehabilitation Engineering Department, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8, Canada and University of Toronto

Sponsor: *Rotary Club of Toronto (Leaside); The Ontario Rehabilitation Technology Consortium funded by the Ontario Ministry of Health; SOS Rehabilitation Technologies (Montreal, Quebec)*

PURPOSE—Many children are being transported in their custom seats while travelling in the family car. We have shown that transporting children in this manner is not safe. Parents usually have no alterna-

tive because commercial car seats do not offer the postural support that their children need. The aim of this project is to develop a transportation system that will allow children weighing from 40 to 75 pounds to use their custom seats in a car. We are also developing a device that will aid parents in transferring their child into and out of the family vehicle.

PROGRESS—We interviewed parents who live in various regions of Ontario, Canada to understand their concerns about transferring their children into and transporting them in the family car. Parents who responded to the survey thought that there were better ways to manage their children when travelling in their vehicles, but the methods suggested were often out of reach financially.

We also created a detailed workshop manual to teach seating clinics how to produce custom car seats using a restraint system we developed for younger children (i.e., the FRAME-IT system). We conducted a multi-center trial to judge the ability and willingness of seating clinics to use this manual to adapt their construction techniques to meet motor vehicle safety regulations. Ten North American clinics participated in its evaluation by reading the manual and constructing a custom car seat. The feedback we received from the clinics is helping us to improve the design of, and consumer instructions for, the restraint system for older, heavier children.

We evaluated the feasibility of two transfer device models with the assistance of ten parents during hands-on product evaluation sessions. Parents reported that they need the device to be safe for both their child and themselves, yet be time efficient in its use. Similar sessions are being held as we develop the restraint system designs.

FUTURE PLANS—Further consumer testing is planned as we refine the designs for these systems. Commercial availability of these products is expected by spring 1995.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Understanding flammability standards: guidelines for classifying materials used to construct seating systems. Rigby P, Ryan S. In: Proceedings of the Canadian Seating and Mobility Conference, 1993, Toronto, ON.

XVI. Wound and Fracture Healing

A. Pressure Sores

[465] EVALUATION OF INTERFACE PRESSURE MEASUREMENT INSTRUMENTS: A PILOT STUDY

Anita Kedas, BS, MEd, PhD
VA Medical Center, Washington, DC 20422

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #B92-364AP)*

PURPOSE—Four electropneumatic interface pressure measurement instruments, Tissue Interface Pressure Evaluator (MiniTIPE), Lotus PR38, Talley Digital Skin Pressure Evaluator Model SD500, and the Talley Oxford Pressure Monitor (OPM MKll) were evaluated. In the following discussion they will be referred to as Devices I through IV, respectively.

Factors that were taken into consideration to determine their effectiveness and benefits under average conditions of use, included simplicity of operation, durability, reliability, and minimization of measurement and data entry error. Other questions asked were whether the published interface pressure data for a pressure-reduction mattress and a mattress overlay in common use in DVA Medical centers could be replicated and whether there were a significant difference between left and right hip and left and right heel interface pressures obtained.

METHODOLOGY—Six nonhospitalized subjects were recruited. The sample was stratified according to gender and body frame, and measurements taken at five body sites (right and left trochanter, sacrum, left and right heel) and upon three mattress support surfaces (mattress replacement, mattress overlay, and standard hospital mattress). Three readings were recorded at each of the sites on each of the support surfaces with the sensor repositioned each time. One week later all the measurements were repeated using the same protocol. The same research assistant collected all data.

RESULTS—Device I failed and was abandoned during the attempt to measure interface pressures. Cells in the original and replacement sensor pads ruptured. Device II was limited because measurements above 110 mmHg could not be recorded, a particular problem in relation to heel interface pressures. The automatic inflation feature of Device III resulted in user subjectivity regarding whether peak pressure had been reached. Device IV is a heavy unit that has to have the battery removed for charging and the manufacturer's claims that data could be transferred on line to a personal computer were not supported. It took 4 months of discussion to get a program to transfer data retroactively. Moreover, the special paper for tape recording of pressures is not generally available in the United States.

There were differences in the magnitude of reproducibility between devices, especially in the measurements of heel pressure. In general, the grid system of Device IV was less sensitive to measurement technique and maximum pressure readings were higher. No statistically significant differences between first and second readings at any of the body sites were found in repeated measures analyses of variance. Left trochanter interface pressure measurements with Devices II, III, and IV were consistently higher when a standard hospital mattress was used. This finding could only be repeated using Devices III and IV for the right trochanter and Device IV for the left and right heels. No significant difference in sacral interface pressure was found according to type of measurement device or type of support surface.

In comparison with published studies, interface pressure readings at the trochanters and sacrum on pressure reduction support surfaces were similar

when Devices II and III were used, but Device IV readings were 30 to 100 percent higher. Device IV heel readings across support surfaces were consistently higher, and Device III consistently lower than published findings. Results of the current study also were in agreement with previous findings that, in general when a standard hospital mattress is in place, interface pressure readings across sites and devices are marked by standard deviations greater than those for other support surfaces.

There is not sufficient reason to reject hypotheses that there are no statistical differences (paired t tests) between right and left trochanter (Devices II, III, and IV), or between right and left heel mean interface pressures. In trochanter measurement comparisons with Devices II and IV there was a trend toward greater differences in interface pressures when on a standard hospital mattress.

Of the devices evaluated Device IV had the widest pressure reading range. It is not clear whether the somewhat higher readings of this device at the trochanters and much higher readings at the heels represented greater sensitivity, possibly because the sensor system localized peak pressure better, or is attributable to some other factor. The tested hand-held models (Devices II and III) are limited by the range of readings, and the subjectivity involved in determining whether peak pressure had been reached.

IMPLICATIONS—Because of the variance in magnitude of the readings at some sites between devices, one device should be used consistently when comparisons between sites and surfaces are required. Since repeated measures ANOVA results could be attributed to offsetting readings among subjects, further data analysis using a concordance coefficient to evaluate reproducibility is planned. When comparing between studies similarity of devices used should be taken into consideration. In addition previous recommendations to report findings as a percentage of interface pressures obtained when on a standard hospital mattress should be assessed in the context of the standard deviations from the means. If the finding that there is little change in interface pressures at the sacrum across surfaces and devices persists, there are clinical positioning, as well as research protocol simplification implications. It could well be that sacral measurements could be eliminated. Findings did not support incorporation of random selection of a single heel, and/or a single trochanter for interface pressure measurement in future study designs.

[466] IN VITRO TEST OF AN ARTIFICIAL/CELLULAR GRAFT FOR PRESSURE SORE REPAIR: A PILOT STUDY

Eric E. Sableman, PhD
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #92-476AP)*

No report was received for this issue.

[467] SKIN COMPOSITION IN SPINAL CORD INJURY

Janusz Markowski, MD; Gladys P. Rodriguez, PhD
VA Medical Center, Houston, TX 77030; Baylor College of Medicine, Houston, TX 77030

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B688-RA)*

PURPOSE—The aim of this research project is to test the following hypothesis: the increased susceptibility among the spinal cord injury (SCI) population to the development of pressure ulcers is due in part to defective collagen biosynthesis below the level of injury. The goal is to identify an important risk

factor which might be amenable to pharmacological intervention. This would directly relate to the VA mission of providing good medical care to veterans.

METHODOLOGY—Skin punch biopsies from nonweight-bearing parts of the body above and below the level of injury will be obtained from SCI subjects that have had pressure ulcers and also from some that have not had pressure ulcers. Biopsies will also be obtained from able-bodied men. Biopsies will be analyzed for content of four amino acids characteristic of collagen (proline, hydroxyproline, lysine, and hydroxylysine). Relative proportions of Type I and III collagen will be determined. Activity of two important collagen biosynthesis enzymes (prolyl hydroxylase and lysyl hydroxylase) will be measured. Comparisons will then be made between skin composition above and below the level of injury among the SCI subjects that have had or have not had pressure ulcers and between the SCI subjects and able-bodied controls. If the hypothesis is true, it is expected that there will be more similarity in the skin composition above and below the level of injury among the subjects that have not had pressure ulcers, and they would also be more similar to the skin composition of the able-bodied controls.

PROGRESS—By October 1993, 20 able bodied controls, 9 persons with SCI that had never had a pressure ulcer, and 7 persons with SCI that had a history of pressure ulcers had been recruited. Amino acid assays and collagen typing have been performed. Preliminary results were presented at the annual meeting of the American Congress of Rehabilitation Medicine in 1994.

RESULTS—Preliminary results demonstrated a trend towards decreasing content of lysine and hydroxylysine in biopsies from below the level of injury in subjects with a history of pressure ulcers compared to subjects with no history of pressure ulcers. A positive association was found between smoking habit and number of previous ulcers.

In subjects that had had pressure ulcers previously, the ratio of Type I to Type III collagen was much lower in the biopsies from below the level of injury. These subjects also had a negative correlation between the ratio of Type I to Type III collagen and years since injury in the biopsies below the level of injury.

FUTURE PLANS—Preparations for the enzyme assays are nearly complete. The project is proceeding on schedule. Plans are being finalized to present a research proposal to the Merit Review Board dealing with a possible pharmacological treatment to improve the quality of skin collagen in persons with SCI as a means to prevent the development of pressure ulcers.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Amino acid content of skin in persons with spinal cord injury with and without a history of pressure ulcers. Rodriguez GP, Markowski J. Arch Phys Med Rehabil 1994:75:719.

[468] TOWARD BETTER METHODS OF NERVE REPAIR AND EVALUATION

Joseph M. Rosen, MD
VA Medical Center, White River Junction, VT 05009

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B003-5RA)*

No report was received for this issue.

[469] ARTIFICIAL NERVE GRAFT: UNION OF CELLULAR AND NONCELLULAR COMPONENTS

Joseph M. Rosen, MD; Eric Sableman, PhD
VA Medical Center, White River Junction, VT 05009

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B588-RA)*

No report was received for this issue.

[470] TREATMENT OF PRESSURE ULCERS

D.S. Feldman, PhD
University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Development of improved clinical protocols may help reduce the staggering morbidity statistics resulting from pressure ulcers in people with spinal cord injury (SCI). In order to develop optimal active treatment protocols for pressure ulcers, basic wound-healing research is essential. The objectives of this study are to determine, in cell culture, the optimal concentration of oxygen and growth factors for fibroblast activation and macrophage deactivation; to test these optimal levels along with a pulsatile electromagnetic field (PEMF) for healing of full-thickness skin defects; and to evaluate the efficacy of these treatments on pressure ulcers in patients with SCI.

METHODOLOGY—The optimal concentration of oxygen for fibroblast activation and macrophage deactivation was determined by growing cells in a controlled environment. The optimal concentration of heparin binding growth factor (HBGF-1) and platelet-derived growth factor (PDGF) was also determined by *in vitro* tests of cellular metabolism and cell growth. The growth factors exhibiting the greatest potential were incorporated into polylactic acid (PLA) and collagen matrices and retested in cell culture.

The optimal growth factor systems and optimal oxygen concentrations as determined *in vitro*, were tested for full-thickness defect healing in rabbits. For the oxygen treatments, 70 percent oxygen for three hours each day, was used to approximate the optimal *in vitro* condition. In addition, two dressings with different oxygen permeability were used in order to examine the effect of altering the oxygen gradient. Further, a 2-2.8m Tesla magnetic field (75 Hz) was also tested for full-thickness defect healing in rabbits.

RESULTS—During the first 2 and one-half years of the grant period, the following progress has been made: 1) Optimal *in vitro* cellular response was obtained with 25 percent oxygen treatment (195 mmHg) and 5 units/ml of growth factor. 2) Both HBGF-1 incorporated into collagen films and PDGF incorporated into collagen sponges significantly increased fibroblast proliferation over the controls. 3) Although no consistent pattern was seen with the growth factors incorporated into PLA films no signs of toxicity were present. 4) The 70 percent oxygen treatment significantly sped up the healing process in the rabbit. The more oxygen impermeable dressing led to a slightly better histological response than the more permeable dressing. 5) The PEMF also significantly sped up the healing process in the rabbit model. 6) Initial *in vivo* testing of collagen and PLA/PGA materials with growth factors also showed increases in the healing rate in the rabbit model.

FUTURE PLANS—*In vivo* testing will continue and clinical trials will be initiated during the next 2 years of this 5-year project.

[471] HISTOPATHOLOGY OF DENERVATED SKIN FOLLOWING SPINAL CORD INJURY

Samuel L. Stover, MD
University of Alabama at Birmingham, Birmingham, AL 35233

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Skin complications represent a leading source of morbidity in the spinal cord injured population, yet relatively little is known about the histopathology of denervated skin. To improve the clinical management of these complications, and ultimately to prevent them, this study examines what happens at the cellular and tissue level when the body's largest organ, the skin, is denervated.

The objectives of this study are 1) to describe and establish the histopathology of denervated skin in patients with spinal cord injury (SCI) using appropriate laboratory and electron-microscopic techniques, 2) to establish the pathogenesis and natural history of skin changes following SCI, 3) to determine the nature of the relationship between the neurologic level and extent of SCI and the occurrence of specific skin changes, and 4) to determine whether there is a meaningful correlation between the severity of post-SCI skin complications and possible covariates such as the histopathologic changes observed, the neurologic level, and extent of lesion.

METHODOLOGY—The study population included 79 patients who received skin punch biopsies of the lower lateral thigh. Twenty subjects were included in a prospective study in which a skin biopsy was obtained within 2 months after injury. Nine of these same patients had a repeat biopsy 2 years post injury for comparison. Fifty-nine of the patients were at least 2 years post injury. All study subjects had complete injuries or incomplete injuries with minimal sensory sparing only. The study subjects were divided into four groups by level of injury: group I, C1-C8; group II, T1-T6; group III, T7-T11; and group IV, T12 and below. Skin biopsies were examined by a dermatopathologist using histopathologic methods of examination, with a subset of the biopsies studied by electron microscopy.

Clinical skin thickening was graded on a 0-4 scale by pinching the skin of the lower lateral thigh, between the thumb and the index finger. Grade 0 indicated normal skin, and Grade 4 indicated severe, almost woodylike, induration of the skin.

RESULTS—The most common histopathology was dermal fibrosis and perivascular infiltration. In the chronic injury group, dermal fibrosis was present in 65 percent of Group I subjects, 11 percent of Group II, 22 percent of Group III, and 40 percent of Group IV. Dermal fibrosis was identified in 65 percent of persons with tetraplegia and 25 percent with paraplegia. There was very little difference in perivascular infiltration in the different neurologic groups. Since grade 1 skin thickening was sometimes questionable, subjects with grade 2 or greater skin thickening were used to correlate with the finding of dermal fibrosis on histopathology. If clinical skin thickening of grade 2 or greater is present, dermal fibrosis was found in 71 percent of persons in group I. The numbers of subjects with grade 2 or greater skin thickening in groups II, III and IV were too small to provide meaningful information.

Of the 20 subjects in the recent onset injury group, 14 showed evidence of dermal fibrosis without any specific relation to the level of injury. Of the nine persons who had repeat biopsies 2 years later, the changes were inconsistent with the biopsies done within 2 months of injury.

Scanning electron microscopy (SEM) in 12 biopsies did not show any difference in the arrangement and size of the collagen bundles when compared with controls.

FUTURE IMPLICATIONS—Whether any of these findings are related to pressure ulcer development or to other skin problems which occur after SCI remains to be answered. A better understanding of the skin would be the obvious benefit. The interactions of denervation, autonomic dysfunction, and possible neuroendocrine changes become very complex but a better understanding may help to provide improved skin care.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Clinical skin thickening following spinal cord injury studied by histopathology (Abstract). J Am Paraplegia Soc 1993:16:254.

Clinical skin thickening following spinal cord injury studied by histopathology. Stover SL, Omura EF, Buell AB. J Am Paraplegia Soc 1994:17:44-9.

B. Fracture Healing

[472] COMPARISON OF EVENTS IN BONE HEALING INFLUENCED BY CCEF AND PEMF SIGNALS

Dennis A. Chakkalakal, PhD; Kevin L. Garvin, MD; Michael H. McGuire, MD
VA Medical Center, Omaha, NE 68105; University of Nebraska Medical Center, Omaha, NE 68198-1080; Creighton University School of Medicine, Omaha, NE 68131

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A623-RA)*

PURPOSE—The osteogenic effects of exogenous electricity in fracture healing have been observed for almost twenty years. However, questions regarding the efficacy and duration of application of various exogenous signals and the predictability of outcome remain to be answered. The purpose of this project is to identify critical events in bone repair influenced by two signals presently in clinical use, the capacitively coupled electric field (CCEF) and the electric field component of pulsed electromagnetic field (PEMF/EF). The results will establish a more rational basis for more effective use of these signals by determining specificity of effectiveness of each signal in different sequential phases of the fracture healing process.

METHODOLOGY—The project is designed to test the following hypothesis: CCEF and PEMF/EF signals stimulate new bone formation in delayed-healing fractures by inducing proliferation of osteogenic cells and the subsequent synthesis of an ossifiable matrix. A corollary hypothesis is that these signals have no direct effect on the process of mineralization. If this hypothesis is proven, the duration of treatment which currently lasts several months, can be reduced significantly.

These hypotheses are tested by evaluating the repair response in segmental defects in canine ulna with and without stimulation by each of the two signals. The signal is applied for various durations ranging from one to six weeks in separate groups of dogs. The repair response is evaluated by determining the effects of each signal on (1) healing of a 6 mm defect as measured in terms of mineralization and mechanical rigidity at 12 weeks after osteotomy, and (2) proliferation of osteogenic cells and synthesis of bone-matrix proteins in a 10 mm segmental defect at various times. In addition, an *in vivo* segmental defect model in the rat fibula and an *in vitro* model that uses explants of canine fracture callus in tissue culture medium are used to obtain supplementary data for interpretation of results from the *in vivo* canine studies.

PROGRESS—The time-average of the electric field was calculated from weekly measurements in the canine models and designated as "electric field dose." With three-point bending rigidity as the "response," the dose-response for the CCEF signal in the 6 mm defect model showed a peak at 257 mV/cm, having a peak rigidity (experiment/intact ratio) of 1.7 and a width at half-maximum of 46 mV/cm. In addition the data also suggest that stimulation for 6 weeks does not have any advantage over a 3-week stimulation.

RESULTS—Biochemical analysis of repair tissue from the 10 mm defect model on days 5, 8, 11 and 22 showed the following results. Total DNA and alkaline phosphatase activity were increased on days

5 and 8, but not on days 11 and 22, by CCEF stimulation. Total protein was unchanged on day 5, but markedly increased by day 8. Preliminary indication is that CCEF also increases both collagen types I and II at all four time points. From measurements of pH of the repair tissue *in vivo* in the rat model and calcium content of the same tissue after sacrifice, we found that the phase of rapid calcification of the repair tissue (2-3 weeks) is associated with a rapid increase of pH from acidic to alkaline values. In the callus-explant culture model, the proximal, middle, and distal segments of the repair tissue were investigated separately. The stimulatory effect of CCEF was mostly in the middle segment: total DNA and protein both increased on day 3, but there was no change in alkaline phosphatase activity. In nonhealing skeletal defects the middle part is usually mostly fibrocartilaginous tissue.

Thus the above result suggests that in our *in vivo* models CCEF may act early to modify the development of the repair tissue. Whether it actively promotes ossification of the middle part remains to be shown in future studies.

C. Other

[473] DIABETIC FOOT ULCER RISK FACTORS AND PATHOPHYSIOLOGY OF WOUND REPAIR

Edward J. Boyko, MD; Douglas G. Smith, MD
VA Medical Center, Seattle, WA 98108; Department of Orthopedic Surgery, University of Washington, Seattle, WA 98195

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A318-3RA)*

PURPOSE—We are conducting a prospective research project that is designed to assess the independent contributions of foot deformity, macrovascular and microvascular disease, peripheral neuropathy, and behavioral factors on risk of developing full thickness diabetic foot ulcer among general internal medicine clinic outpatients with diabetes mellitus at the Seattle VA Medical Center. Our group previously demonstrated the role of foot ulcer in diabetic amputations by demonstrating that nearly 84 percent of these cases of limb loss were preceded by nonhealing lower extremity ulcer.

PROGRESS—Since 1990 we have enrolled 756 diabetic outpatients whom we follow prospectively for the development of several outcomes including foot ulcer, amputation, revascularization of the lower extremity, and death. A baseline examination was obtained on all study subjects during the first 3 years of the study.

METHODOLOGY—Study subjects who meet the criteria for diabetes mellitus by virtue of treatment with a hypoglycemic medication or insulin are appointed for a comprehensive examination to assess presence of suspected risk factors. These factors can be grouped into four categories: lower extremity circulation, neuropathy, foot anatomy/biomechanics, and self-care behavior. Measured circulation factors include segmental lower extremity Doppler blood pressures (including the hallux), transcutaneous oximetry at four lower extremity sites, laser Doppler flowmetry at the dorsal foot, and easily obtained clinical measures including arterial pulses, venous filling time, and capillary refill time. Neuropathy measures in the lower extremity include monofilament testing for sensory neuropathy, bioesthesiometry, deep tendon reflexes, intrinsic muscle atrophy, and cardiovascular reflexes that reflect autonomic function. Foot anatomy measurements include clinical evidence for deformity, edema, posture/gait assessment, foot dorsiflexion, and Harris mat testing for abnormal pressure points. Behavioral factors assessed include type of footwear, diabetes history and control, foot self-care practices, and visual acuity.

Baseline examinations were conducted on all study subjects between 1990-93. To assess development of the outcomes of interest, all subjects received a mailed questionnaire on a quarterly basis which asked them to report to us the occurrence of the target conditions.

Rates of outcome occurrence (incidence) by exposures of interest were compared to determine whether a particular factor was related to risk of diabetic foot ulcer.

RESULTS—As of mid-1993, we had observed a total of 30 foot ulcers occurring over a cumulative 534 person-years of follow-up, equivalent to an overall incidence of foot ulcer in our cohort of 5.6 percent per year. The highest relative risk (RR) of foot ulceration was seen in subjects with hammer or claw toe deformity (RR = 6.8, confidence interval (CI) 3.3–14.1). Statistically significant foot ulcer risk elevations were also seen with inability to feel the 5.07 monofilament at any foot location (RR = 5.5, 95 percent CI 2.4–12.3) or self-reported numbness in either foot (RR = 2.9, 95 percent CI 1.1–9.9). Dorsal foot transcutaneous oxygen $\leq$40 mm Hg at 44°C and Ankle-Arm Index $\leq$0.8 were associated with nonsignificant increases in foot ulcer risk (RR = 1.9, 95 percent CI 0.9–4.2, and RR = 2.0, 95 percent CI 0.9–4.1, respectively).

FUTURE PLANS—It would be premature to conclude that micro- and macrovascular disease is unrelated to diabetic foot ulcer risk at this stage of the study, since about three times as many person-years will have accrued by close-out time, which will substantially enhance the power to detect associations of smaller magnitude. On the other hand, it does appear from our preliminary analysis that structural factors and sensory neuropathy may be more important in the pathogenesis of diabetic foot ulcer than ischemia. We will continue to follow this cohort of subjects until October 1996. We will obtain two additional examinations to assess changes in risk factor status and development of outcomes of interest over this time period. Final analysis when completed in 1996 should provide additional interesting information concerning pathogenesis of diabetic foot ulcer, and potential means for prevention.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Reliability of computerized wound surface area determinations. Ahroni JH, Boyko EJ, Pecoraro RE. Wounds 1992:4:133-7.

Diabetic foot ulcer healing: extrinsic versus intrinsic factors. Ahroni JH, Boyko EJ, Pecoraro RE. Wounds 1993:5:245-55.

Health and functional status of veterans with diabetes mellitus. Ahroni JH, Davignon D, Boyko EJ. Diabetes Care 1993:17:318-21.

XVII. Miscellaneous

[474] THE VOCATIONAL TRAINING FACILITY: INTERACTIVE EMPLOYMENT TRAINING FOR PERSONS WITH PHYSICAL DISABILITIES

Inder Perkash, MD; Charles Burgar, MD; Machiel Van der Loos, PhD; Joy Hammel, PhD, OTR; Pam LePage, MEd; Dan Shafer, OTR; Eric Topp, MSME; David Lees, MSME; Star Teachout, MS
VA Medical Center, Palo Alto, CA 94304

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B635-DA)*

PURPOSE—The goal of the Vocational Training Facility (VTF) Merit Review Project is to develop an interactive training program to teach desktop publishing (DTP) skills to persons with spinal cord injuries (SCI) in preparation for return to employment. Vocational skills are taught in a workstation setting, using adaptive access software, hardware, and devices. Traditional vocational training for individuals with disabilities is hampered primarily by the difficulties of physical access to the curriculum, not the substance of the curriculum itself. The VTF has developed a self-paced curriculum, interactive video tutorials and a robot-equipped workstation to respond to the educational, vocational, and daily living needs of each student.

The goal of the VTF is to assess, train, provide an internship for, and assist in placing each student in successful employment.

METHODOLOGY—The VTF provided workstations equipped with a variety of interface devices for individualized access by disabled users. The robot performs daily living (e.g., beverages, medication, mouth-stick) and vocational support (e.g., printer output, diskettes, phone) tasks under the direction of the student. With these supports, coupled with the multimedia curriculum design, each user is able to independently learn vocational skills. The VTF Project is testing this approach in a study that compares high and low level quadriplegic students to a control group of paraplegic students.

Three students at a time undergo a 12-week, full-time program. Conventional batteries of test instruments are supplemented by software records of user, computer, and robot events to analyze the effectiveness of the VTF concept.

PROGRESS—The VTF Project has completed the development and integration of the DTP curriculum, a process that included assessment of commercial training materials, production of three videodiscs, and the writing of an interactive student learning and testing environment in HyperCard. We have configured and programmed three robot workstations equipped with an integrated set of low and high technology adaptive access and ergonomic technologies.

RESULTS—By the spring of 1994, 13 students had participated in the training and 3 new students were enrolled in the final round. Of the 13 who participated, 11 completed the training and passed all the competency exams; two are employed in competitive DTP-related jobs; the remainder are participating in continuing education or advanced internships with local facilities and businesses or actively searching for employment. Final results will be analyzed and reported. The VTF staff is also exploring transfer of the VTF workstation, curriculum, and vocational training program model to outside facilities, business, education programs, and VA clinics.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

DeVAR transfer from R&D to vocational and educational settings. Van der Loos HFM, Hammel J, Leifer LJ. In: Proceedings of the Fourth International Conferences on Rehabilitation Robotics, 1994, Wilmington, DE.

Use of a rehabilitation robot in a classroom setting. Van der Loos HFM, Hammel J. In: Proceedings of the 17th Annual RESNA Conference, 1994, Nashville, TN.

[475] RESEARCH PROGRAM ON ACCESSIBLE HOUSING

Richard G. Long, PhD
Atlanta VA Medical Center, Decatur, GA 30033

Sponsor: *National Center on Accessible Housing, School of Design, North Carolina State University; National Institute for Disability and Rehabilitation Research, US Department of Education, Washington, DC 20202*

PURPOSE—The purpose of this multifaceted research program on accessible housing was to obtain information about the relationship between housing modifications and limitations in routine daily activities among persons with various types and degrees of physical disability. Information gained in this project has been useful to housing designers, builders, and disabled consumers in determining the housing features that have the greatest impact on independence in routine activities in the kitchen, bath, and other areas of the home.

METHODOLOGY—Information about housing needs of individuals with physical disabilities was obtained via a mailed national survey of housing features and difficulties experienced in various activities of daily living. The mail survey was conducted with approximately 486 individuals who are members of the National Center's Design Advisory Network. Survey questions assessed difficulty and dependence in areas such as bathing, cooking, and home care. Respondents indicated the various types of home modifications they had and whether or not they would like to make additional modifications. They also indicated the most critical issue in accessible housing for persons with disabilities. Respondents were encouraged to send pictures of unique or novel solutions to accessibility issues. A single-subject research design study to assess the impact of home modifications on independence and safety of older blind individuals was also conducted.

RESULTS—There was little variation among groups (i.e., power wheelchair users, manual wheelchair users, users of canes, walkers or other devices) in ranking of task difficulty and dependence. Tasks that were difficult for people who used walking aids were also difficult for individuals who used manual and power wheelchairs. Similar rankings were obtained for task dependency. The three groups did differ, however, on magnitude of difficulty and dependence in performing routine activities. Overall, trends in the data indicate that ambulatory individuals had the least difficulty and were least dependent, and that power wheelchair users had the most difficulty and were most dependent. Chi square analyses of the presence of home modification and task dependency and difficulty reveal that home modifications are important in reducing dependence and difficulty. In bathing and toileting tasks, for example, the presence of raised toilet seats and grab bars were related to reduction of difficulty getting on and off the toilet for manual wheelchair and power wheelchair users. Regression analyses showed a somewhat different patter of result from the chi square analyses, with far fewer modifications associated with difficulty for ambulatory individuals when compared to wheelchair users. This suggests that this population does not need aids or modifications, or that the existing aids or modifications do not meet their needs.

IMPLICATIONS—Researchers at VA Atlanta expect to continue their investigations of person-environment fit, both in evaluation of housing for persons with disabilities and in development and evaluation of devices to aid them in performing routine activities. With a growing population of

older persons with disabilities, we believe this line of research will yield important information for reducing the disabling effects of chronic medical problems.

[476] PREDICTING WAYFINDING ABILITY FROM LABORATORY-BASED SPATIAL TASKS

Richard G. Long; James Grissett, PhD; Bruce Blasch, PhD
Atlanta VA Medical Center, Decatur, GA 30033; Naval Aerospace Medical Research Laboratory, Pensacola, FL 32508

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420; Department of Defense, Washington, DC*
(Project #D525-RA)

PURPOSE—The primary goal of this 3-year study was to determine the relationship of microspatial abilities to macrospatial abilities in college-age individuals. A secondary goal was to explore the factor structure of various spatial tasks. Relevance of this line of research to the VA lies in the fact that many veterans with disabilities, particularly those who are elderly or those with sensory or cognitive deficits, may experience problems in wayfinding and spatial cognition. The ability to identify individuals at risk for disorientation would ultimately facilitate interventions to improve their wayfinding and spatial orientation abilities. Relevance to the Department of Defense (a co-sponsor of this research) lies in the fact that many military activities, such as aviation and troop movement, require good spatial orientation, wayfinding, and map reading skills in unfamiliar and sometimes adverse situations. If measures of tabletop or paper-and-pencil spatial abilities correlate moderately or well with large space wayfinding, then it may be possible to use microspatial tasks for screening and selection of military personnel for tasks requiring a high degree of spatial ability.

PROGRESS—This study has been completed. One hundred ninety-nine subjects ranging in age from 18-35 years were administered a battery of tabletop or paper-and-pencil spatial tests from the Kit of Factor Referenced Cognitive Tests developed by Ekstrom, French and Harman. These tests tapped various aspects of this complex cognitive domain (e.g., spatial visualization, memory for spatial information, and spatial closure). Subjects also performed a set of tasks which involved viewing a 5 ft by 7 ft model town and responding to questions which tapped perspective- and map-verification abilities. Finally, subjects walked predetermined routes inside a building and outside in a residential area/small business area. After these walks, subjects performed tasks that assessed their general Euclidean orientation and their abilities in feature recognition, temporospatial ordering of landmarks, map placement of landmarks, and route reversal tasks.

RESULTS—The analyses revealed that psychometric and experimental tasks loaded on three of the five factors, while topological spatial representation and Euclidean spatial representation each loaded separately on one factor. The regression analyses revealed that psychometric and experimental tasks did not, in general, account for significant variation in the macrospatial tasks requiring Euclidean representation of the outdoor space, but they were related to variance in macrospatial tasks involving topological representation. The results indicate that psychometric and experimental tasks can be useful, when combined with other measures, in evaluating the ability of military personnel to complete tasks such as remembering the location of environmental features on a walk or placing these features on a map. They should also be useful in evaluating the effectiveness of interventions for persons with disabilities.

IMPLICATIONS—This study extends our knowledge of the basic cognitive processes underlying successful wayfinding and spatial orientation in natural travel environments. It complements the ongoing program of research in spatial abilities of persons with disabilities that has been underway at the Atlanta VA Rehabilitation Research and Development Center since 1988.

[477] FEASIBILITY OF A DYNAMIC DERMOFLUOROMETER TO MONITOR SKIN FLUORESCENCE: A PILOT STUDY

Richard L. Magin, PhD; Lewis W. Winter, MD; Jin Kim, MD
University of Illinois at Urbana-Champaign, Urbana, IL 61801; Danville VA Medical Center, Danville, IL 61832

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Pilot Project #A91-260AP)*

PURPOSE—Local tissue perfusion is a critical parameter for the assessment of viability for skin flaps, strangulated bowel, and burns. In addition, patients with diabetes and arteriosclerotic peripheral vascular disease often have impaired local circulation in an extremity. Most current methods (colorometric, pO_2, Doppler ultrasound) for measuring tissue perfusion are locally invasive, exhibit a slow response time, or lack sensitivity. We seek to establish a new prototype dermofluorometer with the capability of performing kinetic studies of tissue blood flow. Such an instrument could provide a faster and more sensitive method for determining skin blood flow. This new technique should ultimately find application in a wide variety of clinical and perhaps even surgical diagnostic situations where it is important to ascertain tissue viability and/or the extent of developing pathology.

The objectives of the research are: to characterize the performance (sensitivity, response time) of the prototype dermofluorometer and to determine the feasibility of making rapid measurements of fluorescein dye wash-in and wash-out kinetics in humans.

METHODOLOGY—The proposed studies involving human subjects will follow the standard experimental protocol used by previous investigators, with the principal difference that the perfusion fluorometry data will be collected in a faster and more complete manner during the crucial wash-in period.

PROGRESS—The dynamic dermofluorometer developed on this project has achieved the original instrument design goals and is now ready for further evaluation in clinical trials.

RESULTS—A series of animal experiments were performed using 20 rats to confirm that the dermofluorometer can measure optical signals in the skin in subjects administered sodium fluorescein i.v. at doses of 4-5 mg/kg. A comparison of the uptake and wash-out kinetics of carboxyfluorescein with the clinically approved sodium fluorescein was performed. These results demonstrated that the two dyes have similar uptake kinetics (time constants of 4-6 minutes), but that sodium fluorescein is eliminated much more slowly (time constant 110 min) from the body than carboxyfluorescein (time constant 65 min). This is an important result because the clinical trials will use the patient approved sodium fluorescein, not the carboxyfluorescein used in previous animal experiments.

Preliminary clinical studies have been conducted on two human volunteers at the Danville VA Hospital. Each patient was given an i.v. bolus injection (4 sec duration) of sodium fluorescein (5 ml, of a 10 percent solution) by the medical staff in the Eye Clinic as part of an opthalmic procedure. Fluorescent signals were recorded from two optical fibers positioned on the interior surface of the forearm beginning approximately 30 min after fluorescein injection and continuing for 30 min. A special foam rubber, elastic net, and plastic frame support was used with the second patient to hold both fibers in direct contact with the skin. The sensor support mechanism allowed stable optical measurements to be made for the entire period. The signal intensity was relatively constant during the measurement period, exhibiting a small negative slope because the measurement period coincided with the plateau phase of plasma concentration.

FUTURE PLANS—For the next stage of our research, we plan to obtain the complete wash-in and wash-out curve of sodium fluorescein in humans. As in the preliminary studies, an i.v. bolus injection of sodium fluorescein will be used. We will also test the use of a steady state injection of dye to obtain a wash-in time constant. It is recommended that skin temperature be measured at the site of each probe since local temperature can influence skin perfusion.

[478] DEVELOPMENT OF A TWO-NEEDLE FRONT END FOR MOTOR UNIT DETECTION

David Hirsch, BS; Patrick J. Foley, MS; L. Donald Gilmore, ABEE; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B594-RA)*

PURPOSE—The recording and electrical conditioning of EMG signals are the first stages in the precision decomposition technique. The Motor Unit Lab employs a Needle Front End (NFE-01) built in 1991 to condition signals recorded with a single quadrifilar needle electrode. However, several projects in the Motor Unit Lab study the simultaneous activity of motor units from different muscles, requiring the insertion of multiple needle electrodes. For these studies a new Front End (NFE-02) has been developed which can condition the signals from two needles.

PROGRESS—The functionality of the system (NFE-02) is based on the design similar to that of NFE-01. For each needle, signals from the cannula and concentric sites are electrically filtered and amplified. In addition, with control from an electrical matrix, we have the flexibility to filter and amplify signals between any two of the needles' four selective recording surfaces. This feature allows us to choose the spatial arrangement of recording sites that results in the most distinctive signal shapes. This is important to the success of precision decomposition which relies on the acquisition of high quality signals with contrasting shapes among different motor units.

While expanding the number of channels of data that can be collected, NFE-02 also features an isolation stage providing galvanic isolation for subjects. In NFE-02, each of the component blocks that filters and amplifies a signal is powered by its own isolated power supply to ensure subject safety.

[479] RECONSTRUCTION EXPANSION AS A GEOMETRY-BASED FRAMEWORK FOR CHOOSING PROPER DELAY TIMES

Michael T. Rosenstein, MS; James J. Collins, PhD; Carlo J. DeLuca, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA)*

PURPOSE—Attractor reconstruction is usually the first step in the analysis of dynamical systems. Typically, an experimenter obtains a scalar time series from one observable of a multi-dimensional system; state-space reconstruction is then needed for the indirect measurement of the system's properties (e.g., dimension). Several techniques for attractor reconstruction are currently employed. The method of delays is the most widespread approach because it is the most straightforward and the noise level is constant for each delay component. However, the drawback with the method of delays is that the quality of the reconstruction depends upon the delay parameter, and presently, there is no commonly accepted procedure for choosing the delay parameter. Existing methods are often inconsistent or too time-consuming for practical application. Thus, the objective of this study was to develop a method for choosing proper reconstruction delays that is consistent and computationally efficient.

PROGRESS—Accordingly, we developed a geometry-based approach that quantifies reconstruction expansion from the identity line of the embedding space. This approach is based on the finding that reconstruction expansion is related to the concept of reconstruction signal strength and that increased expansion corresponds to diminished effects of

measurement error. In short, reconstruction expansion represents a simple, geometric framework for choosing proper reconstruction delays. This method is advantageous because 1) it is computationally efficient, 2) it works well with noisy data sets, and 3) it leads to consistent, accurate estimates of dimension.

[480] VISUALIZING THE EFFECTS OF FILTERING CHAOTIC SIGNALS

Michael T. Rosenstein, MS; James J. Collins, PhD
NeuroMuscular Research Center, Boston University, Boston, MA 02215; VA Outpatient Clinic, Boston, MA 02114

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #B596-RA)*

PURPOSE—Since experimentally obtained data are usually filtered, one should be aware of the effects of filtering chaotic signals. Although several research groups showed that lowpass filters can increase the observed fractal dimension of a chaotic system, there is still insufficient understanding of this phenomenon. Thus, the objective of this study was to provide further insight into the mechanisms underlying the effects of filtering chaotic systems.

METHODOLOGY—With this objective in mind, we found data visualization via three-dimensional ray-tracings to be an intuitive and effective resource. We developed a software utility for converting three-dimensional time series into a model compatible with a ray-tracing scene description language. We then performed a series of numerical experiments with systems that display chaotic dynamics, such as the Lorenz system.

RESULTS—Through the use of the above data-visualization techniques, we found that lowpass filters can induce a non-uniform convergence to a system's mean state-space position. That is, different portions of the attractor move towards the global mean at varying rates. With chaotic systems, this non-uniform convergence results in a distortion of the attractor's normal geometry such that the observed system acquires greater complexity, and, therefore, increased dimensionality.

A report based on this work will be published in *Computers and Graphics*.

[481] HOLTER SYSTEM DEVELOPMENT FOR RECORDING PLANTAR PRESSURES

Jacqueline J. Wertsch, MD; Gerald F. Harris, PhD; Ziad U. Abu-Faraj, MS; Abhijit S. Vengsarkar, BS; Joseph H. Abler, PhD
Zablocki VA Medical Center, Milwaukee, WI 53295; Marquette University, Milwaukee, WI 53233; Medical College of Wisconsin, Milwaukee, WI 53226

Sponsor: *Department of Veterans Affairs, VA Rehabilitation Research and Development Service, Washington, DC 20420 (Project #A624-2RA)*

PURPOSE—Our hypothesis is that a cost-effective Holter-type device can be developed to continuously record plantar pressures for at least 16 hours during normal daily activities. Key questions are to develop and evaluate the system, and study the cumulative plantar pressures and the risk of falling.

METHODOLOGY—The objective of this proposed research is to develop a Holter-type device for long-term recording of plantar pressures during normal daily activities. The goal is to use existing, proven technologies to develop a working system. The Holter-type in-shoe pressure data-acquisition

system will be capable of 16-hour recording. The microprocessor-based system will consist of multiple pressure sensors, a 16-bit microprocessor and 16-MB RAM. The system will be evaluated by testing 10 normal individuals during unrestricted activities for an entire day. Durability, reliability, acceptability, and capability to measure the entire range of plantar pressures will be evaluated and the variability of defined gait parameters (number of steps taken, average cadence, averaged peak pressures, maximum peak pressure, amount of time spent loaded at peak pressures, and minimum peak pressure) during the entire day.

This system utilizes Interlink pressure sensors of 11 mm diameter. These sensors will be used because of their low cost (less than $4 each), reliable output, thin profile, overload tolerance, and electronic simplicity. The sensors are placed under known loading sites of the first, second, and fifth metatarsal heads, heel, and great toe of each foot. The portable system can continuously record all pressure data from 10 sensors for 8 hours at a 35 Hz sample rate, or samples of plantar pressures are recorded during particular activities. Ten normal subjects: 5 males and 5 females are being studied to assess the system's durability, reliability, acceptability, and capability to measure plantar pressures during unrestricted activities and to assure that the system has the dynamic range necessary to measure the defined gait parameters for the entire 16-hour recording period.

PROGRESS—Year one milestones have been sucessfully completed. The Holter unit display hardware, CPU, and memory cards are complete. The system has passed preliminary hardware continuity and communication checks. The system is configured for use with force-sensing resistor sensors (FSRs), and includes a separate port for calibration. All cable collectors are keyed and designed to accept in-line resistors for changes in gain requirements. The unit is capable of three modes of recording (continous, intermittent, and real time) on 14 channels. Further development will focus on software support, bench testing, printed circuit board implementation for size reduction, and clinical validation.

FUTURE PLANS—The data compression algorithms (Lempel-Ziv-Welch) have been selected, validated, and are being implemented into the mircroprocessor system. The system has been used during several preliminary subject trials. Further clinical testing is planned.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Procedures for gait analysis. Harris GF, Wertsch JJ. Arch Phys Med Rehabil 1994:75:216-25.

Holter system development for recording plantar pressures: design and instrumentation. Ziad AF, Harris GF, Wertsch JJ, Abler JH, Vengsarkar AS. In: Proceedings of the IEEE Engineering in Medicine and Biology Society. In press.

Holter system development for recording plantar pressures: software development. Vengsarkar AS, Abler JH, Ziad AF, Harris GF, Wertsch JJ. In: Proceedings of the IEEE Engineering in Medicine and Biology Society. In press.

Human motion analysis: an historical perspective and introduction. Harris GF, Wertsch JJ. In: Harris G, Smith P, eds. Human motion analysis, Ist ed. Piscataway, NJ: IEEE Press. In press.

[482] THE EFFECT OF BOTOX ON WALKING

Elizabeth Sheil, MASc; Elizabeth Harper, RN, PEng; Mercer Rang, MBBS, FRCS(C); Stephen Naumann, PhD
Human Movement Research Programme, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsor: *Allergan, Inc.*

PURPOSE—The purpose of this study is to evaluate the safety and efficacy of intramuscular injections of BOTOX in the management of dynamic muscle contractures and spasticity in ambulatory children with cerebral palsy who have an equinovalgus foot deformity.

PROGRESS—The first section of the study is complete. It evaluated the effects of Botox during the first three months of treatment. Results are currently being processed and analyzed. The second section of this study is assessing the effects of Botox over a two year period. We are approxi-

mately half-way through the collection stage of this study.

FUTURE PLANS—Results from the first section of the study will be processed and statistically and visually analyzed. Data from the second section of the study will continue to be collected and processed as the study progresses.

[483] HEALTH BEHAVIOR IN SCHOOL-AGED CHILDREN WITH PHYSICAL DISABILITIES

Catherine Steele, PhD; Jeffrey Jutai, PhD; Joseph Bortolussi, MSW; Douglas Biggar, MD; Ilze Kalnins, PhD; Elizabeth Stevens, MA
Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8 Canada

Sponsor: *Bloorview Childrens Hospital Foundation, Toronto*

PURPOSE—Health promotion strategies are needed if disabled youth are to reduce their high risk of secondary disabilities (e.g., heart disease and stroke, respiratory problems) and maintain a good quality of life throughout their adult years. Given the lack of attention paid to health promotion for young people with disabilities and the obvious importance of reducing the risk of secondary disabilities through the promotion of healthy lifestyles, we have begun a research program to determine the wellness and risk for health problems of youth with physical disabilities.

METHODOLOGY—An international survey, developed by the World Health Organization, of health knowledge, behaviors, attitudes and lifestyles of school-aged children is being administered to 100 youth with disabilities from schools in Metropolitan Toronto within integrated and special settings.

RESULTS—Results indicate that youth with disabilities are at greater risk than youth without disabilities for some health problems but not others. Youth with disabilities have poorer diets, more sedentary leisure activities, more physical symptoms, and engage in fewer social activities than their peers without disabilities. However, youth with disabilities are less likely to smoke and consume alcohol. They also have comparable levels of self-esteem, and enjoy school as much or more than their non-disabled peers.

PROGRESS—Data collection was to be complete in May 1994. Further work will determine the interrelationships among the demographics, health behaviours, psychosocial factors and disability issues. Ultimately, new health promotion strategies to accommodate the special requirements for youth with disabilities will be developed. In keeping with the broadly adopted definition that the purpose of health promotion is to enable people to take greater control over the conditions that affect their lives, we will again be committed to the active involvement of the young people themselves in this process.

[484] DOCTORAL TRAINING IN PHYSICAL THERAPY

David H. Nielsen, PT, PhD
Physical Therapy Graduate Program, The University of Iowa, Iowa City, IA 52242-1008

Sponsor: *Foundation for Physical Therapy*

PURPOSE—The purpose of this project is to support doctoral training in the Physical Therapy Graduate Program at The University of Iowa. The objective is to develop productive researchers and scholars in the field of physical restoration and rehabilitation services. The project provides support enabling five PhD trainees to concurrently pursue graduate education representing a diversity

of specialty areas (cardiopulmonary, rehabilitation, biomechanics, ergonomics, and musculoskeletal and neuromuscular therapeutics) and research agendas.

PROGRESS—The environment at the University of Iowa is conducive to a multidisciplinary format of higher education and research. The College of Medicine in conjunction with the University of Iowa Hospitals and Clinics is recognized as one of the largest health profession teaching centers in the country. The Physical Therapy Graduate Program has a longstanding history of teaching and research. The multi-year (1991-1994) funded (Foundation for Physical Therapy) Physical Therapy Clinical Research Center grant has been complementary to this mission.

The NIDRR award has provided resources to bring experienced and expert researchers to campus for the purpose of continuing education, consultation and review. All consultants provide seminars available to the entire academic and clinical community. Small group meetings are also scheduled with the NIDRR trainees. Visiting faculty include Dr. Jules Rothstein, Professor and Chair of the Physical Therapy Department at the University of Illinois at Chicago, Dr. Alan Jette of the New England Research Institute, Dr. Kai-Nan An from the Orthopedic Biomechanics Laboratory at the Mayo Clinic, Dr. Roger Enoka from the Department of Biomedical Engineering of the Cleveland Clinic, and Dr. Charles Ciccone, Associate Professor at Ithaca College.

A two-day workshop on "Creating Educational Excellence: Effective Classroom Teaching" was co-sponsored by the Physical Therapy Graduate Program; the consultant was Sandra Stork, MS, RD, CN, Regional Consultant for TIPS (Teaching Improvement Project System). Through the NIDRR project, support was provided for trainees to attend and/or make research presentations at a variety of professional meetings including the Second North American Congress on Biomechanics, Chicago, IL (August 1992); Work Physiology Symposium, Spring Hill, TN (September 1992); Marianjoy Rehabilitation Center CE Conference, Rockford, IL (March 1993); and American Physical Therapy Conferences, Cincinnati, OH (June 1993), New Orleans, LA (February 1994).

Because of overlap with a previous grant and most of the trainees will complete their graduate studies in less than the five-year grant period, potentially a total of 12-13 trainees will be supported by this project. Since the current project began in July 1992, ten trainees have participated in the program, five of whom have graduated with doctoral degrees. These graduates include:

Dr. Sandra Cassady, Lecturer, The University of Iowa, and Assistant Professor, St. Ambrose University, Davenport, IA, is working on exercise testing and training of children with cystic fibrosis and adults with chronic obstructive lung disease who are awaiting lung transplantation. Dr. John Rosecrance, Assistant Research Scientist at the University of Iowa, is evaluating new assessment techniques for the detection of abnormal nerve conduction in carpal tunnel syndrome. Dr. Margaret Weightman, Assistant Professor, College of St. Catherine, Minneapolis, MN, is studying the effects of mechanical stimulus intensity and stimulus location on electromyographic motor unit activity in human soleus muscle. Dr. Deborah Nawoczenski, Assistant Professor, Ithaca College, Rochester, NY, is conducting kinematic analysis (multivideo camera motion analysis) of the lower leg, ankle and foot to investigate the efficacy of a foot orthosis as an alternative strategy to preventing knee injuries. Dr. Kevin McQuade, who is currently interviewing for a faculty position, is working on the scapulohumeral rhythm: a three-dimensional kinematic analysis of the effects of load and fatigue during elevation of the arm in the scapular plane.

Current trainees are in various stages of completing course work and gaining valuable laboratory experience through formulating potential research questions and conducting pilot investigations.

The graduate faculty mentors are highly satisfied with the current level of support and are proud of trainee accomplishments (13 research presentations at scientific meetings and authorship of seven publications in peer-reviewed journals). Students express very positive feelings about the program, noting that receiving a full-time traineeship allows them to effectively focus on developing the knowledge and skills needed for their rehabilitation research careers.

[485] DESIGN OF A CLINICAL REFERENCE SYSTEM FOR POSITIONING ELECTRODES ON THE BACK

L. Donald Gilmore, ABEE
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

PURPOSE—Spectral analysis of the EMG signals detected from the muscles of the lower back provides an objective tool for characterizing muscle fatigue suitable for assessment of muscle dysfunction. A successful clinical implementation of this technique requires the accurate and repeatable detection of the EMG signals from six prescribed muscle sites located in the region of the lower back. These six sites are representative of the major muscle groups involved in producing back extension. Proper positioning of the six EMG detection electrodes with respect to the underlying muscles is critical due to the influence of electrode position on the EMG signal's spectra. To insure correct initial placement of the EMG detection electrodes over the desired muscle sites and their subsequent replacement for follow up testing, the Center is developing a clinical technique suitable for locating electrodes on a patient population ranging from 2.5 percent to 97.5 percent of norm.

METHODOLOGY—The locating technique utilizes a mathematical scaling function to determine the correct x-y coordinates for each electrode site. These coordinates were derived from a data base of physical measurements of the lower back muscles and X-ray images of the spine taken from a sample subject population. An important element of the technique is the determination of a suitable anatomical landmark to use as a stable reference point. A specialized prototype seat was designed to locate the ischium, a bony landmark located at the bottom of the pelvis.

RESULTS—Repeatability measurements using this landmark as a reference point for the scaled x-y coordinates indicate that the EMG electrodes can be positioned within the plus or minus one centimeter tolerance required for accurate clinical determination of EMG spectral parameters. Upcoming work will focus on the integration of the electrode locating apparatus with the devices of the Clinical Back Analysis System.

[486] ELECTRODE ARRAY SIGNAL PROCESSING

P.A. Parker
Institute of Biomedical Engineering, University of New Brunswick, Fredericton, NB E3B 5A3

Sponsor: *Medical Research Council of Canada*

PURPOSE—We seek to improve evoked response measurement signal-to-noise ratio by the use of array beamforming.

PROGRESS—To date a delay and sum array beamformer has been analyzed and implemented. The results demonstrate that the array can, depending on the cross channel correlation, improve signal-to noise by a factor equal to the number of electrodes in the array.

FUTURE PLANS—This work continues with the consideration of the performance of a beamformer in the presence of interfering myoelectric signal.

[487] RESEARCH TRAINING IN REHABILITATION ENGINEERING

J. Milton Adams, PhD
Department of Biomedical Engineering, University of Virginia, Charlottesville, VA 22908

Sponsor: *U.S. Department of Education, National Institute on Disability and Rehabilitation Research*

PURPOSE—Rehabilitation engineering research training is the focus of this program which supports predoctoral and postdoctoral fellows.

PROGRESS—We have appointed six predoctoral fellows and four postdoctoral fellows over the past three years including an African American and two women. Our predoctoral fellows who earn PhD degrees in Biomedical, Electrical or Mechanical Engineering include: Dave Baldwin, PhD in Mechanical Engineering studying structural mechanics of wheelchairs, now Assistant Professor of Mechanical Engineering at the University of Oklahoma; Kristen Bowsher, who will finish a PhD in Biomedical Engineering and begin a Postdoctoral Fellowship in June 1994; Rick Kwiatkowski, PhD in Electrical Engineering, studying seating design and instrumentation for preventing pressure sores; and Jeff Duncan and Brian Riordan, who are completing their second year in the program. Jeff is studying gait accommodation to anterior cruciate ligament repairs and Brian has designed an instrument for studying swallowing activity in patients with drooling.

RESULTS—Two postdoctoral fellows have finished their training and have faculty positions. Dr. Marcus Besser is Assistant Professor in Physical Therapy at Jefferson Medical College and Dr. Joseph Hale is Assistant Professor of Orthopedics and Biomedical Engineering at the University of Virginia. J.H. Ke, PhD, is currently in training studying spinal cord injuries and stabilization and M. Pannunzio, MD, is studying gait and motion analysis.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Joint torques and co-contraction during gait for normal and CP children. Bowsher KA, Damiano DL, Vaughan CL. In: Proceedings of the North American Congress on Biomechanics, 1992:319-320.

Characterization of the dynamic stress response of manual and powered wheelchair frames. Baldwin JD, Thacker JG. J Rehabil Res Dev 1993:30:224-32.

Closed loop automated seating system. Kwiatkowski RJ, Inigo RM. J Rehabil Res Dev 1993:30:393-404.

Indentation assessment of biphasic mechanical property deficits in size-dependent osteochondral defect repair. Hale JE, Rudert MJ, Brown TD. J Biomech 1993:26:11319-25.

Loading at the patellar tendon and distal end in the PTB prosthesis. Besser MP. In: Proceedings of the XIV International Congress of Biomechaics, 1993:180-1.

[488] MEDICAL REHABILITATION PAYMENT STUDY

Gerben DeJong, PhD; Janet Sutton, PhD; Deborah Wilkerson, MA; Sherri Tepper, ScD
National Rehabilitation Hospital Research Center, Washington, DC 20010

Sponsor: *National Institute on Disability and Rehabilitation Research, US Department of Education, Washington, DC 20202*

PURPOSE—The purpose of this study is to evaluate the feasibility of using functionally based payment methods as an alternative to current cost-based methods of financing inpatient medical rehabilitation. The study seeks to develop the policy objectives of a sound payment methodology, identify alternative payment models that incorporate patient functional status, evaluate the financial consequences of alternative payment methods for individual facilities, and make recommendations for the future of medical rehabilitation payment policy.

METHODOLOGY—The policy objectives for a sound medical rehabilitation payment methodology are determined through a Delphi survey (n = 85) of consumers, providers, payers, and health services research. The financial consequences of alternative payment models are determined through an analysis

of two large data sources: 1) the Uniform Data System (UDS) for medical rehabilitation, a national data base containing both patient functional data and facility characteristics and 2) MEDPAR, a national data base containing both patient data and facility financial data for all Medicare beneficiaries. The study team will make recommendations taking into account the policy objectives for a sound payment system and the financial consequences both for facilities and for society at large.

PROGRESS—The Delphi survey has been completed. The Study Team is currently using the study's two main data sources to evaluate the economic consequences of alternative payment methodologies for the medical rehabilitation industry.

RESULTS—The Delphi survey identified 16 policy criteria that should govern the evaluation of alternative payment methodologies and the selection of an appropriate payment reform plan. The survey uncovered considerable consensus across the four respondent groups (consumers, providers, payers, and health services researchers). The Delphi results indicate a desire to have a payment system that is more heavily weighted toward consumer and clinical goals such as maximizing outcomes, access, continuity, and consumer satisfaction as opposed to provider considerations such as minimizing provider financial risk.

FUTURE PLANS—The study will be issuing papers as results are completed. The study is scheduled to be completed in July 1995.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Use of functional measures for payment of medical rehabilitation services. Wilkerson D, Batavia AI, DeJong G. Arch Phys Med Rehabil 1992:73(2):111-20.

Criteria for the selection of a payment methodology for inpatient medical rehabilitation. Tepper S, DeJong G, Wilkerson D, Brannon R. Annual meeting of the American Congress of Rehabilitation Medicine; Minneapolis, MN 1994 June 11.

[489] THE HEALTH CARE UTILIZATION AND COST EXPERIENCE OF WORKING-AGE PERSONS WITH DISABILITIES: AN ANALYSIS OF THE NATIONAL MEDICAL EXPENDITURE SURVEY (NMES)

Gerben DeJong, PhD; Sherri Tepper, ScD; Andrew I. Batavia, JD, MS; Mitch LaPlante, PhD
National Rehabilitation Hospital Research Center, Washington, DC 20010.

Sponsor: *National Institute on Disability and Rehabilitation Research, US Department of Education, Washington, DC 20202*

PURPOSE—The purpose of this study is to investigate access to and utilization of health care services by working-age individuals with disability in the United States. This study seeks to address this problem by conducting an analysis of the 1987 National Medical Expenditure Survey (NMES), an in-depth survey of 35,000 individuals in 14,000 households exploring their health care utilization and cost experience. This study will provide an empirical backdrop for the review of health policy options facing people with disabilities.

METHODOLOGY—Data for this study will be derived from the National Medical Expenditure Survey (NMES). Data will be converted from mainframe files to smaller work files for analyses to be conducted in the PC environment. Files from different components of the study will be linked. These include the household survey, institutional survey, and the health insurance plans survey.

PROGRESS—During the first six months of this two-year study, many of the tapes of data required for the analyses have been acquired, and the study team is seeking to acquire the remaining data. Data have been transferred from mainframe tapes to tapes from the PC, and smaller files are being developed.

FUTURE PLANS—In the next year and a half of the study, data files will be linked and analyses conducted. Several reports will be produced. These

include 1) tabular data to be published as part of a statistical series (these will provide a health care utilization and cost profile of working-age disabled Americans, and their insurance status) and 2) articles for publication in the disability and health policy literature.

[490] OPERATIONAL DEFINITION OF INDEPENDENCE

Margaret A. Nosek, PhD; Marcus J. Fuhrer, PhD; Carol Howland, BA
ILRU Research and Training Center on Independent Living; Center for Research on Women with Disabilities, Baylor College of Medicine, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—This project is designed to develop an operational definition of independence that incorporates four components of the term: perceptions of control over one's life, psychological self-reliance, physical functioning, and behavioral and environmental resources. The objective is to develop an assessment instrument to quantify an individual's independence in each of the above domains.

PROGRESS—After extensive search of the literature and expert consultation, the Personal Independence Profile (PIP) was constructed to operationalize the consensus definition. The PIP consists of four subscales: Part I, Control, 10 items selected from Flanagan's (1978) quality of life domains; Part II, Psychological Self-Reliance, 34 items from Fordyce's Independence Scale (1954) that deal with psychological factors such as competitiveness, self-esteem, and group autonomy; Part III, Physical Functioning, 5 sections from The Arthritis Impact Measurement Scale (AIMS) (Meenan, Gertman, and Mason, 1980), a Guttman-type ordering of general functional ability items; and Part IV, Environmental Resources, containing 16 nominally scaled questions about housing, education, income, employment, and transportation. An additional 6 items on age, gender, race, marital status, age at onset of disability, type of disability, and health comprised demographic variables.

The next step in the development of the PIP was to conduct various tests of its validity. Two hundred subjects in ten independent living centers (ILC) across the country were sent the PIP, 120 of whom also completed questionnaires designed to measure the same or similar constructs to test the convergent validity of the PIP. A sample of 185 of these 200 subjects produced data that were complete enough to enable cluster analysis of the PIP-Psychological Self-Reliance, PIP-Control, and PIP-Physical Functioning scores.

RESULTS—Testing of the reliability of the PIP resulted in Cronbach alpha coefficients of 0.79 for psychological self-reliance, 0.86 for control, and 0.93 for physical functioning. The internal validity of all three constructs of the PIP was supported by high correlations with other scales designed to measure similar constructs and low correlations with scales that do not measure similar components of independence. Cluster analysis of the three PIP scales from 185 subjects using Ward's minimum variance procedure yielded three salient profiles: A, independently minded and less disabled; B, independently minded and more disabled; and C, nonindependently minded.

The 81 Profile A participants had high standardized mean scores on all three subscales. Compared to the other two profile groups, this group reported the highest level of perceived independence, tended to feel in control of the things that were important to them, used the fewest prescription drugs, spent the fewest days in the hospital in the past six months, and had the highest productivity.

The Profile B cluster contained 49 participants who had high scores on Psychological Self-Reliance and Control, but low scores on Physical Functioning. Though similar to Profile A, they differed markedly in their much higher degree of physical impairment. This group had the highest level of perceived health, used the most prescription drugs, made few trips to the hospital emergency room, spent the most days in the hospital, and made the fewest visits to the doctor's office. As in the Profile A cluster, these participants were highly productive.

Profile C differed markedly from the other two clusters. The 55 participants in the Profile C cluster had low scores on the Psychological Self-Reliance and Control subscales, but highly variable scores on the Physical Functioning subscale. Of the three profile groups, this group reported the lowest level of perceived independence, the lowest level of perceived health, the most frequent visits to hospital emergency rooms, a high number of days in the hospital, and the most visits to the doctor. They were the least productive of all three groups.

FUTURE PLANS—The PIP-Control subscale is being used in three studies: 1) a study of relationships among personal assistance services, negative health incidents, and health care utilization; 2) a study of sexuality of women with physical disabilities; and 3) a study of aging, cultural factors, and health of women with physical disabilities.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Independence among people with disabilities. I. a heuristic model. Nosek MA, Fuhrer MF Rehabil Counsel Bull 1992:36:7-21.

Independence among people with disabilities. II. personal independence profile. Nosek MA, Fuhrer MF, Howland CA. Rehabil Counsel Bull 1992:36:21-36.

[491] RESEARCH TRAINING IN ENGINEERING AND REHABILITATION TECHNOLOGY

Charles J. Robinson; Savio Woo; Louis Penrod
Highland Drive VA Medical Center, Pittsburgh, PA 15206; University of Pittsburgh; Pittsburgh, PA 15240

Sponsor: *National Institute on Disability and Rehabilitation Research, Washington, DC 20202*

PURPOSE—The University of Pittsburgh has recently established a new multidisciplinary Department of Rehabilitation Science and Technology. This Department has formulated an innovative curriculum for a Masters level program in Rehabilitation Science and Technology within the School of Health and Rehabilitation Sciences. A parallel series of courses have been established within the Bioengineering Program in the School of Engineering, so that engineers can have a rehabilitation engineering concentration for their MS or PhD degrees. Certificate options have been established for Rehabilitation Technology, Rehabilitation Engineering, and Rehabilitation Service Delivery. A PhD in Rehabilitation Sciences is now in the final stages of approval. This Department has received a 5-year NIDRR Training Grant to help alleviate the shortage of qualified researchers in the field of rehabilitation engineering and technology.

We require that our NIDRR Training Grant Fellows complete a challenging set of didactic courses, clinical practices, and research experiences. The training program focuses on engineering and rehabilitation technology, with a specific emphasis on engineering design, biomechanics, assistive devices, wheeled mobility, and instrumentation. A key feature of our proposal is the use of resources available within the University and the Greater Pittsburgh area to provide training experiences for prospective researchers in all areas of rehabilitation.

By its very design the training is multidisciplinary. The mentoring structure is designed so that all Fellows receive a balanced exposure to research, clinical, and academic approaches to rehabilitation. All aspects of rehabilitation technology are considered, not only in their technical dimension, but also in the clinical, ethical, scientific, and economic aspects. Thus, the definition of rehabilitation extends beyond that implied by a strict medical model. Further, each Fellow is required to interact with community-based consumer groups whose outlook might differ substantially from that held by those in academia. The program has an administrative hierarchy that reflects its multidisciplinary nature. Governance of the program is by a Program Director, an Executive Committee, a Steering Committee, and an external Advisory Council.

METHODOLOGY—The following objectives and goals have been established for the project: 1) we seek to increase the number of qualified rehabilitation researchers by providing intensive postdoctoral training within appropriate clinical and academic settings in the field of Rehabilitation Engineering

and Technology to 12 individuals with a doctoratc in engincering, thc sciences, or medicine. Some of these individuals will have had previous exposurc to rehabilitation; 2) we will work to increase thc number of qualified rehabilitation researchers by providing intensive predoctoral analytical training within appropriate clinical and academic settings in the field of rehabilitation engineering and technology to 7 individuals with a master's degree and experience in engineering or a clinical discipline (like occupational or physical therapy); and 3) we shall develop and disseminate a basic curriculum at thc pre- and postdoctoral level that will produce high quality researchers in the field of Rehabilitation Engincering and Technology.

PROGRESS—For the first year, we have recruited an outstanding and diverse group of Fellows from a variety of backgrounds and disciplines. All Fellows have the potential to be outstanding researchers in the fields of rehabilitation science, technology or engineering.

[492] THE IMPACT OF WAITING FOR COMMUNITY-BASED SERVICES AND THE ROLES OF FORMAL AND INFORMAL SERVICES ON ADULTS WITH MENTAL RETARDATION WHO LIVE WITH THEIR FAMILIES: A LONGITUDINAL PERSPECTIVE

Mary F. Hayden, PhD; Robert Bruininks
University of Minnesota, Minneapolis, MN 55455

Sponsor: *National Institute on Disability and Rehabilitation Research, US Department of Education, Washington, DC 20202*

PURPOSE—The Family Services and Support Project began July 1, 1992. The purpose of the project is to study the experience of adults with mental retardation and other developmental disabilities (MR/DD) and their families as they wait for and, where this occurs, after they received formal community services and supports. The project involves two major components to collect and analyze information through quantitative and qualitative methods. The first component is a comprehensive, longitudinal study in 2 parts: the first part consists of regular interviews with primary caregivers for 3 years; the second consists of quarterly telephone interviews with them the final two years of the project. The second component of the overall project is a consumer opinion survey.

METHODOLOGY—A convenience sample has been obtained. Nearly 32 percent of the subjects lived in urban, 19 percent in rural, and 48.6 percent in suburban areas. The vast majority were white and there were approximately the same number of women as there were men. About 77 percent graduated from high school. The primary diagnosis was mental retardation. Levels of mental retardation included mild (47.6 percent), moderate (21.9 percent), severe (20 percent), profound (5.7 percent), and unknown (4.8 percent).

The majority of the responding caregivers were mothers of the adult family with mental retardation (86.7 percent). Only 6.7 percent were fathers, 2.9 percent were siblings, and 1.9 percent were extended family members. Respondents were primarily 50 to 69 years old (64.2 percent) and married (70.5 percent). They typically did not work (43.8 percent) and the majority had at least a high school education (58.1 percent).

PROGRESS—Staff has completed the first and second year surveys. The final survey will begin in the fall of 1994. The consumer survey and a training manual has been developed and are being field tested. The first two quarterly telephone interviews have been completed. The third interview began July 1994.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Waiting for community services: the impact on persons with mental retardation and other developmental. Hayden MF, Dieppe P. In: Hayden M, Abery BH, eds. Challenges for a services system in transition: ensuring quality community experiences for person with developmental disabilities. Baltimore: Brookes, 1994.

[493] TRANSFERRING TECHNOLOGY FROM THE RESEARCH LABORATORY TO THE COMMERCIAL MARKET

Donald R. McNeal, PhD; Everett Rogers, PhD; J.D. Eveland, PhD; Tom Valente, PhD
Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—This project is one of three supported by the RERC on Technology Transfer. The goal of this project is to provide assistance to investigators who are interested in transferring their research results to manufacturers and service providers. The activities described below have been pursued in the past year.

PROGRESS—A survey was conducted by the Rancho RERC on Technology Transfer of twenty Rehabilitation Engineering Centers (RECs). The survey was aimed at identifying key issues, administrative practices, and experiences in technology transfer between researchers and industry and the overall process of commercialization of research results. The study included RECs currently receiving NIDRR support and those not receiving such funding. For comparison, a modified survey instrument was mailed to another group of centers, the NSF-sponsored Industry/University Cooperative Research Centers (IUCRCs).

RESULTS—RECs were found to have considerable contact with industry, with most having over 50 contacts across two years and a substantial group reporting over 100 contacts. These contacts most typically involve showing off prototypes and general discussions of ideas for products. IUCRCs report similar levels of contact, although their reasons for contact tend to emphasize more general discussions with less immediate product focus.

Among RECs, there are significant differences of opinion about the relative importance of commercialization; three ranked it first or second among five alternatives, while five ranked it last. Service delivery is also bimodally distributed in priority. In general, publishing is considered the most important activity by most RECs, whereas commercialization ranked fourth overall.

Most RECs and IUCRCs have applied for patents on products they have created, but only 25 percent of the RECs and 38 percent of the IUCRCs indicated that it was "very important" to apply for patents. Over half of the RECs have received royalties for products they have created; revenues from royalties are less common among IUCRCs. Neither RECs nor IUCRCs have experienced much reported conflict with manufacturers. Where such conflicts do arise, they usually center around the manufacturer's desire for confidentiality.

An interesting variable that appears to be an overall predictor of commercialization involvement is the presence or absence on the center staff of an individual specifically charged with responsibility for technology transfer and use. In RECs, the availability of such a staff person is associated with higher and earlier levels of contact with industry, more emphasis on commercialization in decision making, and receipt of royalties. Among IUCRCs, by contrast, the presence of a technology transfer staff person does not appear to be related to contact levels or royalties, although it does seem to reflect somewhat different underlying decision making emphasis. Overall, this suggests to us that the RECs, with their generally greater degree of applied research and commercialization emphasis, are equipped to make better use of their transfer specialists than are IUCRCs with their emphasis on basic research.

A series of questions put to the RECs eliciting peer nominations for RECs that are particularly effective in commercialization produced a wide spread of results, ranging from 17 nominations for one center to no nominations for another. We would certainly not claim that peer nomination is in any sense a global indicator of center effectiveness. It is, however, given the nature of the professional community, probably a reasonably effective indicator of technology transfer performance. In general, the group of centers that received the highest number of nominations tended, not unexpectedly, to put more emphasis on commercialization (and less on publishing), and to have higher levels of industry contact. They also tend to have designated technology transfer staff, but devote somewhat less of their staff time to commercialization activities.

[494] IMPLEMENTATION AND FOLLOW-UP OF REHABILITATION TECHNOLOGY

Paul J. Mortola, MS; Jean Kohn, MD; Maurice LeBlanc, MS; Donald R. McNeal, PhD
Packard Children's Hospital at Stanford; Rehabilitation Engineering Center, Palo Alto, CA 94304;
Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—This project tested the hypothesis that the acceptance and successful use of rehabilitation technology is critically dependent upon the following factors: appropriate training in device use, adequate written instructions, and follow-up to determine the outcome of using the device. This project was conducted at the Children's Hospital at Stanford, Palo Alto, California. It is one of three projects supported by the Rancho RERC on Technology Transfer.

PROGRESS—The Rehabilitation Engineering Center at Stanford identified two levels of follow-up care that were intended to increase the use, safety, satisfaction, and longevity of the device used by the subject. These procedures included the use of videotape, phone calls, additional written directions, and home evaluations. Fifty-eight subjects were randomly divided into three equal groups for the one-year study during 1989-1991. One-third received the customary follow-up procedure (control group), one-third received a slightly increased level of follow-up with intermittent phone calls (experimental group A), and the remainder were assigned to the third group who received the highest level of follow-up with both phone calls and videotape of their delivery session (experimental group B).

The second phase of the study involved four different assistive technology centers in California: Assistive Device Center; Rancho Los Amigos Medical Center; Santa Clara Valley Medical Center; and Sharp Memorial Hospital. This phase was completed in January 1993. In this study a total of 104 subjects from the California centers who received a selected piece of assistive technology (power wheelchairs N = 14, bath benches N = 19, communication devices N = 15, custom seat systems N = 56) were divided into two groups. The control group received the customary follow-up care while the experimental group was contacted by phone three times during the seven-month study period.

RESULTS—No statistically significant difference was found between the three groups in the Stanford study, however, overall improvements in quality control and services provided resulted in the following:

Before receiving their new Orthopedic Seat System (OSS), only 18 percent of the clients were able to sit erect with good position compared with 68 percent after 12 months of use with their OSS.

Before receiving their new OSS, clients were able to sit in comfort an average of approximately 5 and one-half hours per day. After 12 months of use with their new OSS those same clients increased their sitting comfort to more than nine hours per day. When asked about the appearance of their old device, 61 percent found it acceptable. After 12 months of use, approximately 96 percent found the appearance of their new OSS to be acceptable.

Fifty percent (50 percent) of clients felt their existing devices were safe at all times. After 12 months of use with their new OSS, 96 percent felt safe at all times.

After 12 months of use, 79 percent found that their overall comfort had improved when compared to their previous seat systems.

FUTURE PLANS—The data from the 104 subjects from the other four centers will be analyzed and combined when possible with Stanford based data. A Quality Improvement packet (including justification for follow-up, follow-up protocol, data collection forms, and strategies for implementation) will be developed based on the findings of this study.

[495] REHABILITATION TECHNOLOGY TRAINING: A PLAN FOR FACILITATING THE DELIVERY OF TECHNOLOGY

Nancy Somerville, BS; Dorothy Wilson, BA; Kathleen Shanfield, MS; Donald R. McNeal, PhD
Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—This project is one of three supported by the RERC on Technology Transfer. The initial goal of this project was to investigate the technology training needs of occupational therapists and to develop and disseminate a training program to address these needs. Another goal was to develop a training program for other disciplines based on the results of the training for occupational therapists.

PROGRESS—A needs assessment was conducted to identify the technology training needs of occupational therapists. A survey instrument was developed and mailed to 2,666 occupational therapists nationwide. The results indicated a perceived need for training in service delivery and in specific types of technologies. Of the service delivery needs, the most frequently identified were information resources, funding, and task analysis. Of the specific technology types, respondents identified training needs most frequently in the high-visibility and high-technology areas of equipment interface, environmental controls, and computers.

Based on this survey and suggestions from our Advisory Committee, a 1-day course entitled "Adding Technology to Your Bag of Tricks" was developed. The content focuses on the process of applying assistive technology. Four occupational therapists were selected to serve as faculty for the workshop. The American Occupational Therapy Association began offering the workshop to its state associations in 1992, using the faculty of four occupational therapists that we had selected. We subsequently revised the workshop content to make it more appropriate for anyone interested in the application of assistive technology, not just occupational therapists. RESNA agreed to offer the workshop as part of their initial effort to develop a continuing education program. Additional faculty from a variety of disciplines were recruited through RESNA. Seven new faculty members received training when they attended the workshop held in April 1993 in Pittsburgh, Pennsylvania. Three additional workshops have been held since, and RESNA has received requests from many groups interested in sponsoring a workshop in their local area.

[496] GATHERING AND DISSEMINATING INFORMATION ON ASSISTIVE TECHNOLOGY FOR CHILDREN

Kathleen Gross; Kathy Henderson; Tracy Uditsky; Don McNeal, PhD; Mark Hoffer, MD
California Children Services; Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The focus of this project is to gather and disseminate information on assistive technology for children. The initial goals were to establish a resource library on assistive technology for children and to provide educational sessions at a local level on a variety of assistive technologies and issues. Dissemination of information on a broader scale will be addressed later. This project is being conducted by the RERC on Technology for Children.

PROGRESS—The resource library is well established; appropriate materials continue to be added and the holdings list updated. The library contains information and training materials (audiovisual materials, publications, journals, brochures, and handouts) pertinent to assistive technology for children. Information on national, state, and local programs and agencies that deal with children with disabilities and/or issues regarding children with disabilities are

also on file. The existence of the library will continue to be publicized for increased dissemination of information. The holdings list is now available for distribution to interested centers or individuals.

In order to further disseminate information on the resources available on assistive technology for children, electronic data bases are being explored as a means of having this information available at a state and national level. Additionally, plans are underway to develop and publish a resource book on Assistive Technology for Children in conjunction with RESNA.

Educational sessions held in the past year were very successful and well received. To further expand efforts to disseminate information this past year, presentations and educational sessions were given in conjunction with local, state, and national events. By collaborating and networking with other groups and centers, dissemination efforts were expanded. Materials to assist others in holding educational events were started this past year, focusing on how to sponsor, organize and hold an adapted toy fair. With these materials, we can share what we have learned about hosting educational sessions, as well as increase the number of individuals or groups disseminating information.

[497] DEVELOPING A CONSUMER'S GUIDE ON FUNDING ASSISTIVE TECHNOLOGY

Judith Craddock; Nancy Somerville; Diana Stearns; Dorothy Wilson; Don McNeal, PhD; Mark Hoffer, MD
Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The goals of this 3-year project are to develop a consumer-oriented guide for acquiring funding for assistive technology and to develop and implement a plan to disseminate the guide nationally. Contents of the guide will be based on results of a survey of disabled children and their families, consultation with funding experts and our editorial board, and a review of current literature. This project is being conducted by the RERC on Technology for Children.

PROGRESS—The survey instrument was developed and pilot tested with 12 families. It was then revised and sent to 602 parents or guardians of children with disabilities. Of the 602 surveys mailed, 179 were returned, a 30 percent return rate. A summary coding sheet was developed and results for the 179 participants were encoded. The data, which are currently being analyzed, yielded the following demographics:

Forty-five percent of the children were between the ages of 4 years and 10 years, and 30 percent were between 10 years and 16 years. Only 11 percent were over 16 years old. One-third of the children had a primary disability of cerebral palsy, with the next largest groups being mental retardation (17 percent), hearing impairment (11 percent), brain injury (7 percent), and muscle disease (7 percent). Ninety-one percent of the respondents had onset of their primary disability before the age of 2. The most frequent secondary disability indicated was visual impairment; followed by mental retardation, learning disorders, brain injury, cerebral palsy and hearing impairment respectively. The children lived in private homes (93 percent) in metropolitan areas (72 percent). The majority attended regular school (64 percent), but, of those, 17 percent had all special classes and 23 percent had some special classes. Only 14 percent of these children were reported as mainstreamed or attending all integrated classes. Twenty-two percent attended special schools for children with disabilities.

Many of the completed surveys included written suggestions for obtaining funding, case histories of attempts to obtain funding, and pleas for help. Written comments, often in the form of letters, were included by many participants, making very clear the need for a consumer oriented guide for funding assistive technology.

A final draft of the funding guide has been completed. This draft includes resources felt to be most helpful to parents of a newly disabled child.

The draft was also edited for clarity and level of language. This final draft is the result of review by ten families and seven rehabilitation professionals and a focused review with two families in order to monitor understanding of material and usefulness of material to the reader. Meetings have been held with a printer and graphic artist to develop ideas for a cover design for the guide, illustrations, potential print format and costs. The funding guide was to be available in 1994.

[498] MAINSTREAMING STUDENTS WITH ASSISTIVE TECHNOLOGY INTO REGULAR EDUCATION

Molly Doyle; Cynthia Cottier; Carol Barua; Ronna Joseph; Kimberly Gilworth; Nick Kirgo; Don McNeal, PhD; Mark Hoffer, MD
Los Angeles Unified School District, Los Angeles, CA 90000; Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—Currently there is limited support for teachers and their students who use augmentative and alternative communication (AAC) systems in regular education. Because of this, as well as a lack of ongoing training for teachers, children using AAC systems often are unable to effectively participate in classroom activities, interact with peers or learn the curriculum. This project is being conducted by the RERC on Technology for Children.

PROGRESS—To help increase participation of students using AAC, project staff developed a training program for instructional aides and technology assistants. These individuals help maintain AAC equipment, training students to use AAC devices, assisting parents in implementing devices at home, and instructing teachers and classmates on how AAC devices operate. Aides and assistants are supervised by a speech-language pathologist. It is the role of the speech-language pathologist to collaborate with teachers on strategies to facilitate integration of students with AAC in regular education activities.

Seven students from Los Angeles Unified School District participated in the project for periods that ranged from 8-16 months. Four of these students had instructional aides that underwent training. The other three students were served by a technology assistant (previously trained by project staff). Each student was assigned to a single special education teacher for the duration of the project. A variety of regular education teachers came in contact with each student during the project period.

Some general findings or trends after completion of the project were as follows: children using AAC and their teachers reported increased competency in using AAC devices, teachers and students reported increased use of technology to complete academic work, students using AAC indicated increased success communicating with classmates and regular education teachers, equipment breakdowns were common, and ongoing troubleshooting to ensure devices were operational was critical. These findings came from questionnaires and observation protocols completed before and after students' participation in the project. Questionnaires regarding students' social and academic participation were completed by teachers, instructional aides and the students. Ratings on the questionnaires varied significantly as each individual's perceptions were based on expectations, knowledge and experience.

Project staff are currently revising a training manual. The manual will provide speech-language pathologists with strategies and guidelines for increasing the independence and participation of students who use AAC in school. Components address training instructional aides, strategies for

working with teachers, and activities to increase socialization with peers. Although a large part of the manual addresses the needs of children in integrated classrooms, some strategies and informational sheets can be utilized by aides and teachers in special education classrooms.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Mainstreaming students with assistive technology. Doyle M, Cottier C, Joseph R. In: Proceedings of RESNA International '92, 1992, Toronto, ON. Washington, DC: RESNA Press, 1992:380-2.

[499] ASSISTIVE TECHNOLOGY USAGE OUTCOME

Frank DeRuyter, PhD; Dan Saldana; Ailene Montalvo; Don McNeal, PhD; Mark Hoffer, MD
Rehabilitation Engineering Program, Rancho Los Amigos Medical Center, Downey, CA 90242

Sponsor: *National Institute on Disability and Rehabilitation Research*

PURPOSE—The goal of this project is to collect and analyze outcome data in the area of assistive technology usage. A measurement protocol has been developed, and data are being collected at four time intervals up to two years after delivery of, and proper training on, all assistive technology equipment. It is anticipated that this project will provide professionals, reimbursing agencies and consumers with objective information on outcomes that are related to the usage of assistive technology. This information should assist in addressing the issues of the appropriateness and the necessity of assistive technology. This project is being conducted by the RERC on Technology for Children.

PROGRESS—The first year of this project involved the identification of variables and elements to be examined, development of the Outcome Measurement Survey Instrument and rating categories, configuration of the relational database management system, and piloting the instrument and data analysis/report generating formats. Upon completion of these activities, data collection was initiated in August 1991 and has continued since that time.

During the past year, this project has concentrated on three areas. First, the primary focus has continued to be on the data collection process. Secondly, the collaborative agreement reached in October 1992 with California Children Services (CCS), which allowed children with assistive technology in the CCS program to participate in the data collection process of this project, required a training effort of CCS staff during the early part of 1993. Finally, some preliminary review and analysis of data has been initiated.

To date, the assistive technology usage outcomes database includes 86 subjects who are at various stages in the data collection process. The study has lost 7 subjects due to families moving out of the area. The CCS agreement has proven to be successful in increasing the number of subjects in the project data pool and will continue throughout the course of this study. The current database encompasses a sex distribution of 57 percent male and 43 percent female. The age of the subjects at the point of initial data input ranges from 2 years, 11 months to 21 years, 8 months with a mean age of 13 years, 7 months. The breakdown of types of equipment includes 59 percent augmentative and alternative communication systems, 27 percent computer systems, 9 percent environmental control units, and 5 percent other types of assistive technology. It is premature to report results at this time, but preliminary data will be presented at a national conference in 1994.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Evaluating outcomes in AAC service delivery programs. DeRuyter F. In: ISAAC Research Symposium Proceedings, 1992, McKee City, NJ: CTA Inc.

Importance of outcomes and cost benefit analysis in AAC. DeRuyter F. In: NIDRR Augmentative and Alternative Communication Intervention Consensus Validation Conference Resource Papers, 1992, NIDRR:Washington, DC: 1992.

[500] REHABILITATION ENGINEERING CENTER, TEXAS A&M

William A. Hyman; Gerald E. Miller
Texas A&M University, College Station, TX 77843

Sponsor: *National Science Foundation; Texas Rehabilitation Commission; local school districts*

PURPOSE—This program provides rehabilitation engineering consultation at schools, rehabilitation facilities and other sites utilizing bioengineering faculty and students. The program provides for design and modification projects which benefit individual clients or are used within the facility for client treatment or education. Technology workshops are also provided. In addition to direct services, the program is also intended to enhance the rehabilitation technology capabilities of present and future practitioners.

PROGRESS—This is an ongoing program. Initial efforts consist of meetings at each facility to acquaint the staff with the program and the types of projects which would be consistent with available resources. This is followed by frequent meetings to identify, refine and implement projects. A wide array of electronic and mechanical devices have been designed and delivered under this program. In addition, design, safety, and electronics workshops have been conducted to enhance the technical skills of on-site personnel.

RESULTS—The direct result of this work is the delivery of new or modified adaptive equipment directly into the rehabilitation and special education settings. Communication devices for non-verbal and motor-limited clients have been developed which allow for simple selection from a limited menu using a variety of input devices. Additional projects included several types of interfaces between clients and environmental devices, and pre-vocational training devices which provide a reward feedback for completed tasks.

Music therapy for the child with disabilities has been enhanced through the design of a joystick-controlled musical keyboard, a laser pointer controlled musical keyboard, and modifications to other school instruments. Additional projects in the school setting included aids for teaching mathematics and writing, modifications of self-feeding aids, and the provision of portable equipment for the district's occupational therapist. A variety of innovative physical therapy and occupational therapy equipment has been developed, including an adjustable height platform and ramp for wheelchair training, a clear ramp with mirrored lower surface for crawling, pediatric "Nordic track" and stepper, and a multi-texture walkway. These devices provide extensive visual and auditory feedback to encourage the young user. Voice/sound controlled systems for speech therapy as well as low cost voice record/playback systems have also been developed to enhance speech/communication training in children.

FUTURE PLANS—Experience with this program has demonstrated that there is an ongoing need for engineering design input for a variety of client problems at these facilities, and that a substantial portion of these needs can be met through undergraduate engineering design projects. The service model has advantages in that continuous engineering services could not be effectively utilized by these facilities at this time. Moreover, this program includes an array of expertise and experience and the resources of the University for fabricating projects. Technology training for therapists and teachers is also being further developed. For the engineering student, this program provides an opportunity to solve real-world problems, obtain exposure to rehabilitation engineering, and gain an understanding of individuals with handicaps and their needs.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Laser diodes for head pointing and environmental control. Hyman WA, Miller GE. In: Proceedings RESNA International '92, 1992, Toronto, ON. Washington, DC: RESNA Press, 1992:377-9.

Rehabilitation engineering opportunities under the ADA. Hyman WA, in Proceedings RESNA International '92, 1992, Toronto, ON. Washington, DC: RESNA Press, 1992:482-3.

[501] ADAPTIVE FILTERS FOR BIOLOGICAL SIGNAL PROCESSING

P.A. Parker
Institute of Biomedical Engineering and Electrical Engineering University of New Brunswick, Fredericton, NB E3B 5A3

Sponsor: *Natural Sciences and Engineering Research Council of Canada*

PURPOSE—We are investigating the application of adaptive noise cancellation filters to the reduction of interfering myoelectric signal in evoked response (ER) measurements.

PROGRESS—To date the adaptive noise cancelling filter using an LMS algorithm is shown to provide good myoelectric interference reduction. However in the presence of significant primary-reference EP crosstalk the performance is badly degraded.

FUTURE PLANS—Crosstalk resistance adaptive cancelling filters are to be investigated.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Multireference adaptive noise cancellation applied to somatosensory evoked potentials. Parsa V, Parker PA. In: Proceedings of the Canadian Medical and Biological Engineering Conference, 1992, Toronto, ON, 824-5.

[502] VLSI TELEMETRY IMPLANT FOR MYOELECTRIC CONTROL

D.F. Lovely
Institute of Biomedical Engineering, University of New Brunswick, Fredericton, NB E3B 5A3

Sponsor: *Natural Science and Engineering Research Council*

PURPOSE—The objective of this study is to design and develop a surgically implantable very large scale integrated (VLSI) telemetry system for the acquisition of site-specific myoelectric signals.

PROGRESS—The initial problems associated with the fabrication of large area CMOS devices have been overcome. Test circuits are currently under evaluation in order to derive noise data for amplifier design. In addition, a prototype current mode differential amplifier has been submitted for fabrication.

RESULTS—All noise test circuits are now functional. Initial results are promising in that the measured noise performance is a good fit to the theoretical noise models.

FUTURE PLANS—A re-design of the differential amplifier is planned taking into account the noise data obtained from the test circuits. In addition, typical device matching using linear and common centroid geometry is to be studied.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Low noise electrode amplifier for use in evoked potential studies. Lovely DF. In: Proceeding of the 19th Canadian Medical & Biological Engineering Conference (CMBEC), 1993, Ottawa, ON.

[503] PORTABLE FORCE FEEDBACK DISPLAY SYSTEM

Peter Maloof, ASCS
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *NeuroMuscular Research Center*

PURPOSE—The use of visual displays enhances the acquisition of optimal test results in experiments, such as the Clinical Back Analysis System (CBAS). One illustration of this method is the display of

instructional text (such as the words "PULL BACK") on a computer screen. A more sophisticated illustration is the graphic display on a screen of the force exerted by a subject during a CBAS test. The subject uses this real-time feedback to maintain his or her force level within the specified target range. We use three separate visual force feedback instruments to provide visual force feedback information to the subject: the Force Ramp Display System, the Maximum Voluntary Contraction (MVC) System and the Muscle Fatigue Monitor Force Display System. Each of these strategies has limitations and incompatibilities which make them unsuitable for universal laboratory and clinical use.

METHOD—This year the Design Lab continued its project to develop a Portable Force Feedback Display System to correct these limitations. The newest iteration of the Force Feedback Display System will provide a standard platform for presenting text and force feedback information to test subjects in a variety of experimental applications performed both in the laboratory and in the field. It uses a state-of-the-art laptop computer to receive forces from the application through a standard serial connection and an active-matrix color LCD screen to display text and graphics. The system is small enough to be coupled with a portable unit, or can be physically integrated with other data acquisition instrumentation. In this way, a user is offered greater flexibility than with previous systems, to create a variety of experimental force feedback applications, which can be implemented by system software.

[504] COGNITIVELY BASED TREATMENTS OF ACQUIRED DYSLEXIA

Rhonda B. Friedman, PhD; Paul R. Rao, PhD, CCC-SLP; Susan Nitzberg Lott, MA, CCC-SLP
National Rehabilitation Hospital Research Center, Washington, DC 20010

Sponsor: *National Institute of Deafness and Communication Disorders, Bethesda, MD 20892*

PURPOSE—The purpose of this project is the development of therapy programs that are shown to be effective in the treatment of acquired disorders of reading (acquired dyslexias). Ultimately, our aim is to guide the speech-language pathologist in choosing a therapy that meets the specific needs of the individual dyslexic patient. To reach our objective, we are developing, implementing, and evaluating several experimental therapies for different types of reading deficit, based upon a cognitive neuropsychological model of reading.

METHODOLOGY—Patients are classified as pure, surface, phonological, or deep dyslexic on the basis of our Reading Screen, and then randomly assigned to one of the treatment programs designed for their dyslexia type. Treatments, which are derived from a cognitive neuropsychological model of reading, consist of one of the following: practice naming letters, practice reading words presented rapidly, strategies for applying rules to sound out words, repeated practice reading words with similar spellings, pairing words with pictures to aid in reading, training in reading whole syllables, and pairing troublesome words with easier words of similar pronunciation. Pre- and post-treatment tests include standardized reading tests as well as a questionnaire which probes subjective assessment of the patient's functional reading abilities on various types of reading materials. In addition, each therapy contains its own external probes, consisting of a list of words targeted for improvement that are never actually trained, but are tested before, after, and at regular intervals throughout treatment. These treatments employ single-subject multiple-baseline designs, and consist of three 1-hour treatment sessions per week. Each treatment will be replicated in several patients.

PROGRESS—During the study's first year, we have completed much of the test and treatment preparation and have three patients participating in treatment.

RESULTS—Preliminary results indicate that our patients are improving on specifically trained items.

FUTURE PLANS—The study will be issuing papers as each case study is completed. The study is scheduled to be completed in September 1996.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Rationale and efficacy of a tactile-kinesthetic treatment for alexia. Lott SN, Friedman RB, Linebaugh, CW. Aphasiology 1994:8(2):181-95.

[505] USERNET: COLLABORATIVE EVALUATION OF COMMERCIAL APPLIANCES AND PRODUCTS

Geb Verburg, MA; Stephen McPherson
Research in Cognitive Development (RiCD) Unit, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8 Canada

Sponsor: *The Ontario Rehabilitation Technology Consortium funded by the Ontario Ministry of Health*

PURPOSE—The purpose of this ongoing project is to evaluate common appliances and tools in focus groups. These groups include managers and industrial designers of large and small appliance manufacturers, consumers with physical, sensory and developmental disabilities, researchers, as well as consumers who have expressed usability concerns.

Consumers with disabilities have seemingly no input in the design, selection, or modification of the appliances that they must use in their homes or daily living environments. By the same token the designers and/or managers of the industrial design operations of appliance or tool manufacturing companies reportedly have little or no specific information and insight about what is required by persons with physical, sensory and developmental disabilities or by consumers who are getting older.

PROGRESS—Three focus groups were held this year: one, that was funded by industry, reviewed an alternative wheelchair concept; two reviewed kitchen related issues and products. Of these latter two focus groups, one discussed general needs in the kitchen, while the other reviewed Camco's newest refrigerator. Camco is Canada's largest manufacturer of home appliances.

FUTURE PLANS—A review of elevator and elevating devices and access and control options will be the topic of focus groups in the next year.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Consumer, researcher, industry collaboration: an approach to device and appliance evaluation. Verburg G, McPherson S, Blancher L, Blancher J. In: Proceedings of European Conference on Advanced Rehabilitation Technology, ECART '93, 1993, Stockholm, Sweden.

[506] MULTIMEDIA SUMMER EXPERIENCE

Jutta Treviranus, BScOT(C); Roger Knox, PhD; Charles Silverman, MA
Microcomputer Applications Programme, Creative Arts Programme, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsors: *Toronto Health Care Fund; North York Grants in Aid; McLean Foundation, The Ontario Rehabilitation Technology Consortium funded by the Ontario Ministry of Health; Canadian Student Employment Experience Development; Ontario Student Employment Experience; Variety Village; IBM Canada Ltd.; Apple Canada Inc.; Hewlett-Packard; McLuhan Programme in Culture and Technology; Roland Canada Music, Ontario Science Centre; Bloorview Children's Hospital; Hugh MacMillan Centre School*

PURPOSE—Many individuals have creative abilities that are untapped and undeveloped because conventional means of creative expression are inaccessible to them. The purpose of this project was to provide individuals who are unable to control traditional instruments and tools due to physical disabilities with opportunities to engage in creative expression together with their nondisabled peers in a community setting. It served as a pilot project to demonstrate to possible sponsors and recreation programs the feasibility and resources required to offer this kind of program on an on-going basis.

PROGRESS—The project operated an accessible multimedia program as part of an integrated nine week summer recreation program at Variety Village. Two week junior, intermediate and senior half-day camps were run consecutively, followed by a residential camp focussing on the production of a performance. The multimedia studio and staff were available to adults during afternoons for the nine-week period.

Activity centers, utilizing multimedia authoring systems, included: music synthesis, interactive video, computer graphics, and virtual reality environments which allow creative expression through movement. The emphasis was on self-directed learning, using a large variety of materials to spark interest and creativity. Each participant's individual goals were supported by staff experienced in the media, the technology, and the alternative access systems. Small group activities were also facilitated. Experienced artists from the community visited the program throughout the summer to act as mentors or models for the participants.

FUTURE PLANS—A modified multimedia program will be offered at the University of Toronto in 1994. Staff are actively exploring methods of integrating the activities and accessible multimedia systems into existing recreation programs and school curricula.

[507] ASSESSMENT OF RHIZOTOMY SURGERY FOR CHILDREN WITH CEREBRAL PALSY

Elizabeth Sheil, MASc; F. Virginia Wright, BSc(PT), MSc; Stephen Naumann, PhD, PEng; James Drake, MD, FRCS; John Wedge, MD, FRCS(C)
Human Movement Research Programme, The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8

Sponsor: *The United Cerebral Palsy Research and Educational Foundation Inc.; Easter Seal Research Institute*

PURPOSE—The purpose of this study is to quantify the effects of selective dorsal rhizotomy on 24 children with spastic cerebral palsy in order to assess its benefits and drawbacks. Studies to date have failed to utilize sufficient objective criteria to provide meaningful evaluation of the post-operative outcome. Specific research questions include: Does a more normal gait pattern develop after rhizotomy? Is tone reduced in the ankle plantarflexors? How long does it take for muscle strength to recover? Do subjects demonstrate improved motor control? Are clinical goals achieved post-operatively?

PROGRESS—This was a randomized controlled study with assessments pre-operatively and 12 months post-operatively. Subjects were assigned to a

control group (n = 12) or rhizotomy group (n = 12). All twenty-four subjects have completed the study. Measurements included: stretch reflex test; isometric contraction test; gait analysis; Gross Motor Functional Measure (GMFM); range of motion; Erhardt Developmental Prehension Assessment; muscle strength; and Klein Bell Activities for Daily Living (ADL). Processing has been performed on all data, and complete statistical analysis is currently underway.

FUTURE PLANS—Full statistical analysis of the results will be completed. This will include an analysis of variance (ANOVA) on baseline results to determine if both groups are statistically similar pre-operatively. T-tests will be performed on the difference scores (12-month minus baseline) for both groups to determine if statistical significance can be seen between assessments. An ANOVA will be performed on the difference scores to determine if statistical significance can be seen between groups. An ANOVA will be performed on 12-month results using the baseline as a covariate for variables showing statistical significance between groups at baseline.

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Randomized control trial of selective dorsal rhizotomy: biomechanical evaluation. Wright FV, Sheil E, Naumann S, Drake J, Wedge J. J Dev Med Child Neurol. In press.

Gross motor function following selective dorsal rhizotomy: results of a randomized controlled trial. Wright FV, Sheil E, Naumann S, Drake J, Wedge J. J Dev Med Child Neurol. In press.

[508] DEVELOPMENT OF A SWIMSUIT FOR INDIVIDUALS WHO ARE INCONTINENT

Stephen Bialowas; Gerry Marshall; Heather Somerville; John Lipitkas; Linda Gurd; Patti Longmuir
Variety Village, Scarborough, ON MIN 2G2 Canada; The Hugh MacMillan Rehabilitation Centre, Ontario M4G IR8 Canada

Sponsor: *Variety: The Children's Charity; Eagle Beaver Sports Ltd.*

PURPOSE—The purpose of this project was to develop a swimsuit which would contain solid fecal matter until the individual could be removed from the pool. The design criteria also specified that the suit should be similar to commercially available swimsuits, in both style and cost.

Swimming is a popular activity for persons with a physical disability because the buoyancy of the water facilitates independent movement. However, for individuals who are incontinent the potential embarrassment of an "accident" while swimming often prevents them from participating. Concerns about personal appearance and function often make wearing diapers unacceptable. Even for young children, the use of a diaper under the swimsuit is often ineffective. For pool operators, who must close the pool for several hours after a fouling, the risk of allowing incontinent individuals to participate is significant.

METHODOLOGY—Initially, several water-impermeable materials were evaluated to determine their ability to withstand the chlorinated pool environment. The material selected was thin, flexible, and available in a variety of colors at a reasonable cost. Shorts were designed using the material with elastic closures at the waist and legs. The use of neoprene to seal the waist and legs was also evaluated but significantly increased the cost of the suits.

PRELIMINARY RESULTS—Several modifications were required to develop a design which would not leak with active movement in the pool. The completed design was incorporated into regular swim trunks for men, and a one piece swimsuit for women. Evaluation of the completed prototype indicated that the design was cosmetically acceptable, and could successfully contain solid fecal matter. The swimsuits are now commercially manufactured, and efforts are focused on ensuring the appropriate dissemination of information about the suits.

[509] LEG GAITERS PROVIDE FLOTATION FOR SWIMMERS WITH LOWER LIMB PARALYSIS

Cindy Graham; Ihsan Al-Temen; Patti Longmuir
Variety Village, Scarborough, ON M1N 2G2 Canada; The Hugh MacMillan Rehabilitation Centre, Toronto, ON M4G 1R8 Canada

Sponsor: *Variety: The Children's Charity*

PURPOSE—The purpose of this project was to develop an inexpensive flotation device which would provide sufficient, but not excessive, support to maintain the lower limbs and body in the correct swimming position.

Swimming is an activity enjoyed by many persons with a physical disability. All swimmers, both able-bodied and disabled, find that their legs will start to sink if they are floating without moving. Individuals who are unable to control the movement of their lower limbs (due to paralysis, spasticity, etc.), encounter difficulties when swimming. As the legs begin to sink, the body position is altered, making swimming less efficient, and additional difficulties are encountered in deep water where the legs may actually pull the swimmer underwater.

METHODOLOGY—Leg gaiters were designed using neoprene to wrap around the lower leg. Various sizes and thicknesses of neoprene were evaluated to determine optimal amounts of flotation for adults and children. The gaiters can be adjusted to fit individuals of different sizes, provide sufficient flotation to maintain the correct body position, and do not inhibit the movement or positioning of the swimmer in the water.

Several commercially available flotation devices were evaluated but found to provide too much flotation for use on the legs, as swimmers had great difficulty lifting their head or assuming a vertical position in the water.

RESULTS—The leg gaiters are now commercially manufactured, and efforts are focused on ensuring the appropriate dissemination of information about the suits.

[510] DISABLED SWIMMERS USE SPECIAL SEAT TO PARTICIPATE INDEPENDENTLY IN AQUABICS CLASSES

Cindy Graham; Linda Gurd
Variety Village, Scarborough, ON MIN 2G2 Canada

Sponsor: *This project was made possible through the generous support of Betty and Ted Johnson, and Harry and Doreen Longmuir*

PURPOSE—The purpose of this project was to develop a seat which would securely support a disabled individual in the shallow end of the pool, with the water level just below the shoulders, in a position suitable for participation in aquabics classes.

Exercise classes, both in the gym (aerobics) and in the pool (aquabics) are a popular form of exercise. Aquabics classes are conducted with participants standing in the shallow end of the pool, and exercises are done using the resistance of the water. Disabled individuals who are unable to stand in shallow water are often unable to participate independently in aquabics classes since they must use their arms for support or be supported by another person.

METHODOLOGY—Initially a floating chair was designed, but stabilizing the device was extremely difficult. Subsequent prototypes utilized an unsealed, plastic frame which would fill with water when placed in the pool and sit securely on the bottom of the pool. Seat position, size, and angle was modified to enable maximum participation in exercise activities for the arms, legs, and trunk. Evaluation of the seat indicated that individuals

with various types of disability (paralysis, multiple sclerosis, cerebral palsy, stroke, etc.) could successfully participate independently in regular aquabics classes.

RESULTS—Information regarding the aquabics chair is now being disseminated to ensure that community aquatic facilities can include individuals with a disability in regular aquatics classes.

[511] INSHOE PRESSURE AND EMG MEASUREMENT

Mr. Rami J. Abboud; Prof. David I. Rowley
Orthopaedic & Trauma Surgery, Dundee Royal Infirmary, University Department, Dundee DD1 9ND, Scotland, UK.

Sponsor: *None listed*

PURPOSE—A portable electromyographic measurement system (EMG) has been synchronised with a sixteen channel piezo-electric inshoe pressure measurement system called Gaitscan. The resulting system provides six channels of EMG and sixteen channels of foot pressure. This system has been used to study relationships between the activity of five muscles of the lower limb (gastrocnemius, soleus, anterior tibialis, peroneus longus and brevis) and foot pressure underneath the eight loading points of the plantar surface of the foot. Barefoot contact pressures have also been assessed using a Dynamic Pedobarograph, for comparison with the inshoe measurements. Inshoe pressure was found to be higher than barefoot pressures by 2 $kg/cm^2 \pm 0.5kg/cm^2$.

The resulting system is being used in three different applications: firstly in clinical research, secondly in conservative clinical treatments (i.e. insole orthosis design) and finally in rehabilitation for all sorts of foot pathologies in clinics as well as for pre-operative and post-operative cases.

PROGRESS—Normal subjects have been assessed to build up a control reference group with which to assess and compare results obtained from pathological studies. One important group under consideration is diabetes, with and without peripheral neuropathy. In some diabetics the period of peak contact pressure was greater than in normal. In those dorsiflexor muscles normally contracting eccentrically at heel strike, there is a measurable delay in contraction in clinically overt neuropathies when compared to a normal population. This delay is related to the degree of neuropathy and ranges from 50 to 200 msec.

FUTURE PLANS—Future work is concentrating on a new 3-D goniometry system (funded by the Scottish Health Department) which we hope to integrate to the above system as well as a foot project for improvement of insole design (funded by Scholl Plc, UK branch).

RECENT PUBLICATIONS RESULTING FROM THIS RESEARCH

Foot pressure/EMG measurement system for use in clinical orthopaedic biomechanics. Abboud RJ, Neville AJ, Abel EW, Rowley DI. 14th Annual International Conference of The IEEE Engineering in Medicine and Biology Society, 1992, Paris.

New technique for in-shoe pressure measurement. Abboud RJ, Neville AJ, Abel EW, Rowley DI. Third EMED USER meeting, 1992, Flagstaff, AZ.

Effect of two types of treatment for metatarsalgia on plantar pressure. McLauchlan PT, Abboud RJ, McFarlane L, Rowley DI. Association of Prosthetists and Orthotists, Edinburgh IX Annual Conference, 1993, Edinburgh, Scotland.

Investigation into a link between lower limb muscle dysfunction and foot ulceration in diabetics. Abboud RJ, Neville AJ, Abel EW, Rowley DI. Biological Engineering Society, 1993, Dundee, Scotland.

Looking after your feet, an objective measurement: the foot, a joint approach. Abboud RJ, Neville AJ, Abel EW, Rowley DI. The Royal Society of Medicine, 1993, London, UK.

Effect of patellae re-alignment on plantar foot pressure. Abboud RJ, Clift BA, Turner MS, Rowley DI. IVth EMED User Group Meeting, 1994, Ulm, Germany.

Section II
Sponsor Index
with Selected Program Summaries

Part A. Department of Veterans Affairs

Rehabilitation Research and Development Service
810 Vermont Avenue, N.W.
Washington, DC 20420

John W. Goldschmidt, MD, Director, Rehabilitation Research and Development Service, Department of Veterans Affairs, Washington, DC

The mission of the Rehabilitation Research and Development Service Program is to improve the quality of life of disabled veterans by making them more functionally independent. This mission is advanced through ongoing research projects in such priority areas as prosthetics/amputation/orthotics, spinal cord injury and related neurological disorders, and communication, sensory, and cognitive aids. Areas of special emphasis include aging, physical fitness, and psychosocial rehabilitation (e.g., dementia, schizophrenia, Alzheimer's disease, etc.).

In areas of prosthetics, amputation, and orthotics, VA-sponsored researchers are continuing to test new materials and use computer technology such as CAD/CAM to develop a new generation of artificial limbs. For spinal cord injuries, the use of robotics continues to be studied, as does the possibility that computer-controlled electrical stimulation can be used to restore function to paralyzed limbs. Research projects in the area of sensory aids include the continuing development of advanced mobility aids for visually impaired people, digital hearing aids for those with hearing impairment, and various studies on treatment strategies and communication systems for aphasic individuals.

The Department of Veterans Affairs Rehabilitation Research and Development Service (Rehab R&D) sponsors a national program to review proposals submitted by researchers in the field of rehabilitation. The Scientific Review and Evaluation Board for Rehabilitation Research and Evaluation for Research and Development, and ad hoc members assess proposals for their scientific and technical merit, budgetary needs, and time requirements.

The VA Rehab R&D Service has a working arm located at 103 South Gay Street, Baltimore, MD 20202, which consists of the following four programmatic sections:

Program Analysis and Review Section

Frank Marchione, Acting Program Manager

The Program Analysis and Review Section (PARS) coordinates the administration of the semiannual Scientific and Evaluation Peer Review Program.

Rehab R&D Service does not issue "grants." The program is primarily intramural and is conducted at VA medical centers (VAMCs) where VA facilities and staff solve problems relevant to the veteran. Rehab R&D Service conducts a comprehensive program of research, development, and evaluation of existing and emerging rehabilitation technology (devices, techniques, and concepts of rehabilitation).

The VA Rehab R&D program accepts research and development proposals from non-VA facilities under the following conditions:

1. The proposal is submitted through a local VAMC.
2. The proposal is reviewed and approved by the R&D Committee and its Subcommittee for Human Studies, or Subcommittee for Animal Studies, as applicable.
3. A VA physician or scientist must be co-principal investigator.
4. VA patients should be involved in the clinical trials.
5. The non-VA facility must meet the eligibility requirements for contractors as specified in the Federal Procurement Regulations.

The Associate Chief of Staff for Research and Development (ACOS/R&D) in the local VAMC coordinates the submissions for the medical center Director. These proposal submissions should follow the prescribed VA format which is available from the ACOS/R&D. In this manner, all proposals are reviewed and coordinated at the local VAMC, whether from an intramural or non-VA source.

Rehab R&D Service has two proposal submission dates per year: April 15 and October 15. A Letter of Intent (LOI) must precede all proposals prior to the submission period. Pilot proposals may be submitted at any time.

Proposals are reviewed by the Scientific and Evaluation Peer Review Program for Rehab R&D, which consists of nationally recognized independent experts in these areas. The Review Board recommends approval only for the most meritorious proposals. The funding decision is made by the Rehab R&D Service Director based on the recommendation of the Board, available resources, and the immediate needs of the VA.

Technology Transfer Section
Saleem J. Sheredos, Program Manager

The Technology Transfer Section (TTS) is responsible for the evaluation of prototypes and new techniques developed under the Rehab R&D program to provide the prompt transfer of promising devices into commercial production and clinical use.

The goals of TTS are to: 1) screen ongoing rehabilitation research and development sponsored by the Department of Veterans Affairs Rehab R&D Service and thereby identify products or techniques that are ready for transfer from research and development to clinical application; 2) coordinate clinical application studies away from the R&D arena on the selected products and techniques to affirm their application in treatment programs; and, 3) foster the commercial availability of successful products by helping to overcome the barriers faced by potential manufacturers.

When a development (techniques or device) is identified as completed, a Request for Evaluation (RFE) is prepared in accordance with VA Circular 10-87-32 and forwarded to the Program Manager, TTS. The RFE must be sent over the signatures of the R&D principal investigators) (PI), the ACOS/R&D, and the Director of the VA Medical Center funded for that R&D effort.

When the RFE is received, it is nominally reviewed by three experts on the readiness and current value for clinical application, which leads to recommendations for a field study, or the need for further development, or project termination.

TTS coordinates the evaluation, collects the data, performs data analysis, issues progress reports, and prepares the final report with special recommendations.

Scientific and Technical Publications Section
Jon Peters, Acting Program Manager

The Scientific and Technical Publications Section (STPS) disseminates the results of VA and non-VA scientific and engineering projects among researchers, engineers, clinicians, and consumers in the United States and throughout the world. The office disperses research, development, and testing information through print and electronic media. STPS publishes the Journal of Rehabilitation Research and Development (JRRD), Rehabilitation R&D Progress Reports, and clinical supplements to JRRD.

Rehabilitation Technology Assessment Section
Ronald I. Lipskin, Program Manager

The Rehabilitation Technology Assessment Section (RTAS) evaluates commercially available products with potential benefit for use by disabled veterans and develops performance and safety standards for durable and reliable rehabilitation products. This information is reported to clinical and procurement officials throughout the system.

Rehab R&D Service has a Rehabilitation Research and Development Center in each of the following locations:

The Rehabilitation Research and Development Center, Edward Hines Jr. Hospital, Department of Veterans Affairs, Hines, IL 60141
Director, Vacant

Fiscal Years 1992 and 1993 were exciting and productive years for the VA Hines Rehabilitation Research and Development Center. Rehab R&D Center and clinical staff have been encouraged to develop pilot studies that can be initially supported with local funds for the purpose of generating pilot

data, which allows a full merit review application to be prepared and submitted for review.

The Rehabilitative Neuroscience Research Section has made excellent progress, especially in the areas of neural regeneration and restoration of bladder function. Studies on spinal cord regeneration have lead to significant new uses for advanced materials and research partnerships with major private-sector materials research laboratories. The work on restoration of bladder function has attracted the attention of clinicians and medical equipment manufacturers who are eager to see our research results put to clinical use.

The Applied Exercise Science and Health Promotion Section has made significant progress in transferring research results. The tests developed by this group have been used on a regular basis to diagnose coronary artery disease in people with mobility limitations.

The Musculoskeletal Disorders Research Section has made considerable progress in the area of characterizing the dynamics of motor tasks. Other studies have lead to techniques that may improve the ability of the clinician to diagnose low-back disorders or track their treatment.

Investigators at the Center have been collaborating with California State University at Sacramento; the Research Department at the National Chiropractic College, Lombard, IL; the Medical College of Wisconsin; University of Illinois, Chicago; Wright-Patterson Air Force Base, Dayton, OH; Clement J. Zablocki VA Medical Center, Milwaukee, WI; and the Departments of Physiology, Urology, Medicine, and Orthopedics at Loyola University Medical Center, Chicago, IL.

In summary, the Rehab R&D Center at Hines VA Hospital continues to be a significant resource for research on disability related problems and the development and commercialization of enabling technologies.

Atlanta Rehabilitation Research and Development Center, Department of Veterans Affairs Medical Center, 1670 Clairmont Road, Decatur, GA 30033
John E. Crews, DPA, Acting Associate Director

The Center primarily conducts research into problems associated with the loss of independence and mobility, and the health status of older people. Aging is the central theme; research into problems affecting disabled people in general is also pursued. The Center is composed of three branches: Engineering and Computer Sciences, Physiological Sciences, and Sensory and Behavioral Sciences. The mission of the Center is twofold: first, to understand (by the knowledge gained through research) the problems, capability, and needs of elderly and/or disabled veterans that impact on their functional independence and quality of life; and second, to apply those understandings to the development and utilization of concepts, technologies, devices, etc. to further the functional independence and quality of life of veterans.

Rehabilitation Research and Development Center, Department of Veterans Affairs Medical Center, 3801 Miranda Avenue, Palo Alto, CA 94304
Felix E. Zajac, PhD, Director

The Palo Alto Research and Development Center is dedicated to developing new state-of-the-art technological aids and treatments for veterans with disabilities. The focus of concentration over the next several years will be on the importance of limb function.

The Center is organized around three sections: Neuromuscular Systems, Orthopedic Biomechanics, and Human-Machine Integration. These sections work together to accomplish goals associated with the preservation, restoration, and replacement of limb function in veterans with disabilities. The Technology Transfer Section assists in assuring that new rehabilitation devices and methodologies reach the veteran as soon as possible.

Rehab R&D Service has established the following Center of Excellence:

VA Center of Excellence in Functional Electrical Stimulation, Department of Veterans Affairs Medical Center, 10701 East Boulevard, Cleveland, OH 44106
P. Hunter Peckham, PhD, Director

The mission of the Functional Electrical Stimulation (FES) Center is to: 1) improve the quality of life of veterans with disabilities through introduction of advanced technology employing FES of paralyzed limbs; 2) advance scientific knowledge in FES in order to generate new knowledge; and 3) promote

additional development of clinical applications. Technology Transfer is the broadest and most complex of the programmatic areas of the FES Center. It includes technology transfer to other clinical centers through FDA-monitored clinical studies and technology transfer to industry. of the various FES research programs in Cleveland, the hand application is the most advanced in terms of clinical application and readiness for transfer to other centers. The FES Center will assess the safety and efficacy of implantable FES hand systems by transferring them to select sites in the VA System.

Technology transfer techniques have been established whereby technology with a proven clinical feasibility is refined for manufacture, and relationships with industrial manufacturers are established to transfer the fabrication of clinical systems to them. Transfer to clinical sites is accomplished by establishing multicenter research collaborations in which VA medical centers jointly work to develop and test FES technology. Coordination of technology development has been accomplished by establishing a central Core Engineering Laboratory and coordinating the development of advanced FES technology through this laboratory. Advanced research is carried out by facilitating and coordinating the research and development activities of clinical and scientific researchers working on FES.

Technology transfer of an implantable upper limb system, which provides control of grasp and release in individuals with high level spinal cord injury, has been the focus of the initial technology transfer project. The technology consists of both internal and external components. Manufacture of these components has been transferred to two contractors. The multicenter research center is underway at four VA medical centers (Baltimore, Cleveland, Palo Alto, and West Roxbury) that have participated in four workshops for planning and training. A total of 13 subjects have received the implantable system in the study to date. Negotiations are underway to transfer the management of this study to a private company.

The establishment of the Core Engineering Laboratory has been completed, and is now in use for advanced technology development. The laboratory has facilities for computer design and modeling, electronic and microelectronic design and fabrication, and clean-room fabrication of technology utilized with implantable FES systems.

Coordination of research activities has focused on the instituting the management and scientific interaction identified above. An interinstitutional FES Council, consisting of representatives from the Cleveland VA Medical Center, Case Western Reserve University, MetroHealth Medical Center, and the Edison Biotechnology Center, oversees the management of the FES Center.

Future research will focus on technology transfer of a lower limb FES system and technical development of a new generation implantable stimulator having additional stimulation channels and an implantable command/control transducer.

The following VA Medical Centers have reported projects sponsored fully or in part by the Department of Veterans Affairs Rehabilitation Research and Development Service.

(Note: VA Centers are listed alphabetically by state.)

VA Outpatient Clinic
425 S. Hill St., Los Angeles, CA 90013

Page
Computerized Adaptive Methods for Seleeting Hearing Aids....270
Nonliteral Language Test and Training Workstation for Patients with Communicative Deficits: A Pilot Study....284

VA Medical Center
5901 E. Seventh St., Long Beach, CA 90822

Page
Efficiency of Dynamic Elastic Response Feet....27
Prosthetie Design for Dysvaseular Below-Knee Amputees....29
Optokinetie Testing for Diagnosis and Rehabilitation of Balance Disorders....87
Computer-Assisted Treatment of Hemi-Inattention in R-CVA Patients....122
Effect of Chronic Theophylline Treatment on Quadriplegia....183
Evaluation of Word-Recognition Performance with Sentenee Materials....271
Computer Assisted Speech Evaluation Expert System.285

VA Medical Center, Wadsworth Division
Wilshire and Sawtelle Blvds.,West Los Angeles, CA 90073

Page
Suitability of Titanium Alloy as a Joint Replaeement Bearing Surface.... 223
Funetional Electrical Stimulation of Spinal Cord Injury Patients....367

VA Medical Center
3801 Miranda Ave., Palo Alto, CA 94304

Page

Determination of Bone and Joint Loads from Bone Density Distributions 36
Maintenance and Adaptation of Bone Tissue: The Importance of Mechanical Stimuli....36
Upright Posture: How Limb Biomechanics Limits the Ability to Stand....37
Bicycle Ergometry to Improve Ambulation in Hemiplegic Stroke Patient 46
Influences on Long Bones: Development Growth and Aging 88
Upper Body Motion Analysis for Amelioration on Falls in the Elderly....88
Pedaling Coordination: Identification of Muscle Control Strategies 184
Muscle Coordination of Multijoint Motor Tasks: An Interactive Computer Workstation Environment .185
Multimodality Image Registration of the Cervical Spine....222
Mechanical Regulation of Skeletal Tissue in Normal and Prosthetic Joints....223
Cartilage Repair: Effects of Mechanical Loading 224
Development of Articulating Joints: The Role of Mechanical Forces 225
Effect of Femoral Collar Geometry in Hip Replacement....242
Influence of Collar Geometry in Femoral Components....242
Tissue Differentiation and Maintenance: The Influence of Mechanical Stimuli 243
In Vitro Test of an Artificial/Cellular Graft for Pressure Sore Repair: A Pilot Study....418
Vocational Training Facility: Interactive Employment Training for Persons with Physical Disabilities...425

VA Medical Center
3350 La Jolla Village Dr., San Diego, CA 92161

Page

Muscle Fiber Strengthening with Electrical Stimulation....186
Physiological Basis of Strength Following Surgical Tendon Transfer....193
Treatment of Muscle Spasticity Using Phenol Nerve Blocks....195
Management of the Musculoskeletal Complications of Spinal Cord Injury....341

VA Medical Center
4150 Clement St., San Francisco, CA 94121

Page

Gait Initiation in Below-Knee Amputees: Analysis of Safe Function 30
Strength of Human Cortical Bone with Simulated Metastatic Lesions 38
Hip Fracture Risk Assessment Using Automated 3-D Finite Element Modeling....226
Patient-Specific Finite Element Modeling of Bone from CT Scan Data 227

VA Medical Center
1055 Clemont St., Denver, CO 80220

Page

Adjusted vs. Unadjusted Foot Orthoses in the Prevention of Foot Ulcers in Diabetics....261
Cortical Auditory Evoked Potentials and Behavioral Measures of Aphasia 286
Verification of the Equivalency of Language Comprehension Measures: A Pilot Study....287

VA Medical Center
West Spring St., West Haven, CT 06516

Page

Effects of Expectation, Reward, and Activity on Subtypes of Schizophrenia 89

VA Medical Center
50 Irving St. NW, Washington, DC 20422

Page

Evaluation of Interface Pressure Measurement Instruments: A Pilot Study....417

VA Medical Center
Archer Rd., Gainesville, FL 32602

Page

Vertebral Fusion by New Osteogenic Agents to Accelerate Rehabilitation....228
Ideomotor Apraxia: Recovery and Treatment 288

VA Medical Center
1201 Northwest 16th St., Miami, FL 33125

Page

Biochemistry of Cartilage in a Model of Disuse and Different Types of Recovery....229
Using Self-Monitoring to Improve Communicative Efficiency in Aphasia....292
Spinal Cord Injury-Induced Bone Loss 342

VA Medical Center (Atlanta)
1670 Clairmont Rd., Decatur, GA 30033

Page

Effects of Head Positioning on Pressure Generation in the Pharynx during Normal Swallowing: A Pilot Study....59
Effects of Sensory-Neural Deficits on Balance and Posture in Individuals with Multiple Sclerosis....63
Selective Neural-Muscular Stimulation Using Magnetic Fields and Implantable Coils 67
Age-Related Changes in the Triceps Surae Stretch Reflex and Postural Control 90
Knowledge-Based System for Selecting Elopement Control Devices....91
Environmental and Behavioral Factors in Falls among the Elderly 92

Evaluation of Interventions to Prevent Elopement among Nursing Home Patients....93
Design of New Toilet Prototypes for Elderly and Disabled Veterans....94
Applicability of Accessibility Codes to Meet the Needs of Elderly People....95
Balance Training in Elderly Fallers an Nonfallers....96
Effects of Strength Changes for Older Adults....97
Restraint of Ambulatory Nursing Home Residents with Cognitive Impairments....98
Predisposing Factors in Disc Prolapse....230
Environmental Information Needs for Wayfinding by Special Populations....293
Design and Testing of an Electronic Travel Aid for Blind Persons....294
Relationship of Auditory Skills to the Mobility of Blind Individuals....295
Development of a Computer Model of Mobility Coverage for the Visually Impaired....296
Revision of the Text : Foundations of Orientation and Mobility....297
Functional Independence Measure for Blind Adults (FIMBA)....298
Development of a System to Assess Locomotion Over Long Distances....299
Design and Evaluation of Liquid Crystal (LC) Dark-Adapting Eyeglasses for Persons with Low Vision....300
Adjustable Power Liquid Crystal Lenses to Assist Persons with Low Vision: A Pilot Study....301
Development and Validation of Criteria for Task Safety in Blind Mobility....302
Enhancement of Balance Testing....303
Adaptive Cane for Special Adult Groups: A Pilot Study....304
Evaluating the Efficacy of a Peripheral Vision Expander System: A Pilot Study....305
National Survey of the Impact of Low Vision Device Use among Veterans....306
Research in Curvilinear Synchronous Motors for Power Wheelchairs....405
Research Program on Accessible Housing....426
Predicting Wayfinding Ability from Laboratory-Based Spatial Tasks....427

VA Medical Center
Highway 6 West, Iowa City, IA 52240

Page

Evoked Otoacoustic Emissions for Ototoxic Monitoring in Adults....272

VA Medical Center (Lakeside)
333 E. Huron St., Chicago, IL 60611

Page

Additive Fabrication Technique for the CAM of Prosthetic Sockets....1
New Control Applications for Upper-Limb Prostheses: Direct Muscle Attachment for Position-Servo Control....4
Direct Muscle Attachment: Multifunctional Control of Hands and Arms....6
New CAD/CAM Methods to Enhance Prosthesis Design....31
Practical Applications of New CAD and CAE Techniques to Socket Design....33

VA Medical Center (West Side)
820 S. Damen Ave., Chicago, IL 60680

Page

Development of a Predictive Model of Driving Performance in Stroke Patients....64
Effects of Age and Resistance Training on Skeletal Muscle....99

VA Medical Center
Danville, IL 61832

Page

Feasibility of a Dynamic Dermofluorometer to Monitor Skin Fluorescence: A Pilot Study....428

Edward Hines Jr. VA Hospital
Hines, IL 60141

Page

Biomechanics of Cervical Diagnostic Maneuvers: A Pilot Study....39
Optimum Implant Stiffness for Lumbar Fusion: A Pilot Study....40
Development of a Low-Dimensional Representation of Lifting Dynamics: A Pilot Study....60
Rehabilitation of the Colon After Spinal Cord Injury: A Pilot Study....68
High Charge Density, Bipolar Electrodes for Chronic FNS....69
Implantable Electrodes Using Iridium Oxide Film Technology....70
Management of Central Ventilatory Insufficiency through Adbominal and Thoracic Stimulation: A Pilot Study....71
Recognition of Hand Gestures by People with Motor Impairments: A Pilot Study....145
Development of Spastic Tolerant Stick Controller: A Pilot Project....196
Use of Microphotodiode Implants to Restore Retinal Function: A Pilot Study....307
Wheelchair Exercise and Digital Echocardiography for the Detection of Heart Disease....343
Urinary Bladder Stimulation Following Spinal Cord Injury....344
Management of Incontinence in SCI Patients with Penile Nerve Stimulation....368
Application of Electric Fields Enhance Recovery Following Spinal Cord Injury....388

Development and Testing of Clinical Workstation for the Reduction of Wheelchair Propulsion Injuries 395

VA Medical Center
1601 Perdido St., New Orleans, LA 70146

Page
Changes in Blood Flow Associated with Intramedullary Nailing 231
Wear Debris Generation in Hip Modular Head and Neck Components....245

VA Outpatient Clinic
21 Causeway St., Boston, MA 02114

Page
Comparative Study of Stabilogram-Diffusion Analysis and Traditional Posturographic Analyses....46
Computational Posturography: In Numero Experiments on Postural Control 47
Initiation of Human Walking 47
Age-Related Changes to Open-Loop and Closed-Loop Postural Control Mechanisms....48
Integration of Visual Input into the Aged Postural Control System 48
Effects of Visual Input on Open-Loop and Closed-Loop Postural Control Mechanisms....49
Random Walking during Quiet Standing....50
Quantitative Posturography: Age-Related Changes in Postural Stability 100
Modelling of EMG Signals....186
Multichannel Surface EMG Signals 187
EMG and Mechanical Manifestations of Muscle Fatigue 188
Estimation of Muscle Fiber Conduction Velocity....188
Biochemical and Myoelectric Events during Fatigue ..189
Improvements to the Technique of Synchronization Evaluation 197
Effects of Hand Dominance on Motor Unit Firing Behavior 198
Neurosim: Investigations in Computational Neuroscience 198
Motor Unit Firing Rates during Sustained Isometric Contractions 199
Common Drive of Motor Units: A Model for Motor Unit Control 200
Rank-Ordered Regulation of Motor Units....200
Database Development for a Clinical Back Analysis System....210
Muscle Performance in the Back Analysis System Compared to Lifting Tasks....210
Development of Test Protocols Related to the Behavior of Back Muscles 211
EMG Parameters of Lumbar Back Muscles 211
Back Assessment of Athletes from Varsity and Freshman Crew Teams....212
Clinical Validation of the Back Analysis System for Treatment Outcome Following Rehabilitation....213
Normative Database Study of Back Muscle Function .213
Back Analysis System (BAS) Update 214
Development of a Two-Needle Front End for Motor Unit Detection....429
Reconstruction Expansion as a Geometry-Based Framework for Choosing Proper Delay Times ...429
Visualizing the Effects of Filtering Chaotic Signals...430

VA Medical Center
1400 Veterans of Foreign Wars Pkwy., West Roxbury, MA 02132

Page
FES-Aided Paraplegic Gait Using a Controlled-Brake Orthosis 76
Bone Substitute Material 232
Pulsed Laser Deposition of Coating for Prosthesis-Bone Bonding 246
Optimized Surface Bonding and Stiffness of Femoral Endoprostheses 247
Coating/Surface Treatments for Prosthesis-Bone Bonding 248
All-Plastic Total Knee Replacement 256
Diagnosis of Cartilage Degeneration: Quantitative Surface Spectroscopy 259
Advanced Technology Neural Information Sensors for Prosthetic Control by Quadriplegics 345
Device for Treatment of Peripheral Nerve Injury 346

VA Medical Center
2215 Fuller Rd., Ann Arbor, MI 48105

Page
Effect of Chair Design on Chair Rise Performance in Disabled Old Adults....101
Effects of Muscle Strength on Balance during Movement in the Elderly....102
NavChair Control System for Automatic Assistive Wheelchair....406

VA Medical Center
54th St., and 48th Ave., South, Minneapolis, MN 55417

Page
Connected Speech Deviations of Aphasic and Non-Brain-Damaged Adults....308

VA Medical Center
4801 Linwood Blvd., Kansas City, MO 64128

Page
Combined Functional Loading and Laser Photostimulation of Regenerating Tendons....193

VA Medical Center
St. Louis, MO 63125

Page
Prokinetic Agents for Constipation in Spinal-Cord Injured (SCI) Patients: A Pilot Study....347

VA Medical Center
508 Fulton St., Durham, NC 27705

Page
Do Changes in Strength Improve Balance and Function in Elderly Men and Women? 103

VA Medical Center
4101 Woolworth Ave., Omaha, NE 68105

Page
New Strategies for Long-Term Performance of Femoral Prostheses.....251
Comparison of Events in Bone Healing Influenced by CCEF and PEMF Signals 422

VA Medical Center
Tremont Ave. at Centre St., East Orange, NJ 07019

Page
Intergrated Assessment of Factors Affecting Functional Capacity for Locomotion 51
Programmable Hearing Aids: Evaluation and Prediction of Benefit 273
Effects of Presence vs. Absence of Prolonged Amplification on Audition 274
Effect of Lack of Amplification on Persons with Unilateral Hearing Loss.....275

VA Medical Center
Castle Point, NY 12511

Page
Correlation of Streaming Potentials with Stages of Bone Repair/Remodeling.....41
Predicting Ischemia in Use of the Lower-Limb Prosthesis 218
Noninvasive Measurement of Changes in Muscle Oxygent with Claudication 219
Omental Angiogenic Factor to Reverse Peripheral Vascular Insufficiency: A Pilot Study.....219
Viscoelasticity of the Limb in Compartment Syndrome: A Pilot Study.....220

VA Medical Center
423 E. 23rd St., New York, NY 10010

Page
Computer-Aided Socket Design and Computer-Aided Manufacturing for Above-Knee Prosthetics 24
Computer-Aided Design and Computer-Aided Manufacturing of Orthopedic Footwear.....262

VA Medical Center
3200 Vine St., Cincinnati, OH 45220

Page
Synchronized Electrical Stimulation Therapy in Elderly Incontinent Men: A Pilot Study.....104

VA Medical Center
10701 East Blvd., Cleveland, OH 44106

Page
Restoration of Gait for the Stroke Patient 52
Electrical Activation of the Diaphragm for Ventilatory Assist.....72
Functional Neuromuscular Systems for Upper Extremity Control.....74
Development of an On-Line Correction Capability for FNS Locomotion: Computer Simulation of Paraplegic Gait through Multiple Gait Cycles 77
Development of an On-Line Correction Capability for FNS Locomotion: Mathematical Models for Muscles Control.....78
Development of an On-Line Correction Capability for FNS Locomotion: A Fuzzy Logic Rule Base for Gait Phase Detection and Correction.....79
Development of an On-Line Correction Capability for FNS Locomotion: State Estimation of Electrically Stimulation Muscle Using the EMG Surface Response.....80
Restoration of Standing Pivot Transfer for Quadriplegic Patients Using a Totally Implanted FNS System...81
Functional Paraplegic Walking with Electrical Stimulation.....82
Restoration of Sit-to-Stand Function in Elderly Patients Using FNS 133
Neuroprosthetic Control of Bladder and Bowel in SI Patients.....369

VA Medical Center
4100 West 3rd St., Dayton, OH 45428

Page
Evaluation and Optimization of FES Techniques for Exercise.....73
Exercise Testing and Training of Multiple-Sclerosis Patients.....201
Improving Exercise Performance of Quadriplegics ...348
SCI Responses to Wheelchair Propulsion during Fatigue: A Pilot Study.....396
Wheelchair Propulsion Performance in Young, Middle-Aged, and Elderly.....398

VA Medical Center
3710 Southwest U.S. Veterans Hospital Rd., Portland, OR 97201

Page
Early Detection of Hearing Loss from Ototoxic Agents by High-Frequency Auditory Evaluation 276

VA Medical Center
University and Woodland Aves., Philadelphia, PA 19104

Page
Calcium Phosphate Ceramic Coatings as Vancomycin Carriers.....252

VA Medical Center (Highland Dr)
Highland Drive, Pittsburgh, PA 15206

Page
Manipulating Joint Compliances and Ground Reaction Forces to Predict Falling Potential: A Pilot Study.....105

Biochemical Analysis of Synovial Activation in Joint Dysfunction 233
Analysis of a Treatment for Apraxia of Speech in Adults with Aphasia 288
Promoting Generalized Language Use: An Analysis of Treatment Variables 309

Ralph A. Johnson VA Medical Center
109 Bee St., Charleston, SC 29403

Page
Fiber-Reinforced Polymer Femoral Components for Hip Arthroplasty 254

Alvin C. York VA Medical Center
3400 Lebanon Rd., Murfreesboro, TN 37130

Page
Behavioral Treatment of Urinary Incontinence 106

VA Medical Center
1310 24th Ave., South, Nashville, TN 37203

Page
Origin and Character of Regenerate Bone 234

VA Medical Center
2002 Holcombe Blvd., Houston, TX 77211

Page
Objective Assessment of Spasticity in Spinal Cord Injury 349
Skin Composition in Spinal Cord Injury 418

Audie L. Murphy Memorial Veterans Hospital
7400 Merton Minter Blvd., San Antonio, TX 78284

Page
Restoration of Oral Function with Maxillary Bone Grafts and Implants 235

Olin E. Teague Veterans' Center
Temple, TX 76501

Page
Evaluation of a Coping Strategies Program in Aural Rehabilitation: A Pilot Study 277

VA Medical Center
500 Foothill Blvd., Salt Lake City, UT 84148

Page
Effects of Aging on the Bone Tissue of the Femoral Neck on Men and Women 107
Effect of Autologous Bone Paste, Hydroxyapatite, and Bone Morphologic Protein on Bone Fixation into Porous Coated Devices 255

Hunter Holmes McGuire Hospital
1201 Broad Rock Rd., Richmond, VA 23249

Page
Basic Mechanisms and Rehabilitative Strategies for Presbycusis 278

VA Medical Center
White River Junction, VT 05001

Page
Continuation of the Center for Retrieved Orthopedic Prostheses 236
Toward Better Methods of Nerve Repair and Evaluation 419
Artificial Nerve Graft: Union of Cellular and Noncellular Components 420

VA Medical Center
1660 South Columbian Way, Seattle, WA 98108

Page
Clinical and Laboratory Study of Amputation Surgery and Rehabilitation 18
Contact Pressure in the Hind Foot 238
Effect of Exercise on Upper Extremity Recovery Following Quadriplegia 370
Diabetic Foot Ulcer Risk Factors and Pathophysiology of Wound Repair 423

William S. Middleton Memorial Veterans Hospital
2500 Overlook Terrace, Madison, WI 53705

Page
Swallowing Dysfunction in Elderly Head and Neck Cancer Patients 108
Swallowing Physiology Related to Normal Aging 108
Treatment of Dysphagia in Age-Related Disease: Stroke 220
In Vivo Measurement of Vertebral Displacement after Lumbar Fusion 239

Clement J. Zablocki VA Medical Center
5000 West National Ave., Milwaukee, WI 53295

Page
Contralateral vs. Ipsilateral Cane Use 61
Age-Related Changes in Sensory-Motor Performance 109
Development of a Portable Biofeedback Cane: A Pilot Study 134
Development of a Miniature 'Shear' Sensing Transducer: A Pilot Study 135
Toward the Design of a New Bowel Care/Shower Chair: A Pilot Study 399
Design of a Videofluoroscopy Chair for SCI and Other Disabled Patients: A Pilot Study 412
Holter System Development for Recording Plantar Pressures 430

The following reports represent research supported by VA Medical Center Core Funds

Edward Hines Jr. VA Hospital
Hines, IL 60141

Page
Neuroactivation SPECT Imaging for Assessment of Rehabilitation Potential Following Cerebral Infarction 123

Regrowth of Corticospinal Axons Following Co-Implantation of Carbon Filaments and Fetal CNS Tissue 202
Regrowth of Injured Axons on Non-Biological Substrates 203
Can Improvement in Reading Rates in Patients with Macular Disease be Predicted Prior to Vision Rehabilitation? 310
Reading Rehabilitation of Geriatric Patients Post Exudative Maculopathy 310
Validating a Measure of Low Vision Functional Status 311
DC Field Effects on Axonal Transport in the Corticospinal Tract Following Spinal Cord Injury 350
Effect of Serine Protease Inhibitors on Neurite Outgrowth 351
Carbohydrate Metabolism and Cardiovascular Risk Factors in Persons with Spinal Cord Injury....352
Effect of Supported Standing and Upper Body Exercise on Lower Extremity Spasticity in Persons with Spinal Cord Injury 353
Sodium Pump Expression in Spinal Cord Trauma: A Pilot Study 355
Thin-Film Peripheral Nerve Electrode 370
Preparation of Genetically Modified BDNF and NT-3 Secreting Fibroblasts and Evaluation of Their Capacity to Enhance Regrowth of Injured Spinal Cord Fibers 389

Part B. Non-VA Sponsoring Organizations

Albert Einstein Medical Center
5501 Old York Rd., Philadelphia, PA 19141

Page
Biomechanical Optimization of Lower Orthoses Using Dynamic Surface Polyelectromyography 263

A.I. duPont Institute
1600 Rockland Rd., Wilmington, DE 19803

Page
Rehabilitation Engineering Research Center in Robotics 140
Improving the Functional Utility of Rehabilitation Robotics Through Enhanced Sensory Feedback ..141
Rehabilitation Robotics Information Program 142
Recognition of Gestures for Expressive Communication 151
Flexible Abbreviation Generation 152
Compansion: A Rate Enhancement Method that Utilizes Natural Language Processing Techniques....153
Application of Natural Language Processing to AAC 154
Human Factors Studies in Eye Movements Related to AAC Head Mounted Unit 155
Augmentative Communication Information Program.156
Human Factors Studies in Eye Movements Related to AAC Head-Movement Studies 156
Language Facilitation Through Graphics and Graphical Animation 157
Spatialization and Spatial Metaphor in AAC 158
Speech Processing Program 159
Speech Synthesis Program 160
Development of an AAC Software Architecture 161
Development of AAC Systems Based on Personal Computers 162
Evaluation of Human-Systems Interaction in AAC...163
Enhancing Picture-Based Communication Via Computer-Assisted Design and Instruction 164
Vestibular Stimulation and Cerebral Palsy 208
Feature Extraction Methods for a Video Telephone for Deaf and Hard-of-Hearing People....281
Natural Language Processing Principles for Improving Deaf Writing 282

Allergan, Inc
No Address Listed.

Page
Effect of Botox on Walking....431

Alzheimer's Disease Diagnostic and Treatment Center
No Address Listed.

Page
Attention in Early Dementia 111

American Association of Spinal Cord Injury Nurses
75-20 Astoria Blvd., Jackson Heights, NY 11370-1177

Page
Application of the Nursing Minimum Data Set to Spinal Cord Injury Care 371
Catheter Cleaning for Re-Use in Intermittent Catheterization 372

American Association of SCI Psychologists & Social Workers
75-20 Astoria Blvd., Jackson Heights, NY 11370-1178

Page
Understanding Leisure Behavior of People with Spinal Cord Injury 356
Proposal for a Survey of Attendant Care Arrangements for Indigent Spinal Cord Individuals in Louisiana 372
Assessment of Post-Traumatic Stress Disorder in Spinal Cord Injury 374
Consumer Perception of Resources Needed for Long-Term Recovery from Spinal Cord Injury 374
Factors Affecting Employment Status among Persons with Spinal Cord Injury....375

American Medical Systems and Pfizer Hospital Products Group
No Address Listed.

Page

Treatment of Vesicosphincter Dyssynergia Using the Urolume Prosthetic Stent: Effect on the Maximum Urethral Pressure Gradient 375

American Occupational Therapy Association, Inc.
1500 Highland Ave., Madison, WI 53705

Page

Occupational Therapy Functional Assessment Compilation Tool (OT FACT).....136

American Printing House for the Blind
Louisville, KY 40206-0085

Page

Braille Literacy: Training, Mentoring, and Technological Services Program for Blind Adults 312

American Society for Surgery of the Hand
3025 South Parker Road, Suite #65, Aurora, CO 80014

Page

Skeletal Muscle Architectural Design: Implications for Tendon Transfer.....190

Apple Computer, Inc.
20525 Mariani Ave., Cupertino, CA 95014

Page

Occupational Therapy Functional Assessment Compilation Tool (OT FACT).....136
Development of User-, Professional-, and Public-Accessible Database Interface Techniques .137
Development of Extensions for Standard Computers and Operating Systems to Allow Access by Users with Motor Impairments 145
Effects of Gain and Movement Range on Performance Using Head-Controlled Computer Input Devices .146

Bloorview Children's Hospital Foundation
Toronto M4G 1R8 ON Canada

Page

Health Behavior in School-Aged Children with Physical Disabilities 432

Brisbane North Regional Health Authority
Brisbane, QLD Australia

Page

Quality Implications of Information Capture, Transfer, and Use in a Cross-Discipline Rehabilitation Engineering Team.....413

Camera di Commercio di Torino
Torino, Italy

Page

Modelling of EMG Signals.....186
Multichannel Surface EMG Signals 187
Estimation of Muscle Fiber Conduction Velocity.....188

Centers for Disease Control
1600 Clifton Road, NE, Atlanta, GA 30333

Page

Integrating Trauma and Rehabilitation (ITR).....124

Center for Orthokinetics Research and Education
Williamsville, NY 14221

Page

Orthokinetic Orthosis: Systematic Replication of a Clinical Efficacy Study of Orthokinetics Treatment for a Patient with Upper Extremity Hemiparetic Movement Dysfunction in Post-Acute CVA 125

Commission of the European Communities - TIDE -
Rue de la Loi 200, Brussels, B1019 Belgium

Page

Restoration of Muscle Activity Through FES and Associated Technology: The RAFT Project, A Concerted Action 83

Delft University of Technology, Laboratory for Measurement & Controll
Mekelweg 2, Delft, 2628 CD The Netherlands

Page

Development of Test Protocols Related to the Behavior of Back Muscles 211 EMG Parameters of Lumbar Back Muscles.....211

Department of Health and Human Services
200 Independence Ave., Washington, DC 20201

Page

Secondary Prevention of Back Pain and the Development of Chronicity: The OIOC-NIOSH Model Clinic 215

Dole Foundation
No Address Listed.

Page

Return to Productivity, On Your Mark, Project Incubator, Bridge: Four Employment Demonstration Projects.....357

Drexel University (The Calhoun Fellowship Endowment)
No Address Listed.

Page

Biomechanical Optimization of Lower Orthoses Using Dynamic Surface Polyelectromyography 263

Dundee Limb Fitting Centre
133 Queen St., Broughty Ferry, Dundee DD5 1AG U.K.

Page

Computer-Aided Movement Analysis in a Rehabilitation Context.....52
Dundee Limb Fitting Centre Lower Limb Amputee Survey.....23

Dutch Innovation Research Programme/Assistive Devices for the Disabled
No Address Listed.

Page

Functional Assessment of the Performance Capacity of the Wheelchair-User Combination during Rehabilitation 386

Easter Seal Research Foundation
70 E. Lake St., Chicago, IL 60601

Page

Assessment of Rhizotomy Surgery for Children with Cerebral Palsy 450

Easter Seal Research Institute of Ontario
250 Ferrand Dr., Suite 200, Don Mills M3C 3P2 ON Canada

Page

Modification of the Van Nes Prosthesis 26
Musical Attention Training Program 126
Evaluation of the IBM Voicetype Recognition System with Speech-Impaired Individuals 289
Refinement and Evaluation of a Computer-Based Program for Training Speech Rate with Neurologically Impaired Individuals 290
Multi-Modal Computer Feedback 313

EEC Social Fund
No Address Listed.

Page

Computer-Aided Movement Analysis in a Rehabilitation Context 52

EIC Laboratories
Norwood, MA 02062

Page

Implantable Electrodes Using Iridium Oxide Film Technology 70

Foundation for Physical Therapy
111 North Fairfax, Alexandria, VA

Page

Doctoral Training in Physical Therapy 432

Hospital for Sick Children Foundation
555 University Ave., Toronto M5G 1X8 ON, Canada

Page

Eye Position Interface for the MANUS Manipulator .144
Modular Custom-Fitting Ankle-Foot Orthosis 264

Hugh Steeper Ltd.
No Address Listed.

Page

Myoelectric Control Strategies 12

Hugh MacMillan Rehabilitation Centre
350 Rumsey Rd., Toronto M4G 1R8 ON, Canada

Page

VV59 Prosthetic Hand Enhancements: Cosmetics, Electronics, and New Larger Size 7
Analysis of a Paediatric Ankle-Foot Orthosis 264
Modular Custom-Fitting Ankle-Foot Orthosis 264

IBM Canada, Ltd.
3500 Steeles Ave. East, Markham L3R 2Z1 ON, Canada

Page

WiVik 2REP: Rate Enhancement Package 166
WiViK 2 Scan: 1-5 Switch Scanning Access 167
Evaluation of the IBM Voicetype Recognition System with Speech-Impaired Individuals 289
Refinement and Evaluation of a Computer-Based Program for Training Speech Rate with Neurologically Impaired Individuals 290
Multi-Modal Computer Feedback 313
KeyREP: Keyboard Rate Enhancement Package 362

IBM Corporation
1000 NW 51st St., Boca Raton, FL 33429

Page

Development of User-, Professional-, and Public-Accessible Database Interface Techniques .137
Development of Extensions for Standard Computers and Operating Systems to Allow Access by Users with Motor Impairments 145
Effects of Gain and Movement Range on Performance Using Head-Controlled Computer Input Devices .146

Illinois Society for the Prevention of Blindness
175 W. Jackson Blvd., Chicago, IL 60604

Page

Measuring Needs of Elderly Patients for Low Vision Devices 314

Information Technology Foundation
1616 N. Fort Myer Dr., Suite 1300, Arlington, VA 22209

Page

Development of Design Guidelines Computers and Other Electronic Devices to Increase Usability by Persons with Disabilities 150
Auditory Redundancy of Computer Information for Hearing-Impaired Individuals 280

Innovative Research Programme/Aids for the Handicapped
PO Box 1039, Bisonspoor 3600 Maarssen, The Netherlands

Page

Ergonomics of Manual Wheelchair Propulsion 400

Italian Ministry for University and Scientific Research
Lungotevere Thaon di Revel 76, Rome 00100 Italy

Page
Biomechanical Analysis of Paraplegic Walking with Orthoses and FES....84
Estimation of Electrical Stimulus: Torque Relationship in Quadriceps Muscle for FES Application on Paraplegic Patients....85
Quantification of Spasticity by Pendulum Test and EMG Activity Analysis....357

Labatt's Blue Light Relay
Ottawa, ON, Canada

Page
Comparison of CAD/CAM and Conventional Techniques for the Fabrication of Trans-Tibial Sockets with Supracondylar Suspension....34
Clinical Analysis of a CAD/CAM System for Custom Seating....414

Lexington Center
Jackson Heights, NY 11370

Page
Rehabilitation Engineering Research Center on Hearing Enhancement and Assistive Devices....279

Liberty Mutual Insurance Company
71 Frankland Rd., Hopkinton, MA 01748

Page
Myoelectric Control Strategies....12
Triphasic Patterns in Above-Elbow Amputees....13
Liberty MyoSelector: An Adaptable Scheme to Select Multiple Functions....14
New Boston Elbow: Increased Capabilities....15
MyoArray: A Diagnostic Tool to Test and Train Amputees to Use Myoelectric Prostheses....16
Effects of Visual Input on Open-Loop and Closed-Loop Postural Control Mechanisms....49
Effects of Head Injury on Open-Loop and Closed-Loop Postural Control Mechanisms....53
Feigning Postural Instability....54
Postural Control Adaptability during Prolonged Spaceflight....54
Biochemical and Myoelectric Events during Fatigue..189
Improvements to the Technique of Synchronization Evaluation....197
Effects of Hand Dominance on Motor Unit Firing Behavior....198
Motor Unit Firing Rates during Sustained Isometric Contractions....199
Common Drive of Motor Units: A Model for Motor Unit Control....200
Rank-Ordered Regulation of Motor Units....200
Motor Unit Control Strategies during Sustained Isometric Contractions....204
Synchronization Across Muscles....205
Synchronous Behavior of Motor Unit Firings....205
Database Development for a Clinical Back Analysis System....210
Muscle Performance in the Back Analysis System Compared to Lifting Tasks....210
Back Assessment of Athletes from Varsity and Freshman Crew Teams....212
Clinical Validation of the Back Analysis System for Treatment Outcome Following Rehabilitation....213
Normative Database Study of Back Muscle Function .213
Back Analysis System (BAS) Update....214
Design of a Clinical Reference System for Positioning Electrodes on the Back....434

Loyola Medical Center
Department of Medicine, Maywood, IL 60153

Page
Management of Central Ventilatory Insufficiency: Adbominal and Thoracic Stimulation: A Pilot Study....71

Lighthouse National Center for Vision and Aging
800 Second Ave., New York, NY 10017

Page
Rehabilitation of Visually Impaired Older Persons...314

The Lyndhurst Foundation
520 Sutherland Dr., Toronto M4G 3V9 ON, Canada

Page
Music Making in Rehabilitation for Persons with Spinal Cord Injuries....376

Metropolitan Atlanta Community Foundation
Atlanta, GA

Page
Return to Productivity, On Your Mark, Project Incubator, Bridge: Four Employment Demonstration Projects....357

Medical Research Council of Canada
20 th Floor, Jeanne Mance Building, De l'Eglantine St., Tunney's Pasture, Ottawa K1A 0W9 ON, Canada

Electrode Array Signal Processing....434

Medtronic, Inc.
Minneapolis, MN 55432

Page
Intrathecal Baclofen for Treatment of Intractable Spinal Spasticity....377

Mississippi State University Rehabilitation Research
P.O. Drawer 6189, Mississippi State, MS 39762

Page
Identification of Differential Costs and Time Usage of Blind and Visually Impaired Persons....321
Identification of Skills, Knowledge, and Steps Necessary for Students with Visual Impairments Entering Postsecondary Institutions....321

Identification of Skills and Knowledge Necessary for People with Visual Impairments Beginning Jobs after Graduating from Postsecondary Institutions....322

National Aeronautics and Space Administration
Office of Commercial Programs, Code CU, NASA Headquarters, Washington, DC 20546

Page
Postural Control Adaptability during Prolonged Spaceflight....54
Muscle Adaptability during Prolonged Spaceflight ...190

National Easter Seal Society
1350 New York Avenue, NW, Suite 915, Washington, DC 20005

Page
Fax-Based Communication Augmentation System for the Print-Handicapped....322

National Rehabilitation Hospital Research Center
National Rehabilitation Hospital, 102 Irving Street, NW, Washington, DC 20010

Page
Development of an Instrument to Predict Compliance with Self-Care Behaviors in a Spinal Cord-Injured Population Using the Theory of Reasoned Action....358

National Institute on Disability and Rehabilitation Research
400 Maryland Ave., SW, Washington, DC 20202

Page
Prosthetic/Orthotic Materials 2
Resource Unit for Information and Education....3
Biomechanical Study to Improve Grip in Children's Terminal Devices....7
Prosthetic Arm Design and Simulation System: PADSS....8
EPP-Type Position Servo Control of Electric Elbows for Children....10
Application of Ultrasound and Computer Techniques to Lower Limb Prosthetic Socket Design 20
Computerized Methods in Prosthetics and Orthotics...21
Functional Biomechanical Characterization and Functional Design Specification: Lower-Extremity Prosthetics....21
Dynamic Response Prosthetic Feet and Their Role in Human Ambulation....22
Femoral Displacement in Above-Knee Sockets....25
Development of a Direct Ultrasound Ranging System for the Quantification of Ambulation....55
Functional Analysis of Feeding and Interaction Disorders with Young Children Who are Profoundly Disabled....65
Novel FES System Improving Locomotion Abilities in SCI Subjects by Enhanced Voluntary Control Based on Sensory Integration and Extended Sensory Perception....86
Later Life Effects of Early Life Disability: Comparisons of Age-Matched Controls on Indicators of Physical, Psychological, and Social Status 112
Evaluation of Adaptive Device Use by Older Adults with Mixed Disabilities....113
Use of Technology to Promote Rehabilitation of Older Persons: Reducing the Barriers to Independence..114
Role of Training to Enhance Utilization of In-Home Support: A Comparison Between Older Hispanics and Anglos With A Disability 115
Policy and Funding Alternatives to Promote Community and Supportive Services for Older Persons with A Disability 116
Analysis of Policy Barriers to Accessing Technology Services for Individuals Aging with a Disability ..117
Analysis of Policy Barriers to Accessing Technology Services for Individuals Aging with a Spinal Cord Injury 118
Predictive Value of Cognitive/Behavioral Measures in Patients After Stroke in Assessing Functional Outcome....127
Reducing Motor Disability in Hemiparetic Stroke by Manipulation of Sensory Input from the Paretic Upper Limb: A Quantitative Evaluation 127
Effectiveness of a Telephone Support Group for Stroke Caregivers....128
Improving Vocational Outcomes of Individuals Who Have Sustained a Stroke 128
Controlled Study of the Effects of EMG Feedback and Electrical Stimulation on Motor Recovery in Acute Stroke Patients 129
Effects of Aerobic Exercise on Young Persons Post-Stroke....129
Co-Morbidities and Complications in Stroke: Incidence, Risk Factors, and Effects on Outcomes 130
Course of Recovery of Cognitive-Communicative Problems in Right Brain Damage Individuals 130
Prevention of Thromboembolism in Stroke Rehabilitation Patients....131
Development of User-, Professional-, and Public-Accessible Database Interface Techniques .137
Rehabilitation Engineering Research Center in Robotics....140
Improving the Functional Utility of Rehabilitation Robotics Through Enhanced Sensory Feedback ..141
Development of Extensions for Standard Computers and Operating Systems to Allow Access by Users with Motor Impairments 145
Effects of Gain and Movement Range on Performance Using Head-Controlled Computer Input Devices .146
Project LITERAAC: Literacy Intervention to Enhance Reading and Writing through Augmentative and Alternative Communication 147

Interface Training and Use By Persons with Cognitive Disabilities 148
Interface Training and Use By Young Children 149
Development of Design Guidelines Computers and Other Electronic Devices to Increase Usability by Persons with Disabilities 150
General Input Device Emulating Interface (GIDEI) Standard 150
Recognition of Gestures for Expressive Communication 151
Flexible Abbreviation Generation 152
Compansion: A Rate Enhancement Method that Utilizes Natural Language Processing Techniques 153
Application of Natural Language Processing to AAC 154
Human Factors Studies in Eye Movements Related to AAC Head Mounted Unit 155
Augmentative Communication Information Program 156
Human Factors Studies in Eye Movements Related to AAC Head Movement Studies 156
Language Facilitation Through Graphics and Graphical Animation 157
Spatialization and Spatial Metaphor in AAC 158
Speech Processing Program 159
Speech Synthesis Program 160
Development of an AAC Software Architecture 161
Development of AAC Systems Based on Personal Computers 162
Evaluation of Human-Systems Interaction in AAC 163
Enhancing Picture-Based Communication Via Computer-Assisted Design and Instruction 164
Rehabilitation Engineering Research Center: Technology Evaluation and Transfer 169
Evolution of Independent Living Programs: A Longitudinal Study 170
Assisting Community-Based Rural Independent Living Programs 171
Life Satisfaction of People with Physical Disabilities: Relationship to Personal Assistance, Disability Status, and Handicap 172
Development of an Instrument to Measure Adequacy of Personal Assistance Service 173
Use of Personal Assistance Services by Persons with Spinal Cord Injury 174
Effect of Personal Assistance Services on the Long-Term Health of a Rehabilitation Hospital Population: Perceptions of Rehabilitation Professionals 175
Demonstrating a Model Approach to Independent Living Center-Based Assistive Technology Services 176
Increasing the Ability of Independent Living Centers to Serve the Hispanic Population 177
Increasing the Ability of Independent Living Centers to Serve the Population of African Americans with Disabilities 178
Relationships among Age at Onset, Adequacy of Personal Assistance, Negative Health Incidents, and Health Care Utilization for Persons with Physical Disabilities 178
Neuromuscular Function in PostPolio Subjects: A Three-Year Follow-Up Study 206
Effect of a 12-Week Non-Fatiguing Muscle Strengthening Exercise Program in PostPolio Patients 207
Vestibular Stimulation and Cerebral Palsy 208
Vermont Rehabilitation Engineering Research Center for Low Back Pain 216
Advanced Contracture Reduction Orthosis (CRO) 265
Lightweight, Cosmetic, Articulating Ankle-Foot Orthosis 266
Sexuality Issues Among Women with Physical Disabilities 268
Auditory Redundancy of Computer Information for Hearing Impaired Individuals 280
Feature Extraction Methods for a Video Telephone for Deaf and Hard-of-Hearing People 281
New Nystagmus Tester 315
Improved Visual Evoked Potential Recording System 316
Photorefractive Vision Screening Research 316
Early Intervention: Clinical Efficacy of Alternate Occlusion in Infantile Esotropia 317
Evaluation of Heads-Up Displays for Low Vision Applications 318
Impact of Vision Impairments on Everyday Tasks 318
SKILL Card: Evaluation and Technology Transfer 319
Study of Driving and Visual Impairment 320
Identification of Differential Costs and Time Usage of Blind and Visually Impaired Persons 321
Identification of Skills, Knowledge, and Steps Necessary for Students with Visual Impairments Entering Postsecondary Institutions 321
Fax-Based Communication Augmentation System for the Print-Handicapped 322
Identification of Skills and Knowledge Necessary for People with Visual Impairments Beginning Jobs after Graduating from Postsecondary Institutions 322
Access to Computer-Music Software by Blind and Vision-Impaired Musicians 323
Digital Speech Recorder and Programmer 324
Assistive Devices for Blind Diabetics 325
New Approach to Specialized Job Adaptations: Knitting Machine Counter Example 325
Audible Stud Finder 326
Computer Interfacing of Digital Multimeters 327
Rolling Ruler 327
OEM Audible Carpenter's Level 328
Special Light Probe for a Multi-Line Telephone 328
Desktop Broadcasting 329
Electronic Formboard 335
Investigating Use of the Universal Product Code by Visually Impaired Shoppers and Vendors 335
Auditory Arcade 336
Talking Keyboard 336
Investigating Some Basic Parameters of Multi-Finger Tactile Perception 337
Survey of Deaf-Blind Technology Needs 337

Dexter: The Fingerspelling Mechanical Hand for Deaf-Blind Persons....338
Vibrating Medication Reminder for the Deaf-Blind...338
Smith-Kettlewell Vibratory Battery Tester for the Deaf-Blind....339
Immune Responses to Pneumococcal Vaccine in Spinal Cord Injury....359
Natural History and Clinical Course of Urinary Tract Complications in Patients with Spinal Cord Dysfunction....360
Collaboration Between Medical Rehabilitation Programs and Independent Living Centers in Facilitating Independent Living By Persons with Recently Incurred Spinal Cord Injury....361
Cardiorespiratory Responses to Exercise Testing in Acute Spinal Cord Individuals....363
Spinal Cord Injury Occurring in Patients with Ankylosing Spondylitis: A Multicenter Study....364
Adjustment of Spinal Cord Injured Who Are Victims of Intentional vs. Unintentional Injuries....378
Rehabilitation Research and Training Center: Complications of Spinal Cord Injury....378
Baclofen Pump: Functional and Neuropsychological Impact....379
Longitudinal Analysis of Well-Being in Persons with Spinal Cord Injury and Their Caregivers....380
Clinically Derived Protocol for Changing Condom Catheters in Males....381
Problem-Solving Skills Training in the Treatment of Pressure Ulcers in Persons with Spinal Cord Injury....382
Pathologic Effects of Recurrent Bacteriuria in Patients with Spinal Cord Dysfunction....383
Ultrasound for Urinary Tract Surveillance of Persons with Spinal Cord Injury....384
Natural History and Clinical Course of Skin Complications (Excluding Pressure Ulcers) in Persons with Spinal Cord Injury....385
Assessment of Deficiencies in Assistive Technology for Personal Transportation Systems....401
Methodology for Evaluating Equipment Used When Assessing Individuals' Needs for Vehicle Modification and Adaptive Equipment....402
Testing Procedures for Wheelchair Lifts....402
Evaluation of Structural Integrity and Dynamic Stability of Modified Vans....403
Testing Procedures for Wheelchair Sacrament Systems....403
Wheelchair Research at the University of Pittsburgh RERC....404
Cognitive Readiness for Powered Wheelchair Mobility....407
Determining the Appropriateness of Integrated Control of Assistive Devices....408
Treatment of Pressure Ulcers....420
Histopathology of Denervated Skin following Spinal Cord Injury....421
Research Program on Accessible Housing....426
Medical Rehabilitation Payment Study....435
Research Training in Rehabilitation Engineering....435
Health Care Utilization and Cost Experience of Working-Age Persons with Disabilities: An Analysis of the National Medical Expenditure Survey (NMES)....436
Operational Definition of Independence....437
Research Training in Engineering and Rehabilitation Technology....438
Impact of Waiting for Community-Based Services and the Roles of Formal and Informal Services on Adults with Mental Retardation Who Live with Their Families:
A Longitudinal Perspective....439
Transferring Technology from the Research Laboratory to the Commercial Market....440
Implementation and Follow-Up of Rehabilitation Technology....441
Gathering and Disseminating Information on Assistive Technology for Children....442
Rehabilitation Technology Training: A Plan for Facilitating the Delivery of Technology....442
Developing a Consumer's Guide on Funding AssistiveTechnology....443
Mainstreaming Students with Assistive Technology into Regular Education....444
Assistive Technology Usage Outcome....445

National Institutes of Health
900 Rockville Pike, Bethesda, MD 20892

Page
Improving Prosthetic Prehension....12
Vision Research: A National Plan, 1994-1998....333

National Cancer Institute
National Institutes of Health, Executive Plaza North, Room 300, Bethesda, MD 20892

Page
Cricopharyngeal Myotomy Study....292

National Center on Accessible Housing
School of Design, North Carolina State University, Raleigh, NC

Page
Research Program on Accessible Housing....426

National Eye Institute
National Institutes of Health, Bethesda, MD 20892

Page
New Nystagmus Tester....315
Improved Visual Evoked Potential Recording System.316
Photorefractive Vision Screening Research....316
Early Intervention: Clinical Efficacy of Alternate Occlusion in Infantile Esotropia....317
Evaluation of Heads-Up Displays for Low Vision Applications....318
Impact of Vision Impairments on Everyday Tasks...318

SKILL Card: Evaluation and Technology Transfer...319
Study of Driving and Visual Impairment.....320

National Institute of Arthritis and Musculoskeletal Disorders
National Institutes of Health, Bethesda, MD 20892

Page
Mechanism of Torque Generation in the Frog Hindlimb 191
Muscle Fiber Damage Due to Eccentric Contractions .191
Intraoperative Measurement of Human Muscle Sarcomere Length.....192

National Institute of Child Health and Human Development
National Institutes of Health, Bethesda, MD 20892

Page
Polio Disability: Personal Meaning, Well-Being, and Age 118

National Institute on Deafness and Other Communication Disorders
National Institutes of Health, Bethesda, MD 20892

Page
Biomechanical Measurements and Classification of Dysphagia.....217
Cognitively Based Treatments of Acquired Dyslexia ..448

National Rehabilitation Hospital
Washington, DC 20010

Page
Development of an Instrument to Predict Compliance with Self-Care Behaviors in a Spinal Cord-Injured Population Using the Theory of Reasoned Action.....358

National Science Foundation
Biomedical Engineering and Aiding Disabled, 1800 G Street NW, Washington, DC 20550

Page
Computational Posturography: In Numero Experiments on Postural Control 47
Random Walking during Quiet Standing.....50
Assessing Individuals' Predispositions to the Use, Avoidance, or Abandonment of Assistive Technologies 138
Rehabilitation Robotics Information Program 142
Modeling of Performance with Computer Access and Alternative Communiation Systems.....164
Natural Language Processing Principles for Improving Deaf Writing 282
Rehabilitation Engineering Center, Texas A&M.....446

National Science Foundation, Information Robotics & Intelligent Systems Division
Wilmington, DE

Page
Rehabilitation Robotics Information Program 142
Natural Language Processing Principles for Improving Deaf Writing 282

Natural Sciences and Engineering Research Council of Canada
200 Kent St., Ottawa K1A 1H5 ON, Canada

Page
Short Range Telemetry of Surface Myoelectric Signals..4
Electromechanical Prosthetic Hands and Visual Feedback 11
Myoelectric Control Strategies.....12
Modification of the Van Nes Prosthesis 26
Assessment of Variability in Human Walking 56
Three-Dimensional Pointing Interface for the Manus Manipulator.....143
Eye Position Interface for the MANUS Manipulator .144
Analysis of a Paediatric Ankle-Foot Orthosis.....264
Selection, Fitting, and Evaluation of Hearing Aids...283
Adaptive Noise Cancellation Applied to Spinal Cord Monitoring.....362
Adaptive Filters for Biological Signal Processing.....447
VLSI Telemetry Implant for Myoelectric Control 447

National Department of Science and Research
Institute of Mechanics, Sofia - 1113 Bulgaria

Page
Robotic Workstation with Optoelectronic Control ...409
Powered Wheelchair Controller with Dynamic Stability Checking.....410

Nemours Foundation
1600 Rockland Rd., Wilmington, DE 19803

Page
Rehabilitation Engineering Research Center in Robotics 140
Improving the Functional Utility of Rehabilitation Robotics Through Enhanced Sensory Feedback ..141
Rehabilitation Robotics Information Program 142
Recognition of Gestures for Expressive Communication.....151
Flexible Abbreviation Generation 152
Compansion: A Rate Enhancement Method that Utilizes Natural Language Processing Techniques.....153
Application of Natural Language Processing to AAC 154
Human Factors Studies in Eye Movements Related to AAC Head Mounted Unit.....155
Augmentative Communication Information Program .156
Human Factors Studies in Eye Movements Related to AAC Head Movement Studies 156
Language Facilitation Through Graphics and Graphical Animation 157
Spatialization and Spatial Metaphor in AAC 158
Speech Processing Program 159
Speech Synthesis Program 160
Development of an AAC Software Architecture 161
Development of AAC Systems Based on Personal Computers 162

Evaluation of Human-Systems Interaction in AAC...163
Enhancing Picture-Based Communication Via Computer-Assisted Design and Instruction.....164
Vestibular Stimulation and Cerebral Palsy 208
Feature Extraction Methods for a Video Telephone for Deaf and Hard-of-Hearing People.....281
Natural Language Processing Principles for Improving Deaf Writing 282

NeuroMuscular Research Center
Boston University, 44 Cummington St., 5th Floor, Boston, MA 02215

Page

Postural Control Adaptability during Prolonged Spacelight.....54
Modelling of EMG Signals.....186
EMG and Mechanical Manifestations of Muscle Fatigue 188
Muscle Adaptability during Prolonged Spaceflight ...190
Modelling of Force Production in the Muscle 208
Muscle Performance in the Back Analysis System Compared to Lifting Tasks.....210
Development of Test Protocols Related to the Behavior of Back Muscles 211
EMG Parameters of Lumbar Back Muscles 211
Portable Force Feedback Display System 447

Netherlands Organization for Research
No Address Listed.

Page

Coordination of Muscles in Gait.....58

National Institute of Deafness and Communication Disorders (NIDCD)
102 Irving St., Washington, DC 20010

Page

Cognitively Based Treatments of Acquired Dyslexia ..448

North York Grants in Aid
No Address Listed.

Page

Multimedia Summer Experience 450

Northern California Society for the Prevention of Blindness
No Address Listed.

Page

Evaluation of Heads-Up Displays for Low Vision Applications.....318
Impact of Vision Impairments on Everyday Tasks ...318
SKILL Card: Evaluation and Technology Transfer...319
Study of Driving and Visual Impairment.....320

Office of Special Education Programs
U.S. Department of Education, 300 Maryland Ave. SW, Washington, DC 20202

Page

General Input Device Emulating Interface (GIDEI) Standard.....150

Ontario Ministry of Health
Queen's Park, Toronto M7A 1L3 ON, Canada

Page

Selection, Fitting, and Evaluation of Hearing Aids...283
USERNET: Collaborative Evaluation of Commercial Appliances and Products.....449

Ontario Rehabilitation Technology Consortium
Ottawa, ON, Canada

Page

EMG Pattern Recognition 17
Pediatric Above-Knee Endoskeletal Running Prosthesis.....27
Comparison of CAD/CAM and Conventional Techniques for the Fabrication of Trans-Tibial Sockets with Supracondylar Suspension 34
WiVik 2REP: Rate Enhancement Package 166
WiViK 2 Scan: 1-5 Switch Scanning Access 167
Selection, Fitting, and Evaluation of Hearing Aids...283
WiVox: Voice Output for Windows.....329
KeyREP: Keyboard Rate Enhancement Package 362
Consumer Involvement in Children's Seating Design .415
Custom Car Seats for School-Aged Children 415
USERNET: Collaborative Evaluation of Commercial Appliances and Products.....449

Orthokinetics Research Foundation
5 Sedgemoor Court, Williamsville, NY 14221

Page

Orthokinetic Orthoses: Systematic Replication of a Clinical Efficacy Study of Orthokinetics Treatment for a Patient with Upper Extremity Hemiparetic Movement Dysfunction in Post-Acute CVA 125

Orthopedic Research Laboratory
Department of Surgery, College of Medicine, University of Arizona, Tucson, AZ 85724

Page

Tibio-Femoral Contact Stress and Stress Distribution Evaluation of Total Knee Relacements.....257

Otto Bock Orthopedic
Canada

Page

Clinical Analysis of a CAD/CAM System for Custom Seating 414

Paralyzed Veterans of America, Spinal Cord Research Foundation
801 18th Street, N.W., Washington, DC 20006

Page
Ion Channel Expression in Astrocytes 390
Physiological Effects of Glial Cell Transplantation in theMyelin-Deficient Spinal Cord 391
Studies on Secondary Injury in Anoxic White Matter.392
Molecular Organization and Pharmacology of Mammalian Axons 393

Patricia Roberts Harris Foundation
No Address Listed.

Page
Hard-Wired Central Pattern Generators for Quadrupedal Locomotion 56
Effects of Noise on a Locomotor Central Pattern Gencrator Model.....57

Pennsylvania Bureau of Blindness and Visual Services
Harrisburg, PA 17105-2675

Page
Study to Assess the Feasibility of Contracting with a Nominee Agency for the Business Enterprise Program 330

Poona District Leprosy Committee
Manisha, 2nd Floor, Flat #35, 2-A Moledina Rd., Pune, 411 001 India

Page
Effect of Wax Therapy on the Plantar Skin in Leprosy.....209

Queen's University of Belfast
Belfast, BT7 1NN N. Ireland

Page
Orthopaedic Research Unit 241

Rehabilitation Institute of Chicago
345 Superior St., Chicago, IL 60611

Page
Community Re-Entry and Functional Status of People Following Brain Injury Rehabilitation 131

Rehabilitation Institute of Michigan
261 Mack Blvd., Room 302, Detroit, MI 48201

Page
Psychosocial Adjustment of Spinal Cord Injured Who Are Victims of Gunshot Wounds.....387

Rehabilitation Research and Training Center on Aging
Rancho Los Amigos Medical Center, 7600 Consuelo St., Downey, CA 90242

Page
Discussing CPR/DNR Choices with Geriatric Inpatients: The Psychological Impact on the Patient.....119
Caregiver Health 120
Psychosocial Factors and Health in the Elderly 121

Research Committee of the Orebro County Council
Orebro Medical Center, Arm Prosthetics Unit, Orebro, Sweden

Page
EPP-Type Position Servo Control of Electric Elbows for Children 10

Richards Medical Company
1450 Brooks Rd., Memphis, TN 38116

Page
Music Making in Rehabilitation for Persons with Spinal Cord Injuries 376

Rotary Club of Toronto
Toronto, ON, Canada

Page
Consumer Involvement in Children's Seating Design .415
Custom Car Seats for School-Aged Children 415

Royal National Institute for the Blind
Torquay TQ1 2NG England

Page
Assessment of Psychometric Tests for Use by the Visually Impaired 331

The Scottish Office, Home and Health Department
Chief Scientist Office, St. Andrew's House, Edinburgh, EH1 3DG Scotland

Page
Development of 'Talksbac', a Computer-Based Communication System 167

Smith-Kettlewell Eye Research Institute
2232 Webster St., San Francisco, CA 94115

Page
New Nystagmus Tester 315
Improved Visual Evoked Potential Recording System.316
Photorefractive Vision Screcning Research 316
Early Intervention: Clinical Efficacy of Alternate Occlusion in Infantile Esotropia.....317
Evaluation of Heads-Up Displays for Low Vision Applications.....318
Impact of Vision Impairments on Everyday Tasks ...318
SKILL Card: Evaluation and Technology Transfer...319
Study of Driving and Visual Impairment.....320
Fax-Based Communication Augmentation System for the Print-Handicapped 322
Access to Computer-Music Software by Blind and Vision-Impaired Musicians 323
Digital Speech Recorder and Programmer.....324
Assistive Devices for Blind Diabetics 325
New Approach to Specialized Job Adaptations: Knitting Machine Counter Example 325
Audible Stud Finder 326
Computer Interfacing of Digital Multimeters 327
Rolling Ruler 327
OEM Audible Carpenter's Level.....328
Special Light Probe for a Multi-Line Telephone 328

Desktop Broadcasting 329
Talking Signs 332
Ergonomic Low-Vision Telescope Grip 333
Electronic Formboard 335
Investigating Use of the Universal Product Code by Visually Impaired Shoppers and Vendors.....335
Auditory Arcade 336
Talking Keyboard 336
Investigating Some Basic Parameters of Multi-Finger Tactile Perception.....337
Survey of Deaf-Blind Technology Needs.....337
Dexter: The Fingerspelling Mechanical Hand for Deaf-Blind Persons.....338
Vibrating Medication Reminder for the Deaf-Blind...338
Smith-Kettlewell Vibratory Battery Tester for the Deaf-Blind 339

The Spanish Research and Development National Plan
No Address Listed.

Page

Transplants of Ensheathing Glia from Adult Olfactory Bulb Facilitate Axon Regeneration in the CNS...394

Sport Aiding Medical Research for Children (SPARKS)
No Address Listed.

Page

Study to Investigate the Benefits of Physiotherapy and External Supports on the ACL Deficient Knee 42

STipT Technology Programme
No Address Listed.

Page

Wheelchair Performance Capacity and Physical Strain in Spinal Cord Injured Subjects 365

Swedish National Board for Industrial and Technical Development
No Address Listed.

Page

EPP-Type Position Servo Control of Electric Elbows for Children 10

Tarbiat-Modarres University
Tehran, Iran

Page

Development of an On-Line Correction Capability for FNS Locomotion: State Estimation of Electrically Stimulated Muscle Using the EMG Surface Response.....80

Telethon-Italy
No Address Listed.

Page

3-D Analysis of Spinal Deformities by Means of the Auscan System 240

Texas Rehabilitation Commission
No Address Listed.

Page

Rehabilitation Engineering Center, Texas A&M.....446

Toronto Health Care Fund
Toronto, ON, Canada

Multimedia Summer Experience 450

United States Department of Education
400 Maryland Ave. SW, Washington, DC 20202

Page

Evaluation of Adaptive Device Use by Older Adults with Mixed Disabilities 113
Rehabilitation Engineering Research Center in Robotics 140
Improving the Functional Utility of Rehabilitation Robotics Through Enhanced Sensory Feedback ..141
Recognition of Gestures for Expressive Communication.....151
Flexible Abbreviation Generation 152
Compansion: A Rate Enhancement Method that Utilizes Natural Language Processing Techniques.....153
Application of Natural Language Processing to AAC 154
Human Factors Studies in Eye Movements Related to AAC Head Mounted Unit.....155
Augmentative Communication Information Program .156
Human Factors Studies in Eye Movements Related to AAC Head Movement Studies 156
Language Facilitation Through Graphics and Graphical Animation 157
Spatialization and Spatial Metaphor in AAC 158
Speech Processing Program 159
Speech Synthesis Program 160
Development of an AAC Software Architecture 161
Development of AAC Systems Based on Personal Computers 162
Evaluation of Human-Systems Interaction in AAC...163
Enhancing Picture-Based Communication Via Computer-Assisted Design and Instruction.....164
Applications of Technology to Enhance Quality of Life: A Multidisciplinary Consortium Approach 179
Applications of Technology: A Multidisciplinary Consortium and Service Delivery Model.....180
Assessing the Capabilities of Independent Living Center Staff to Deliver ADA-Related Services.....181
Vestibular Stimulation and Cerebral Palsy 208
Feature Extraction Methods for a Video Telephone for Deaf and Hard-of-Hearing People.....281
Cardiorespiratory Responses to Exercise Testing in Acute Spinal Cord Individuals.....363
Spinal Cord Injury Occurring in Patients with Ankylosing Spondylitis: A Multicenter Study 364
Medical Rehabilitation Payment Study 435

Health Care Utilization and Cost Experience of Working-Age Persons with Disabilities: An Analysis of the National Medical Expenditure Survey (NMES) 436
Impact of Waiting for Community-Based Services and the Roles of Formal and Informal Services on Adults with Mental Retardation Who Live with Their Families: A Longitudinal Perspective 439

University of Akron
Akron, OH 44325

Page
Bedsore Biomechanics 139

United Cerebral Palsy Research Educational Foundation

Page
Assessment of Rhizotomy Surgery for Children with Cerebral Palsy 450

University College of Cork
Dept. of Orthopaedic Surgery, Dublin, 3 Ireland

Page
Development of an Instrument to Predict Compliance with Self-Care Behaviors in a Spinal Cord-Injured Population Using the Theory of Reasoned Action 358

University of Michigan
Rackham Dissertation Grant
Ann Arbor, MI 48109-1070

Page
Modeling of Performance with Computer Access and Alternative Communication Systems 164

University of Warwick
Coventry, U.K.

Page
Group-Theoretic Approach to Rings of Coupled Biological Oscillators 58

University of Wisconsin-Madison Graduate School
Madison, WI 53705

Page
Interface Training and Use by Young Children 149

Variety Ability Systems
Toronto, ON, Canada

Page
Pediatric Above-Knee Endoskeletal Running Prosthesis 27

Variety Village Sport Training and Fitness Centre .. 3701 Danforth Ave., Scarborough M1N 2G2 ON, Canada

Page
VV59 Prosthetic Hand Enhancements: Cosmetics, Electronics, and New Larger Size 7
Warning Device Allows Swimmers Who Are Deaf-Blind to Swim Independently 340
Hand Grip Assistive Device Allows Quadriplegics to Play Tennis 364
Development of a Swimsuit for Individuals Who Are Incontinent 451
Disabled Swimmers Use Special Seat to Participate Independently in Aquabics Classes 452
Leg Gaiters Provide Floatation for Swimmers with Lower Limb Paralysis 452

Vrije Universiteit
Faculty of Human Movement Sciences, Van der Boechorststraat 9, Amsterdam, 1081 BT The Netherlands

Page
Skeletal Muscle Characteristics during Submaximal Activation 43
Skeletal Muscle Reaction to Growth and Immobilization 43
Quantitative Functional Anatomy of the Upper Extremity 44
Coordination of Muscles in Gait 58
Wheelchair Performance Capacity and Physical Strain in Spinal Cord Injured Subjects 365
Functional Assessment of the Performance Capacity of the Wheelchair-User Combination during Rehabilitation 386

Wayne State University
Office of Research and Development, Faculty Research Award, Detroit, MI 48202

Page
Adjustment of Spinal Cord Injured Who Are Victims of Intentional vs. Unintentional Injuries 378
Psychosocial Adjustment of Spinal Cord Injured Who Are Victims of Gunshot Wounds 387

Whitaker Foundation
4718 Old Gettysburg Rd., Suite 405, Mechanicsburg, PA 17055-4325

Page
Development of a Prosthesis for Elbow Disarticulation Amputees 16

Woodward Foundation
Address not listed.

Page
Return to Productivity, On Your Mark, Project Incubator, Bridge: Four Employment Demonstration Projects 357

No Sponsor Listed

Page
Comparison of Van Nes Rotationplasty and Syme's Amputation 35
Kinematic and Dynamic Analysis of the Shoulder Mechanism 45

Investigational Study of the Effect of Platelet Derived Growth Factors on Non-Healing Pressure Ulcers .140
Corrective Head Orthosis for the Treatment of Occipital Plagiocephaly.....267
Vision Research: A National Plan, 1994-1998 333
Voice Enhanced Oven: Software Emulation 334
Voice Enhanced Oven: Software Emulation 334
3-D Optical Analysis of Chest Wall Motion 366
Smart Wheelchair Modules 411
Inshoe Pressure and EMG Measurement 453

Section III
Author Index

Abadee P 122
Abboud RJ 453
Abel N 377
Abello G 84, 357
Abler JH 430
Abrahamson J 277
Abrams M 357
Abrams R 190
Abu-Faraj ZU 430
Adam A 198
Adams JM 435
Adler J 222
Agarwal G 105
Agre JC 206, 207
Al-Temen I 7, 452
Albert D 47, 198
Albert SF 261
Albright SJ 395
Alden A 318, 319, 320, 322, 323, 324, 325, 326, 327, 328, 329, 332, 333, 335
Alexander NB 101
Aliverti A 366
Alman B 35
Altman RD 229
Amerson TL 399, 412
An KN 44
Angenot E 365
Anson C 364
Anzel SH 27, 29
Aoki T 200, 205
Apple DF 140, 364
Arcot K 61, 134
Atwell S 357
Averbuch M 129
Avignone E 186
Ayyappa E 27, 29

Baan GC 43
Bajd T 86
Bakke MH 279
Banwell JG 369
Barnes E 123
Barr A 241
Barua C 444
Basham T 193
Batavia AI 436
Batra HP 197, 205
Baumann MF 99
Beaupre GS 36, 223, 225, 242, 243
Beck S 306
Behrens M 111
Belbin G 264
Bell M 89
Bell T 271
Bender RS 164
Bennett JK 375
Bennett JL 268
Berg WK 65
Berkenblit SI 259
Berman MS 59, 412
Berry JF 372
Best HL 106
Beulcke G 366
Bexiga P 34
Bialowas S 451
Biden E 16, 56
Biggar D 432
Bignami A 345
Binard JE 399
Bird B 314
Bishop J 7
Black J 254
Blanks RHI 87
Blasch BB 293, 294, 295, 296, 297, 427
Bloebaum RD 107
Bobbert MF 58
Bodine-Fowler S 195
Bodner DR 369
Boda WL 51
Boles M 123
Bombard DL 259
Boninger ML 395
Bontrager EL 29
Boothroyd A 279
Borden PA 145
Borowski SR 25
Bortolussi J 432
Botte MJ 190, 195

Boudet JF 43
Bovolenta P 394
Boyette L 97
Boyko EJ 423
Brabyn J 315, 316, 317, 318, 319, 320, 322, 323, 324, 325, 326, 327, 328, 329, 332, 333, 335, 337, 338, 339
Brandon LJ 97
Brink R 264
Brisson PB 215
Brodie JK 167
Brookshire RH 308
Brouwn G 45
Brown C 191
Brown DA 46
Brown I 241
Brubaker C 404
Bruckner M 347
Bruininks R 439
Brummel-Smith K 112, 119
Bruninga K 68
Buell AB 385
Buijs R 210, 211, 213, 214
Bunnell TH 159
Burgar C 46, 425
Burgess EM 18
Burgh DY 113
Burrows A 46, 48
Bush G 7, 11

Cagir B 219, 220
Cagle TG 367
Cai W 344, 370
Cairns AY 167
Campbell J 252
Campbell ML 112
Campello M 215
Campisi A 85
Candadai RS 139
Canilang EP 139, 217
Cann CE 227
Carlson LE 12
Carnevali P 366
Carr N 279
Carson MC 26
Carter DR 36, 88, 223, 224, 225, 242, 243
Caton H 312
Cavenaugh B 330
Caves K 408
Chakkalakal DA 251, 422
Champion HR 124
Chan DK 334
Chan H 318, 319, 320
Chandler J 103
Chang S 78
Chau T 17
Cheal EJ 248, 256
Cheesman M 283
Cheetham A 144
Chen D 378
Chen S 140
Cherney LR 130
Chignell M 313
Childress DS 1, 2, 3, 4, 6, 8, 10, 21, 22, 25, 31, 33, 55
Chiu CH 2
Chizeck HJ 77, 78, 79, 80
Cienkowski K 273
Cleghorn WL 11, 26, 264
Cochran GVB 41
Cody DD 36
Cogan S 69, 70, 370
Cohen EH 374
Colborne J 364
Colenbrander A 318, 319, 320
Collier JP 236
Collins C 337, 338, 339
Collins JJ 46, 47, 48, 49, 50, 53, 54, 56, 57, 58, 100, 198, 429, 430
Collins SR 73
Condie D 52
Connell BR 91, 92, 93
Coogler CE 96
Cook SD 231, 245
Coombs F 91
Cooper RA 395
Copes WS 124
Cordero DL 51
Corlew M 412
Cornelisse L 283
Costa H 264
Cotell CM 246
Cottier C 444
Couch WP 73
Craddock J 443
Crago PE 74
Crandall W 322, 323, 324, 325, 326, 327, 328, 329, 332, 333, 335
Crane M 215
Cress CJ 148, 149

Crews JE 298
Crown D 128
Cuckler JM 252
Cudahy E 279

Dairaghi CA 184
Dallmeijer A 365
Daniel D 186
Dattilo J 356
Dauzvardis MF 202, 203, 355, 388, 389
Davey KR 67, 405
Davis MP 333
Dawson J 234
de Groot JH 45
De l'Aune WR 63, 295, 296, 302, 303, 306
Deftos LJ 341
DeJong FJ 117, 118
DeJong G 124, 435, 436
DeLuca CJ 46, 47, 48, 49, 50, 53, 54, 100, 188, 189, 190, 197, 198, 199, 200, 204, 205, 208, 210, 211, 212, 213, 214, 429
Demasco PW 152, 153, 154, 158, 161, 162, 164
Dennis F 167
DeRuyter F 445
Devaney E 215
Devaney LP 345
Dewald J 127
Dirks DD 270
Doll T 295
Donlon B 224
Dorrough K 357
Doyle M 444
Doyle P 289
Doyle PJ 288, 309
Doyle W 30
Drace J 222
Drake J 450
Drescher G 358
Ducheyne P 252
Duggan MC 235
Dunaway J 161, 162, 163
Duncan P 103
Dunlop RJ 277
Dunn RB 71, 344
Durfee WK 76

Edell DJ 345
Edman M 10
Edwards LC 343
Ehrlich E 314
Elliot TB 382
Ellison BE 224
Elmer WA 230
Emley M 54, 190, 210, 212, 213, 214
Emmer MB 274, 275
Ensminger G 395
Enwemeka CS 193
Epstein CM 303
Erenshteyn R 151
Erfanian A 80
Erim Z 197, 198, 200, 205, 208
Ershler WB 108
Espinosa IF 394
Esquenazi A 263
Esser S 136
Evans CH 233
Eveland JD 440

Faghri PD 73
Fairgrieve S 42, 52
Fan Y 187, 188
Fangmeier R 314
Farr S 329
Fausti SA 276
Faye EE 314
Fazeli B 190
Fee JW 140, 208
Fehr LS 353
Feldman DS 420
Fels D 313
Ferencz DC 77, 78
Ferrarin M 84, 85, 357
Ferrigno G 366
Fields J 68
Figoni SF 73, 348, 396, 398
Findley TW 51
Firoozbakhsh KK 367
Fischer KJ 36
Fisher MA 353
Flores A 51
Foley C 268
Foley PJ 199, 200, 204, 429
Fontaine C 29
Foote J 375
Ford K 137
Foulds R 140, 141, 142, 151, 155, 156, 160, 281
Fowle T 322, 323, 324, 325, 326, 327, 328, 329, 332, 333, 335, 337, 338, 339
Fowler CG 87, 276
Fraim M 311

Frank EH 259
Fregly BJ 184
French G 148, 149
Friden J 191, 192
Frieden L 181
Friedman RB 448
Frigo C 357
From W 415
Fuhrer MJ 172, 173, 437
Furumasu D 265, 266
Furumasu J 266, 407

Galuska S 151, 155, 281
Galvin R 167, 290
Gamradt J 148, 149
Gannon R 289, 290
Garbarini MA 24, 262
Garvin KL 251, 422
Garvin L 131
Gates R 126
Gayle GW 396, 398
Gelfand SA 274
Georgiou D 177, 178, 268
Gerhart KD 341
Gerken L 170
Gerrey W 322, 323, 324, 325, 326, 327, 328, 329, 333, 335
Geruschat DR 305
Gilbert JL 2
Gilden D 332, 333, 335, 336, 337, 338, 339
Gilmore LD 189, 190, 210, 214, 429, 434
Gilworth K 444
Giori NJ 243
Giphart JE 211, 213, 214
Gitlin LN 113
Given J 127
Glaser RM 73, 201, 348, 396, 398
Glaus KO 201
Goldojarb M 284
Goldsmith HS 219
Goodman R 127
Goodman SB 242
Goossens R 386
Gordon M 185
Graham C 452
Grahn EC 4, 6
Gray JG 164
Gray M 375
Green BG 375
Green D 131, 378
Green P 217
Greener EH 2
Greenfield J 265, 266
Gregor P 167
Gregor RJ 367
Grissett J 427
Grodzinsky AJ 259
Gronley JK 29
Gross K 442
Gross M 102
Gudavalli MR 39
Guerette P 114, 407, 408
Gunter C 357, 375
Gupta M 224
Gupta SC 73, 201, 348, 396, 398
Gupta V 217
Gurd L 340, 451, 452
Guth D 299

Haegerstrom-Portnoy G 318, 319, 320
Hale A-M 385
Hall E 284
Halper AS 130
Hamann G 166, 167, 329, 362
Hamilton B 124
Hammel J 425
Hansen M 310
Hanson WJ 16
Hare T 411
Harkins J 279, 281
Harmon RL 207
Harper E 431
Harris GF 61, 134, 135, 430
Hartke R 128
Harwin W 140, 141
Harwood K 215
Hashemi RM 80
Haskell GB 272
Havey R 39
Hayden MF 439
He P 20
Healy KE 2
Heckathorne CW 4, 6, 8, 10
Heegaard JH 225
Heinemann AW 130, 131
Helt J 262
Hemler PF 222
Henderson K 442
Hennessy CH 98
Henwood P 372

Hermansson L 10
Herndon TO 345
Heslinga JW 43
Hibler J 129
Hiebert R 215
Higgins MJ 267
Hill EL 342
Hinkens J 136, 145
Hirai B 263
Hirsch D 429
Hitzman S 372
Hobson D 404
Hoffer M 7, 265, 266, 407, 408, 442, 443, 444, 445
Hofmann AA 255
Holets VR 342
Hollander AP 365
Holzapfel KM 106
Hons JP 372
Hopp JF 99
Horowitz A 314
Houston VL 24, 262
Howard GA 229, 342
Howell DS 229
Howland CA 170, 171, 178, 268, 437
Hubbard S 11, 35
Hudgins B 12
Hudson JI 235
Huijing PA 43
Hutton WC 230
Hwang MH 343
Hyman WA 446

Jabre JF 100
Jackson RT 63, 303
Jacobs CR 36
Jacobs JL 52, 133
Jacobs JR 292
Jacobson M 190
Jacques G 11
Jain AS 23
Jamieson DG 283
Jampolsky A 315, 316, 317, 318, 319, 320, 337, 338, 339
Janssen TW 365
Jeffreys Y 267
Jhoun J 21
John T 34
Johnson FE 347
Johnson KD 234
Joseph G 127
Joseph R 444
Joyce A 155, 281
Jutai J 126, 432

Kabo MJ 223
Kalnins I 432
Kandarian S 189
Kang T 256
Kaptein B 45
Kedas A 418
Keeley S 331
Keith MW 74
Kelly MJ 186
Kelso DP 137
Kemp B 112
Kennedy JM 254
Kernohan G 241
Kerr G 42
Kerrigan C 53, 54
Keshavarzian A 68
Keyak JH 38, 226, 227
Khan T 202, 203, 350, 351, 355, 388, 389
Kheirallah CI 283
Kilgore KL 74
Kilgus DJ 223
Kim J 428
King R 128
Kingsley DM 88
Kirchner C 321
Kirgo N 444
Kirschner K 127
Kleiber DA 356
Knox EH 22
Knox R 126, 376, 450
Kobayashi M 396
Kobetic R 82
Kochersberger G 103
Koester DJ 101
Koester HH 164
Kofman J 143, 264, 415
Kohn J 441
Koppenhaver DA 147
Korres E 281
Kotler A 289
Kozak K 213
Kraft MR 371
Krag MH 216
Krajbich I 35
Kralj A 86
Krick H 8

Krouskop T 176
Kula J 215
Kulkarni VN 209
Kunkel C 367
Kunov H 17
Kuo A 37
Kupa E 186, 189
Kurta L 367
Kurtz I 7, 17
Kuyk T 295

LaBlanc KP 24, 262
Lane JP 169
Lang BJ 371
Langbein WE 343, 352, 353, 395
LaPierre N 372
LaPlante M 436
Larson BC 345
Larson VD 276
Latour RA 254
Lautenschlager EP 2
Lavalle DJ 372
Lebar AM 135
Leblanc M 7, 441
Lee Brenda 314
Lee B 376
Lee BY 41, 218, 219, 220
Lee IY 226, 227
Lee M 264
Leeper HA 289
Lees D 425
Lehneis HR 24, 262
Lemaire ED 34, 267, 414
LePage P 425
Leslie DP 140, 377
Levenston ME 36
Levine R 108
Levine SP 164, 406
Levins J 213, 214
Levitt H 273, 279
Lewis S 215
Licameli JN 55
Lieber RL 186, 190, 191, 192, 193
Light RW 183, 271
Lightfoot M 411
Lim T 40
Linn JG 106
Linskell J 42, 52
Lipitkas J 451
Lipsitz LA 46, 48
Little JW 370
Lloyd LK 360, 384
Loan JP 185
LoConte LR 186, 188
Logan GD 413
Logemann JA 292
Long RG 293, 294, 298, 299, 426, 427
Longmuir P 35, 340, 364, 451, 452
Longo WE 347
Lorenze EJ 24, 262
Lott SN 448
Louie EK 343
Lovely DF 4, 362, 447
Lowery R 314
Luborsky M 118
Lunsford T 265, 266
Luschei E 108
Lutolf J 274, 275
Lysaker P 89
Lytton R 163

Mace R 95
Magin RL 428
Mahoney AM 15
Mahoney R 140
Maino J 306
Maki K 343, 352
Malassigne P 94, 399, 412
Maloof P 210, 214, 447
Mancil GL 300, 301
Mancil RM 304, 305
Mandell JA 242
Mann JR 345
Mann WC 169
Manuel S 304
Maric B 264
Markowski J 349, 418
Marshall G 451
Marsolais EB 81, 82, 133
Martel G 34
Martin E 341
Martinez AS 270
Mason CP 24, 262
Mathews T 73, 201
Matsumoto K 367
Matthes R 273
McAnear JT 235
McBroom LW 321, 322
McCaffrey M 70, 370
McClure B 340

McCoy KF 152, 153, 154, 282
McGregor M 39
McGuire J 129
McGuire MH 251, 422
McKnitt W 153, 154
McLane JA 350, 351, 370
McMahon R 128
McMahon TT 310
McMillan G 7
McNeal DR 7, 265, 266, 407, 408, 440, 441, 442, 443, 444, 445
McNelis S 210
McPherson S 449
Mehta JM 209
Mehta PP 342
Melton SL 363
Merfeld D 190
Merletti R 186, 187, 188
Mesplay K 21
Messing L 151, 281
Meyerink L 111
Meythaler JM 379
Mifsud M 7
Mikic B 88
Miler J 143
Millar DM 167
Miller GE 446
Miller J 148, 149
Miller PC 81
Milner M 7, 11, 26, 144, 166, 167, 289, 290, 313, 362, 415
Milo T 123
Mineo BA 157, 163, 164
Mineo K 200
Mitchell J 115, 119, 120
Mitchell SL 232
Mlcoch AG 123
Mohamed O 160
Mohtai M 224
Mollan RAB 241
Molteni F 366
Montalvo A 445
Moodie S 283
Moore JE 330
Moran P 134
Morey-Holton ER 88
Morin RJ 47
Morris AR 27
Morris T 60
Morrison K 167
Morrison SA 363
Mortimer JT 72
Mortola PJ 441
Morton P 145
Mote CD 227
Moy F 407
Muniz OE 229
Murka P 20
Mussman M 262
Mutton DL 367
Myklebust BM 109
Myklebust JB 388

Nakai R 114, 408
Nantais T 166, 362, 376
Napel S 222
Naumann S 7, 11, 17, 26, 27, 35, 143, 264, 431, 450
Neeman M 125
Neeman RL 125
Neil S 235
Nelson AL 399
Nelson KA 321
Nemchausky BA 343, 352
Nerry J 61
Neuman A 279
Newell AF 167
Ng SK 79
Nielsen DH 432
Nielsen-Brown N 120
Nieto-Sampedro M 394
Nitschke T 412
Noffsinger PD 270, 276
Norcia A 315, 316, 317
Nordin M 215
Nosek MA 170, 171, 172, 173, 174, 175, 176, 177, 178, 181, 268, 361, 437
Novak M 137, 145, 150, 280

O'Beirne H 143
O'Donnell PD 104
Oddsson L 210, 211, 214
Oliver P 310
Orr TE 232, 247, 250
Ostrander LE 219, 220
Ottenbacher KJ 169
Otter M 41

Paialunga J 414
Pajak TF 292
Palreddy S 217

Parker K 264
Parker PA 12, 434, 447
Parker WD 348, 398
Parthemore JG 341
Patwardhan AG 39, 40
Pavlik A 47, 53, 54
Peachey NS 307
Peckham PH 74
Pedotti A 83, 84, 85, 240, 357, 366
Peischl D 154, 157, 162, 163
Pennington C 153, 154, 157, 161, 282
Penrod L 438
Perell KL 367
Perkash I 222, 425
Perry J 27, 29
Peters SM 159
Pettersson SO 10
Philipson L 10
Phillips CA 196
Piech R 140
Pierce PL 147
Pilkey WD 402, 403
Pizzimenti CE 64
Polikoff JB 159
Ponichtera-Mulcare JA 73, 201
Pons C 386
Potter CG 172
Powers CM 27
Prescott TE 286, 287
Priebe M 349
Pumpian IR 179, 180
Pyne L 314

Raasch CC 184
Rabuffetti M 84
Radcliffe DF 413
Radin S 252
Radnitz CL 374
Radwin RG 146
Rahman T 140, 141
Ramon-Cueto A 394
Rang M 264, 431
Rao PR 448
Rao S 29
Rapp B 159
Ratcliffe A 229
Redding MJ 8
Reddy NP 139, 217
Redfern M 105
Repperger DW 196
Rice M 415
Richards JS 380
Richards L 170
Richmond SA 56, 57
Riedy L 68, 69, 70, 344
Rigby P 415
Rintala D 268
Roatta S 187
Robbins J 108
Robertson RN 395
Robinson C 370
Robinson CJ 105, 438
Rodgers MM 73, 201, 348, 396, 398
Rodrigues A 190
Rodriquez AA 206, 207
Rodriquez GP 418
Roecker E 108
Rogers E 440
Roos BA 229
Rosen JM 419, 420
Rosenbek JC 220
Rosenbloom A 314
Rosenstein MT 429, 430
Ross CK 311
Ross DA 67, 300, 301, 405
Ross M 279
Rossi D 361
Rossi SA 30, 38
Roszek BR 43
Roth E 130
Rothi LG 288
Rouleau S 265
Rovick JS 1, 31
Rowley DI 52, 453
Roy SH 54, 186, 189, 190, 210, 211, 212, 213, 214
Rozendaal LA 45
Rozendal RH 43, 44, 58, 365, 386, 400
Ruff RL 52
Rumney P 126
Runge C 37
Rust KL 136
Ryals BM 278
Ryan S 264, 415

Sabelman EE 88, 418, 420
Saldana D 445
Saltzstein R 399
Sam M 352
Samila I 364
Samworth K 160, 208

Sanchez V 21
Sandler M 142, 156
Sandri G 186
Sanford JA 93, 94, 95
Sangeorzan BJ 238
Santambrogio GC 240
Santoro D 219
Santos RA 208
Sartori MJ 145
Sassoon CSH 183
Sataar SA 372
Saunders G 273
Saunders M 235
Savrin R 86
Sax CL 179, 180
Sayers ST 202, 203, 355, 388, 389
Schaab JA 146
Schauer J 137, 145, 150
Scheer J 118
Scheiner A 52, 77
Scheinholtz D 318, 319, 320
Schenckman M 103
Scherer MJ 138
Schlesinger LC 231, 245
Schmidt MF 131
Schmit, BD 72
Schneck M 318, 319, 320
Schneider T 283
Schultz AB 101
Schurman DJ 224, 242
Schutte HD 254
Schwartz HS 234
Sciadini M 234
Scott M 367
Scott RN 12
Scremin AME 367
Scremin OU 367
Seewald RC 283
Segal RL 90
Seidman K 314
Seliktar R 140, 263
Selinger M 286, 287
Setoguchi Y 7
Sha BB 210
Shafer D 425
Shanfield K 442
Shaperman J 7
Sharon B 97
Shaw CG 401, 402, 403
Sheil E 35, 264, 431, 450
Shein F 143, 166, 167, 329, 362
Sherwood AM 349
Shimada S 395
Shoemaker S 191
Sibilla P 240
Sibley P 368
Siegel GJ 355
Silman S 274, 275
Silva P 186
Silverman C 450
Silverman CA 274, 275
Silverstone B 314
Simmons C 247
Simon H 337, 338, 339
Simpson C 357
Sinclair S 283
Sisto S 51
Skelly M 79
Skinner HB 30, 38, 226, 227
Skovron ML 215
Slack M 264
Smith A 162
Smith C 235
Smith D 264
Smith DG 423
Smith RA 377
Smith RL 224
Smith RO 136, 137
Smits MP 13, 14, 15, 16
Snijders CJ 386
Snyder T 136, 137, 148, 149
Soede M 386
Soemarwoto G 160
Somerville H 451
Somerville N 442, 443
Spector M 232, 246, 247, 248, 256
Sprigle S 401
Springthorpe SV 372
Stanger C 140
Stearns D 443
Steege JW 31, 33
Steele C 432
Stefanov D 409, 410
Stelling J 381
Stelmack J 306, 310, 311, 314
Stelmack T 311, 314
Stern G 151
Stevens E 432
Stewart CPU 23
Stewart GW 372

Stewart IN 58
Stewart KJ 395
Stockelbach E 290
Stover SL 360, 385, 421
Straneva-Kalpakoff S 119
Strasser DC 98
Strates BS 228
Stroeve S 45
Stroud S 140
Strysik JS 4, 6
Studenski S 103
Stuen C 314
Stum G 152
Sukthankar S 217
Sumanaweera T 222
Sumi E 408
Suri LZ 282
Suryanarayanan S 217
Suryaprasad AG 73, 348
Sutton J 435
Szeto AYJ 179, 180
Szivek JA 257
Szlyk JP 64
Szollar S 341

Talaty M 263
Tapp WN 51
Tate GT 374
Taylor H 213
Teachout S 425
Teare PR 16
Tefft D 407
Temkin A 357, 375
Templer J 92
Tencer AF 238
Tennessen EM 3
Tepper S 124, 435, 436
Thacker JG 401, 402, 403
Thomas IH 59, 412
Thomas-Stonell N 289, 290
Thompson D 415
Till JA 285
Topp E 425
Torburn L 27
Torres-Gil FM 116
Trausch T 202
Treviranus J 167, 450
Triano J 39
Trilling SL 247, 248, 256
Trimble J 60
Truong T 334
Turk R 86
Turner M 370
Uditsky T 442
Uellendahl JE 8
Upton D 414

Valente T 440
Van As H 365
Van der Helm FCT 44, 45
Van der Loos M 425
Van der Meulen MCH 88
Van der Woude LH 44, 365, 386, 400
Van Ingen Schenau GJ 58
Van Lancker D 284
Vanderheiden GC 136, 137, 145, 146, 148, 149, 150, 280
Vanderheyden P 154
VanSickle DP 395
Veeger HE 44, 58, 386, 400
Vengsarkar AS 430
Venkateswaran V 193
Ventureyra EC 267
Venus C 235
Verburg G 143, 144, 334, 411, 449
Vernava AM 347
Vesmarovich SH 140
Viana M 310
Villars P 232, 248, 250
Virgo KS 347

Wacker DP 65
Waites KB 359, 383
Walczak E 415
Walden E 171, 181
Waller A 167
Walsh JM 71
Walter JS 68, 69, 70, 71, 344, 368, 370
Wambaugh JL 288
Watson GR 306
Waxman SG 390, 391, 392, 393
Weaver P 340
Webster JS 122
Wedge J 264, 450
Weir RF 4, 6
Weiser S 215
Weiss M 279
Wertsch JJ 61, 134, 135, 430
Wesley RL 378, 387
Wheeler JS 344, 368

Whipp BJ 367
Whitaker F 357
Whitney JL 292
Wiegner A 76
Wilkerson DL 124, 435
Willems ME 43
Williams J 322, 323, 324, 325, 326, 327, 328, 329, 335
Williams TW 15
Willis L 111, 120, 121
Wilson D 442, 443
Wilson MG 248
Wilson RH 271
Winderl M 318, 319, 320, 322, 323, 324, 325, 326, 327, 328, 329, 332, 333, 335
Winograd CH 88, 102
Winter LW 428
Wisaksana A 220
Wit V 126
Wolf SL 90, 96
Woo S 438
Wood JL 108
Wray LA 116, 117, 118
Wright V 450
Wurster RD 344
Wyckoff E 265

Xue K 20

Yannas IV 346
Yarrington D 160
Yip K 415
Young L 190
Young ME 268
Young P 290

Zajac FE 184, 185
Zaszczurynski P 69, 70, 344, 368, 370
Zdeblick TA 239
Zhang G 159
Zhu H 61, 134, 135
Zindrick M 40
Zizz CA 87

*U.S. G.P.O.:1994-301-908:80009

JRRD On-Line

Selected portions of the *Journal of Rehabilitation Research and Development (JRRD)* are being put on-line via CompuServe. Abstracts of scientific articles, Calendar of Events, Publications of Interest, and Progress Reports are available to readers through **JRRD On-Line**. They are also available on our BBS: (410)962-2525 or through TELNET/FTP: 199.125.193.50.

USING THE EXISTING VA REHABILITATION DATABASE ON COMPUSERVE

I. **What you need: Access to equipment and software.**
- Personal computer
- Modem with communication software
- Subscription to CompuServe (connect time costs on the standard pricing plan: 2400 baud = $4.80/hour, 14400 baud = $9.60/hour).

II. **What to do:**
- Type "GO REHAB" (or "GO HUD" and select the "Research and Development" menu option).

III. **You can get help if needed:**
- VA Rehabilitation Database — write or call
  Scientific and Technical Publications Section
  VA Rehabilitation R&D Service (117A)
  103 South Gay Street
  Baltimore, MD 21202-4051
  Phone: 410-962-1800

IV. **Eligibility:**
- The VA Rehabilitation Database is available for use by all persons interested in rehabilitation research and development.

To place an order for a *JRRD* or *Progress Reports* issue, and/or to be added to the mailing list, you may also use Internet Mail: pubs@balt-rehab.med.va.gov.

RECEIVED
DEC 9 1994
CSERIAC

Department of Veterans Affairs
Veterans Health Administration
Washington, D.C. 20420

Rehabilitation R&D Progress Reports 1992-1993
Vol 30-31, December 1994