

AWARD NUMBER: W81XWH-22-1-0836

TITLE: Trunk Stability and Seated Reaching After Spinal Cord Injury

PRINCIPAL INVESTIGATOR: Dr. Musa Audu, PhD

CONTRACTING ORGANIZATION: Case Western Reserve University, 10900 Euclid Avenue, Cleveland, Ohio, 44106.

REPORT DATE: October 2023

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Development Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release; Distribution Unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

REPORT DOCUMENTATION PAGEForm Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE: October 2023		2. REPORT TYPE: Annual		3. DATES COVERED: 1SEPT2022 - 31AUG2023	
4. TITLE AND SUBTITLE: Trunk Stability and Seated Reaching After Spinal Cord Injury				5a. CONTRACT NUMBER: W81XWH-22-1-0836	
				5b. GRANT NUMBER: SC210292	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S): Dr. Musa Audu, PhD, E-Mail: mxa93@case.edu				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES): Case Western Reserve University, 10900 Euclid Avenue, Cleveland, Ohio, 44106.				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Development Command Fort Detrick, Maryland 21702-5012				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT: The overall goal of this expansion project is to leverage the achievements made with prior SCIRP support to transfer our trunk control and transfer systems to the Network Neuroprosthesis (NNP) platform, verify the control systems in a series of laboratory experiments, and prepare the trunk control package for future clinical dissemination and commercialization. Specific aims: (1) Estimate global orientation metrics for trunk and pelvis pose by fusing signals from a variety of implanted IMU sensors of the NNP and assess their suitability as feedback signals for controlling seated posture; (2) Implement advanced feedback control systems that assure robust seated stability, balance, and reach, and facilitate efficient wheelchair propulsion, transfers and other activities of daily living in NNP recipients.					
15. SUBJECT TERMS NONE LISTED					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
U	U	U	UU	26	USAMRDC

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

V1-20210107

TABLE OF CONTENTS

	<u>Page</u>
1. Introduction	4
2. Keywords	4
3. Accomplishments	3 - 15
4. Impact	16
5. Changes/Problems	16
6. Products	17
7. Participants & Other Collaborating Organizations	18
8. Special Reporting Requirements	19
9. Appendices	20 - 26

1. INTRODUCTION: *Narrative that briefly (one paragraph) describes the subject, purpose and scope of the research.*

The overall goal of this expansion project is to leverage the achievements made with prior SCIRP support to transfer our seated balance and assisted transfer control systems to the Network Neuroprosthesis (NNP) platform, verify the control systems in a series of laboratory experiments, and prepare the trunk control package for future clinical dissemination and commercialization. The new control systems will be available to a wider population of individuals paralyzed by SCI by seeking regulatory IDE approval from the FDA that will extend the NNP to individuals with paraplegia due to SCI all in preparation for ensuing clinical trials.

2. KEYWORDS:

Trunk control, Seated balance, Functional Neuromuscular Stimulation (FNS), Spinal cord injury, Feedback control, Musculoskeletal modeling, Network Neuroprosthesis (NNP).

3. ACCOMPLISHMENTS:

What were the major goals of the project?

1. Recruit, assess and train three individuals implanted with NNP system and develop subject-specific musculoskeletal models for each (Months 1 -6).
2. Quantify characteristics of volunteers with NNP implants and develop subject-specific musculoskeletal models (Months 6-9).
3. Test sensor fusion algorithm with NNP implant recipients (Months 6-18).
4. Commence submission process to FDA for IDE approval to extend NNP technology deployment to individuals with paraplegia (thoracic level SCI) (Months 1-36).
5. Deploy Self-Righting Controllers for Seated Stability and Reaching (Months 1-24).
6. Deploy Disturbance Rejection and Posture Changing Controllers for Wheelchair Propulsion and Activities of Daily Living (Months 22-30).
7. Develop feedback Controllers to enhance Assisted Transfers (Months 1-36).

What was accomplished under these goals?

This year our major accomplishments are in satisfying Major Tasks 1.1, 1.2, 1.3 and 1.4 as detailed in the Table below:

	Timeline Months	Progress	Percent Complete
<u>SPECIFIC AIM 1:</u> Estimate global orientation metrics for trunk and pelvis pose by fusing signals from a variety of implanted IMU sensors of the NNP and assess their suitability as feedback signals for controlling seated posture, improving balance and extending reach in persons with complete or partial paralysis (3 No. NNP Subjects).	1-18		
Major Task 1.1: Recruit, assess and train three individuals implanted with NNP system and develop subject-specific musculoskeletal models for each.			100
Subtask 1.1.1: Obtain local IRB approval to undertake the study with human volunteers.	1-3	Local IRB approval was obtained on 12/08/2022 after certain HRPO determinations had been accommodated. The current IRB letter of approval (good through 12/07/2023) is attached to this report as Annex II .	100
Subtask 1.1.2: Obtain Human Subject study (HRPO) approval to undertake the study with human volunteers.	4-6	HRPO approval obtained after IRB approval via email dated 06/05/2023, from Jill Graygo, jill.m.graygo.civ@health.mil . In addition, the Food and Drug Administration (FDA) has reviewed the submission of a supplement to our Investigational Device Exemption (IDE) application regarding the feasibility study for a significant risk device in which we proposed a temporary software modification to the Network Neuroprosthesis System (NNP) to allow control algorithm testing in the laboratory setting, and addition of a sub-study to explore the possibility of creating a new feature of the NNP that provides	100

	Timeline Months	Progress	Percent Complete																												
		automatic trunk stabilization based on accelerometer readings. The FDA determined that we have provided sufficient data to support continuation of our human clinical study and therefore approved the supplement application as per the attached Letter labelled Annex III .																													
Subtask 1.1.3: Recruit SCI NNP-implanted volunteers and measure and document anthropometric characteristics of each volunteer.	3-6	<p>Three NNP recipients have been recruited from the pool of available subjects that would be suitable for our control studies. The recipients are listed in Table 1 below along with their basic anthropometric characteristics.</p> <p>Table 1: Three NNP recipients and their anthropometric characteristics</p> <table border="1"> <thead> <tr> <th>Recipient ID/ Characteristics</th> <th>Injury</th> <th>Date of Injury</th> <th>Height</th> <th>Weight</th> <th>Age</th> <th># of trunk sensors</th> </tr> </thead> <tbody> <tr> <td>NNP4/p68</td> <td>C5-6 AIS A</td> <td>05/31/1089</td> <td>5'6"</td> <td>89</td> <td>58</td> <td>4</td> </tr> <tr> <td>NNP5/ p366/c102</td> <td>C4-5 AIS A</td> <td>03/23/2016</td> <td>6'0"</td> <td>195</td> <td>29</td> <td>4</td> </tr> <tr> <td>NNP6/g102</td> <td>C5 AIS A</td> <td>10/11/2014</td> <td>5'10"</td> <td>170</td> <td>53</td> <td>1</td> </tr> </tbody> </table>	Recipient ID/ Characteristics	Injury	Date of Injury	Height	Weight	Age	# of trunk sensors	NNP4/p68	C5-6 AIS A	05/31/1089	5'6"	89	58	4	NNP5/ p366/c102	C4-5 AIS A	03/23/2016	6'0"	195	29	4	NNP6/g102	C5 AIS A	10/11/2014	5'10"	170	53	1	100
Recipient ID/ Characteristics	Injury	Date of Injury	Height	Weight	Age	# of trunk sensors																									
NNP4/p68	C5-6 AIS A	05/31/1089	5'6"	89	58	4																									
NNP5/ p366/c102	C4-5 AIS A	03/23/2016	6'0"	195	29	4																									
NNP6/g102	C5 AIS A	10/11/2014	5'10"	170	53	1																									
Major Task 1.2: Quantify characteristics of volunteers with NNP implants and develop subject-specific musculoskeletal models.			50																												
Subtask 1.2.1: Quantify baseline contractile properties of the paralyzed trunk and hip muscles in response to stimulation for each volunteer.	6-9	We are waiting to fully characterize the implanted sensors before commencing the exploration of the nature of muscle response from each participant.	0																												

	Timeline Months	Progress	Percent Complete
<p>Subtask 1.2.2: Develop subject-specific musculoskeletal models of the trunk and hips.</p>	<p>1-6</p>	<p>We developed a suitable generic musculoskeletal model of the trunk to enable us to explore the various characteristics of the implanted NNP accelerometer sensors. A very important characteristic of all implanted sensors is their random orientations within the body of the recipient. In our previous single external sensor studies, the sensor was taped on the skin with its axes aligned as closely as possible to the trunk pitch (medial-lateral, ML), roll (anterior-posterior, AP) and twist (inferior-superior, IS) axes. Any other placement away from these axes will result in poor sensitivity of the sensor to trunk tilt. NNP sensors are typically randomly aligned in the body often because of surgical constraints and anatomic convenience. We explored the potential impact of sensor orientation on tilt estimation using our musculoskeletal model of the trunk.</p> <p>Accelerometer sensors were randomly placed at different locations on the trunk (typically where NNP sensors would be implanted; or in line with our previous external sensor placement). In particular, we placed 5 sensors at C7 and sternum and at the left and right anterior flanks and the right exterior flank as depicted in Figure 1. Each sensor was randomly oriented with its axes rotated away from the anatomic (AP, ML, IS) axes at well-defined angles of rotation.</p> <p>We then conducted a simulation with the model to move the trunk dynamically by bending backward, forward, to the left and to the right. Each movement starts from the erect posture and returns to the erect posture</p> <div data-bbox="709 267 1291 738"> <p>Figure 1: Randomly oriented accelerometer sensors in the trunk of the musculoskeletal model.</p> </div> <div data-bbox="1375 747 1858 1315"> <p>Figure 2: Estimates of dynamic movement of the trunk (pitch angles left panes and bend or roll angles right panes) from 5 accelerometer sensors in the trunk.</p> </div>	<p>70</p>

	Timeline Months	Progress	Percent Complete
		<p>before the next. The actual trunk pitch and roll angles traversed by the trunk are well defined. The estimated angles measured by each accelerometer are captured and compared to the actual angles.</p> <p>The results are plotted in Figure 2. The poor correlation between the actual and estimated angles clearly indicates that most of the accelerometers did not provide a robust and clear measure of trunk tilt at their random, non-aligned orientations. An important question we posed is: Is it possible to re-orient the signals from the sensors so that they provide more robust outputs? The answer relies on using a mathematical strategy used in the aerospace industry – determine the orientations of each sensor within the body and use matrix transformation to make the signals from each sensor as if it was aligned with the anatomic axes. This requires the development of a direction cosine matrix N:</p> $N = \begin{bmatrix} n_{11} & n_{12} & n_{13} \\ n_{21} & n_{22} & n_{23} \\ n_{31} & n_{32} & n_{33} \end{bmatrix}.$ <p>The data for developing the matrix N requires developing two orthogonal matrices K and \tilde{K}. For developing \tilde{K}, we collect a couple seconds of data with the model (or person) first statically sitting erect and then another few seconds of data while lying supine as depicted in Figure 3. The means of the x, y and z accelerations of each sensor during these two trials are used to define two vectors \tilde{r}_1 and \tilde{r}_2. The third vector, \tilde{r}_3, is computed using Gram-Schmidt orthogonalization. The three vectors are used to define the direction cosine matrix $\tilde{K} = [\tilde{r}_1 \ \tilde{r}_2 \ \tilde{r}_3]$. It is also noted that if anatomic trunk X, Y and Z axes are oriented with X pointing in the AP direction, Y in the lateral direction and Z pointing downward, then when the person is sitting erect, the normalized</p>	

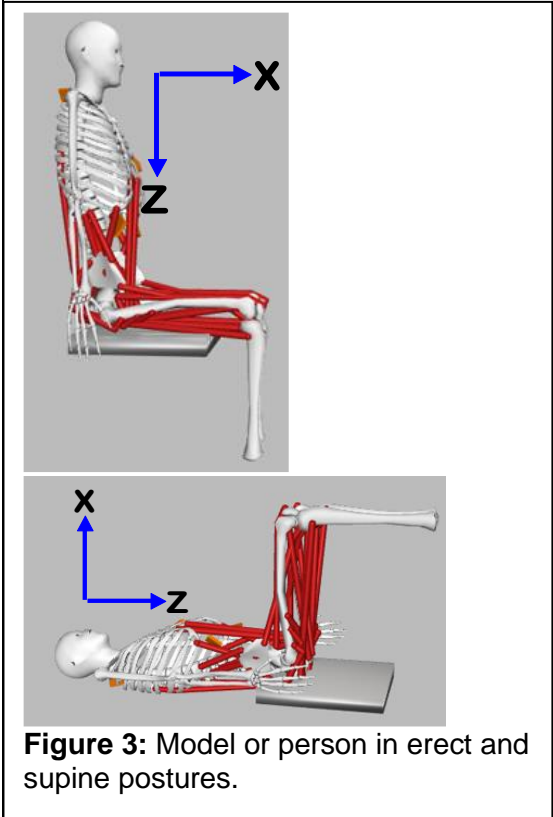


Figure 3: Model or person in erect and supine postures.

	Timeline Months	Progress	Percent Complete
		<p>gravity vector has the value $r_1 = [0 \ 0 \ 1]^T$ and while lying supine, it has the value $r_2 = [-1 \ 0 \ 0]^T$. Using the Gram-Schmidt orthogonalization process we compute the third vector r_3. These three vectors are used to construct the matrix $K = [r_1 \ r_2 \ r_3]$.</p> <p>The matrix N is defined as $N = \tilde{K}K^{-1}$. By comparing elements of matrix N and those of the Euler angle direction cosine matrix $R(\phi, \theta, \psi) = R_y(\theta)R_z(\psi)R_x(\phi)$, it is possible to extract the exact, albeit unknown orientation of the sensor. Multiplying any signal from the sensor with the direction cosine matrix N will produce the most robust output from the sensor as depicted in Figure 4.</p> <p>Clearly from this figure, the sensor outputs have a much higher correlation compared to the desired or commanded joint angles of the trunk.</p> <p>Since model outputs are normally ideal outputs, we also set out to explore the effects of noise and drift on the sensor re-orientation algorithm we developed above. To do that, we injected 10% white noise into the x, y and z signals output by the sensors as well as adding a sinusoidal drift to model the effects of subject movements during calibration static trials. Figure 5 depicts the actual signal from the model while Figure 6 depicts the noisy output from each sensor during the erect static seated posture. A similar noisy plot applies to the output during the supine posture. The results comparing</p>	

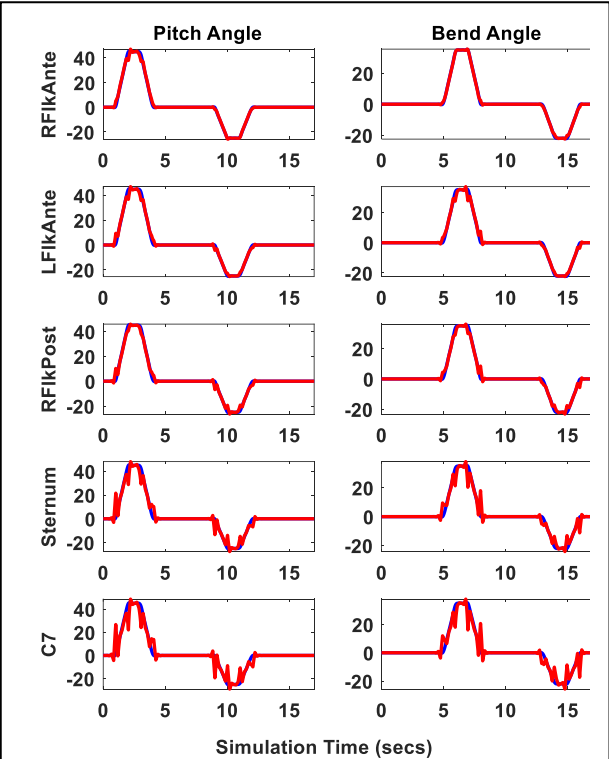


Figure 4: Sensor signal outputs after applying re-orientation matrix. The difference between actual angles (blue) and estimated angles (red) are hardly perceptible.

**Timeline
Months**

Progress

**Percent
Complete**

the actual orientation angle of each sensor as compared to the estimated value from the algorithm are shown in **Table 2**. From this table, it is clear that the algorithm performs very well even in the presence of noise and drift with the maximum error not exceeding 12%.

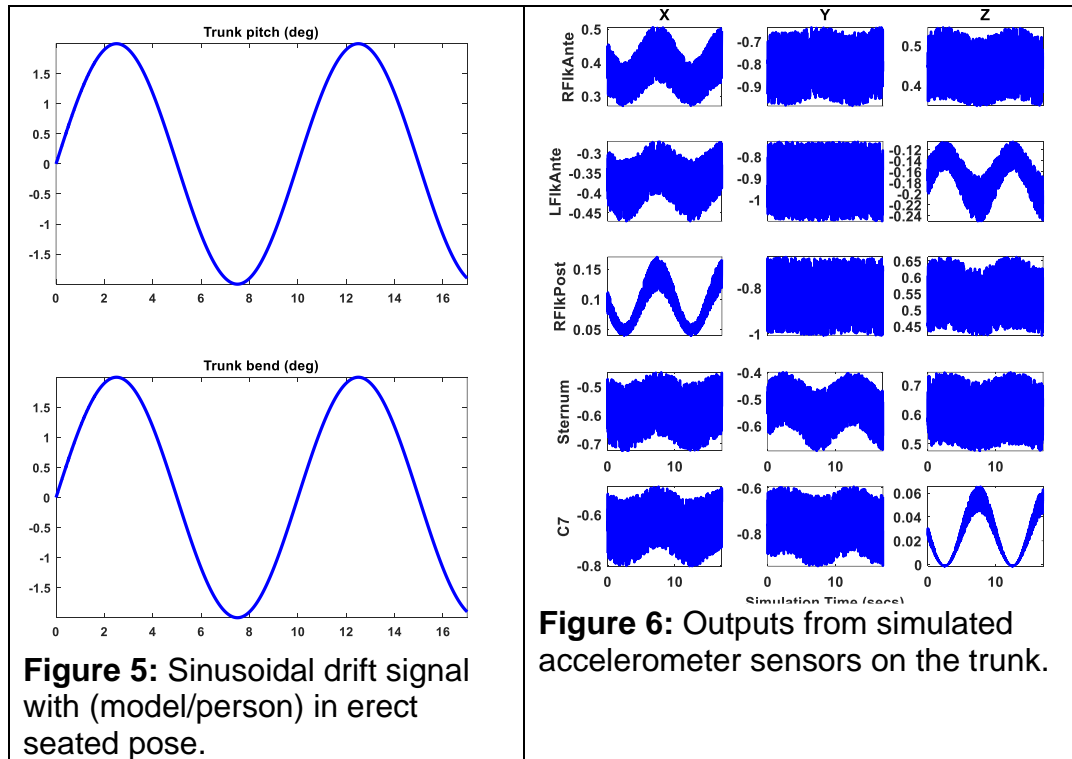


Table 2: Comparing actual and estimated sensor orientations in the presence of noise and drift.

Sensor	X			Y			Z		
	Actual	Estimated	Percent Error	Actual	Estimated	Percent Error	Actual	Estimated	Percent Error
1	30.00	29.93	-0.23	27.00	27.26	0.95	-40.00	-39.60	-0.99
2	-10.00	-9.75	-2.54	-10.00	-10.01	0.06	20.00	20.20	0.98
3	35.00	35.07	0.21	20.00	20.16	0.81	-20.00	-19.76	-1.18
4	40.00	40.23	0.58	19.00	19.20	1.06	32.00	32.27	0.85
5	10.00	8.89	-11.07	81.00	81.13	0.16	30.00	31.40	4.68

	Timeline Months	Progress	Percent Complete
<p>Subtask 1.2.3: Design sensor fusion algorithm in 3D musculoskeletal model of the trunk and hips.</p>	<p>1-9</p>	<p>Simple sensor fusion algorithms (such as simple averaging, weighted averages and averaging based on Townsend algorithm) have been defined and will be tuned appropriately for each NNP recipient. A typical plot of the output from a sensor fusion algorithm combining information from 5 sensors to create a single measure of trunk tilt (pitch and bend) is depicted in Figure 7.</p> <div data-bbox="722 391 1856 1268" style="border: 1px solid black; padding: 10px;"> <p style="text-align: center;">(a)</p> <p style="text-align: center;">(b)</p> <p>Figure 7: <i>In-silico</i> (model) sensor estimates. (a) Individual estimated trunk angles from 5 sensors randomly attached to various parts of the trunk and (b) results of a 'simple average' fusion algorithm combining results from all sensors to a single measure of trunk tilt to and away from the erect posture.</p> </div>	<p>100</p>
<p>Major Task 1.3: Test sensor fusion algorithm with NNP implant recipients.</p>			<p>80</p>

Subtask 1.3.1: Characterize and document the signal features of the NNP implanted IMU sensors.

6-12

We have collected sensor data from all 3 candidates that we have recruited. Each participant was sat on a mat placed in the middle of the work volume of a 16-camera motion capture system. Reflective markers were placed on anatomical landmarks on the pelvis (anterior and posterior iliac spine, sacrum) and arms (shoulder, upper arm, elbow, forearm, wrist, hand). These markers were used to estimate



Figure 8: NNP5 undergoing dynamic motions to capture information from his implanted sensors.

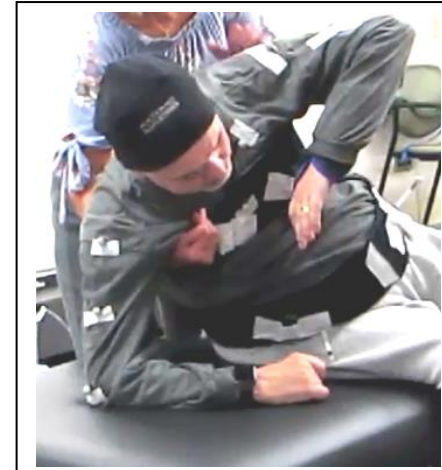
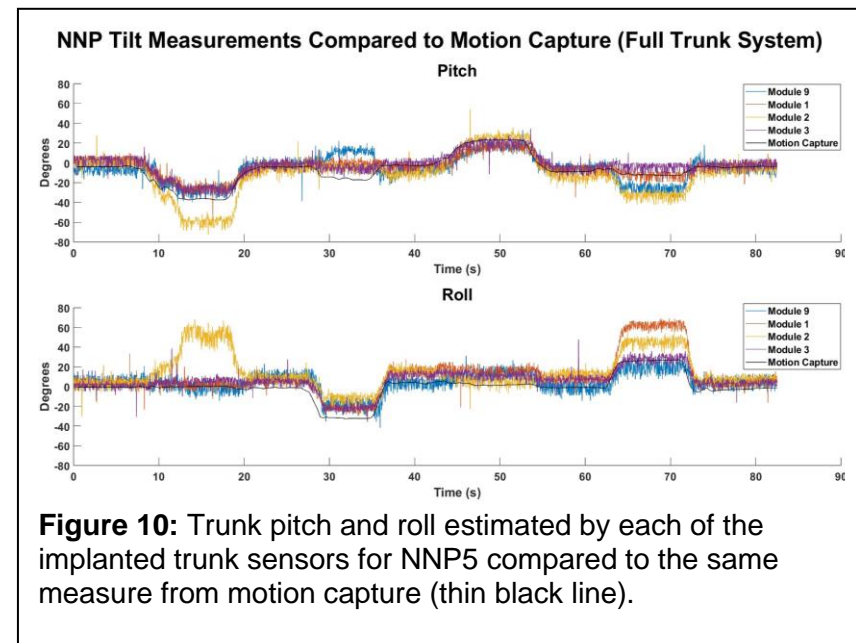


Figure 9: NNP5 undergoing dynamic motions to capture information from his implanted sensors.

the joint angles of the trunk exhibited during the seated motions at a sampling rate of 100 Hz.

For each participant, we conducted two static trials – one with the participant sitting erect and the other lying supine. These two are used by the algorithm we developed to determine the angles at which the implanted sensors

of the work volume of a 16-camera motion capture system. Reflective markers were placed on anatomical landmarks on the pelvis (anterior and posterior iliac spine, sacrum) and arms (shoulder, upper arm, elbow, forearm, wrist, hand). These markers were used to estimate



	Timeline Months	Progress	Percent Complete
		<p>are oriented within the body. This information is critical in ensuring a robust output of trunk tilt from each of the sensors.</p> <p>Thereafter, we captured dynamic motions including leaning forward, leaning backward, leaning to the right and leaning to the left. All motions were guided by a physical therapist since the participants are unable to undertake them themselves. In addition to the data captured from the external markers placed on the body, we also captured the x, y and z accelerations from each of the implanted NNP sensors. These signals were captured at a frequency of 40Hz and radioed to the control computer.</p> <p>So far, we have processed the data for NNP5 (Figure 8) and NNP6 (Figure 9) and in the process of doing same for the third participant. For each sensor, we determined its estimate of trunk pitch and trunk roll during the dynamic motions and compared these estimates with the same information obtained from the motion capture system which acts as the gold standard. Figure 10 shows a plot of the estimated pitch and roll angles from the sensors in the trunk of NNP5 compared to the same measure from motion capture. Compared to motion capture, most sensors produce reasonable estimates of trunk tilt with the most deviation estimated by sensor in Module 2. This module is located at the lower abdomen and may be close to the lumbar joint, making it less sensitive to trunk motion. Figure 11 shows the equivalent plots for the one sensor in the trunk of NNP6. Here also, we observe that the one sensor produces a reasonable estimate of trunk pitch and roll. These results may be further improved if we included sensors in the arms of the subject. However, this could only be useful for some selected control paradigms where the arm is not involved in the desired movements.</p> <div data-bbox="726 805 1360 1477" data-label="Figure"> </div> <p>Figure 11: Trunk pitch and roll estimated by the one implanted trunk sensor for NNP6 compared to the same measure from motion capture (thin black line).</p>	

	Timeline Months	Progress	Percent Complete
Subtask 1.3.2: Refine and tune SFA to work with input signals from embedded NNP module IMUs.	9-18	We have developed excellent sensor fusion algorithms and tested them successfully using data from our musculoskeletal model (Figure 7(b)). We are confident that these algorithms will work well with data from NNP recipients as well. We will test these as soon as we have processed the data captured from all participants in our study.	80
Major Task 1.4: Commence submission process to FDA for IDE approval to extend NNP technology deployment to individuals with <i>paraplegia</i> (thoracic level SCI)			
Subtask 1.4.1: Assemble necessary FDA documentation required to apply for IDE approval.	1-3	The FDA expert on the NNP Development team graciously helped us assemble all the FDA documents and approvals regarding the application of the NNP for arm function in individuals with quadriplegia (cervical level SCI).	100
Subtask 1.4.2: Understudy setup of all documents that led to current IDE approval for NNP implantation in individuals with <i>quadriplegia</i> (cervical level SCI).	3-6	We studied the documents carefully and passed all relevant ones to the Case Western Reserve University Clinical and Translational Science Collaborative (CTSC) who have expertise in FDA submissions.	100
Subtask 1.4.3: Adapt documents to fit application for IDE approval to extend NNP technology deployment to individuals with paraplegia.	3-6	The CTSC provided a quote to provide an idea of what it would cost for them to take over the submission process. The quote is attached here as Annex IV . With support from the Cleveland APT Center, the CTSC has been contracted to take charge of the FDA submission process.	50
Subtask 1.4.4: Submit all necessary documents to FDA and commence any follow-up processes.	6-36	The CTSC is in the process of preparing the documents for FDA consideration.	0
Milestone 1.1: <i>SCI volunteers recruited, and subject-specific models</i>	6-18	Plans are underway to draft a manuscript and/or conference abstract to report our progress on sensor characterization as soon as data for all participants are processed.	

	Timeline Months	Progress	Percent Complete
<p><i>completed.</i></p> <p>Milestone 1.2: <i>Sensor Fusion Algorithm developed in-silico.</i></p> <p>Milestone 1.3: <i>Sensor Fusion Algorithm tested in able-bodied volunteers.</i></p> <p>Milestone 1.4: <i>Sensor Fusion Algorithm fine-tuned in NNP-implanted SCI volunteers.</i></p> <p>Milestone 1.5: <i>Paper(s) summarizing Sensor Fusion Algorithm design and development.</i></p>			

What opportunities for training and professional development has the project provided?

Nothing to report.

How were the results disseminated to communities of interest?

Nothing to report.

What do you plan to do during the next reporting period to accomplish the goals?

Plans for the next reporting period include:

1. Continue processing all subject data collected so far and use same to finalize sensor fusion algorithm for each participant.
2. Recruit at least two additional participants to expand the subject pool for the study.
3. Commence work on characterizing the implanted muscles for all participants.
4. Commence work on simple controller studies – such as self-righting control.
5. Commence work on developing transfer controllers *in-silico* (using our musculoskeletal models).

4. IMPACT:

What was the impact on the development of the principal discipline(s) of the project?

Nothing to report.

What was the impact on other disciplines?

Nothing to report.

What was the impact on technology transfer?

Nothing to report.

What was the impact on society beyond science and technology?

Nothing to report.

5. CHANGES/PROBLEMS:

Changes in approach and reasons for change

Nothing to report.

Actual or anticipated problems or delays and actions or plans to resolve them.

Currently a number of NNP recipients have some problems with their implanted systems and are due for revision of their systems. Recruitment will resume as soon as many of them have revised working systems that will satisfy the inclusion criteria (having at least one trunk sensor module).

Changes that had a significant impact on expenditures.

Nothing to report.

Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents.

Significant changes in use or care of human subjects.

Nothing to report.

Significant changes in use or care of vertebrate animals.

Nothing to report.

Significant changes in use of biohazards and/or select agents.

Nothing to report.

6. PRODUCTS:

- **Publications, conference papers, and presentations**

Journal publications

Nothing to report.

Books or other non-periodical, one-time publications.

Nothing to report.

Other publications, conference papers and presentations.

Nothing to report.

- **Website(s) or other Internet site(s)**

Nothing to report.

- **Technologies or techniques**

Nothing to report.

- **Inventions, patent applications, and/or licenses**

Nothing to report.

- **Other Products**

Nothing to report.

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Name:	Musa L. Audu
Project Role:	Principal Investigator
Researcher Identifier (ORCID):	0000-0001-5737-1708
Nearest person month worked:	3.6
Contribution to Project:	<ol style="list-style-type: none"> 1. Preparing and submitting regulatory documents to the local IRB/R&D Committee and HRPO. 2. Overseeing administrative aspects of the award.

Name:	Lisa M. Lombardo
Project Role:	Co-Principal Investigator
Researcher Identifier:	
Nearest person month worked:	2.4
Contribution to Project:	Helping with experiments with individuals with SCI.

Name:	Matthew Morrison
Project Role:	Graduate Student
Researcher Identifier:	
Nearest person month worked:	12
Contribution to Project:	<ol style="list-style-type: none"> 1. Participating in the development of the musculoskeletal model of human trunk and pelvis in preparation for multi-sensor study.

	2. Processing experimental data after experiments and preparing reports and presentations.
--	--

Name:	Ronald Hart
Project Role:	Rehabilitation Engineer
Researcher Identifier:	
Nearest person month worked:	2.4
Contribution to Project:	Preparing the NNP for sending stimulation signals from control computer to power module and then to the individual modules.

Name:	Joris Lambrecht
Project Role:	Lead Software Engineer
Researcher Identifier:	
Nearest person month worked:	0.6
Contribution to Project:	Preparing possible modifications to NNP software in preparation for desktop testing and future implementation in real NNP systems.

Name:	Kevin Foglyano
Project Role:	Biomedical Engineer
Researcher Identifier:	
Nearest person month worked:	2.4
Contribution to Project:	Assisting in collection, processing, and management of all kinematic, kinetic, and electrophysiological data, including quantitative motion analyses, for the study.

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

Nothing to report.

What other organizations were involved as partners?

Nothing to report.

8. SPECIAL REPORTING REQUIREMENTS

COLLABORATIVE AWARDS: Not Applicable.

QUAD CHARTS: Quad Chart is attached as **Annex I**.

9. APPENDICES: These follow as **Annexes II – IV**.



Trunk stability and seated reaching after spinal cord injury

PI: Musa L. Audu

Org: Case Western Reserve University

Award Amount: \$ 1,305,395

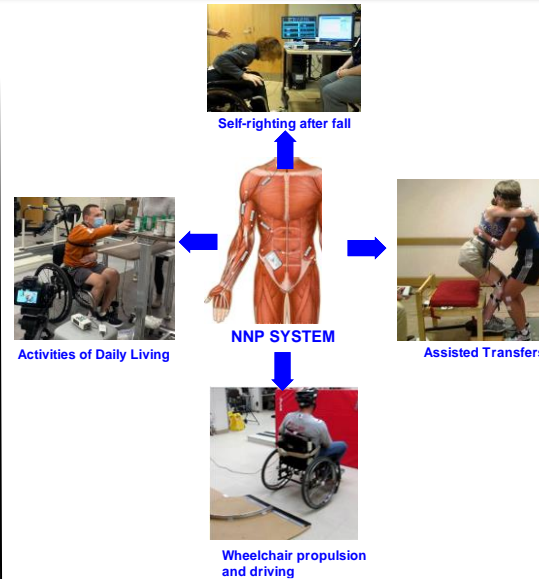
Study/Product Aim(s)

The overall goal of this expansion project is to leverage the achievements made with prior SCIRP support to transfer our trunk control and seated balance control algorithms to the Network Neuroprosthesis (NNP) platform, verify the control systems in a series of laboratory experiments, and prepare the trunk control package on the NNP platform for future clinical dissemination and commercialization.

- Aim 1: Estimate global orientation metrics for trunk and pelvis pose by fusing signals from a variety of implanted IMU sensors of the NNP and assess their suitability as feedback signals for controlling seated posture, improving balance and extending reach in persons with complete or partial paralysis.
- Aim 2: Implement advanced feedback control systems that assure robust seated stability, balance, and reach, and facilitate efficient wheelchair propulsion and other activities of daily living in NNP recipients.

Approach

We will adapt our control algorithms for seated balance to the NNP platform and quantify controller clinical performances and subjective impressions of satisfaction in three individuals implanted with the NNP System.



Controllers based on the NNP system will be deployed to enforce seated stability and enable SCI volunteers otherwise paralyzed at the trunk to undertake activities of daily living that would otherwise be impossible without the controllers. Controllers will be deployed to ensure seated stability while allowing for safe reaching and wheelchair propulsion and driving. In addition, controllers will be deployed to aid assisted transfers to minimize back and shoulder injuries to caretakers. The whole system, when completed will prepare the NNP for large scale clinical dissemination and commercialization.

Timeline and Cost

Activities	CY	22/23	23/24	24/25
Recruit, assess and train 3 volunteers implanted with NNP		[Gantt bar spanning 22/23 to 23/24]		
Apply for IDE to expand NNP to paraplegics		[Gantt bar spanning 22/23 to 24/25]		
Develop Sensor Fusion Algorithm		[Gantt bar spanning 22/23 to 23/24]		
Deploy and test trunk controllers for seated balance after SCI		[Gantt bar spanning 23/24 to 24/25]		
Estimated Budget (\$K)		\$433	\$429	\$433

- **Updated:** October, 2023
- Projected Expenditure: \$1,305,000.00; Estim. Expenditure: \$194,000

Goals/Milestones

CY1 – CY2 Goal: Recruit Subjects; Design and Test SFA

Aim 1: Develop Sensor Fusion Algorithm (SFA)

- 1(a) Recruit, assess and train three individuals implanted with NNP.
- 1(b) Quantify characteristics of volunteers with NNP implants.
- 1(c) Design sensor fusion algorithm in 3D musculoskeletal model.
- 1(d) Deploy and tune SFA in NNP recipients.
- 1(e) Apply for IDE to extend NNP to paraplegics.

CY2 – CY3 Goal: Transfer feedback controllers to NNP technology

Aim 2: Deploy and test seated balance controllers in NNP recipients.

- 2(a) Deploy self-righting controller in reaching experiments with SCI individuals implanted with NNP
- 2(b) Deploy Disturbance Rejection and Posture Changing Controllers for Wheelchair Propulsion and ADLs.
- 2(c) Develop musculoskeletal model for caregivers in poses relevant to assisting SCI volunteers transfer.
- 2(d) Develop feedback Controllers to enhance Assisted Transfers in NNP recipients and their caregivers.
- 2(e) Develop smartphone user interface to enable users select controllers.

Annex II



DEPARTMENT OF VETERANS AFFAIRS
VA Northeast Ohio Healthcare System Institutional Review Board (IRB)
VA Northeast Ohio Healthcare System

Date: December 20, 2022

From: VA Northeast Ohio Healthcare System (VANEOHS) Institutional Review Board (IRB)

To: Musa Audu, Ph.D.

Protocol Title: [1695449-1] - Trunk Stability and Seated Reaching After Spinal Cord Injury

Submission Type: New Project

Risk Determination: Greater than Minimal Risk

Review Type: Full Committee Review

Action: Approved

Effective Date: November 10, 2022

Dear Dr. Audu:

This NEW STUDY project was reviewed and **approved** by the **VANEOHS IRB** at the convened meeting on **December 8, 2022** 38 CFR16. The modifications required have since been made and verified and the project is approved. The Board determined that this is a **Greater than Minimal Risk** study and has a **Significant Risk device** with an IDE.

This research project is subject to Continuing Review by the IRB and has been approved for a period of 12 months. It is the responsibility of the Principal Investigator (PI) to submit the request for Continuing Review 60 days prior to the IRB meeting date for which the study is scheduled for review. The current approval period will expire on December 7, 2023.

The **VA Notice of Privacy Practices** is required to be **given to any non-veteran** enrolled in the study. The non-veteran subject must sign the acknowledgement page which must be filed with the Privacy Officer.

This project is not allowed to begin until the Research and Development (R&D) Committee has approved the project and notification from the ACOS-Research that the research may begin is received by the Principal Investigator. The IRB will notify the R&D Committee of this approval.

Contact the IRB Office at **(216) 791-3800 x64650**; or via email at **Monica.O'Loughlin@va.gov** for any questions or further information.

Sincerely,

Monica O'Loughlin
IRB Administrator

Documents Reviewed:

- Application Form - SC210292 - ERDSP (6-6-22) updated 8-30-22.pdf (UPLOADED: 09/1/2022)
- Application Form - Audu - RPSS VA Form 10-0398.pdf (UPLOADED: 08/9/2022)
- Application Form - SC210292 - SRSS Local Appendix_signed.pdf (UPLOADED: 07/27/2022)
- Application Form - SC210292 - Data Management and Access Plan - signed.pdf (UPLOADED: 06/17/2022)
- Application Form - SC210292 - RDC Non-Veteran Application_MLA.pdf (UPLOADED: 06/17/2022)
- Consent Form - 1695449 - Informed consent_tracked_11.7.2022_.docx (UPLOADED: 11/8/2022)
- Consent Form - 1695449 - Informed consent_clean_11.7.2022_.docx (UPLOADED: 11/8/2022)
- CV/Resume - Audu_CV 11.2022.pdf (UPLOADED: 12/1/2022)
- Other - SC210292 - VA 10-250 Fillable Sept 2020_7.14 updates.pdf (UPLOADED: 07/20/2022)
- Proposal - Summary Statement.pdf (UPLOADED: 06/6/2022)
- Proposal - SC210292 Amended Full Submission (including budget) (UPLOADED: 06/6/2022)
- Protocol - 1695449 - Protocol - December 1 2022_tracked_.docx (UPLOADED: 12/7/2022)
- Protocol - 1695449 - Protocol - December 1 2022_clean_.docx (UPLOADED: 12/7/2022)
- Questionnaire/Survey - SCI-FCS-Self-Questionnaire.pdf (UPLOADED: 06/17/2022)
- Questionnaire/Survey - URS stability questionnaire.pdf (UPLOADED: 06/17/2022)
- VA - IRB Information Sheet - VA - IRB Information Sheet (UPLOADED: 11/8/2022)
- VA - Project Cover Sheet - VA - Project Cover Sheet (UPLOADED: 09/1/2022)

The Human Research Protections Program at the VA Northeast Ohio Healthcare System operates under the HHS Federal Wide assurance number FWA00004231.

This electronically generated document serves as official notice to sponsors and others of approval, disapproval or other VA Northeast Ohio Healthcare System Institutional Review Board (IRB) decisions. Only those individuals who have been granted authority by the institution to create letters on behalf of the VA Northeast Ohio Healthcare System Institutional Review Board (IRB) are able to do so. A copy of this document has been retained within VA Northeast Ohio Healthcare System Institutional Review Board (IRB) IRBNet records. The IRBNet System is fully compliant with the technology requirements for Electronic Records per CFR 21, Part 11, Section 11.10 - Controls for Closed Systems, and the technology requirements for Electronic Signatures per CFR 21, Part 11 Subpart C - Electronic Signatures.

Annex III



May 12, 2023

Cleveland FES Center
% Megan Moynahan
Institute for Functional Restoration
Room SM1-054, MetroHealth Systems, Old Brooklyn Campus
4229 Pearl Road
Cleveland, Ohio 44109

Re: G140225/S020

Trade/Device Name: Early Feasibility Study of the Networked Neuroprosthesis for Grasp and Trunk
Function in Spinal Cord Injury

Dated: April 4, 2023

Received: April 12, 2023

CMS Category: B

Annual Report Due: December 12, 2023

Dear Megan Moynahan:

The Food and Drug Administration (FDA) has reviewed the supplement to your Investigational Device Exemption (IDE) application regarding your feasibility study for a significant risk device proposing a temporary software modification to the Network Neuroprosthesis System (NNP) to allow control algorithm testing in the laboratory setting, and addition of a substudy to explore the possibility of creating a new feature of the NNP that provides automatic trunk stabilization based on accelerometer readings. FDA has determined you have provided sufficient data to support continuation of your human clinical study; this means that there are no subject protection concerns that preclude continuation of the investigation. Your supplement is therefore approved, and you may implement that change in your study. Your investigation is limited to 4 US institutions and 24 US subjects.

Future correspondence concerning this application should be identified as an IDE supplement referencing the IDE number above, and must be submitted following eCopy guidelines to:

U.S. Food and Drug Administration
Center for Devices and Radiological Health
IDE Document Control Center - WO66-G609
10903 New Hampshire Avenue
Silver Spring, MD 20993-0002

The Federal Food, Drug, and Cosmetic Act (the Act), as amended by section 1136 of the Food and Drug Administration Safety and Innovation Act (FDASIA), authorizes FDA to require an electronic copy (eCopy) for certain types of submissions. An eCopy is an exact duplicate of a paper submission, created and

submitted on a CD, DVD, or other electronic media, accompanied by a single paper copy of your signed cover letter. This authorization applies to the original, amendments, supplements, and reports, as applicable, for your submission type.

For more information about FDA's eCopy program, including the technical standards for an eCopy, refer to the guidance document, "eCopy Program for Medical Device Submissions" at <https://www.fda.gov/media/83522/download>. In addition, we strongly encourage you to visit FDA's eSubmitter website at <https://www.fda.gov/industry/fda-esubmitter/cdrh-esubmitter-program> in order to develop an eCopy in accordance with the technical standards prior to sending it to FDA.

If you have any minor clarification questions concerning the contents of the letter, please contact Michael Raucher at Michael.Raucher@fda.hhs.gov.

Sincerely,

for Vivek Pinto, PhD
Director
DHT5B: Division of Neuromodulation
and Physical Medicine Devices
OHT5: Office of Neurological
and Physical Medicine Devices
Office of Product Evaluation and Quality
Center for Devices and Radiological Health

Draft Work Order

Research Support Core

To Recipient:

Musa Audu, PhD
Case Western Reserve University
 Louis Stokes Cleveland VA Medical Center
 Motion Study Laboratory C15
 10701 East Boulevard
 Cleveland, Ohio 44106-1702

mx93@case.edu
 216-791-3800 ext 3821

From Covered Entity:

University Hospitals Cleveland Medical Center
 Clinical Research Center - Research Support Core
 11100 Euclid Avenue
 Cleveland, Ohio 44106

Heather.Tribout@UHhospitals.org
Erin.Gorrell@UHhospitals.org

Elizabeth.Pop@UHhospitals.org

Date: May 3, 2023

Protocol: Early Feasibility Study of a Neuroprosthesis Device for Applications to Persons with Paraplegia

IRB: Louis Stokes Cleveland VA Medical Center | IDE TBD

PI: Musa Audu, PhD

Department: Case Western Reserve University, Biomedical Engineering

Research Support Core Services Fixed Costs		
Service	Cost	Frequency
FDA Regulatory Support – Pre-Submission Research Support Core Efforts & Responsibilities: <ul style="list-style-type: none"> • Project assessment • Preparation, review, and revision as necessary of Pre-Submission • Submission to FDA • FDA liaison • Assistance during FDA meeting (if required) • Responding to FDA feedback as necessary • Preparation and submission of meeting minutes (if required) • Closure and completion of submission 	\$5,500	Once
FDA Regulatory Support – Original IDE Research Support Core Efforts & Responsibilities: <ul style="list-style-type: none"> • Preparation, review, and revision as necessary of Original IDE • Submission to FDA • FDA liaison • Responding to FDA deficiencies as necessary • Closure and completion of submission 	\$8,600	Once
FDA Regulatory Support – IDE Annual Reports Research Support Core Efforts & Responsibilities: <ul style="list-style-type: none"> • Preparation, review, and revision as necessary of Annual Report and Current Investigator Report • Submission to FDA • FDA liaison • Responding to FDA deficiencies as necessary • Closure and completion of submission 	\$1,300/each	Annually
FDA Regulatory Support – IDE Ad-Hoc Submissions Research Support Core Efforts & Responsibilities: <ul style="list-style-type: none"> • Preparation, review, and revision as necessary of IDE Ad-Hoc submissions (e.g. Supplements, Safety Reporting) • Submission to FDA 	\$850/each	As needed

Draft Work Order

Research Support Core



<ul style="list-style-type: none"> FDA liaison Responding to FDA deficiencies as necessary 		
Closure and completion of submission		
FDA Regulatory Support – IDE Withdrawal & Final Report Research Support Core Efforts & Responsibilities: <ul style="list-style-type: none"> Preparation, review, and revision as necessary of IDE Final Report Submission to FDA FDA liaison Responding to FDA deficiencies as necessary Closure and completion of submission 	\$5,600	Once
Total	TBD	

By signing this Work Order, Recipient agrees to the terms and conditions listed above in the Description of Work. Recipient agrees to comply with the Standards for Privacy of Individually Identifiable Health Information (the “Privacy Rule”) issued under the Health Insurance Portability and Accountability Act of 1996 (“HIPAA”) and the American Recovery and Reinvestment Act of 2009 and associated Health Information Technology for Economic and Clinical Health Act (“HITECH”).

It is expected to acknowledge our UH Clinical Research Biostatistician(s) by including them as an author on any poster, presentation or publication.

Any poster, presentation or publication submission must include an acknowledgement of the UH Clinical Research Center by citing:

This publication was made possible through the support of the Clinical Research Center of University Hospitals Cleveland Medical Center (UHCMC) and the Case Western Reserve University Clinical and Translational Science Collaborative (CTSC) 4UL1TR000439. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of UHCMC or NIH.

Recipient acknowledges and agrees that the information contained in this Work Order, including all budget information, is the confidential information of University Hospitals and should be protected in accordance with UH policy GM-21. Recipient agrees not to disclose this Work Order or any budget information to any individual or entity that is not a UH employee or UH entity. If it becomes necessary to disclose this Work Order or any budget information, Recipient will contact the UH Grants and Contracts office at UHCRCGrantsContracts@UHhospitals.org in order to obtain a confidentiality agreement to cover the disclosure.

Account: _____

Recipient Signature

Account Authorized User (if other than Recipient)
