

# Naval Submarine Medical Research Laboratory



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## A HISTORY OF COMPUTER-ASSISTED MEDICAL DIAGNOSIS AT NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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Commanding Officer  
Naval Submarine Medical Research Laboratory

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Naval Submarine Medical Research Laboratory  
Report 1186

Naval Medical Research and Development Command  
Work Unit 63706N M0095.005-5010

Approved and released by

A handwritten signature in black ink, appearing to read 'P. K. Weathersby', is written over the printed name.

P. K. Weathersby, CAPT, MSC, USN

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## SUMMARY PAGE

### PROBLEM

In the 1970's NSMRL was tasked with development of computer assisted diagnostic aids for Independent Duty Corpsmen serving aboard submarines and other health care practitioners at remote duty stations.

### FINDINGS

This report details the history and development of the nine computer-assisted medical diagnostic aids at NSMRL.

### APPLICATION

This report would be of use to individuals interested in the history of medical diagnostic product development in the submarine medical community. Several of these programs have been released by the Commanding Officer of NSMRL for distribution and can be obtained by request.

### ADMINISTRATIVE INFORMATION

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## ABSTRACT

Independent duty hospital corpsmen assigned to submarines are normally the sole provider of medical care for the crew. Corpsmen with varying levels of experience and training must make diagnoses with limited diagnostic tools and without expert consultation. A medical evacuation (MEDEVAC) can potentially expose a submarine's position, is hazardous to both the patient and the rescuers, especially in high sea states, and is expensive because it entails the movement of large numbers of ships, aircraft and men. For these reasons, the Naval Submarine Medical Research Laboratory (NSMRL) was tasked in the 1970's with developing computerized diagnostic aids for these corpsmen with the goals of reducing the number of unnecessary medical evacuations and improving the quality of health care at sea.

This report details the history and development of the computer assisted medical diagnostic aids at this laboratory and would be of benefit to individuals or Commands interested in continuing this type of work. Several of these programs have been approved for distribution by the Commanding Officer, NSMRL, and may be obtained by request.

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## A HISTORY OF COMPUTER-ASSISTED MEDICAL DIAGNOSIS AT NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

Independent duty hospital corpsmen assigned to submarines are normally the sole provider of medical care for the crew. Corpsmen with varying levels of experience and training must make diagnoses with limited diagnostic tools, e.g., there are no radiographic and few laboratory capabilities onboard, and the corpsman is without expert consultation. A medical evacuation (MEDEVAC) can potentially expose a submarine's position, is hazardous to both the patient and the rescuers, especially in high sea states, and is expensive because it entails the movement of large numbers of ships, aircraft and men. For these reasons, the Naval Submarine Medical Research Laboratory (NSMRL) was tasked with developing computerized diagnostic aids for these corpsmen with the goal of reducing the number of unnecessary medical evacuations and of improving the quality of health care at sea.

In 1971, Dr. Rupert Hester of NSMRL reported that the three most common medical problems encountered aboard submarines requiring MEDEVAC were abdominal pain, chest pain, and psychiatric disturbances<sup>1</sup>. With the rapid technical advances of microcomputers occurring during the 70's, there was increasing interest in developing computer-aids to medical diagnosis in both the civilian and military communities. The United States Navy, in particular, was interested in producing a system that would assist corpsmen aboard submarines and other health care practitioners in remote duty stations. This report details the history and development of the computer assisted medical diagnostic aids at this laboratory. Many of the

details in this report are not recorded in any other retrievable publication.

### Abdominal Pain Programs

A survey of the literature<sup>2</sup> in 1979 revealed several computer algorithms developed for evaluation of gastrointestinal complaints including acute abdominal pain, epigastric pain, and dyspepsia. One of these, the acute abdominal pain program being developed by Dr. Timothy de Dombal of the University of Leeds, England, was determined to meet submarine requirements. de Dombal's program did not require extensive memory which meant that it could be installed on computers other than the large main frames of the time<sup>3</sup>. It used a Bayesian algorithm to generate disease probabilities and did not require results of laboratory tests to arrive at a diagnosis. The Bayesian approach incorporates the prior probability of a disease to guide the interpretation of signs and symptoms. During the early 1980's, in cooperation with Dr. de Dombal, his program was modified for an active duty population (young, healthy males who are seen within the first 48 hours of illness) so that it could be used by corpsmen at sea on a Tektronix 4051 desk top calculator with 32 K of memory and a 300 K tape cartridge.

After a series of experimental evaluations both at Naval hospitals<sup>4,5,6</sup> and at sea, this program was placed on four operational fleet ballistic missile (FBM) submarines for extensive at-sea testing in 1979<sup>7</sup>. To ensure use of the system in a predictable way, preselected crew members were trained to simulate abdominal complaints and then presented to the corpsman at some time during the patrol. The

corpsman did not know which cases were fabricated and which were real. Commanding (CO) and executive (XO) officers participated in the simulated cases by knowing who the actors would be.

During this study, nine simulated and four genuine cases of abdominal pain were evaluated at sea. Following deployment, the corpsman, CO, and XO of each patrol were debriefed at NSMRL. These participants believed that the simulated cases appeared genuine and that this method provided for realistic evaluation of the system. The corpsmen perceived the computer as an aid to, rather than a replacement for, their clinical judgment and found the program valuable in organizing and summarizing data before discussing MEDEVAC decisions with the commanding and executive officers. All participants felt that the system assisted in MEDEVAC and other patient care decisions and endorsed its use aboard submarines. Subsequent at-sea trials revealed several limitations of the system. Operational access to the Tektronix was limited because of its location in Sonar spaces and use by other personnel, primarily Sonarmen. The system was felt to be clumsy to use because of the antiquated magnetic tape storage system. The users also found that the results of the computer analysis were difficult to interpret, and the hard copy unit failed to provide legible computer printouts for the majority of cases. It was concluded that before full scale clinical sea trials, the computer system must present diagnoses in a format which is more easily interpreted by the practitioner making patient care decisions. Finally, user training needed to be improved.

In January 1982, approval was granted by the Chief of Naval Operations (CNO) for Fleet Test & Evaluation support. Sub-

sequently, in May 1982, training of Squadron Medical Officers and Squadron Corpsmen was begun with the concomitant distribution of computer tapes and instructional materials. Individual submarine corpsmen were, in turn, trained by Squadron medical personnel. In July 1982<sup>8</sup>, sea trials were initiated with 103 submarines--52 in a control group and 51 in the experimental group. The enrollment numbers fluctuated with new additions to the fleet and decommissioning or transfers to the shipyard. The Control Group was given the data sheets, reference manual, and training program; the Experimental Group received those same items *and* the computer diagnostic program. These sea trials were to last a period of five years.

After six months at sea, only two cases of abdominal pain had been reported to NSMRL<sup>8</sup>. Periodic interviews of Squadron Corpsmen revealed that the "Control" group was unhappy with their role of data collection without the benefit of the diagnostic program. The "Experimental" group was unhappy with the extra paperwork involved in data collection.

After another 15 months, only 30 cases of abdominal pain at sea were reported to NSMRL. Review of the sick call logs and personal communication with the corpsmen disclosed that 80-90% of the cases went unreported to NSMRL, largely because of the increased paperwork. The corpsmen were also concerned that this data would be used for other purposes, such as to "second guess" the corpsman's diagnosis in the event of an adverse medical outcome. Personal visits were made to submarine corpsmen to ease their concerns.

Despite these problems, several *subjective* advantages of using this system were noted by

the users and researchers. First, the data sheet was found to be very helpful when used during collection of clinical information. By providing a template, the corpsmen were more likely to gather a more complete history and physical examination. Second, the corpsmen felt that the system was reliable because the computer's diagnosis supported their initial diagnosis at least 75% of the time. Finally, when the computerized diagnostic program was used, it was *subjectively* appreciated by corpsmen as an aid or adjunct to diagnostic problems.

Concurrent with the sea trials, in July 1982, a similar study was begun at the Emergency Room of Naval Hospital Groton, CT using physician-collected data<sup>9</sup>. A total of 90 cases along with supporting documentation (51 male cases, 39 female cases) were collected. For the male data, agreement between the practitioner's initial diagnosis and the final diagnosis was 88% (45 out of 51 cases). The initial diagnosis of the practitioner was the discharge diagnosis noted on the emergency room treatment record. The final diagnosis was determined after follow-up with the patient by phone at least seven days after the emergency room visit. If the patient was admitted to the hospital, the final diagnosis was the discharge diagnosis noted in the patient record. Agreement between the computer diagnosis and final diagnosis was 84% (43 of 51 cases), and agreement between the practitioner's initial diagnosis and the computer diagnosis was 88%. For the purposes of this comparison, the computer diagnosis was arbitrarily set to be that diagnosis with a calculated probability of 50% or greater.

Although not relevant to the submarine force, the female data collected was analyzed. Agreement between the practitioner's initial diagnosis and the final diagnosis was 85% (33

of 39 cases), agreement between the computer diagnosis and final diagnosis was also 85%, and agreement between the practitioner's initial diagnosis and the computer diagnosis was 69% (27 of 39 cases).

During fiscal year (FY) 1985, evaluations were initiated to replace the Tektronix machine which was being phased out Navy wide. A decision was made that programs would be IBM compatible and run under the MS-DOS operating system.

For this reason, the abdominal pain module was programmed using Microsoft Quick-BASIC<sup>®</sup> by Southerland and Fisherkeller<sup>10</sup>. Supporting user documentation<sup>11</sup> was also provided. In its present form, version 3.0 of the abdominal pain program provides diagnostic and treatment suggestions for appendicitis, cholecystitis, renal colic, perforated duodenal ulcer, small bowel obstruction, and non-specific abdominal pain. This program also contains a database for the diagnosis of the following disorders associated with female abdominal pain: appendicitis, pelvic inflammatory disease, urinary tract infection, ovarian cyst, ectopic pregnancy, incomplete abortion, and non-specific abdominal pain. The female only program incorporated the Bayesian knowledge base developed in England (no U.S. Navy data was used), with the diagnosis of dyspepsia categorized as non-specific abdominal pain. Changes were made to the user interface and disease information and treatment protocols were updated. Corrections were made to the abdominal pain training cases and a subroutine which generated a standardized medical record entry (SF-600) form was added. Following these improvements, the program was approved for distribution by the Commanding Officer, NSMRL.

During FY 88, the operational diagnostic programs (abdominal and chest pain) were given to the Navy Management Systems Support Office (NAVMASSO) for insertion into the SNAP II Medical Module to be placed aboard all U.S. Navy vessels on microcomputers as per NAVMASSO's timetable. This allows data collection from both submarine and surface crews. The microcomputers were IBM MS-DOS compatible to allow for the widest possible range of microcomputers to be utilized.

In 1988, NSMRL undertook a prospective study collecting data from the emergency rooms at Naval Hospitals San Diego and Portsmouth, VA. An apparently large total of 616 cases of abdominal pain were collected from the two facilities. Since this program was designed to initially be deployed on submarines, it was tested against the 146 male cases<sup>12</sup>. Overall diagnostic accuracy of the program was found to be 69% compared to the 80% accuracy rate of emergency room physicians. Sensitivity and specificity for distinguishing surgical from non-surgical cases were 56% and 85% respectively. The study suffered from a small number of cases in any but the non-specific abdominal pain category. This report concluded that it was not possible to assess the clinical adequacy of the NSMRL abdominal pain diagnostic program based on this case data and recommendations for further study were made. Study of the usability of the abdominal pain program was also completed during this time period<sup>13</sup>.

The abdominal pain module for females has not been formally validated in a prospective study. In 1990, LCDR Michael Hughey, a reservist and gynecologist, evaluated this area by conducting a retrospective review of medical records at his institution of 97 females, age 17 to 50 presenting with ab-

dominal pain. In unpublished results, the program disagreed with the emergency room physician in 43% of the cases. All three cases of appendicitis were diagnosed incorrectly by the program, as were 71% of the cases of pelvic inflammatory disease (PID) and 64% of the cases of urinary tract infection (UTI). The program failed to diagnose all 12 cases of appendicitis confirmed by pathologic examination. It was concluded that the female abdominal pain module would require further examination and testing before it could be safely implemented.

#### Gynecology Consultant (GYN)

Developed during 1990-91 by LCDR Michael J. Hughey, MC, USNR, this system was designed to provide expert advice to those who treat women with gynecological problems and offer guidance in the continuing care of women<sup>14</sup>. This program was developed in response to a medical officer's dissatisfaction with the female portion of the abdominal pain (ABDX) program.

It is designed to assist the corpsman in assessing gynecological problems with the following limitations:

- 1) Women who are previously healthy and of childbearing age.
- 2) Only "common" problems are considered.
- 3) Non-gynecological illnesses are not considered.
- 4) Surgical complications or trauma are not considered.
- 5) Results may be misleading when the clinical presentation is atypical.

Table 1. Scope of Gynecology Program

Clinical Symptoms

1. Abdominal/Pelvic Pain
2. Vulvar Pain
3. Abnormal Bleeding
4. No Menstrual Flow
5. Vaginal Discharge
6. Itching/Irritation
7. Odor

Clinical Problems

8. BCP Problems
9. Menstrual Problems
10. Abnormal Pap Smear
11. IUD Problems
12. Painful Intercourse
13. Urination Problems
14. Warts (Condyloma)
15. Venereal Disease

The gynecology program provides help in 15 clinical areas -- 7 clinical symptoms and 8 clinical problems (Table 1).

Depending on the selection, the health care practitioner would be given immediate advice, or, in other cases, additional questions may be asked. Treatment protocols, a tutorial, and general guidelines for treating gynecological illnesses are also available to the corpsman.

At this point, the program has not been entirely completed and also has not been approved for distribution pending formal testing. To date, it has only been informally reviewed by gynecologists and general medical officers. Work on this program at NSMRL has been terminated.

### Chest Pain Programs

The second diagnostic program was developed to aid the corpsmen in the diagnosis and treatment of acute chest pain. This program was also initiated at the University of Leeds, England by Dr. de Dombal in the early 1980's<sup>15</sup> and consisted of three modules: diagnosis, prognosis, and management of acute chest pain. It provided diagnoses in the categories of myocardial infarction, angina, chest infection, and non-specific chest pain.

Conditional probabilities were derived from several hundred adult male patients presenting to hospitals in England and these probabilities were then analyzed by the Bayesian method to develop a symptom/disease matrix. This approach was similar to that used by the abdominal pain program. The initial program was tested in a small number of adult male patients and found to have a low false positive rate for myocardial event (5%). It was also found that the program could predict death or survival in about 2/3 of all patients. Recommendations for management on-board submarines were also delivered under the contract.

Testing of de Dombal's algorithm then moved to the United States. In 1982, de Dombal's model was prospectively tested against that of one developed by Dr. Goldman at Brigham & Women's Hospital, Boston<sup>16</sup>. The algorithm developed by Goldman used a recursive partitioning model derived from approximately 500 patients seen at Yale-New Haven Hospital prior to the Navy contract. This new model appeared to perform well with a subgroup of patients similar to that seen in the submarine community (males under age 60 with no prior history of myocardial infarction or angina). The high sensitivity and specificity of Goldman's model in

the diagnosis of acute myocardial infarction was dependent on simple electrocardiographic (ECG) criteria not used by the de Dombal model. It was suggested that this model could be used as an alternative in a deployed situation if an ECG was available.

Between November 1982 and July 1983, a brief study was undertaken at the Naval Hospital, Groton, to determine the corpsmen's ability to understand and collect data required by the computer program developed by de Dombal<sup>17</sup>. Sixteen Navy Hospital corpsmen performed medical history and physical examinations of 102 patients presenting to the emergency room with a chief complaint of chest pain. They then completed a chest pain data sheet (no computers were used for data collection) for each patient. It was found that the corpsmen were very accurate in gathering medical history information but less accurate in performing physical examinations. "Accuracy" was defined as agreement with emergency room physicians. It appeared this type of data collection format may be useful in gathering information for the computer assisted diagnostic program.

During April 1984, a preliminary version of the chest pain program was completed based on de Dombal's disease/symptom matrix<sup>18</sup>. The program would run on a Tektronix 4051 computer and was very similar to that produced for the first version of the abdominal pain program. This program was not completed for distribution.

The Tektronix version of the chest pain program was then recoded in Microsoft QuickBASIC to run on a PC based system<sup>19</sup> and released by the CO of NSMRL for distribution along with supporting user documentation<sup>20</sup>. The program was intended for use in patients between the ages of 17 and 79 (male

or female) and considered myocardial infarction, angina, chest infection, and non-specific chest pain in the differential diagnosis. Treatment suggestions were given for each of these diagnoses. A training module was included to test the corpsman's ability to abstract information from simulated patient narratives and a SF-600 generator was added to print medical record entries based on the patient data entered into the program.

Again, the original de Dombal data set was used, but a priori data derived from cases seen at Naval Hospitals in the United States were added to the program in hopes of enhancing diagnostic accuracy. Also, results of electrocardiographic data were included in the patient data set. A revised database was forwarded by Dr. de Dombal which provided for use of ECG data. The user interface was modified based on the opinions of individuals observing several alternatives. Although this made the program more user 'friendly,' the source code became increasingly more complex and difficult to modify. Finally, treatment protocols were updated. With changes having been made to the knowledge base, this program would need additional validation.

Between May 31, 1988 and September 30, 1988, cases of chest pain were collected prospectively at the Emergency Rooms of the Naval Hospitals in Portsmouth, VA, Charleston, SC, and San Diego, CA, to be used in the validation process<sup>21</sup>. The subjects were 132 male and female active duty Navy personnel or their dependents between the ages of 15 and 50 who presented with chest pain as a chief complaint. Six research technicians (two at each hospital) worked consecutive 8-h shifts between the hours of 8 a.m. and midnight five days a week. When patients presented to the emergency room with a complaint of chest pain, they were interviewed by

the technician who described the study and solicited their participation. Patients who agreed to participate then signed a consent form and the technician recorded case history details while waiting for the physician to examine the patient. The doctor was asked to verbalize his findings so that the technician, who was in the exam room listening, could record the answers on the chest pain data sheet. If the physician was too busy to provide a complete report, the technician obtained the missing data from the patient's emergency treatment record. The research technician was not permitted to interview the patient without the doctor's permission and would leave the exam room if the patient was uncomfortable.

The data collected on each patient was later entered into the computer program to obtain its diagnosis. Results of the study showed that the diagnostic accuracy (defined as percentage of correct diagnoses) of the computer program for the 132 patients was 72%, not significantly different from the physician's which was 79%. "Correct" diagnoses were determined in one of two ways. If the patient was admitted, the correct diagnosis was considered discharge diagnosis. Otherwise, if the patient was not admitted, a follow-up telephone call was made to the patient by a nurse or physician at least three weeks after the emergency room visit to determine if further events were consistent with the emergency room final discharge diagnosis. It was concluded that the computer program was able to distinguish myocardial infarction from the other diseases (angina, chest infection, and non-specific chest pain) as well as the physicians (83% vs 84%).<sup>21</sup>

## Chest Pain and the Electrocardiogram (ECG)

Medical Officers attached to submarine squadrons suggested that they would like to have electrocardiographic data available to assist both corpsmen and themselves in the diagnosis of chest pain. At this time, chest pain data including ECG tracings were being collected for NSMRL by physicians at Naval Hospital Groton so that the accuracy of computerized diagnosis with and without ECG tracings could be compared<sup>22</sup>. It was determined that there would be sufficient improvement in diagnostic accuracy to warrant the inclusion of ECG data (this addition was made to the most recent version of the chest pain program as previously described). However, the existing ECG recorders were not deployable because of weight and space constraints aboard submarines. Under contract with Marquette Electronics, NSMRL cooperatively developed a portable ECG machine which could be used in conjunction with the chest pain program. This device measures 12 x 8½ x 3¾ inches, weighs 10 pounds, can be battery operated, and has all the capabilities of the larger MAC-II ECG machines. This new portable ECG machine, the MAC-PC, can be interfaced with the computer and is compatible with the Computer Assisted Processing of Cardiograms (CAPOC) system used by the Tri-Service Medical Information Systems (TRIMIS) programs<sup>23</sup>.

During FY 90 a pilot study was undertaken in cooperation with Marquette Electronics Inc. and Submarine Squadron Twelve to determine the feasibility of transmitting ECG data via radio waves from submarines. Three standard Marquette ECG recorders (Mac PC) were updated to allow transmission of the ECG by way of a RS232 board on the Mac

PC into an IBM compatible computer with an RS232 port. A commercially available communications software (ProComm Plus<sup>TM</sup>) was used to transfer the data via the x-modem protocol. A stored ECG data strip was placed on a floppy disk and brought onboard the USS John Adams (SSBN 620) where it was transmitted via satellite to Norfolk, VA and then on to the USS Von Steuben (SSBN 632), again via satellite. Upon examination of the transmitted file, it was found that the file size and ECG strip readings were unchanged during transmission. Although these results were encouraging, additional testing would be required before consideration for deployment.

### Dental Pain Program

Interest in the design and development of a system for diagnosis of dental emergencies began in the early 1980's at the Naval Dental Research Institute in Great Lakes, Illinois. The initial program, written in Apple Basic language, was completed and underwent preliminary testing. This rule-based system considered 35 trauma and non-trauma related dental emergencies and provided a differential diagnosis of soft tissue lesions based on clinical appearance. Other modules provided treatment recommendations and definitions of dental terms which may be unfamiliar to the corpsman.

Validation of this program consisted initially of review by a group of dentists who simulated over 200 dental emergencies which were then entered into the program<sup>24</sup>. Based on the results, minor changes were made to the algorithm, and this system was then tested in a large Navy Dental Clinic<sup>25</sup>. Dental technicians were responsible for first entering responses to the computer-displayed questions. The patient was then referred to a dentist who made a diagnosis (a list of the 35

diagnoses was available to the dentist for standardization of terminology). The diagnoses generated by the computer were compared with those of the dentist for 80 symptomatic patients. Results of the study were favorable (87.5% of cases were exact or logically consistent matches defined as a "proper diagnosis in the absence of certain diagnostic information not evaluated by the system"). Unfortunately, there were no trauma-related emergencies to test the system.

This program was then reprogrammed in Microsoft QuickBASIC<sup>R</sup> to run on MS-DOS systems<sup>26</sup>, supported with user documentation<sup>27</sup>. The conversion was essentially 'line-for-line' to keep the knowledge representation (the "brains" of the program) intact. This knowledge representation was also extracted from the BASIC code during this period<sup>28</sup>.

Evaluations at the Naval Dental Clinic in Groton, CT<sup>29</sup> found 83% agreement between the computer's diagnosis and that of a dentist in 32 cases. The "accuracy" of this program was tested against "classic presentations" of dental emergencies<sup>30</sup>. Basically, 19 dentists completed questionnaires, providing expected responses after interviewing and examining patients with dental conditions considered by the program. The program produced the correct diagnosis 78% of the time when these "classic" responses were entered. More importantly, it appeared the program was able to distinguish between dental conditions requiring immediate evacuation and those which could be managed safely by an independent duty corpsman.

This program was released during 1990 by the Commanding Officer, Naval Submarine Medical Research Laboratory, for distribution.

## Computer-Supported Assessment and Treatment Consultation for Emotional Crises (CATCEC)

Computer-Supported Assessment and Treatment Consultation for Emotional Crises (CATCEC), was developed under contract in 1982 to Dr. James Hedlund of the Missouri Institute of Psychiatry. Dr. Hedlund first focused on development of a structured interview that would be problem and treatment oriented and appropriate to the psychiatric training and experience of the corpsman. CATCEC includes a detailed interview for corpsmen to use in collecting patient information, computer-generated patient summaries, treatment suggestions, four special glossaries, and a computer-aided training module<sup>31</sup>. The corpsman uses a highly structured paper-and-pencil interview guide, the Groton Interview Schedule (GIS), to obtain specific information about the problem including a physical examination of the patient, and available collateral information or observations. He then enters this information into the computer and obtains a patient summary which gives a probable diagnosis and a listing of all related symptoms. The corpsman may then make specific changes or corrections to the data entered or obtain treatment suggestions. The four glossaries (Emergency Treatment Principles, a Diagnosis and Treatment Glossary, a Medications Glossary, and a Glossary of Psychiatric Terms) are available at any time both on the computer and in hard copy. The program was designed to be "user-friendly" with many screen prompts and provisions for making changes and corrections easily.

The diagnostic/treatment modules are primarily rule-based, recording patient information and comparing it against the diagnosis and treatment rules. CATCEC's diagnostic and treatment logic were tested by manually

entering and checking the results of over 400 GIS profiles<sup>32</sup>. Initial validation was done by six experienced psychiatrists and one clinical psychologist (two of these were career Naval officers) who systematically evaluated the structured interview, all diagnostic and treatment modules, and all glossaries. This validation provided strong expert corroboration of the diagnostic and treatment procedures.

This program was also clinically tested in 60 patients presenting to the psychiatry department at a Naval hospital<sup>33</sup>. Accuracy (defined as agreement between the program's and clinician's diagnosis) was 73% (22 of 30 cases) of the types of cases which a corpsman may encounter aboard a submarine. This program is not in use in the submarine community.

## The Submarine Medical Administrative Records and Tickler System (SMARTS)

Since 50% or more of a corpsman's time is spent in keeping administrative records, preparing required reports, and maintaining continually updated inventories of medical supplies, SMARTS was created in 1985 to fill most of the requirements for medical record keeping aboard submarines to allow the corpsman more time to carry out his primary duty of monitoring and supporting the health needs of the crew<sup>34,35</sup>. The initial functions supplied by SMARTS were management of crew member information files, processing of radiation health data, preparation of radiation health reports, management of medical inventory data, and generation of requisition lists for supplies that are on hand below required quantities or are out-of-date.

Although this program was approved for release by the Commanding Officer of

NSMRL, it has been replaced by SAMS (Snaps Automated Medical System) which contains this type of administrative function.

### Medical Tickler System

Also created in 1985, this program was a computerized version of a medical tickler filing system for use by corpsmen aboard submarines and designed to increase the corpsman's productivity while decreasing his administrative workload<sup>36,37</sup>. The program enabled a corpsman to track the crew members' immunization dates, physical exam dates, and other requirements of the general health maintenance programs in effect on submarines. Along with SMARTS, this program was also canceled in favor of the SAMS system being developed by NAVMASSO.

### Trauma Modules

A computer-based trauma program was developed during the late 1980's to assist with the management of patients with multiple injuries<sup>38</sup>. The system was initially designed to be used by hospital-based physicians trained in Advance Trauma Life Support (ATLS). The expert system was rule based utilizing both forward and backward chaining. A user could enter sign and symptom data directly or be prompted for clinical information by the program. The program then provided specific protocols for management of injured patients.

This knowledge-base was then modified by emergency room physicians for use in the submarine force primarily by independent duty corpsman who would not have access to hospital facilities. Two separate knowledge bases were delivered. One dealt with management of penetrating injuries of the chest and abdomen<sup>39</sup> and the other considered injuries to the upper extremities<sup>40</sup>. These programs

were designed with regard to the available resources and level of expertise of the user. For example, the modules make conservative assumptions when certain information is not available (e.g., radiographs). Treatment recommendations were modified based on the resources available in the submarine environment and capabilities of the Independent Duty Corpsman.

There have been several methods of validation of these diagnostic modules. The penetrating abdominal and chest injury module has been tested by entering approximately 400 theoretical cases of penetrating trauma<sup>41</sup>. Treatment recommendations were compared to actual care given to patients with common presentation of both abdominal and chest trauma. The recommendations were found to be "acceptable" but specific results are not available. The hospital version of the abdominal/chest module has been in use at the Trauma Center of the Medical College of Pennsylvania where about 85 cases had been entered through 1990. Again, results have not been published. The upper extremity module has also received testing against 25 common presentations of upper extremity injury.

The trauma programs developed at NSMRL have not been approved for fleet use. Neither of the programs modified for submarine corpsmen have been field tested or evaluated against a series of actual prospective or retrospective cases. The display format of the penetrating wound module was evaluated from a human-factors standpoint in 1988<sup>41</sup>. The interface was compared with that of the available chest and abdominal pain programs. Recommendations such as to use of color to highlight information were made to make the trauma interface consistent with that of the other programs.

Efforts at the end of FY 92 within this diagnostic domain were taking place primarily at Northwest Research in Seattle, Washington. Specifically, a rule-based expert system for the evaluation and intervention of closed head injury is under evaluation.

#### Eye Disease Program

Created in FY 90, this is a rule-based program generated using the EXSYS<sup>TM</sup> (Expert System Development Package) system<sup>42</sup>. It provides diagnostic assistance for eye disorders (Table 2).

This program also provides a help system to ensure easy and accurate use of the knowledge base and graphics, including drawings and photographs to illustrate clinical concepts, and a complete description of each illness described along with treatment recommendations.

This program has not been approved for distribution pending validation of the knowledge base. Over 1000 case descriptions from Navy and civilian hospital records were collected to assist in verifying the module but they were not in a format that could be used by the program. The program has been informally evaluated by several optometrists and ophthalmologists, but it has not been rigorously tested against actual cases.

#### Medical Practice Support System (MEPSS)

In FY 90, the development and testing of existing and future stand-alone modules used by submarine corpsmen was redirected to a cooperative effort involving NSMRL, Naval Health Research Center (NHRC), and Johns Hopkins University. The goal of this effort was to develop a broadly capable computer-based medical system called MEPSS (Medi-

Table 2. Diagnoses considered by Eye Module

|                                                |                            |
|------------------------------------------------|----------------------------|
| Acute angle closure glaucoma                   | Dislocation of the lens    |
| Acute iritis                                   | Flash burn                 |
| Allergic conjunctivitis                        | Gonococcal conjunctivitis  |
| Bacterial conjunctivitis                       | Herpes simplex keratitis   |
| Blepharitis                                    | Hordeolum                  |
| Chalazion                                      | Hyphema                    |
| Chronic iritis                                 | Inclusion conjunctivitis   |
| Contact lens tear                              | Ocular foreign body        |
| Contact lens deposit                           | Orbital blowout fracture   |
| Contact lens induced superior limbic keratitis | Penetrating injury         |
| Contact giant papillary conjunctivitis         | Pneumococcal corneal ulcer |
| Contact lens solution allergy                  | Retinal detachment         |
| Contact lens inversion                         | Rupture of the globe       |
| Corneal abrasion                               | Subconjunctival hemorrhage |
| Corneal foreign body                           | Traumatic iritis           |
|                                                | Viral conjunctivitis       |

cal Practice Support System). MEPSS provides its users with computer-assisted medical diagnostic support, a large medical library, access to the Navy's CAMIS system, medical record keeping, and the ability to communicate with data sources outside the medical unit. MEPSS is integrated to share data between the record keeping and diagnostic modules. A prototype version was demonstrated at the 15th Annual Symposium on Computer Applications in Medical Care in November 1991<sup>43</sup>. Usability testing resulting in recommendations to increase the ease of use and acceptance of this system has also been completed<sup>44</sup>.

#### Black Boat Alpha Configuration

During FY 92, NSMRL commenced a joint study with the Public Health Service (PHS) to develop a computer-based medical information system for use by Navy and PHS medical personnel stationed in isolated areas. The goals of this project were to provide an integrated system with the following capabilities: 1) diagnostic decision support or an aid to clinical decision making, 2) storage and retrieval of a large amount of current medical and operational material, 3) administrative support functions, and 4) continuing medical education. It was felt that the most important use of the system was as an educational tool that could be used by the corpsmen as a means of maintaining and increasing their skills.

A computer system was configured with hardware and software that would be evaluated in operational settings. Three identical prototype computer systems were configured and delivered to separate operational test sites for evaluation during the spring of 1992. These test sites included: The Naval Undersea Medical Institute (NUMI) in Groton, CT;

Submarine Group Two (CSG 2) in Groton, CT; and Submarine Group Ten (CSG 10) in Kings Bay, GA.

On delivery to the test sites, NSMRL staff provided a demonstration of the system's capabilities along with brief initial training. It was expected that the system would be usable with a minimum amount of formal instruction. Reference materials pertaining to the operation of the system were provided. The computers were to remain at each site for approximately three months. Medical personnel who used the system either as part of their routine or to only evaluate the system were requested to complete a standardized questionnaire.

#### System Hardware

The system hardware was selected during the fall of 1991 jointly by NSMRL and PHS. Specifically, the hardware was sized to fit on the newer SSBN's. The system included a large internal hard drive to accommodate additional software either developed or procured from commercial medical software providers. In addition to the large hard drive, the system included an internal CD-ROM (Compact Disk-Read Only Memory) drive. The CD-ROM was selected as the mass storage device to be used in the evaluation of electronic medical reference systems and other medical data bases. The computer workstation consisted of:

- 80386-33 MHz CPU with 64kb Cache
- Standard AT case with 5 drive bays
- 4 MB RAM (80ns) expandable to 16Mb on motherboard
- 330Mb SCSI Hard Disk Drive
- 1.2Mb, 5.25" Teac Floppy Drive
- NEC 680Mb Internal SCSI CD-ROM Drive
- 250Mb Internal Tape Drive
- 9600/2400 Internal Sendfax/Modem

- 14 Inch Super VGA Monitor
- Hewlett-Packard LaserJet<sup>TM</sup> IIIP Printer
- Logitech Space-Saver Mouse

#### Software Components:

a. Diagnostic System. The medical decision support tool at the heart of this software configuration was the program DxPlain<sup>TM</sup>. This program was developed by the Massachusetts General Hospital Laboratory of Computer Sciences as a continuing medical education tool. This program was only available on mainframe computers until placed on the Black Boat systems. DXplain<sup>TM</sup> continues to be used on mainframe computers where personal computer users access the mainframe through modems<sup>45</sup>. DXplain<sup>TM</sup>'s knowledge base is extremely large, consisting of over 2000 disease descriptions and greater than 4700 patient descriptors (signs, symptoms, laboratory tests, etc)<sup>46</sup>. The program covers more diseases than are discussed in most textbooks of medicine. However, as noted by its developers, DXplain<sup>TM</sup> may be incomplete in certain areas. For example, there is only a limited coverage of dermatologic diseases, where diagnosis often depends on the visual appearance of the lesion<sup>47</sup>. The knowledge base is continuously updated based on comments of users who are experts in various areas of medicine.

DXplain<sup>TM</sup> operates by allowing a user to enter clinical terms such as signs, symptoms, physical findings, and laboratory results. Based on this clinical complex, the program then produces a ranked list of diseases associated with these findings. The user may also request information on a particular disease, request information about diseases associated with a particular finding, and submit

a differential diagnosis for analysis. The program occupies approximately 30Mb of hard disk space.

b. Reference Material. Medical references are located on both CD-ROM disks and the computer's hard drive. The CD-ROM's supplied by CMC Research Inc. under the trade name DiscPassage<sup>TM</sup> included the "1989-1991 Year Books of Medicine" from Year Book Medical Publishers, Inc., the "American Family Physician" by the American Academy of Family Physicians, and the "New England Journal of Medicine" were supplied.

This particular reference system was selected after independent duty corpsmen were asked to compare several competing systems in terms of functionality and ease of use. The corpsmen felt that DiscPassage<sup>TM</sup> was the most usable of the programs tested. This program also retrieved text considerably faster than the other programs.

DiscPassage<sup>TM</sup> allows a user to search reference material on CD-ROM's utilizing simple boolean logic. A user may search for titles of articles, topics, or for individual words contained in the text.

So that additional references could be placed on the system, the Public Health Service purchased the rights to utilize the CMC Research Inc. DiscPassage<sup>TM</sup> search engine. After converting medical and operational documents into an ASCII format, NSMRL and PHS succeeded in indexing and interfacing these materials with the CMC Research search engine. Two additional reference texts were placed on the hard drive of the Black Boat computer. These were the "General Medical Officers Manual" and "Communicable Diseases in Man."

c. Utility Software. The utility software consists of work station software, proprietary general-purpose commercial software, and Department of Defense software. Specific utilities included:

**Work Station Software:**

- Micronetics standard MUMPS Version 3.0.0
- MS-DOS, Version 5.0 (distributed by Phoenix)
- JUMBO Tape Backup software (Colorado Memory Systems)
- Quick Link II<sup>TM</sup> Communications/FAX software (Practical Peripherals)
- Device Drivers for SCSI Host Adapter (Data Technology Corporation)
- Utilities and Device Drivers for Orchid ProDesigner II VGA adapter
- Utilities and Device Drivers for the Logitech Trackball
- Utilities and Device Drivers for the Z-Nix Mouse

**Proprietary General-Purpose Commercial Software:**

- WordPerfect<sup>TM</sup>, Version 5.1
- PC Tools<sup>TM</sup>, Version 7.1
- Laplink Pro<sup>TM</sup>, Release 4

**Department of Defense Software:**

- HMCM (Hazardous Material Control and Management)
- HMIS (Hazardous Materials Information System)

Enhancements.

Several additional products underwent preliminary evaluation during the test period

of the Black Boat Alpha configuration. All of the programs tested were compatible with the other software on the system. These programs include:

1. Micromedix's CCIS<sup>TM</sup> (Computerized Clinical Information System) - This CD-ROM was installed by Micromedix for evaluation. CCIS<sup>TM</sup> provides several modules which are particularly strong in the area of emergency medicine.
2. Teton Data System's STAT!-REF<sup>TM</sup>. A Window's based CD-ROM which contains both medical texts and journals. Of special interest to corpsmen were the various Lange textbooks in topics such as emergency medicine, internal medicine, and general surgery.
3. SAMS (Snaps Automated Medical System) Version 7.0 - The most recent release of SAMS was successfully integrated under the Black Boat shell. This program provided additional administrative capability to the informatics system.

Additional enhancements were considered during the trial. Several Navy specific medical and operational medical reference materials (including various instructions and manuals) were identified as of potential benefit if transferred to electronic media. A longitudinal medical record which could track individual medical encounters would be an important function if it could be successfully integrated with the other modules. Training capabilities of the system could be expanded without a large effort. With the increasing popularity of Microsoft Windows<sup>TM</sup> over the past year, this program deserves consideration as a way of standardizing the user interface.

### Initial Evaluation.

Through feedback obtained from a small number of questionnaires returned and personal communication between the investigators and the users, broad generalization can be made concerning the alpha-configuration. Most users approved of the hardware design and felt that the system was capable of providing a continuing medical education function. The users were unanimous in their desire for medical reference materials on CD-ROM or other mass-storage devices. There continues to be resistance to the use of diagnostic programs, but when a system such as DXplain<sup>TM</sup> is presented as an education aid, there is much greater acceptance. Involvement of the end-users in every phase of development would lead to greater approval of any medical informatics system. This project ended with the termination of this work-unit at the end of FY 92.

### Conclusions

This report outlined the history of computer assisted medical diagnosis at NSMRL and presented major results of these efforts. A historical record would be useful to individuals interested in tracing the development of these systems in the submarine community because several areas are poorly documented.

All work occurring under this work unit was terminated at the end of FY 92 for many reasons. Although several of these programs have been released by the Commanding Officer of NSMRL, they have *not* been approved for general distribution by a higher authority such as the Surgeon General of the Navy. Therefore, it has not been possible to distribute these programs on a widespread basis, resulting in frustration for program managers, users, and developers. Additional-

ly, it has not been feasible for a small research facility to upgrade and maintain these programs properly.

Much of the difficulties encountered in the development of medical diagnostic aids (a problem not unique to the military) occur during the validation phase. It is necessary to obtain a large amount of *high quality* clinical data to test these programs. This is both a time consuming and expensive process that is often not considered in the long-range development planning of these programs. The validation procedure is imperative and diagnostic programs should not be distributed before this process has been satisfactorily completed.

Future efforts in this area should concentrate on the delivery of updated and relevant medical information to health care practitioners in remote duty station. Advances in high capacity electronic media have made storage and delivery of vast amounts of medical and operational information possible, and prospects for the future are even brighter. Tools (software and hardware) to speed the development of diagnostic systems are available. By incorporating existing technology, the high costs of independent development and long time periods between program conception and delivery can be lowered. End-users must be involved in *all* stages of the development cycle to ensure success and acceptance of any diagnostic system.

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## REPORT DOCUMENTATION PAGE

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| <p>Independent duty hospital corpsmen assigned to submarines are normally the sole provider of medical care for the crew. Corpsmen with varying levels of experience and training must make diagnoses with limited diagnostic tools and without expert consultation. A medical evacuation (MEDEVAC) can potentially expose a submarine's position, is hazardous to both the patient and the rescuers, especially in high sea states, and is expensive because it entails the movement of large numbers of ships, aircraft and men. For these reasons, the Naval Submarine Medical Research Laboratory (NSMRL) was tasked in the 1970's with developing computerized diagnostic aids for these corpsmen with the goals of reducing the number of unnecessary medical evacuations and improving the quality of health care at sea.</p> <p>This report details the history and development of the computer assisted medical diagnostic aids at this laboratory and would be of benefit to individuals or Commands interested in continuing this type of work. Several of these programs have been approved for distribution by the Commanding Officer, NSMRL, and may be obtained by request.</p> |       |                                        |                                                                                                                |                                                                                          |                                                          |
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