

ADAPTATION OF A COMPUTER-ASSISTED DIAGNOSIS PROGRAM
FOR USE BY HOSPITAL CORPSMEN ABOARD NUCLEAR SUBMARINES

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Abstract

Acute illness occurring aboard a patrolling nuclear submarine is costly in terms of risk to the patient, the expense of evacuation, and compromise of national defense (if the submarine's mission must be terminated). There are currently no physicians assigned to submarines and medical responsibilities are borne by a senior enlisted paramedic who is a Hospital Corpsman especially trained for submarine duty. However, in spite of this advanced training, their clinical experience is not optimal since their duties are largely administrative. A microcomputer-based medical information system is being developed to assist Corpsmen in dealing with acute illness aboard submarines. Primary emphasis has been placed in the area of diagnosis since this is likely to result in a) appropriate therapy and b) a decrease in unnecessary evacuations. A system developed for use by physicians at the University of Leeds, England accurately diagnoses acute abdominal pain. We have modified the system for use by Hospital Corpsmen testing in a Naval hospital emergency room. We found that with proper training, Corpsmen diagnose abdominal pain as well as surgical residents. Also such a system used aboard submarines might reduce unnecessary evacuations by 50%.

Introduction

Evacuation of an ill crew member from a nuclear submarine at sea is a costly event in three ways. First, since evacuation can profoundly interfere with the mission of nuclear submarines, our national security is affected, especially in the case of fleet ballistic missile (FBM) submarines, primary deterrents to nuclear attack by other powers. Second, evacuation, especially in heavy sea states, is dangerous both to rescuers and those being rescued. Finally, evacuation can be expensive, since movement of large groups of ships and men are sometimes involved. Thus, the decision to evacuate is a difficult one and the Commanding Officer of the submarine must rely heavily on the medical advice he is given. The problem is compounded on FBM submarines, where radio silence must be maintained and outside medical advice cannot usually be sought until after the decision to evacuate is made; the decision to evacuate must be based on the advice given by the medical consultant on board the submarine.

Since 1972, physicians have not been regularly assigned to our nuclear submarines. The medical responsibilities on board submarines have been assumed by paramedics, senior enlisted Navy Hospital Corpsmen. All Hospital Corpsmen assigned to submarines have been given a six month special course of instruction at the Naval Undersea Medical Institute, New London, CT. Some have received further training at one of the Navy's "Independent Duty" schools where they are trained to function in isolated areas where no physician is immediately present. However, clinical abilities of these Corpsmen to deal with serious illness may not be adequate in view of the unique situation of the submarine mission. This is due to several factors: 1) the career pattern for hospital corps personnel involves early transfer from clinical to administrative duties in the majority of cases, thus minimizing clinical experience; 2) advanced training for both submarine and independent duty Corpsmen is largely didactic with little opportunity for patient contact; 3) due primarily to the heavy deployment commitments of nuclear submarines, opportunities for continuing medical education in formal courses are practically nil; 4) since submarine crews are medically well screened, there is a low incidence of disease and thus opportunities to gain or maintain clinical judgment and skills are decreased. Thus, the Submarine Corpsman, by the constraints of his career pattern, his lack of clinical exposure in his advanced training, and lack of opportunities for continuing medical education, has had little occasion to acquire the clinical judgment essential to making the difficult medical decisions he may face. It is not surprising that problems exist, especially in the area of unnecessary evacuations from submarines.

At our Laboratory, we are attempting to help alleviate these problems by providing an on-board computer-based medical support system for the Submarine Corpsman. In its eventual form programs will be written to help in two main areas: to attempt to compensate for clinical inexperience by providing programs for real-time patient management, including diagnosis, prognosis, and treatment of common serious medical problems such as abdominal and chest pain; and to provide computer-assisted instruction for continuing medical education while on patrol (e.g. in

cardiopulmonary resuscitation) and to complement the patient-management programs (e.g. simulation of patients with acute abdominal pain).

Since patients with acute abdominal pain are those most commonly considered for evacuation¹, we began our efforts in this area. In our survey of the literature we found one system with demonstrated clinical effectiveness in the area of abdominal pain. The system, developed by deDombal et. al. at the University of Leeds², is ideally suited to our purposes since computer-aided diagnosis is made without laboratory tests, can be implemented on a micro-computer, and has been shown to have a diagnostic accuracy (91%) exceeding that of senior clinicians (82%)². Dr. deDombal and the University of Leeds have provided our Laboratory with copies of this program and data base, which we have adapted for use by Navy Corpsmen aboard submarines.

The Leeds abdominal pain program has been shown to accurately diagnose abdominal pain if data are gathered by physicians. This paper presents initial results of a study to determine diagnostic accuracy of a system adapted from the Leeds program using data gathered by non-physicians, i.e. Navy Corpsmen trained for "independent duty".

Methods

The computer-aided diagnosis program from Leeds was adapted and programmed on a Tektronix 4051 desk-top computer with 32 kilobytes of RAM and an internal 3-M cartridge magnetic tape capable of storing up to 300 kilobytes. This computer was selected primarily because it is already aboard nuclear submarines for other applications. Additional programs have been devised to provide computer-generation of data sheets for gathering patient information, definitions of history and physical examination terms used on the data sheets, and instructions for using the system.

Figure 1 is a flow chart showing the method used in making a computer-aided diagnosis. After the computer generates data sheets (shown in Figs. 2 and 3), the Corpsman examines the patient and fills in the necessary information. He then returns to the computer which loads into memory a data base consisting of an attribute-disease matrix compiled by deDombal's group from patients with abdominal pain admitted to a surgical service. After the Corpsman enters patient identification information, the computer displays sections of the data sheets with code numbers for each attribute listed. As each code number appropriate to the patient is entered, the computer displays its name for verification by the Corpsman. If the Corpsman enters a wrong attribute, he simply re-enters the mistaken code. The computer removes that attribute from the probability calculations and informs the user that the attribute has been "taken out" (See Fig. 4). Probabilities are calculated

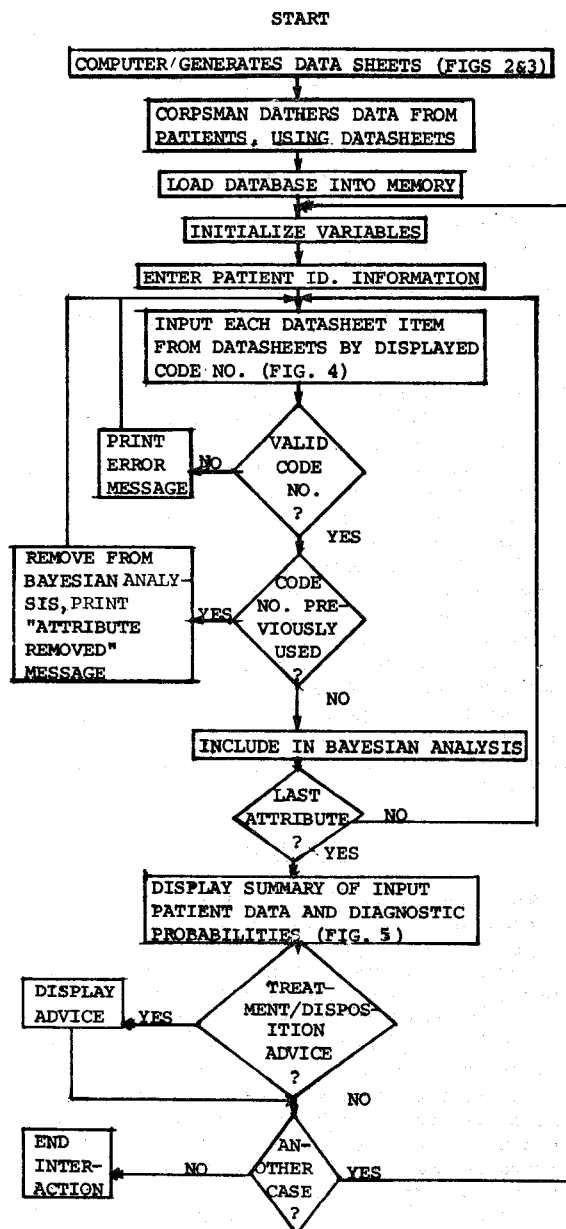


FIG. 1. Flow chart of steps used in computer-aided diagnosis by Corpsmen

DATASHEET: Acute Abdominal Pain---
PAGE 1- History

Patient SSN: 1600 78 JUN 07
Time/Date: 1600
Age: 18

PAIN

SITE: TYPE AT ONSET: INTERMITTENT/STEADY COLICKY
TYPE AT PRESENT: INTERMITTENT/STEADY COLICKY
SEVERITY: MODERATE SEVERE
PROGRESS: BETTER/ SAME WORSE
DURATION: 12h 12-24h/24-48h/48+h

AGGRAVATING FACTORS: MOVEMENT COUGH BREATHING/FOOD/OTHER/NONE

RELIEVING FACTORS: LYING STILL VOMITING ANTACIDS FOOD/OTHER/NONE

OTHER SYMPTOMS NAUSEA: YES NO VOMITING: YES NO
APPETITE: DECREASED NORMAL JAUNDICE: YES NO
BOWELS: NORMAL CONSTIPATED/DIARRHEA/BLOOD IN STOOL/MUCUS IN STOOL
URINATION: NORMAL/FREQUENCY PAINFUL DARK URINE/BLOOD IN URINE

PAST HISTORY PREVIOUS INDIGESTION: YES NO
PREVIOUS SIMILAR PAIN: YES NO PREVIOUS SURGERY: YES NO
PREVIOUS ILLNESSES: YES NO (Comment on pertinent on back)
TAKING MEDICATIONS: YES NO (Physical Exam on next sheet)

FIG. 2 Datasheet for taking history

DATASHEET: Acute Abdominal Pain---
PAGE 2-Physical Exam

Patient SSN: 1600 - 78 JUN 07
Time/Date: 1600

VITAL SIGNS TEMP- 99.8 PULSE- 100 BP- 80/120 RESP- 18

GENERAL EXAM

MOOD: NORMAL/DISTRESSED ANXIOUS
COLOR: NORMAL PALE FLUSHED/JAUNDICED/CYANOTIC

ABDOMINAL EXAM

INSPECTION: NORMAL VISIBLE PERISTALSIS/DECREASED RESPIRATORY MOVEMENT
SCARS: YES NO DISTENTION: YES NO
REBOUND: YES NO GUARDING: YES NO
RIGIDITY: YES NO MASSES: YES NO
MURPHY'S SIGN: PRESENT ABSENT
BOWEL SOUNDS: NORMAL/DECREASED OR ABSENT HYPERACTIVE
RECTAL EXAM: NORMAL MASS FELT/GUAIAC TEST FOR BLOOD POSITIVE
TENDERNESS- ON LEFT/ON RIGHT/GENERAL



FIG. 3 Datasheet for physical examination

HISTORY: Abdominal Pain---

SITE AT- RUQ(11) LUQ(12) RLQ(13) LLQ(14) UPPER1/2(15) LOWER1/2(16)
ONSET

RT.HALF(17) LT.HALF(18) CENTRAL(19) GENERAL(20)
RT.FLANK(21) LT.FLANK(22) NONE(23)

SITE AT- RUQ(24) LUQ(25) RLQ(26) LLQ(27) UPPER1/2(28) LOWER1/2(29)
PRESENT

RT.HALF(30) LT.HALF(31) CENTRAL(32) GENERAL(33)
RT.FLANK(34) LT.FLANK(35) NONE(36)

TYPE AT- INTERMITTENT(56) STEADY(57) COLICKY(58)
ONSET

TYPE AT- INTERMITTENT(59) STEADY(60) COLICKY(61)
PRESENT

ENTER SYMPTOM CODES (Key RETURN for next section):

CODE: 19	CODE: 61
PAIN ONSET CENTRAL	PAIN NOW COLICKY
CODE: 26	CODE:
PAIN NOW RLQ	
CODE: 26	
PAIN NOW RLQ	(OUT)
CODE: 32	
PAIN NOW CENTRAL	
CODE: 58	
PAIN ONSET COLICKY	

FIG. 4 Computer display for entering patient data. Upper half of screen gives code numbers for data on corresponding section of datasheets. Bottom half of screen allows Corpsman to check that entry is correct.

PATIENT SSN:

TIME/DATE ENTERED: 1600/78JUN07

SYMPTOMS

<p>MALE AGE 10-19 PAIN ONSET CENTRAL PAIN NOW CENTRAL MOVEMENT AGGRAVATES COUGH AGGRAVATES REL. BY LYING STILL ANTACIDS RELIEVE PAIN NOW WORSE PAIN DUR <12h PAIN ONSET COLICKY PAIN NOW COLICKY PAIN NOW MODERATE NO NAUSEA NO VOMITING APPETITE DECREASED NO PREV INDIGESTION NO JAUNDICE BOWELS NORMAL</p>	<p>DYSURIA PRESENT NO PREV SIMILAR PAIN NO PREV ABD SURGERY NOT TAKING MEDS MOOD: ANXIOUS COLOR: PALE ABD INSPECT NL NO ABD SCARS ABD IS DISTENDED GENERAL TENDERNESS REBOUND PRESENT GUARDING PRESENT NO RIGIDITY NO ABD MASS NEGATIVE MURPHY'S HYPERACTIVE BNL SOUNDS RECTAL EXAM NL</p>
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 APPEND	 DIVERT	 PERFDU	 NONSAP	 CHOLE	 SMOBS	 RCOLIC	 PANC	
 98.38	 0.02	 0.02	 1.51	 0.01	 0.14	 0.00	 NO PROBI	

FIG. 5 Computer display summarizing data input from datasheets shown in Figs. 2 and 3. Diagnostic probabilities are shown as a percentage. Computer "diagnosis" in this case was appendicitis. This was verified at the time of surgery.

using a Bayesian³ approach. When the last item of data is entered, the computer displays a summary of patient identification information, attributes ("symptoms") entered, and the probabilities for each of the diseases considered in the differential (Fig. 5). As shown at the bottom of Figure 5, these diseases are Appendicitis, Diverticulitis, Perforated Duodenal Ulcer, Non-specific Abdominal Pain (e.g. gastroenteritis, mesenteric adenitis, negative laparotomy), Cholecystitis, Small Bowel Obstruction, Renal Colic, and Pancreatitis. Note in Figure 5 that there is no probability given for Pancreatitis; the data base for this disease is under development.

Clinical trials of this system are being conducted at the Emergency Room at Balboa Naval Hospital, San Diego, CA, using students of the Independent Duty Technicians (IDT) School, Health Sciences Education and Training Command, San Diego. IDT students are given about eight hours of instruction in the use of this system. Approximately 45 minutes are spent in familiarization with the computer. The remainder of the period is spent in carefully defining data sheet items, especially emphasizing the best means of accurately eliciting information from the patient. Participating Corpsmen are in the last phase of IDT school during which they rotate for two week periods in the Emergency Room of the nearby Naval hospital. Patients who have abdominal pain, not previously diagnosed and lasting less than seven days are entered into the study. When possible, the IDT student is the first to evaluate the patient. Either during or immediately after the patient interview, he completes the data sheet on the patient and, only after disposition of the patient has been made, he enters the case into the computer. Determination of final diagnosis in admitted patients is made from discharge diagnosis, pathological diagnosis, and/or definitive laboratory tests; for those patients not admitted, with the exception of those cases where diagnosis is made without hospitalization (e.g. by laboratory studies, radiographically, etc.), passage of a 12 week period without a subsequent visit to the Naval hospital will establish a diagnosis of "Non-specific Abdominal Pain." This is probably an adequate means of follow-up since all significant disease in Naval personnel in the San Diego area is referred to Balboa Naval Hospital. However, given the nature of our military population, it is likely that a few of our patients may be transferred from the area during the period of the study. When sufficient patients have been entered into our study, we will check our records against military change-of-station records at the Bureau of Naval Personnel.

After final diagnosis has been determined, diagnostic accuracy of computer-aided Corpsmen is determined by comparing the computer-generated "diagnosis", taken as any probability exceeding 50%, to the final

diagnosis. A diagnosis of "Non-specific Abdominal Pain" is recorded as the computer "diagnosis" when no disease probability exceeds 50%.

Results

Figure 6 compares the diagnostic accuracies of physicians and computer-aided Navy Hospital Corpsmen. On the left, physicians and surgeons in Leeds, evaluating 552 patients without use of a computer between January 1971 and August 1972, had diagnostic accuracies ranging from 42% to 81% depending on their level of training². Navy physicians and surgeons at the Emergency Room, Balboa Naval Hospital, evaluating 88 patients without use of a computer had diagnostic accuracies of 77%; levels of training within this group ranged from intern to attending physician. On the right are shown the diagnostic accuracies of the first (Class 78-7) and second (Class 78-8) groups of Corpsmen participating in this study, 48% and 70%, respectively, with a combined diagnostic accuracy of 61%.

Figure 7 shows diagnostic accuracies if we consider only whether an illness requires evacuation or not, for Classes 78-7, 78-8, and both classes combined. As currently programmed, the computer recommends evacuation in cases of appendicitis, perforated duodenal ulcer, and small bowel obstruction; all other cases are to be treated aboard the submarine unless complications develop. Thus, had these patients presented aboard a submarine and had the recommendation of the computer been followed, the appropriate management (AM) would have been made by Class 78-7 in 68% of the cases, by Class 78-8 in 75% of the cases, and by both classes combined in 73% of the cases. Inappropriate evacuation (IE) would have occurred 29% of the time for Class 78-7, 20% of the time for Class 78-8, and 23% of the time if both classes are considered. Finally, a few of the patients would have been inappropriately held (IH) aboard the submarine: 3% of the time for Class 78-7, 5% of the time for Class 78-8, and 4% of the time overall.

Discussion

The initial IDT group (Class 78-7) comprised a learning period for all involved in the study; we were unfamiliar with the strengths and weaknesses of this system and had no real idea of level of training and clinical judgment held by the IDT students. We applied the experience we gained in the first group to the training of the second group.

Significant increases in diagnostic accuracy occurred between the first and second groups of IDT Corpsmen, with the second group equalling the performance of house surgeons at Leeds and approaching the accuracy of physicians and surgeons at a major Naval hospital. Although we are encouraged with these results we have identified significant problems in the area of Corpsman training. The performance of the first

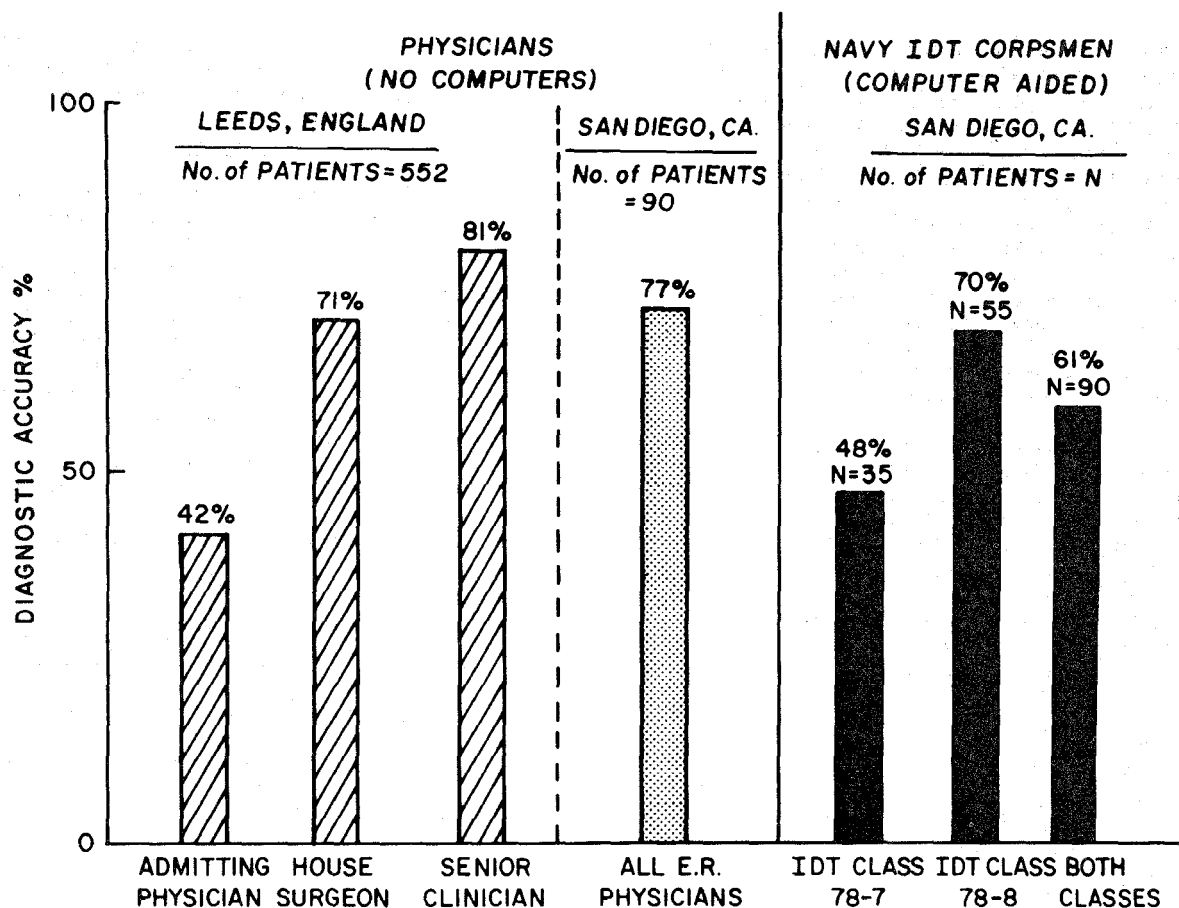


FIG. 6 Comparison of the diagnostic accuracies of physicians in England² and in San Diego with computer-assisted Navy Corpsmen. Accuracy of English physicians is presented at different levels of training. The San Diego physicians accuracy is an average for Navy physicians at different levels of training (intern to attending physician), who evaluated the patients in our study. IDT Class 78-8 received classroom instruction with emphasis on areas of patient assessment determined from experience with Class 78-7 to be prone to misinterpretation.

FIG. 7 Presentation of diagnoses according to whether the condition would have required evacuation from a submarine at sea or not. Percentages reflect percentages of patients who might have been appropriately managed (AM), inappropriately evacuated (IE), and inappropriately held (IH). See legend of Figure 6 for differences between IDT Classes I and II.

		CLASS 7-78			
COMPUTER DX	HOLD	1	19	AM - 68%	
	EVAC	5	10	IE - 29%	
	EVAC, HOLD			IH - 3%	
		FINAL DX			
		CLASS 8-78			
COMPUTER DX	HOLD	3	32	AM - 75%	
	EVAC	9	11	IE - 20%	
	EVAC, HOLD			IH - 5%	
		FINAL DX			
		OVERALL			
COMPUTER DX	HOLD	4	51	AM - 73%	
	EVAC	14	21	IE - 23%	
	EVAC, HOLD			IH - 4%	
		FINAL DX			

group especially emphasizes the dependence of the computer system on the accuracy of information entered by the Hospital Corpsman. From our analysis of questionnaires, and comparison between Corpsman data sheets and patient evaluation performed by physicians, it is clear that there are significant gaps in the clinical knowledge and experience of graduating IDT Corpsmen. Many IDTs have particular difficulty assessing those signs and symptoms which most depend on clinical judgment, e.g. severity of pain, sites of pain and tenderness, rebound tenderness, bowel sounds, rectal examination. Traditionally, clinical judgment is gained through experience with patients. As discussed above, submarine and IDT Corpsmen have few opportunities for contact with seriously ill patients. They thus have little occasion to acquire and maintain clinical judgment. From the results shown in Figure 6, however, it appears that a relatively short period of didactic training with emphasis on proper data acquisition can significantly improve computer-aided diagnostic accuracy. The computer in turn appears to partially compensate for deficiencies in clinical experience in Navy Corpsmen. Although these results are encouraging we are cautious in judging these trends since the number of patients for each class is small. Also, deDombal² has reported that the accuracy of computer-aided diagnosis (91%) exceeded that of senior clinicians if data entered into the computer are gathered by surgeons. It is likely that with additional opportunities to gain clinical judgment, Corpsmen could further improve their performance, and, with computer assistance, could conceivably diagnose acute abdominal pain as well as or more accurately than physicians. In order to improve on our training program, we are currently engaged, with the Navy's Health Sciences Education and Training Command, in developing an abdominal pain instruction module using video tapes and computer-aided instruction.

Actual experience with Corpsmen aboard submarines reveals a problem with unnecessary evacuation, especially in the area of appendicitis. In the past two years, approximately 50% of patients evacuated for appendicitis were found not to have appendicitis⁴. Since most of the patients entered into our study had either appendicitis or non-specific abdominal pain, we can estimate from Fig. 7 that computer-assisted diagnosis might have decreased that figure to about 25%; i.e. the unnecessary evacuations from submarines for abdominal pain would have been halved.

With regard to the number of patients who would have been inappropriately held aboard, this comprises a false negative rate of 3-5%, on the same order as the appendicitis false negative rate (3-4%) of Leeds senior clinicians². In addition, it is likely that as the patients' illness progressed the diagnosis would become more obvious and evacuation would ensue. Nevertheless we are concerned about this problem and are currently collaborating with deDombal's group at Leeds in the development of a database for the early detection of appendicitis in our population.

The decision to evacuate suspected emergencies is a problem whenever a physician is not available: in rural areas, especially in less developed countries, surface ships and off-shore oil platforms, etc. On the other hand, personnel with medical training are often found in such situations

The results in this paper suggest that a computer-based diagnostic program, originally developed for use by physicians in a hospital setting, can be adapted for use by paramedics and nurses in more demanding environments. Since the system is microcomputer-based and since training programs in its use could be of relatively short duration, the cost-effectiveness of such a system might be quite reasonable. In addition, the requirement of this diagnostic approach for organization of patient information might greatly facilitate communication of data to medical experts, e.g. a simple probability or "symptom" list could replace a lengthy two-way exchange of instruction and information. The result might be a significant impact in the cost and quality of health care delivered.

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Disclaimer

The opinions in this paper are those of the authors and do not necessarily reflect the views of the Navy Department at large.

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