20. PROBLEMS AND PRIORITIES FOR HEALTH CARE TECHNOLOGY

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At the present time the physician plays the prime role in the delivery of health care. Although this role may change in the next few years, it seems doubtful that technological development will displace the physician as the prime confidant of the person who is sick and needs help. With the introduction of new technology into the practice of medicine, we must consider the role of the doctor, since his role must remain challenging and rewarding if medicine is to continue to attract the best possible candidates.

In recent years applications to medical school have far exceeded the positions available. Perhaps we should ask what has made medicine so attractive as a career. I believe there are four factors: first, the responsibility and the power of making life and death decisions regarding a patient and his illness; second, recognition by society and, in particular, by patients and fellow workers; third, the independence that comes from self-sufficiency; and finally, a financial reward that permits him to live comfortably without real worry about material needs.

Technology has already provided many tools for extending the physician's powers of observation and making more effective his role as a therapist. A few of these include the microscope, the stethoscope, the fluoroscope, the oscilloscope, and the spectrophotometer, all of which provide tools for data acquisition, but at the same time these instruments have contributed significantly to the noise level. It is only through experiment and experience with these tools that the signal is being differentiated from the noise sufficiently well to make them useful to the practicing physician. In fact, the excellence of the physician is best judged by his ability to perform this filtering of signal from noise in data representing his patient and coming from a variety of sources. To this point in time, however, it is certainly true that development of tools for data acquisition has far outstripped the development of useful tools to assist the physician with interpretation of his data.

The role of technology in providing the clinician with help in his role as a therapist needs little comment. Modern anesthesia contributes techniques for the control of respiration, muscle tone, analgesia, circulation, and even amnesia to make possible the exploration and surgical modification of even the remotest body component. Even here, however, many problems still exist. It has been said that when a patient is put on the heart-lung bypass machine, he starts to die. The statement is based on the fact that surgical mortality indeed is related to the time the patient is on the bypass. Clearly, much needs to be done before the bioengineer can truly claim to control the internal environment with his artificial devices as well as normally functioning organs do. Progress here will be limited by our understanding of the intricacies of the physiological control mechanisms more than by our ability to build devices to simulate what we know of them.

I have organized my comments about the future into the four categories of data acquisition, data analysis and decisionmaking, communication, and control because I think these are the four areas where studies already under way provide good examples of what we may expect in the next few years from technology in the practice of medicine.

The acquisition of data from a transducer attached directly to a patient provides many advantages, particularly if that transducer does not require human intervention for each reading. For example, direct recording of the intra-arterial pressure by an indwelling catheter allows measurements to be made directly into a computer that can test for validity of the signal and trends in the data and can derive through indirect calculation other variables such as stroke volume and peripheral resistance, which might be difficult to obtain otherwise on a routine basis. It is important that the measuring tool not unduly disturb the patient or alter his physiological state. For this reason it seems likely that many direct methods for measuring physiological state will be used primarily to calibrate new and less traumatic indirect methods from which the desired data can be derived by the use of clever computer algorithms and statistical methods.

Eighty percent of all diagnoses are still made from information supplied by the patient himself. The goal of the self-administered history research currently under way in this country is to minimize the amount of time needed by the physician to assimilate and digest the patient's complaints. Some investigators have attempted to direct the questioning under program control to minimize the total number of questions asked while at the same time acquiring sufficient information in those areas where the patient has real complaints. As with any data-gathering tool that involves people, the success of any such new method will depend upon two things: first, whether it is easier to use than the old method; and second, whether the information derived from the new method has facilitated solving a particular problem, in this case making a diagnosis or a prognosis or other decisions related to management of the patient. The only hope for the on-line approach is that the computer indeed provides enough information not only to guide the questioning process intelligently but also, to utilize available medical logic fully to suggest explicit decisions based on the data collected.

As an example, we have developed a history-taking system based on conditional probabilities. A matrix was generated containing questions that a patient with any one of the specified diseases would probably answer affirmatively. Five questions are presented on a television screen in a patient's room. He can answer yes to one or more of these by pressing the corresponding numbers on the touchtone pad of his telephone. From the answers to the first five questions, the computer estimates the probability that the patient has any one of the possible set of diseases. Then, using the two most likely diseases, the next set of five questions is chosen. In this way questioning proceeds until either a diagnosis is established or all pertinent questions have been asked. The program then proceeds to another set of key questions representing another group of diseases.

From this program the physician is provided with not only a list of the questions asked and the answers given but also suggestions of the diagnostic implications of these answers. This type of application, in which the computer does some of the intellectual work rather than just stores and retrieves data, will provide the justification for the computer as an integral part of the medicine of the future.

An active terminal such as this is also being used in other areas of the hospital where vital information must be gathered. Programs have been developed that permit the physician to interact directly with the computer in a convenient fashion to enter diagnoses, using an expanded version of SNOP (Systematized Nomenclature of Pathology). The physician, dealing only with key words, begins by entering the first two letters of one of the words, such as HE for heart. The computer quickly searches its directory for terms beginning with HE. If a small enough number are found to allow presentation on one page of the terminal, the list is presented and the physician proceeds to choose the item of interest. If not, the system waits for the third letter and repeats the search. Since physician diagnosis presents a key element at several stages of the health care process; namely, admission, preoperative, postoperative, discharge, and tissue diagnosis, this program has wide applicability and represents the keystone of the medical record. Current interest in peer review and quality control clearly must rely on a computer record if it is to incorporate sufficient detail and ready accessibility to perform an adequate job. Integration of outpatient records with hospital data is already under way in several locations. Once again, however, even in this audit function, the computer's most important role will be as a means for storing a logical model of medical management against which actual performance of the health care team may be evaluated.

Several types of medical data are currently acquired in the form of two-dimensional arrays. Technology may play its most important role by providing systems that can effectively handle this kind of data and reduce it to a form in which it can be readily integrated with other medical data for decisionmaking. I will describe an example of such an undertaking from the field of cardiology.

With the advent of definitive surgical approaches for the repair of cardiovascular abnormalities and more recently the surgical correction of inadequate coronary perfusion, attention has focused on the evaluation of myocardial function. To accomplish this, radio-opaque dye is injected into the left ventricle and the angiocardiographic image on the fluoroscope is detected by a video camera and recorded at 60 fields per second on a video disc. A computer program controls the injection and stores the field count and left ventricular pressure values for later correlation. At the end of the recording, the computer replays the disc and stops at the first frame following the onset of systole as determined from the left ventricular pressure wave. The operator sitting at a console views the picture of the ventricle replayed from the disc on a television monitor. By moving a "mouse" on a flat surface, he positions a cursor on the TV monitor image to define the first approximation to the left ventricular borders. The computer then digitizes the video signal in the vicinity of these approximate border coordinates and uses a statistical algorithm to determine the actual border. From here on the computer proceeds automatically to bring up the next frame and uses the actual border on the last field to define the first approximation to the border of this new field. In this way all of the pictures during a single systole are analyzed.

Following this, the border coordinates are transformed to a radial coordinate system measured from the centroid of the heart shadow on each frame. The correlation of each radius at a particular angle throughout systole with the area of the left ventricular shadow is plotted as a function of the angle of the measurement at each 5 degrees. This provides a measure that is consistent for a given plane among normal subjects but will separate these from similar measurements made from patients who have had myocardial infarction and resulting disorders in contractile sequence. This same technique is suitable for analysis of signals other than X-ray, such as ultrasound echos, which also require high-frequency data-handling methods.

Other forms of two-dimensional data may show only slowing, changing, or even stable images but present an even greater challenge because of their complexity. Certainly two-dimensional pattern recognition will be a productive area for study and, hopefully, a fruitful source of improved medical services in the years ahead.

An important difference in doctors that accounts for much of the highly publicized unevenness in quality of care in the United States is the performance of the doctor as a diagnostician and decisionmaker. What can technology provide for the physician that might improve his performance in this role?

For 5 or 6 years we have been actively involved in testing a variety of computer programs designed to help the physician or surgeon provide better care for acutely ill patients in an intensive care ward. We have learned that automated sampling of physiological variables under computer control and detection of trends with display of this information in graphical or summary form is only part of the answer. A difficult task facing the physician or nurse involves the integration of clinical, laboratory, and physiological information into a form that will permit recognition of decision criteria appropriate to the situation. We have developed a program called HELP that permits the physician, once having specified the type of data upon which a decision is based and the algebraic or Boolean combinations of such data which specify the criteria, to store the criteria for this decision in a form that is available to the computer from that time on. Furthermore, any changes or additions in the logic for any decisions can be modified very easily without having to alter the program itself, thus making the tool flexible, under the control of the clinician himself, and able to reflect improvement suggested through his own experience or by medical literature.

When this program was first implemented on our coronary care ward, there was an immediate reaction from the physicians who used it. To be presented with the decision "suggest the patient be given digitalis" was not enough. They wanted to know why the particular decision was made. To do this, an appendix to the program called BECAUSE was developed, which presents the logical set of circumstances that led to the decision to the doctor. The essential ingredient for such a program is a computer-based medical record that files data by patient and permits easy entry from a variety of sources and efficient retrieval of any piece of information by data identifier and time. Also required is a time-sharing system that can be accessed through remote terminals. At least one such system is now operational and is self-supporting from fees charged to hospitals for services rendered directly to patients.

A training program must inevitably be coupled to any new technological development, particularly one that requires from the people using it a significant change in their patterns of behavior. Simulation has proven useful in training pilots and others who must obtain experience with complex systems to make correct decisions the first time in what may be a life and death situation. This approach can be implemented as an integral part of a medical computer system. Such a program, which uses random numbers and tables of probability, has been devised to generate interesting and meaningful data combinations to represent theoretical patients for the nurse, medical student, or physician to practice on during lulls in activity in the intensive care ward. The program not only provides experience in making decisions but also utilizes the same options for data review and display that are available on real patient data from the same terminals. Thus, in a short time the student can gain experience that might take months or years to gain from real patients. Also, of course, this kind of exercise provides experts in program design and medical logic with a valuable tool for detecting flaws in the logic before mistakes occur with a real patient.

Widespread application of many of these technological developments to the areas of medicine where they might have the greatest impact on medical care will depend on improvements in communication. Techniques already exist for accomplishing the communication link required, but costs are the limiting factor. The video phone is already a reality. Coupled to existing technological developments such as the scan converter, the character generator, and the video camera and disc, it makes possible the superimposition on a single display of graphic, alphanumeric, and pictorial information. The selection and multiplexing of such information can already be done under computer control as described earlier in this paper.

An audio response system for almost any medical application requires a large vocabulary. A system has been devised and already tested in a medical application that permits storage of one spoken word in digital form using only 2400 bits per word. The program assembles these words into sentences under computer control and, using a special piece of equipment, regenerates the spoken words. Such a scheme permits storage of a 20,000-word vocabulary at a cost of \$10.00 per day. This permits a standard touch-tone or dial telephone to act as the only input-output device to the computer and provides a means for extending several of the services just described not only to doctor's offices but even to the patient's home.

Automated closed-loop control of treatment under some circumstances is already being attempted. Nonlinearities and complexities of the physiological component of such a closed loop provides the most challenging area for study before precise control of physiological functions with these systems will be possible. Particularly in the control of artificial organs, interface with human tissue both on the sensing and controlling end remains the challenge. In the case of the artificial hand, much progress has already been made.

In summary, it is apparent that new techniques for data acquisition will mean that others in the health care team will share some of the physician's responsibility for the control and practice of medicine. On the other hand, new communication methods will give the physician tools through which others, even quite remote, can be of assistance. The physician will then represent a team and a system when he confronts the patient with the results of a decision and will have the added confidence of knowing that others before him have made the same decision from similar facts. His role in society will still be that of the interface between the patient and the health care system, and he must know enough to recognize a malfunction of the system if it occurs. Thus, he must not only understand the patient and his illness but also the system that he manipulates to manage the patient. He will lose much of his independence since he cannot become master of all these complexities, but in turn he will have automated servants available around the clock who will relieve him of much of the drudgery. The final incentive, his income, will depend not on technology but on the social factors imposed by society at large. Certainly much that technology will bring to medicine will enhance its attractiveness as a profession if we can select those innovations which improve the signals and reject those that only emphasize the noise in the health care system. We must face the reality, however, that one man's signal may be another man's noise.