



The Future Effect of the Computer and the Research Scientist on Medical Practice

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The title of this presentation is concerned with the future effect of the computer and research scientist on medical practice. I will try to avoid the pitfalls of prediction outlined by Dr. Mount,* namely that if one predicts the immediate future he will be too optimistic, and if he predicts 10 years or so in the future he will be too pessimistic. So I will not put any time limits on my comments.

Quantitation of Medicine

Perhaps the greatest contribution to medical research and practice of the computer and the methodologies surrounding it has been the introduction of a quantitative attitude into medicine. Let us examine quantitation for a moment. In order to begin, let me explain my concept of biometry. Biometry may be defined as the study of the application of quantitative scientific methods to biological phenomena. Today biometry is represented by five overlapping, but yet separately organized, disciplines: biostatistics including demography and public health statistics, biomathematics, biophysics, bioengineering and biomedical computer sciences. Although these separate disciplines utilize somewhat different approaches to problems, they all make use of a knowledge of math-

ematics. Not everyone will agree with the use of the word biometry in this general sense, but since the five disciplines mentioned above overlap in their interests, a single term to describe their entirety is useful.

With the increasing emphasis on quantitation in biology, biometry can be expected to play an important role in the future of medicine by leading in the development of methods to accomplish such quantitation. However, we must remember that quantitation, per se, is not the goal of biometry. Rather, quantitation is a means to increase our understanding of biological phenomena with resultant improvement in our ability to care for the ill. What does quantitation actually accomplish, or in other words, why quantitize? There are basically three reasons.

1. It increases our ability to be precise in describing biological processes. By precision, I mean, in effect, reproducibility. It is easier to reproduce quantitative measurements than subjective ones. In part, this is because subjective impressions change as one learns, which is desirable, but it reduces reproducibility.

2. It increases sensitivity, that is the ability to discriminate between two objects or processes that are different. This is due in part to having greater resolution of the measurement scale.

3. It makes information collected earlier easier to interpret and in general makes the information

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—Ed.

* Dr. Joseph Mount, of the IBM Research and Development Center in Houston, had spoken earlier on "A Model of the Heart."

more useful. As an example, compare the relative values of an electrocardiogram as compared to a physician's written description of an electrocardiogram to another physician.

In any move to quantitate, we must be sure that we are measuring something worth measuring, that is, that we are in fact measuring an entity for which we desire information. The concept of quantitation is receiving much scientific attention today. The problem of what to measure, and how to measure it, are two of the greatest challenges facing medicine. It is essential to identify those qualities whose measurements will yield information sufficient for decision making. Let me give you an example; how does one measure the effect of treatments in mental disorders? What are the criteria to be used in arriving at a decision as to whether the patient has benefited from the therapy? These are considerations for which there is not now a mutually acceptable answer, although various criteria have been put forth. One reason for this is our lack of sound basic principles, expressed in a quantitative sense, of the functioning of the emotional aspects of man. The first step in implementing a computer application is to gain good quantitative information to build upon. In some systems, mathematical models of that system suggest variables that need to be measured. For example, Dr. Mount has pointed out that given a model for the electrical activity of the heart, the question arises as to where measurements should be obtained to get the optimum amount of information. The fact that he started with 130 leads gives some idea of the amount of experimentation that must take place before the computer system is finalized. In others, empirical results from large epidemiological studies will provide the clue. And in still others the discerning eye of good clinicians will suggest an answer. After some item has been

suggested, it becomes necessary to determine how to measure it, that is, the technological requirements to accomplish this measurement. This is where the biological engineers have been and will continue to be important. This includes a group of people called human engineers who are interested in problems of how best to get information from and to human beings.

Study of Variability and Its Causes

However, once a decision has been made as to what to measure and how to measure it, we must then determine the properties of this measurement. That is, how is this measurement distributed in healthy persons and in disease states. What sorts of factors influence this measurement, and in particular, what sorts of technical considerations influence it? Are these technical biases constant over the full range of measurement? We are beginning to consider measurements made in man as dynamic rather than static quantities. We have started to examine the variability of quantities such as the serum cholesterol and the electrocardiogram during the day to day routine activities of a person as well as during unusual physical and emotional stresses being placed upon the individual. The concept of intra-individual variation as opposed to inter-individual variation is receiving more and more attention. Hampton and co-workers (1966) have found, for example, that the plasma fibrinogen levels in patients with documented myocardial infarction as compared to a series of matched controls without previous myocardial infarction or other signs or symptoms of coronary artery disease differed very little in their mean levels, and in their subject-to-subject variation. However, if one makes the determination of the plasma fibrinogen over time and adjusts these data for those factors known to influ-

ence the serum fibrinogen such as infection, it turns out that the intra-subject variability of the serum fibrinogen is much greater, as a matter of fact, five times greater on the average than it is in the matched controls. The exact significance of this finding is not yet known. Other workers are examining the variability of serum cholesterol, of the electrocardiogram and of other variables in man. The study of such variability over various time spans has presented difficulties in experimental design and in the analysis of the resulting data. We are currently studying more effective ways to measure variability from non-independent observations as well as more effective experimental designs.

A more detailed study of the factors influencing the values of such measurements is extremely important, that is, the influence of the environment upon biological processes. We are now able to look at interrelationships of several factors and of their influence on measurements, and can thereby better evaluate the meaning of the particular observation. Various workers are critically examining the concepts of normality and of the distribution of measurements in a healthy or normal state. The concept of *optimal value* has been put forth by L. E. Lamb (unpublished manuscript), that is, those values which are most highly associated with the state of continued good health.

What are the sources of information concerning the distribution of measurements in various states and the expected variability of such measurements? Of course the time-honored sources are the studies specifically designed to obtain this information. Design of such studies must be rather flexible, in the sense that they do not impose unrealistic rigidity, and they must be broad in the scope of their considerations.

A second major source of such information has been made possible by the computer. This is the

routine screening of individuals for particular measurements by use of automated multi-test laboratories. Dr. Morris Collen has applied computer technology to the periodic health examination by using the results of multiple screening techniques, and a specially designed and constructed facility. This system has been described in some detail elsewhere (Collen, 1966), but basically it consists of patients passing through some 20 stations where a procedure such as chest x-ray, electrocardiogram, etc., are performed. Information from these procedures is entered into punch cards and then into the computer, which prints out a report constituting advice as to any additional procedures which should be done prior to the next examination. This advice is based upon decision rules, previously established by internists, based upon specific test results. A second approach has been that of routine MMPI evaluation, such as has been reported by the Mayo Clinic (Pearson et al., 1965). Both such systems will be useful for the acquisition of data concerning the problems of particular items of measurement and the interrelationship of such measurements.

The third source of such data should come from the increasing use of physiological monitoring. Physiological monitoring seems to be a workable system for yielding a valuable continuous evaluation of the status of the patient during surgery, intensive care, and the performance of diagnostic and therapeutic procedures, and should be useful in long-term monitoring of subjects performing various tasks in various environments. Of course, the astronauts provide perhaps the best example of monitoring of subjects in unusual environments, but similar information is needed about those of us who are earthbound and going about our usual tasks. We need to know both the short and long term behavior of various physiological parameters. By monitoring patients receiving medica-

tion, it should be possible to obtain more dynamic information concerning response to therapy. In this way we can study the influence of various factors upon the behavior of variables and can then hopefully evaluate the relative value of such measurements as parameters of therapeutic effect. This is not an easy task, nor is it one that is currently as effective as it will be. Many important and competent people are working in the area of physiological monitoring, and I look forward to the time when this provides us, not only with a source of dynamic information, but great assistance in the clinical care of patients as well. Such a system should provide us with up-to-date meaningful information, upon which realistic decisions can be made.

Other sources of basic quantitative information should come from computer processing of images. Although the work in this area is still primitive, information about size and spatial relationships should be forthcoming in the future from this source. Still another method for obtaining information especially about the natural history and therapeutic aspects of disease should be the automation of the flow of information within a hospital. It is my feeling that such a system holds great promise for increased efficiency in patient care as well as a valuable source of management, patient care and disease process information.

Much information is currently being gathered, and more will be in the future. What are we going to do with this information? How are we going to disseminate it so that it can be readily available to persons requiring it? Hopefully, current research in information retrieval techniques will lead us to a system for the systematic organization of medical information. Such an organization should accomplish two things. It should in the first place provide for easy retrieval of desired information and

secondly it should point out our information deficits. Various approaches to the systematic organization of medical knowledge have been put forth. The National Library of Medicine makes use of a very detailed system for organizing published knowledge. Whether any scheme now on the scene is totally effective remains to be seen. However, the point is that various workers are now investigating ways to organize our knowledge so that it is retrievable, so that it can be brought up to date, and so that it becomes useful. Such information should conceivably be available in an immediately retrievable form for maximal usefulness.

Computer Assisted Instruction

Up to now we have been discussing ways in which information should be gathered and stored. Now let us address ourselves to the problem of disseminating the information, that is the problem of education of medical students and house staff officers, and the continuing education of practicing physicians and scientists. This is an area in which some of the most exciting work is now being done involving computers, that is, utilizing the computer as an instructional aid in the imparting of medical knowledge to people. We have been interested in this approach to the teaching of medical information for some time and unfortunately do not yet have a working system.* However, other workers, particularly Feurzeig and co-workers (1964) and Entwisle and Entwisle (1963), have reported working systems in the teaching of differential diagnoses. Basically what they do is to have the computer simulate a patient, have the student sit at the

* Since this presentation, we have developed a working system which will be described in Harless, W. G. The implementation of a computer-assisted instruction program in a medical center environment. *J. Med. Educ.* (in press).

computer or at a console, and the student asks the computer questions much as he would ask questions of a patient or of a clinical laboratory. One method even has built into it delays, so that if you ask for a blood culture, you do not get the results immediately. The point is that the student is asking the questions and the computer is giving him the information that he needs. It will provide answers to specific questions and it can be set up to answer any question, within limits, that a student asks, even though the question does not pertain to the particular patient being simulated. This is one approach to the problem of computer-assisted instruction. In the future the computer will be used not only in this fashion, but also will have available to it visual and auditory aids. For example, it will turn on a tape recorder so that the student can listen to heart sounds and flash slides so that he can look at biopsies, blood smears, or electrocardiograms. The modern digital computer can communicate with students in a conversational mode, and courses can be developed for computer-aided instruction without requiring a student to learn a special code, computer programming, or other technology. It should be pointed out that it is not the purpose of this form of instruction to replace human instructors, but rather to assist them in their task. As a matter of fact, it should actually improve their teaching, since the computer can maintain records on the progress of students including information as to student deficiencies, so that the instructor can be aware at all times of how effective his teaching has been. This should allow for a more dynamic teaching, in that the material being presented to the students can be altered to fit the needs of the particular students receiving the instructions.

Modern computers can respond within micro-seconds to student questions and can accommodate sev-

eral students virtually simultaneously. Therefore, student experiences can be multiplied greatly with only a small increase in time. The primary advantages of such instruction are that it allows each student to progress at his own rate, it provides feedback information to the instructor so that he can provide the kind of instruction that is needed, and permits students to use it at times convenient to them. This latter consideration could, of course, be advantageous to the student by more effective utilization of his available time. This form of instruction is still in early developmental stages, but it should be an effective method for the future.

Conclusion

The computer is here. It has become a part of medicine. We have talked for a day and a half now about some of the applications of computers in medicine, and of the future of at least some of these applications. There is a language problem in communicating with computers, but certainly the future is going to see a medical language, comparable to the scientific language Fortran, built to enable physicians to communicate with the computer. The real advancements in computer application depend at least in part upon active use by physicians of computers.

In closing, let me summarize by saying that I feel that the major effects of current research will be to:

1. provide more quantitative information concerning man's physiology especially as it is affected by his environment;
2. provide a classification, storage, and retrieval system for the collected information; and
3. provide more effective means for continuing medical education. It should be emphasized that modern medical research should provide us with the information necessary for physicians to make meaningful decisions concerning the care of their patients, and after all

good patient care is the goal of all of medicine.

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