Biomedical Electronics: Potentialities and Problems

With public support and cross-disciplinary training of workers, great gains can be made in a short time.

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The full application of electronic engineering technology to biomedical science is long overdue. The tremendous capabilities offered by electronics are clearly evidenced by its indispensability in many of mankind's most spectacular achievements: the investigations and applications of nuclear physics, which have already produced nuclear reactors as new power sources and nuclear bombs as ultimate military weapons, and which promise even greater advances in the future; missile research and development, which has already penetrated some of the secrets of space and has produced vehicles capable of delivering bombs against which no defense is known, and which holds promise for future manned space travel and exploration; the development of electronic computers, or "giant brains," which are being used by the thousands in industry, business, and government to vastly increase communication, production, and planning capabilities, and which in the future may be capable of performing automatically such "human" tasks as translating, abstracting, pattern recognizing, and learning. None of these achievements would have been possible without electronic technology. In a directly analogous manner the use of electronic methods in biomedical science is equally necessary, to explore, and obtain and apply knowledge about, that most striking phenomenon known to man—life itself. The need for electronics in biomedical science is mounting ever higher because there has been excessive delay in such application.

The advantages of utilizing electronics in biology and medicine are many. They range from increased quantitative capabilities afforded the research worker to the great benefits of better health standards that may be derived from medical applications and to the possibility of opening up entirely new fields for technological advances and developments. The threshold of a dynamic new era in biomedical science has recently been crossed; biological processes are now being examined in terms of atomic structures, energy levels, binding forces, molecular configurations, and the kinetics and thermodynamics of biochemical reactions. Increasing quantification, with concurrent emphasis on the biophysical and physiochemical basis of biological systems, has already shed light on the mechanisms of nerve conduction and muscle contraction, on genetic structure, and on brain organization. Even such developments have depended in part on a modest amount of electronic equipment, and future development in these and many other areas throughout biomedical science clearly requires extensive use of electronic techniques.

For example, to learn how end organs, or receptors, originate sensory impulses, how neurons function and what role they play in specific areas of the brain, or how smooth, cardiac, and striated muscle and gland tissues function requires the detection, measurement, and analysis of small electric potentials, by means of electronic apparatus and computing machines. The electron microscope has permitted the finer intracellular molecular structures to be investigated, for correlations between chemical configuration and physiologic function. X-ray diffraction studies, in which digital computers as well as x-ray spectrographic apparatus are utilized, have already yielded the exact atomic configurations of some very important proteins, and such work is being continued. Low-temperature spectroscopy, light-scattering techniques, nuclear magnetic spectrophotometry, all demanding electronic techniques, will further the investigation of enzymatic metabolic mechanisms. Electronic flowmeters make advances in circulation research possible (Fig. 1); the pupillometer, an electronic device that instantaneously and continuously measures the diameter of the pupil of the eye, enables study of certain aspects of brain reflex mechanisms; electron analog simulation enables quantitative investigation of the complicated feedback control mechanisms involved in dynamic physiological responses (Fig. 2); and so forth.

Already a modest amount of electronic equipment is necessary for certain phases of medical diagnosis and other procedures—for example, the electrocardiograph, the electroencephalograph, the electrical heart pacemaker, and detectors for injected radioisotopes, in diagnosis. But the extensive use of electronics in medicine holds immediate promise of possibly spectacular developments in the field of artificial organs that can keep patients alive while their own diseased organs are healing; in new, electronically aided methods for analyzing vectorcardiograms, phonocardiograms, electroencephalograms, gastroenterograms, and so forth; in the maintenance of general anesthesia by automatically monitored patient-feedback systems; in preventive medicine, where changes in periodically assessed physiological health indices of individual patients can indicate a predispositional or imminent disease state; in public health, where a cytoanalyzer may enable automatic, mass screening for cervical cancer, cancer of the lung, stomach, prostate, and so on; in automatic x-ray analysis, for tuberculosis screening; and in many other areas. It is impossible to say what the long-range future may hold for applications of electronics to medicine, but one need only observe the effect electronics has had on the growth and development of other fields of science and technology to recognize its possible extent.

Another role of electronics in biomedical science is the analysis of some of the remarkable natural devices that abound in the biomedical world, and the

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possible utilization, in commercial and military applications, of the principles on which they are based. For example, ultrasonic receptors in bats enable these animals to fly successfully through a maze of wires in spite of total darkness and loud external noise; a single cell in the ear of a certain type of moth can detect an approaching bat from a greater distance than any known device yet developed by man; some insects have selective receptors for polarized light; some snakes have infrared energy detectors; and so forth. The biological operation of such mechanisms is based on the same laws of physics and chemistry that the operation of transistors and other components devised by man is based on. Just as the investigation of semiconducting, ferromagnetic, and other types of devices is predicated on the extensive use of electronic equipment, so will be the investigation of the mechanism and fabrication of nature's devices. Whole new fields of biotechnology may be awaiting the thorough investigation of such biological phenomena with appropriate electronic instrumentation.

Problems and Obstacles

The evident lag in the application of electronic techniques in biomedical fields leads one to consider the causes for this lag and the obstacles that must be overcome. Lack of personnel and facilities may be considered, but this is not the true cause. In almost every field of complex, modern technology, advances are nearly always proportional to the amount of money invested. This is particularly true of the applications of electronics (which, by their very nature, are costly). Hence, the basic cause of delay is lack of appropriate financing; if appropriate financing were made available, then the personnel and facilities would also become available. Consider the handful of physicists in this country in 1942 as compared with the thousands who worked on the original atom-bomb project and on subsequent nuclear developments. Or consider the few dozen individuals who, in 1948, were familiar with the concepts of electronic computers as compared with the many thousands who are today engaged in this field, and compare the facilities available in 1948 with the facilities available a decade later.

Private industry has been reluctant to enter the field of biomedical electronics because of the prevalent opinion that there is a small market. As the chairman of the board of a large electronics firm observed recently when discussing biomedical electronic research, unless a research and development program ultimately yields a profitable commercial product, it occupies engineering time that might otherwise be devoted to a product which would be profitable. We believe that industry would like to participate in this new field and that it should participate, because it represents a major portion of the instrumentation resources of the country. If the extensive electronic resources of private industry are to be utilized for biomedical electronics, industry must find this profitable, just as it finds participation in defense projects profitable. The fact that the National Institutes of Health allows a much lower rate of overhead than the Department of Defense and uses research grants rather than contracts may limit industry's enthusiasm for the field of biomedical electronics. This problem needs to be studied at length.

There are three other problems which present formidable obstacles to industry participation.

1) The problem of finding what devices need to be made. Surveys have been quite unsuccessful because of the great diversity of individual opinion. Through some hard and persistent work, small panels of experts selected by organizations such as the Department of Medical Physics and Rehabilitation of the American Medical Association and the Joint Committee on Electrical Techniques in Medicine and Biology could compile a list of devices for which there is urgent need.

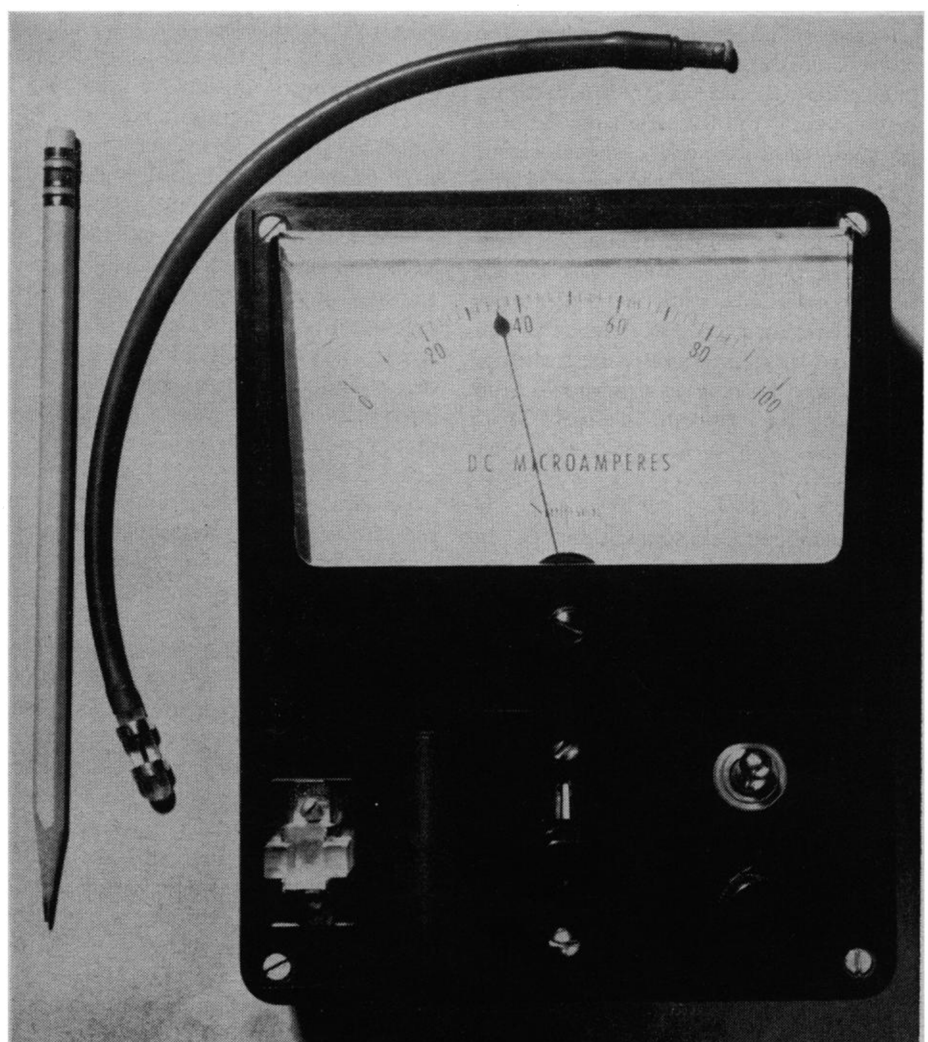

Fig. 1. An electronic hematocrit meter. The meter, which operates with transistors, is suitable, in size or weight, for bedside or office use. The total volume of blood required is 0.02 ml, an amount easily obtained by the finger-prick method, and the accuracy is ± 5 percent. [R. H. Okada and H. P. Schwan, *IRE Trans. on Med. Electronics* **ME-7**, 188 (1960)]

2) The problem of getting the devices tested. Instruments for clinical use should be tested in a clinical environment, but industry does not have ready access to this environment. Many hospitals and medical schools do not wish to use their facilities to test instruments. To help solve this problem, the establishment of regional biomedical instrumentation centers has been proposed, but as yet none have been built. At most, two or three such centers may be constructed in the immediate future. Since much of the developing and testing of clinical instruments could be done with primates, we suggest that some of the regional biomedical instrumentation centers be placed near the primate centers now being planned.

3) The problem of selling the instruments. The consumers for biomedical electronic instrumentation are often not well known to the industry sales representatives. This is true particularly for clinical instrumentation, where company salesmen have had no experience in contacting the physician or the hospital administrative staff. It would seem that there is no easy solution to the problem. Companies which are now interested in the field of biomedical electronics are trying one or more of the obvious solutions, such as trying to develop their own sales experience in the new field or asking assistance from the experienced sales organizations of the medical supply or drug houses.

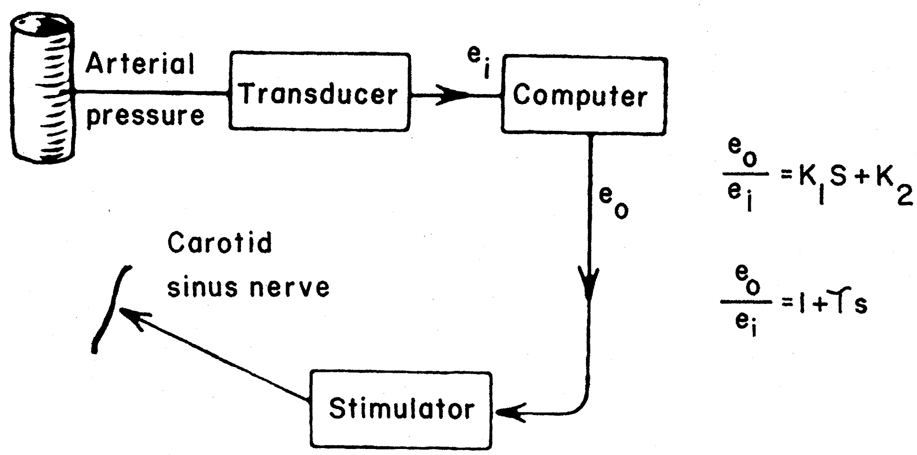

Fig. 2. Arrangement of an experimental analog computer employed to simulate part of the blood-pressure-regulating system. The rate of stimulation of the carotid sinus nerve is proportional to the output voltage e_0 from the computer. [H. R. Warner, *Proc. I.R.E.* (*Inst. Radio Engrs.*) **47**, 1913 (1959)]

Cross-Disciplinary Training and Technical Communication

Let us turn to another of the obstacles mentioned above—the problem associated with the biomedical researchers themselves, who frequently are not used to the high costs involved in electronic applications and who therefore cannot comprehend fully the necessity for such large expenditures. These scientists are generally used to working under average annual budgets of about $15,000. But the cost of electronic equipment, even of a multichannel magnetic tape recorder adequate for scientific use, usually starts at about $15,000, as a bare minimum. In addition, biomedical research is customarily oriented about an individual researcher, who carries through almost all phases of the research himself, often with little or no assistance. However, the extensive use of electronic equipment frequently requires a team of specialists, ranging from electronic design and maintenance engineers to mathematical analysts, and this further augments the cost of using electronic equipment.

The solution to this important problem lies in obtaining personnel with cross-disciplinary training—with knowledge in engineering, mathematics, and the physical sciences as well as in the biological and medical sciences, and with a thorough understanding and appreciation of the technical problems involved in biomedical electronics, from the points of view of both electronic instrumentation and biomedical-research potential. It is not enough to bring together a group of people each expert in his own field but ignorant of the fundamental concepts, language, capabilities, and limitations of the others' fields. Experience has demonstrated that a team will be successful only when each member, though having his own primary interests, is also knowledgeable in all the other disciplines involved.

Personnel with cross-disciplinary training can be obtained from several sources. First, there is the surprisingly large number of individuals presently working in one field or another who nevertheless have acquired a high level of cross-disciplinary training in the course of their careers. These people more frequently than not are working in other than biological fields, primarily because the salaries offered these highly trained individuals are almost consistently lower in biomedical research than in other engineering fields. There is no reason why biomedical research should not be put on a basis competitive with the other basic and applied sciences and technologies.

Second, there are the engineers, mathematicians, and physicists who would be interested in additional training in biology and medicine at the graduate-school level. Because of the extensive mathematical training he has already received, it is usually easier for a physical scientist or an engineer to become a biomedical researcher than for a biomedical researcher to become a physicist or engineer. Such an electronics trainee in the biomedical cross-disciplinary fields should not be required to forfeit an adequate salary, offered by private industry in his original field, for the usually inadequate fellowship or other stipend granted for training in the new fields. The same holds for physicians or biologists who desire training in, or even an understanding of, the methods and techniques of electronics. One way for industry to increase its knowledge of biomedical electronics would be for companies to send engineers to participate in the biomedical engineering programs which have been started at several universities. By paying the expenses and tuition of their engineers and thus encouraging them to participate in a program in biomedical engineering, the company would be meeting its own needs for engineers trained in biomedical electronics and simultaneously would be helping to meet a national need for more trained workers in this field.

Third, personnel with cross-disciplinary training can be obtained by setting up entirely new university curricula, in the interdisciplinary sciences, at undergraduate levels. Although there are several instances of such programs already in operation, many more need to be initiated. This is usually a difficult job and requires adequate planning as well as support.

Finally, locating biomedical research units at national physics laboratories could greatly stimulate cross-disciplinary self-education among research workers in both the physical and the biological sciences. Propinquity can apply an exceedingly strong force, particularly among naturally curious scientists. Workers in purely biological organizations become isolated in many ways from the interdisciplinary approach, for they rarely obtain opportunities to see, appreciate, or gain direct contact with the methods and techniques used in the physics and applied-mathematics laboratory. Actually, some biomedical research is carried out in such laboratories, but it is usually of a relatively limited and often of a specialized nature. Biomedical research in these laboratories should be greatly extended to general and basic studies.

Coupled with the need for cross-disciplinary training is the parallel increase in the need for more adequate communication between workers in the physical and biomedical sciences, as well as among the interdisciplinary scientists themselves. One of the most potent methods for stimulating such communication is to subsidize, partially or fully, the writing of textbooks by researchers in the field. Rarely if ever can adequate compensation be given for this arduous and exacting task, in view of the long hours and personal sacrifices so frequently required of an author of a technical treatise, even in the presently rare cases where the writing of the text is a full-time job. Books are practically the only means of presenting the exact and detailed treatments of basic fundamentals which are so important in scientific fields. Journals are of course important vehicles of technical communication for current research; however, existing journals, such as the *IRE Transactions on Bio-Medical Electronics*, seem adequate for this purpose, even with future growth of the field. National research centers, where scientists may meet for frequent direct exchange of ideas, can serve in technical fields as vital adjuncts to communication. Finally, international meetings give American scientists important opportunities to learn about the frequently outstanding work of other biomedical scientists throughout the world in the application of electronic techniques and also enable foreign scientists to obtain directly the results of work in the United States.

Conclusions

The present annual expenditure in the biomedical sciences, now less than 2 percent of the funds appropriated for defense, must be significantly increased if the great gain that can result from the adequate application of electronic technology in biomedical science is to be realized. Such use of electronics in biomedical science holds promise of tremendous advances in the study of the origins of the life processes; it may result in spectacular advances in medical science, which could have a definite effect on individual health and longevity; it might pave the way for the discovery and development of whole new technologies based on intimate knowledge of biological processes. Great strides can be made in surmounting the major obstacles by combating apathy, through making the public and the industrial community aware of the potentialities of modern biomedical research, and by giving scientists adequate cross-disciplinary training and using the abilities of those so trained (*1*).

Note

1. We thank the director and staff of the Medical Research Project, Subcommittee on Reorganization and International Organizations, Committee on Government Operations, U.S. Senate, for allowing us to see some parts of the extensive data collected by the project. Much of the material contained in this article is based on these data.

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