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A SURVEY OF APPLICATIONS FOR TECHNOLOGY IN BIOLOGY AND MEDICINE

by
Richard R. Hibbard

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I. INTRODUCTION

Many current medical problems could benefit from the application of engineering principles and practices. Some of the obstacles that now hinder the advancement of medicine and the delivery of health care can be overcome by modern technology and have been identified during the study reported here.

This brief, limited survey attempts an overview of the interdisciplinary research of engineers, life scientists, and physicians. Much of the information presented comes directly from conversations with these researchers and reflects what they believe to be the problems of medicine which engineers can aid in solving.

In the process of organizing this study, some coherent framework had to be developed into which the individual problems could be fitted to give a better overall picture of engineering opportunities in medicine. To do this, eight topics were selected to represent both the classes of problems identified and the categories of opportunities for engineering:

1. Artificial organs and assistive devices
2. Automation of clinical laboratories
3. Clinical instrumentation
4. Hospital information systems
5. Medical telecommunication
6. Monitoring patients under intensive care
7. Multiphasic screening
8. Prosthetics, sensory aids, and rehabilitation

Clearly even a compilation of a comprehensive list of the problems for engineering within each of these eight categories would be a tremendous task. It was therefore decided that the approach most useful to the sponsor of this study, the NASA Office of Technology Utilization, would be (1) a description of the overall significance of each category to the nation's health care capability, (2) the identification, within each category, of major subclasses of problems that show a need for engineering, and (3) a few selected examples taken from the field of current biomedical engineering research showing typical approaches to the solution of these problems.

The bulk of this report, then, is devoted to presenting the findings of the study in the format just described. Appendix I identifies those researchers who contributed information on their efforts to apply engineering methods to the problems of medicine. For the reader who is unfamiliar with the program pursued by the NASA Office of Technology Utilization, Appendix II will provide background information.

The author thanks the many researchers who generously volunteered their time to make this report possible. The opinions expressed are solely those of the author and not of the contributors or of the National Aeronautics and Space Administration.

II. PROBLEMS IN MEDICINE AND BIOLOGY

A. ARTIFICIAL ORGANS AND ASSISTIVE DEVICES

Rapid progress in surgical technology is producing extensive opportunities for replacing damaged tissues and organs with man-made substitutes and at the same time demanding increasingly better assistive devices both during and following surgery. Progress is being made along many lines of research as a result of the interplay of the diverse disciplines of medicine and engineering.

The National Institutes of Health Medical Devices Applications Program* is an example of the type of organization necessary to attack an interdisciplinary problem involving biologists, chemists, materials specialists, physicians, engineers, and technicians. The problems and the approach of this program are discussed in this section. Also discussed is one major problem common to the artificial organ and assistive device area: the incompatibility of man-made substitutes with the body's blood and tissue.

Looking first at the Medical Devices Applications Program, we can get some indication of its relevancy to the health of the nation's citizens by considering the following facts.

Coronary heart disease accounts for half a million cardiovascular deaths a year in the U.S. Heart disease ranks first of all causes of death in this country. A recent National Health Survey indicates that almost 15 million Americans have heart disease, while 13 million more are suspected of having it. Thus approximately 25% of American adults have, or are suspected to have, heart disease. Of these, perhaps 2 million are seriously handicapped by their disease.[1]

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*Formerly the Artificial Heart Program.

Drug and surgical therapies offer promise of only limited help. It appears that among the major contributing causes of the disease are man's diet and his lack of regular physical activity. Preventive measures therefore may be more promising as a remedy.

In the future, efforts to identify preventive measures to reduce the deleterious effects of the disease may succeed in eliminating it as the number one killer of man. In the meantime, there will remain a great need to develop those devices which can assist man to survive in spite of the disease effects.

To seek solutions to the technological problems associated with developing cardiovascular assist and replacement devices, the Medical Devices Applications Program of the National Heart Institute of NIH is using the modern systems management techniques developed by the aerospace industry. It has often been said that these methods are of greater value as spin-offs from the space program than all the instrumentation and hardware.[2] It is worth considering why the director of the program decided to use the systems approach rather than the more conventional step-by-step approach to solving medical problems. The reasons he has given[3] are:

- To permit technology to be rapidly translated into workable and practical devices, while allowing for research to proceed simultaneously in other critical areas
- To take into consideration the information gaps that need to be closed and plan for the research to close them in order to achieve the major goals of the program
- To insure that the interdependencies of the subsystems and subprograms are accounted for, and to relate them to the overall system to insure that it will perform as required
- To provide for a continuous involvement, as opposed to a fragmented one, of all members of the team involved in the

continuous matching of specific efforts to the immediate objectives, as well as the completion of the major objectives of the overall program

- To provide the necessary emphasis to cut across the traditional functional lines of each of the areas of research, development, and production to establish effective, coherent, interdisciplinary teams composed of biologists and physical scientists; medical equipment developers, testers, evaluators; clinicians; and others in the medical care community

The major problems of the Medical Devices Applications Program currently being investigated include:

- Development of materials, for use in circulatory assist and replacement devices, that are blood compatible and that minimize adverse blood-tissue/foreign surface interface reactions
- Analysis of the physical and chemical effects of materials on blood
- Development of a basic theory and supporting data pertaining to blood flow through and adjacent to such sites as prosthetic valves, points of connection, and pumping sites in order to define the design limitations for devices in contact with flowing blood
- Development of practical control systems of circulatory assist devices
- Development of a blood oxygenator which solves the present problem of long-term denaturation of proteins and lipoproteins and destruction of cellular and noncellular elements and which also overcomes the limitations of poor gas transport, poor hemodynamics, high cost, and difficult assembly

- Development of a wide range of peripheral electronic instrumentation applicable to artificial heart development and use
- Development and testing of a long-term percutaneous electrode or conduit system that can transmit electrical or fluid energy into the thoracic cavity for energizing and controlling circulatory assist devices
- Investigation of a totally implantable energy supply and conversion system using either a biological fuel cell that would operate on chemical species normally found within the body, or a long-term energy storage device

A major problem to be solved in the program is the unsatisfactory interface of artificial organs and assistive devices with the blood or tissues. All materials now used in these devices are incompatible to some degree with the body tissue and blood. This incompatibility causes irritation, rejection, fibrosis, or thrombosis which prohibits the long-term use of the devices. Until this problem is solved, progress toward a variety of objectives--an implantable artificial heart, a long-duration heart-lung machine, an economical artificial kidney, to name a few--will be impeded.

One of the many studies aimed at exploring this problem is that of the Cornell Aeronautical Laboratory, Buffalo, New York, and Johns Hopkins Hospital, Baltimore, Maryland, which are investigating surface properties of candidate biomaterials.[4] Stated simply, the question addressed is this: What surface properties are required for candidate biomedical materials to be as nonthrombogenic as possible? Or, rephrased in terms of how technology can assist in this investigation: What measurements of surface composition, structure, and function can be made to expand our knowledge of interface processes at the molecular and cellular level; and how may these processes be characterized to allow physicists, chemists, and metallurgists to design, evaluate, and fabricate materials that incorporate desired features?

Cornell Aeronautical Laboratory uses a common method for investigating surface interaction to identify the surface constitution of any solid. It is based on contact-angle measurements between a liquid and a solid surface (Fig. 1). A large body of reliable data has been accumulated, correlating contact-angle data with surface properties of solids. A Zisman plot of the cosines of the contact angles for a variety of pure liquids versus the surface tensions of the liquids on a sample solid surface (Fig. 2) provides the useful parameter "critical surface tension," which is conceptually related to the free energy of the material surface. Low critical surface tension is a feature of naturally thromboresistant blood-vessel walls. It is not certain that synthetic low-energy surfaces are intrinsically nonthrombogenic, but it appears that such a surface feature does correlate well with thromboresistance, by some mechanism.[5] Additional study of this mechanism is needed, as well as additional methods of measuring and understanding other surface interactions.

B. AUTOMATION OF CLINICAL LABORATORIES

The work load in clinical laboratories has doubled approximately every five years during the past two decades and is expected to continue at least this growth rate in the foreseeable future.[6] Expanding health and medical programs will soon overwhelm all existing laboratory facilities.

Ten years ago clinical laboratories routinely performed approximately 12 different biochemical determinations. Today, increasing knowledge of the nature of disease requires laboratories to perform any one of 400 different tests on tissues, blood, urine, feces, and products of disease.

In the future the clinical laboratory will be called on increasingly to assist in diagnosis and treatment in ways which were unknown a few years ago. Procedures such as (1) mass screening of large groups of the population for earlier detection of disease and (2) minute-by-minute support of intensive-care patients will become possible. To accomplish

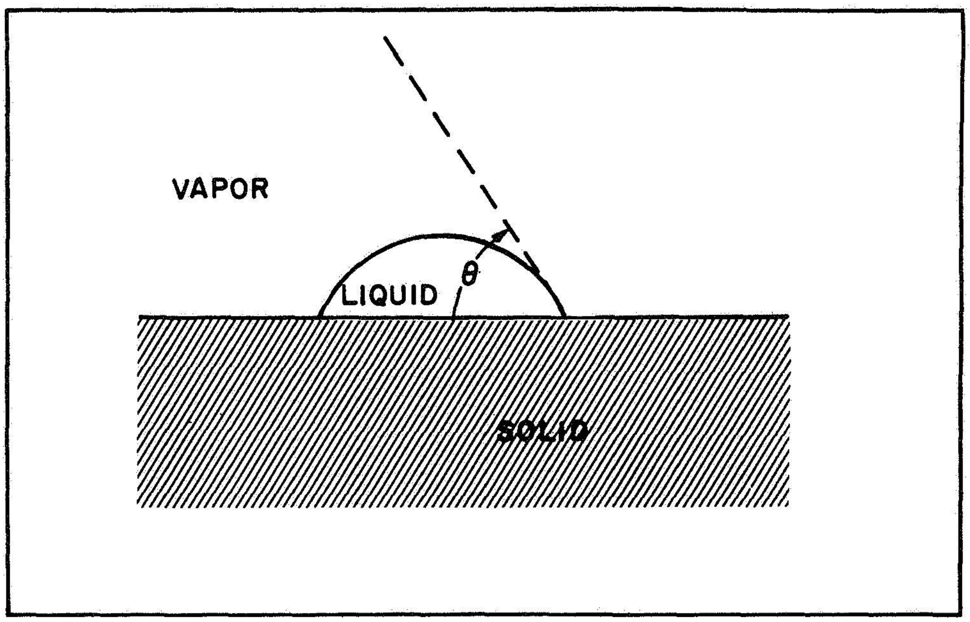

Figure 1. Definition of the Surface Contact Angle θ

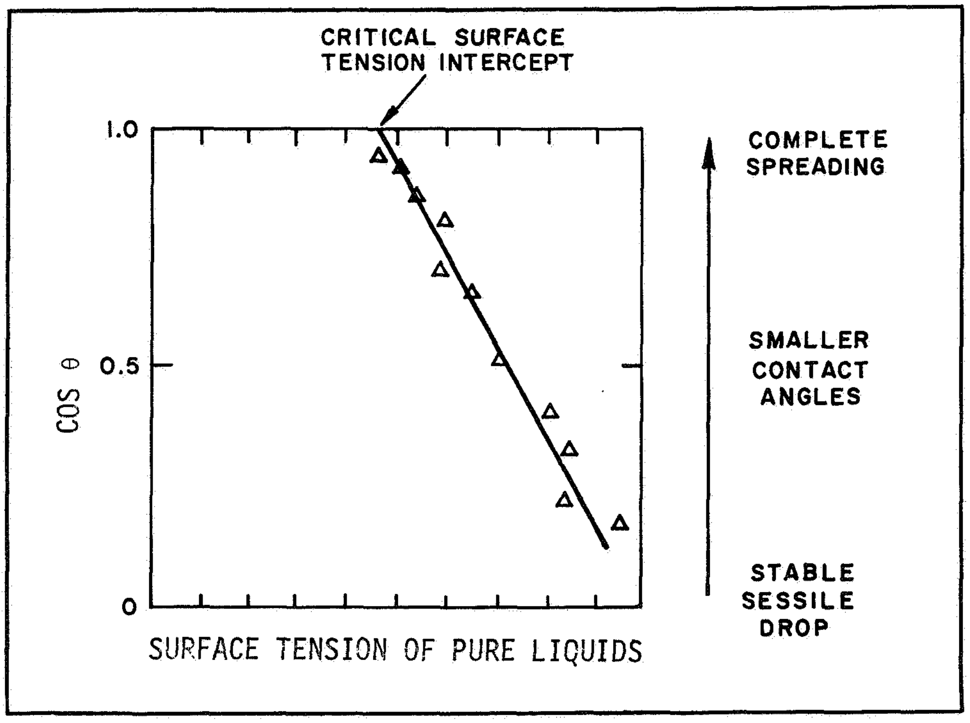

Figure 2. The Zisman Plot

this, the laboratory procedures must be brought up-to-date with the latest in instrumentation, automation, and data processing. Without such modernization it is clear that our present medical system will be taxed beyond limit by the expanding national and regional health care programs.

The engineering objective is to automate the entire clinical laboratory procedure to the fullest extent possible. Where present procedures cannot be automated, new means of testing must be investigated while existing procedures are semiautomated to speed results and increase reliability.

Automation to the extent possible by conventional methods has been tried in one clinical laboratory in a 500-bed hospital. The trial demonstrated that automation permitted three times as many tests to be performed, while the average cost per test decreased tenfold.[7] Extending automation to the nearly half a billion tests now done yearly throughout the country could have a major impact on health care quality and cost.

1. Automated Leukocyte Recognition

Some clinical laboratory tests cannot at present be automated because they depend on human visual recognition and interpretation. This is true for many commonly performed laboratory tests such as differential leukocyte (white blood cell) count. This routine blood test requires visual counting of individual leukocytes by type (there are five types). In the U.S. alone, the counting runs to more than a million cells per hour, every hour, every day at an annual cost of about $200 million.[8]

The test is presently performed by smearing a blood sample on a glass slide, drying and staining it, and examining it under a microscope. Only 100 or 200 cells are counted from each sample, taking 2 to 5 min per sample, although a statistically accurate count would require more like 500-1000 cells.[9] The count of each type of leukocyte (Table 1) is an important indication of disease and treatment progress.

TABLE 1

MORPHOLOGICAL AND SPECTRAL CHARACTERISTICS OF LEUKOCYTES; WRIGHT'S STAIN APPLIED[8]

Cell Type	Population (%)	Diameter (µm)	Cytoplasm		Nucleus		
			Color	Amount (%)	Color	Shape	Amount (%)
Lymphocyte	25-33	7-12	Clear light blue	10-30	Purple	Round	70-90
Monocyte	2-6	13-20	Grayish blue	50	Light purple	Indented	50
Neutrophil	60-70	10-12	Pink to lilac	50	Reddish purple	Segmented	50
Eosinophil	1-4	10-14	Red stippling	60-70	Dark blue	Two-lobed	30-40
Basophil	0.25-0.5	10-12	Blue	50	Purple	Elongated	50

To be able to automate this test, leukocytes must be distinguished, optically or physically, from (1) nonleukocytes and (2) other leukocytes by type.

A Massachusetts Institute of Technology research project has been working toward computer-assisted location and identification of leukocytes by visual information processing. Leukocyte nucleus size and color and cytoplasm size and color are the characteristics used for statistical pattern recognition by cluster analysis, parameter weighting, and decision metrics. The method, now shown to be feasible in MIT research, awaits further development for economical application in the clinical laboratory.

An alternative approach may eliminate the need for detailed visual information processing: developing new stains and preparations which allow individual cell differences (e.g., in absorption, scattering, fluorescence) to be more easily identified by such instruments as the rapid cell spectrophotometer described by Kamentsky.[10] Technological contributions to the development of this instrument have been significant. They include the use of fluidic switching capability for process control as well as advanced measurement techniques. Much of the remaining problem lies in finding stain and cell-preparation processes which clearly distinguish the different classes of leukocytes.

2. Automated Bacterial Growth Measurement

Although it is currently possible to automate 70%-90% of the total laboratory work load in clinical chemistry, and 60% in hematology, the figure drops to 20% in microbiology.[11] Measurement techniques have not yet been devised to substitute for the standard methods of isolating the microorganisms, growing them in nutrient media, and identifying them by morphology, metabolism, pathogenicity, and antigenicity.* Yet, if a

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*Development of equipment to detect the presence and number of bacterial colonies is now under way. The identification and recognition process, however, is not yet feasible without visual evaluation.

systematic understanding of microorganisms is to be achieved, it can only be achieved by uniformly conducted, repeatable investigation on a scale beyond that which can be supported by present clinical laboratory capacity.

In a forthcoming National Institutes of Health study described by Dr. Andre Leroy of the Biomedical Engineering and Instrumentation Branch of the National Institutes of Health,[12] an attempt will be made to automate the growth measurement of a particular bacterial strain. Bacteria which frequently occur in conjunction with dental caries will systematically be cultured in tens of thousands of different nutrient combinations to determine the effect of each on growth and viability.

To provide uniformity and speed in making the measurement, automation is essential. A dedicated hybrid mini-computer which processes data and controls the experiment in a manner similar to real-time guidance and control of a spacecraft or an airborne vehicle may become the heart of the automated system. In addition, the project requires new measurement techniques to be developed by engineers cooperating with bacteriologists to measure automatically the growth and viability of the bacteria colonies. Light scattering, turbidity, acid production rate, and pH-indicating colorimetry are measurements initially being considered.

C. CLINICAL INSTRUMENTATION

Clinical instrumentation is the field to which the engineering disciplines have made their most visible contributions. To the layman, the array of modern instrumentation present in most clinics today is truly impressive. The fact is, however, that many of these instruments are nothing more than transistorized versions of medical devices that were common in the clinic decades ago. A host of supportive equipment--recorders, amplifiers, analog-to-digital converters, and computers--has not altered to any great extent the type of information being gathered from the patient. The potential advancement that modern technology offers to medicine by way of new measurement techniques, computer-assisted analysis and data processing, and time-saving automation, lies untapped and frequently unrecognized.

Engineers and technicians should note that a cause of the lag in the application of modern technology in the clinic lies in the nature of the medical market itself. Industry is not strongly motivated toward investing large sums in medical instrumentation research and development because the market is small, highly specialized, and entails high risks in product acceptance. Aggravating this problem is the fact that medical instrumentation has no distribution system comparable to that for industrial instrumentation, where accurate forecasts for demand are possible. Also, even when a clearly defined technical approach to the solution of a medical problem exists, research and development funds may not be committed because the time lag between first clinical trial and final widespread medical community acceptance of a new device may be too great to provide an adequate return on the dollar investment. This delay period endorsed by the medical community primarily to insure that a device is safe, reliable, and effective, favors the development of instrumentation which makes only marginal changes in customary clinical practice and consequently deters the development of instrumentation which changes radically or fundamentally any aspect of clinical techniques.

Lack of substantial technical innovation in the clinic is due to considerations of hospital economy as well. In U.S. industry and commerce, technological advances are eagerly sought because their application generally is followed by increases in productivity per wage earner, thereby permitting increases in wages to be borne without loss of profits or comparable increases in prices to the consumer. This trend has been reversed in the hospitals; technological advances have increased the number of wage earners required on the payroll for a given level of productivity, as measured in patients treated. Personnel costs are the major part of hospital expenditures; thus the result has been upward-spiraling medical costs (Fig. 3). It is no wonder that technology in the medical field has been received with dampened enthusiasm.

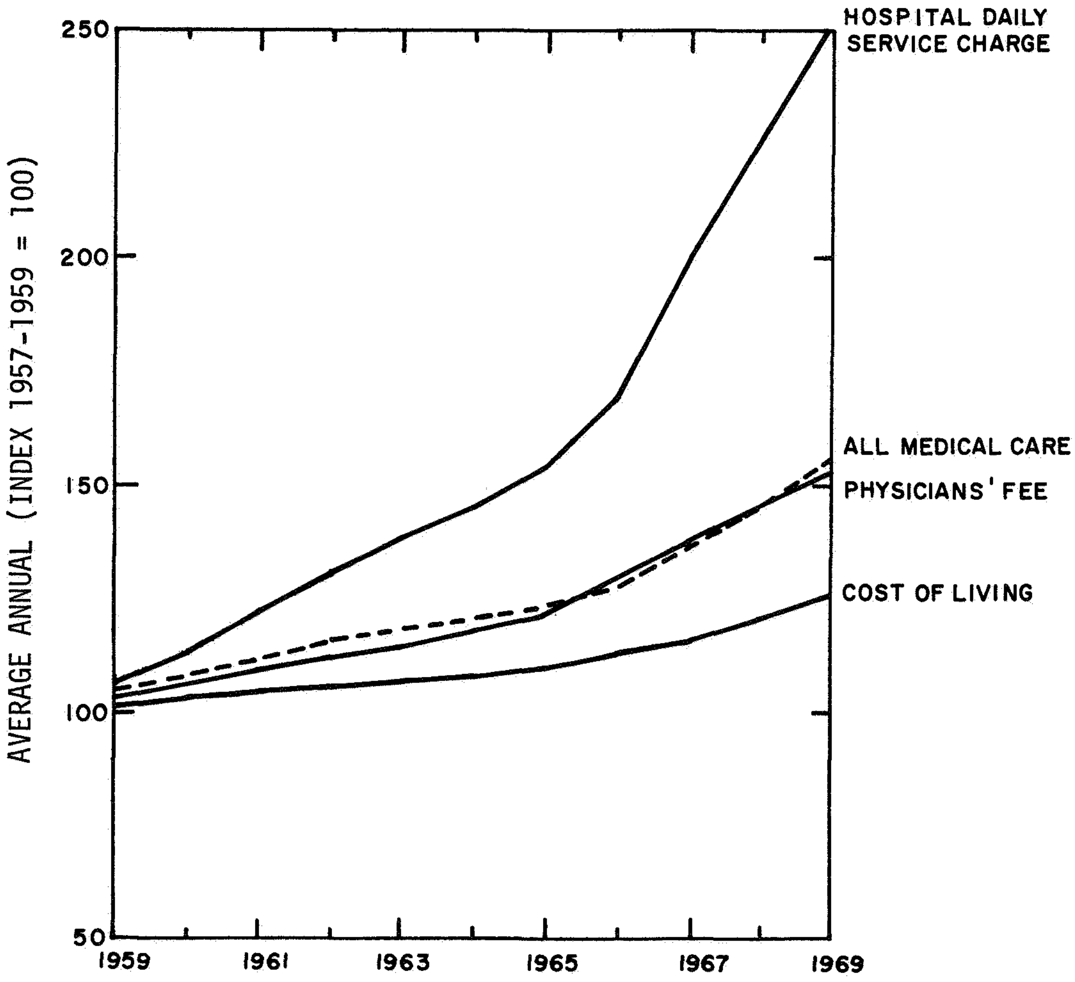

Figure 3. Relative Rise in Cost of Medical Care, 1959-1969
(Source: U. S. Bureau of Labor Statistics)

In 1954, when nationwide hospital costs totaled $1.5 billion, general hospitals providing acute care averaged 207 employees for every 100 patients. By 1964, when costs had risen to $6.0 billion, the number of employees per 100 patients had risen to 247.[13] Under growing criticism from the public for failure to keep rising medical costs within reasonable bounds, the hospital administrator and medical professional will clearly be more discriminating in his purchase of new instrumentation by asking whether the benefits to be gained are really worth the time and money spent.

The problem in clinical instrumentation, therefore, is a combination of circumstances in economics, science, technology, and the nature of the practice of medicine itself. New measurement techniques must be found, but markets must be stimulated and priorities within medicine must be reevaluated if significant achievement is to be made in bringing modern technology into the clinic.

1. Heart Instrumentation

Heart disease and other cardiovascular disorders are the major causes of death in the U.S. (Table 2). It is not surprising, therefore, that a major part of the medical research performed in this country is directed toward detecting, understanding, and treating cardiovascular disease (Table 3). Advanced clinical instrumentation can aid this research by providing new devices and methods which are faster, more reliable, and more practical, and which provide more quantitative information than conventional techniques.

In an example of the type of ongoing interdisciplinary research in this field, conducted by Aerospace Corporation engineers and Loma Linda (California) Hospital doctors,[14] a computer is employed to aid in measuring the pumping efficiency of the human heart. An x-ray camera takes motion pictures of the heart (cineangiograms) injected with an opague dye. The pictures are subjected to analysis by an optical processing instrument (a flying-spot scanner) and a computer to measure heart volume, rate, and efficiency.

TABLE 2

CAUSES OF DEATH IN THE U.S.

Rank	Cause of Death	Number of Deaths	Death Rate per 100,000 Population	% of Total
	All causes	1,851,323	935.7	100.0
1	Heart diseases	721,268	364.5	39.0
2	Cancer	310,983	157.2	16.8
3	Stroke	202,184	102.2	10.9
4	Accidents	113,169	57.2	6.1
5	Influenza and pneumonia	56,892	28.8	3.1
6	Early infancy diseases	48,314	24.4	2.6
7	Arteriosclerosis	37,564	19.0	2.0
8	Diabetes Mellitus	35,049	17.7	1.9
9	Other circulatory system diseases	29,944	15.1	1.6
10	Other bronchopulmonic diseases	29,360	14.8	1.6

Source: U. S. Public Health Serivce, based on 1967 data.

TABLE 3

RESEARCH GRANTS BY SUPPORTING INSTITUTE
OF THE NATIONAL INSTITUTES OF HEALTH

Rank	Institute	Millions of Dollars
1	Heart	95.0
2	Arthritis and metabolic diseases	85.5
3	General medical sciences	74.0
4	Cancer	71.6
5	Neurological disease and blindness	65.6
6	Allergy and infectious diseases	49.0
7	Child health and human development	38.0
8	Dental research	14.3
9	Environmental health sciences	8.0

Source: U. S. Public Health Service Fiscal Year 1968 Funds.

The still-unsolved problems in the California study are amenable to an engineering solution. These problems encompass (1) man-machine interaction between the clinical specialist and the optical display and data processing console, (2) computer algorithms that need improving, for estimating heart volume, rate, and efficiency from the optical density of the angiogram, and (3) documentation of measurements in a format that will be of greatest value to the clinical diagnostician.

Although angiography has been used in clinical diagnosis of cardiovascular disorders for more than a decade, the evaluation process has always been painstakingly slow, requiring a doctor's visual analysis of film, frame by frame, in order to measure the heart's performance. If modern visual processing equipment and computer methods can be applied to this clinical diagnosis, they offer the promise of more rapid, accurate measurement and will provide more objective data to the diagnostician.

2. Other Cardiovascular Instrumentation

Atherosclerosis, the leading source of cardiovascular disease, is characterized by the deposition of fatty substances in the inner lining of the blood vessels. The resulting stenosis (narrowing) of the blood vessels cuts down the blood flow and may ultimately cause stroke, heart attack, or damage to other major organs. Instrumental techniques are needed to determine the location, extent, and severity of atherosclerotic lesions in man without subjecting him to pain or hazard and preferably without mechanical penetration of his skin.

Some current research indicates the wide range of interest in this problem:[15] (1) attempts to correlate acoustic measurements of blood flow with the degree of stenosis (C. F. Dewey, Jr., Massachusetts Institute of Technology); (2) further quantitative investigation of the thermal dilution technique and flow profiles (S. Berger, University of California, Berkeley); (3) exploitation of the nuclear magnetic resonance properties of blood flow (J. R. Singer, University of California, Berkeley); (4) application of catheter-mounted transducers to measure blood flow properties

(J. Goerke, San Francisco Medical Center); and (5) use of a hot-film anemometer probe for blood flow measurement (R. Vidal, Cornell Aeronautical Laboratory). The use of Doppler acoustics and measurement of pressure pulse transmission velocity have also been suggested.

The major problem remaining to be solved is the lack of a practical noninvasive means of determining the blood flow and vessel wall characteristics accurately. Particular priority should be given to developing methods that would allow early detection of the disease and facilitate preventive measures where such are possible. The disease is chronic and widespread, with all over the age of 20 affected to some degree. An earlier indication of its progress is important to therapeutic and preventive treatment.

3. Eye Instrumentation

Vision impairment ranks first among the physical disabilities in this country, as identified in a recent study for Congress performed by the National Academy of Engineering (Table 4).[16] Public assistance expenditures for aid to the blind exceed $100 million annually.[17]

TABLE 4
PHYSICAL DISABILITIES

1.	Vision impairment	6.	Benign neoplasm
2.	Hearing	7.	Asthma, hay fever
3.	Arthritis, rheumatism	8.	Bronchitis, sinusitis
4.	High blood pressure	9.	Hemorrhoids
5.	Heart condition	10.	Mental and nervous disorders

If better clinical instrumentation for eye examination were available, it would aid in the earlier detection and diagnosis of visual disease and the onset of visual impairment, thereby allowing earlier corrective or therapeutic measures. By such earlier treatment we can hope to reduce the incidence of vision impairment.

Some of the instrumentation needs, as described by Dr. W. McEwen of the Francis I. Proctor Foundation for Research in Ophthalmology, San Francisco, are listed below.

1. Indirect ophthalmoscope with safe light level
2. Optic disc collagen rapid identification for glaucoma screening
3. Noninvasive retinal blood pressure and flow measurement
4. Quantitative visual-field testing
5. Eye muscle control measurement

Routine, thorough eye examination is hampered by the allowable intensity and duration of light which can be endured by the sensitive inner surfaces of the eye. The type of ophthalmoscope needed could present a continuous image of the inner surface of the eye to a diagnostician without requiring a high-intensity beam of light to be aimed into the eye. Optimally, an ambient, room-level source of light should be sufficient to illuminate the retina for observation. Modern advances in the field of optics--fiber optics, electronic processing, image enhancement, and infrared detection--may provide the requisite technology.

By applying the technique of electronic processing of images to the image of the eye's inner surface, it may be possible to detect several characteristic indicators of eye disease automatically, making such tests available for widespread public screening. In addition, modern optics technology may provide a better visual method for measuring retinal blood flow and pressure--of growing importance not only to the early detection of eye disorders but also as indicators of potential stroke occurrence. Better imagery of the recessed internal structure of the eye (gonioscopy) may lead to better understanding of the physical processes involved in aqueous-flow control, a primary factor involved with the onset and advance of glaucoma, a leading cause of blindness.

Better instrumentation for quantitative visual-field testing is a final example of eye research needs. A continuous measure of the breadth, depth, and detail of the perceived field while the eyes are free to roam over an object, printed page, film, or entire visual environment would add greatly to our knowledge of eye muscle control mechanics and visual field perception, two features which are especially important to man-machine system design.

4. <u>Instrumentation to Locate Gastrointestinal Bleeding</u>

The need to develop instrumentation which could identify and locate gastrointestinal bleeding was expressed recently by Dr. I. Selikoff of Mt. Sinai School of Medicine, New York.[18]

> If engineers could help develop . . . a method or an instrument to tell where gastrointestinal bleeding was occurring, or even when it stopped, there wouldn't be a hospital in the country without one. That's a real problem . . .

Gastrointestinal bleeding is a frequent manifestation of serious intestinal disorders. It may become apparent as blood in the stool, or it may remain occult and be inferred from a continuing anemia of the patient. Even if blood becomes apparent and chemically detectable in the stool, the source of the bleeding, within tens of feet of intestine, remains to be determined. The problem becomes particularly acute when the rate of blood loss is great enough to require continual replacement by whole blood transfusion and subsequent surgical intervention.

Where and how should one look for the lesion? Only occasionally, when the origin of the bleeding is at the site of an ulcer, can x rays be useful. Better methods are badly needed. At present there is no clear indication of the technology which would provide a solution. A variety of sensing techniques--chemical, radioactive, physical--might, for example, be coupled with electronic minaturization and telemetry to provide a blood-detecting "pill." This device, when swallowed, would transmit the desired signal from the body's interior as it passed through the digestive tract. Such a scheme is just one of a number of possible solutions, none at present offering a clear indication of likely success but all indicative of appropriate applications for technical assistance.

D. HOSPITAL INFORMATION SYSTEMS

A hospital information system consists of all those elements within the hospital dealing with the collection, transmission, storage, retrieval, and presentation of information relied upon by the administrative and medical staff to provide the proper medical care to a patient and to manage the hospital efficiently. A well-planned, effective information system improves the quality of medical care by providing the physician with more timely, accurate, and comprehensive information on his patients. The system also aids hospital management by accounting for admissions, inventories, catering requirements, hospital services, and all other routine administrative functions of the hospital.

Effective information handling is particularly important to hospital medical care because a significant part of the patient care process is the proper acquiring and handling of pertinent data. The process consists of patient testing, diagnosis, treatment, and evaluation repeated as often as necessary in an iterative, step-by-step manner, until the patient returns to good health. Particularly in larger hospitals with more than 500 patients the problems associated with handling patient data are considerable.

To understand the technological problems which must be solved to achieve an efficient, effective hospital information system, one should be aware of why past successes have been limited. In industry, commerce, and science the handling of information has led to a high degree of reliance on formal language, mathematics, statistics, and quantifiable data, which could convey information without misinterpretation. In the practice of medicine, however, where service has always been characterized by close personal contact--between doctor and patient, among the auxiliary medical staff, and between the doctor and his colleagues--there has developed a high degree of reliance on natural language as the means of communicating facts and subjective feelings, and with it all the subtleties that are inherent in the context and intonation of the spoken language. Most attempts to speed up or automate the process of information flow in the hospital by use of computers and peripheral input/output devices have achieved only limited successes because the systems devised have failed to communicate information other than raw data and facts.

Partial success has been achieved in the portions of hospital procedure that rely to a lesser degree on natural language and to a greater degree on factual data: clinical laboratories, admissions, inventory, account, and occasionally, in administration of medication and radiological treatment. It appears likely that future progress in automating hospital information systems will come from the extension of these successes in the laboratory and business office to areas also dealing with a high degree of factual information and data, integrating these into larger, more comprehensive systems. This extension should include automation of (1) communications concerning the "doctor's order"; (2) information processing of test results, observation, and medications; and (3) storage and retrieval of summary medical records.

The major technical improvements remaining to be achieved include:

- More flexible interaction between the computer and the patients, doctors, and auxiliary medical personnel including the use of computer graphics for data input and output

- Improved physiological monitoring that can interface with medical record keeping capabilities of the information system
- Automated clinical laboratory equipment that can display patient data throughout the hospital for physician viewing and can also record the data automatically in the patient's medical history
- Improved peripheral computer equipment which is reliable, inexpensive, quiet, and practical for the non-specialist to operate
- Improved retrieval of papers published in medical journals which would allow descriptive prose to guide the literature search as well as selected "key words"

E. MEDICAL TELECOMMUNICATION

Improving medical care in America is becoming increasingly limited by a problem of inability to deliver rather than lack of capability to perform. Urban hospitals are overcrowded, and rural physicians in ever greater numbers are shifting their practices to modern suburban hospitals and group clinics, leaving rural medical care woefully inadequate. Modern technology may possibly remove this limitation to improvement. Electronic methods can be adapted to bring up-to-date health and emergency medical service to limited-access areas (small towns and settlements, and rural places). Similar methods could be utilized for urban ghettoes with insufficient hospital facilities, and they would also have the potential for providing medical service to disaster areas, and for mobile servicing of accidents.

Technical assistance plus more extensive use of auxiliary medical personnel seems to be the only way to counter the trend of physicians to practice in larger hospitals and group clinics where they can take advantage of (among other things) the facilities and instrumentation that smaller practices cannot afford. To extend medical care into the field will require a combination of health teams and modern communications for telephone transmission, radio telemetry, and closed-circuit television imagery between the patient's bedside or remote outpatient clinic and the hospital.

To give an example of the great magnitude of the remote health care problem, a recent study by the New Mexico Department of Health and Social Services, assisted by NASA personnel, has discovered that there are only 68 doctors in an enormous seven-county area of southwestern New Mexico to serve an estimated population of 130,000--with the result that most children receive no medical examinations during all their school years.[19] Modern communication technology may be adaptable to enabling the individual physician to see more patients by closed-circuit television, monitor and diagnose their condition by telephone, and recommend therapy after communicating electronically with a health records center for the area and with colleagues if necessary.

"Telemedicine," as the concept has become known, could also be used to aid disaster and accident victims by early transmission of patient data to the receiving ward to allow for emergency preparation for surgery or special aid. In addition, physical relocation of acutely ill patients for treatment could be minimized, and outpatient recovery from recurrent disease could be closely monitored if better telemetry were available.

The NASA experience in telemetry and communications can contribute substantially to the development of remote health care. Many NASA contractors have already begun applying the techniques developed for the space program to the medical field. For example, Hamilton Standard, a division of United Aircraft, entered the medical electronics field by way of the space industry. In the early 1960's, the company won a research contract from NASA to develop and build a telemetry-type cardiac monitor for use by astronauts. Out of that research grew a variety of products for commercial sale, including a $660 telephone monitoring system for cardiac patients. With this relatively inexpensive unit, a postcoronary patient can relay electrocardiogram data from his home to a central medical facility by telephone.

Telephone telemetry of physiological information appears to offer considerable opportunity to improve remote health care because of (1) the widespread availability of the telephone, (2) the existence of proven methods of transmitting data via the telephone network, and (3) a move by the medical profession toward greater quantification of physiological information.

Although advancements in the transmission of information in analog or digital form via telephone have produced such equipment as data-phones and interface amplifiers and recorders, several practical needs remain to be satisfied before medical telemetry can become widespread. First is the need for sensor equipment, operable at a remote station or in the patient's home, by a nonprofessional for the purpose of bedside monitoring and diagnosis as well as by a trained technician or physician for more sophisticated and specialized usage. Second is the need for a more practical means of transmitting multiple channels of data simultaneously to eliminate multiple data-phone arrangements. Multiple channels are particularly important in the transmission of neurological and bioelectric signals such as recorded by the electrocardiogram (ECG) and electroencephalogram (EEG), where separate signals interrelate and provide a significant diagnostic tool.

These needs for technological advancement were discussed by Dr. I. Levine of the Veterans Administration Outpatient Clinic of Boston, an early pioneer and continuing contributor to the development of telephone telemetry of bioelectric signals. The neurological research section of the Outpatient Clinic, as part of its research program in multiple sclerosis and muscle relaxant drugs, frequently uses telephone telemetry between Boston area hospitals and from the patient's bedside to the clinic to minimize discomfort to the patient and also to obtain his response to drug treatment, which is most reliable in his customary environment.[20]

F. MONITORING PATIENTS UNDER INTENSIVE CARE

The intensive care concept, as evolved in the last ten years, includes concentrated, continuous observation of the critically ill, thereby increasing their chance of survival. Here monitoring techniques exhibit their maximum utility to medicine by providing physicians and nurses with minute-to-minute observations of an acutely ill patient's condition and a continuous record of his progress.

Intensive care facilities are often specialized to perform one type of intensive care more effectively than another. The University of Southern California Shock Research Unit at the Los Angeles County General Hospital was created for the intensive care of patients in shock resulting from a variety of catastrophes: pneumonia, drug overdose, internal bleeding, diabetic coma, body burns, stroke, heart attack, and others. The intensive care ward of the Pacific Medical Center, Presbyterian Hospital, San Francisco, on the other hand, has been designed and used mainly for postoperative cases from open-heart surgery. The underlying principles involved in any intensive care unit, however, are the same: better monitoring of the patient's condition, better management of the data to aid physician decision-making, and automation of measuring and controlling devices used for life support.

The problem of managing an increasing number of physiological measurements has drawn the digital computer into the intensive care ward, and with it all the problems associated with medically applied computers: (1) development of data acquisition methods (e.g., analog-to-digital devices which include analog data filtering techniques); (2) informational input procedures which are acceptable to physicians and which can record such non-numerical observations of a patient's condition as alertness, color, evidence of pain, quality of pulse, and responsiveness; (3) informational output format which condenses the data in a form that can provide the physicians and nurses with a useful, reliable decision-making aid; and (4) modeling, both of the patient's physiological behavior and of the decision-making processes of the doctors and nurses, to guide in the development of the computer software for predictive and diagnostic purposes.

There is likely to be slow but steady progress toward solving these computer related problems, as many researchers continue to advance the state of the computer applications art. Other significant engineering problems in the intensive care ward, however, have for the most part been neglected by researchers. One of these is the development and validation of primary physiological sensors which are practical, reliable, automated, and provide information needed by the doctor to make a decision. Some of the quantities required to be monitored for comprehensive patient care are shown in Table 5.

For lack of suitable monitoring devices, many of these measurements must now be performed manually, a time consuming and often inaccurate process. Blood chemistry in particular requires manual sample taking, transporting the sample to the clinical laboratory for priority analysis and returning the results, frequently hours later, to the intensive care unit.

Another problem area is the development of reliable support equipment for intensive care. Some examples of servomechanisms needed for life support of the critically ill are:

- Pacemakers which automatically respond to defects in heart rate
- Fluid infusion devices which automatically replace lost blood
- Respiration assist devices which respond to the pO_2 and pCO_2 of the blood

TABLE 5

ASPECTS OF COMPREHENSIVE PATIENT MONITORING

Information monitored or recorded	Physiological parameter derived
electroencephalogram (EEG)	brain wave rhythm
electrocardiogram (ECG)	heart rate
arterial pressure	systolic pressure diastolic pressure mean arterial pressure pulse rate
central venous pressure	mean venous pressure respiration variations in venous pressure
respiration air flow	minute volume tidal volume respiration rate
transpulmonary pressure	airway resistance lung compliance work of breathing
CO_2 concentration	end-tidal pCO_2
O_2 concentration	end-tidal pO_2 oxygen uptake
blood chemistry	pO_2 (arterial and venous) pCO_2 pH O_2 percent saturation O_2 consumption sodium content potassium content chloride content hematocrit blood urea nitrogen (B.U.N.)
fluid intake, output	
temperature, rectal and skin	
patient history; height, weight, age, medication and treatment	

The intensive care ward of the Pacific Medical Center, San Francisco, has been described in detail in a recent publication[21] which discusses the computer system central to the intensive care capabilities. Less well documented is the need for improved sensors which could be used in this intensive care unit. Limitations could be lifted if more reliable, practical sensors and monitoring methods were designed and developed. Examples discussed by Dr. R. C. Eberhart of the Institute of Medical Sciences are noted briefly below.

To monitor pulmonary gas flow for its volume rate, oxygen content, and CO_2 content, an improved method is needed for accurate and rapid response (5-msec response to a step-function input) to the transient variations in respired gas. For the comfort of the critically ill patient, both the flow-measurement and the mass-constituency-measurement devices should not require obstructive masks, tubes, or mouthpieces, and of course, should not interfere with other aspects of intensive care. A currently available automated, rapid-response mass spectrometer when suitably mated with a sampling device may be suitable for constituency determination.

A noninvasive continuous aortic blood-flow measurement would be a considerable aid to intensive care, particularly for postoperative cardiac patients.

Temperature measurement of the body's peripheral region (fingers and toes) relative to vital-organ temperature appears to offer promise of a new means of monitoring the progress of a patient recovering from major surgery. The peripheral regions appear to receive less blood flow following surgery and hence exhibit lower temperatures for the initial recovery period, but exhibit a sudden marked rise in temperature if recovery progresses normally and satisfactorily. Abnormal and unsatisfactory recovery does not appear to produce this noticeable rise in temperature. New methods of measuring body temperature more conveniently and comprehensively will be required if the relation of peripheral temperature to recovery is verified. More practical means to measure temperature over the surface of the body to tenth-of-a degree accuracy may be desirable.

Internal body temperature, a routine intensive care observation, is usually monitored by a rectal temperature device. It has been suggested that a more significant location for measuring this temperature would be near the tympanic membrane, the site nearest to the blood supply of the brain, but a reliable thermistor ear-insert device to provide this temperature is not available.

Development of a mobile life-support and monitoring bed with sensors built in or permanently attached would seem to be desirable. Such a bed could serve to monitor the critically ill after arrival in the hospital, and also during any necessary transport within the hospital. If a telemetry capability were added, such a system could be put to use for first aid and emergency care of accident victims, and for transporting the critically ill from one medical facility to another.

The solution to these problems is within present-day engineering capability and should receive immediate attention. Other advances in intensive care, such as the identification of early signs indicating patient failure by pattern recognition of the monitored variables, are thought to be farther in the future. It is likely that such pattern recognition will require additional measurements than those of temperature, pulse, respiration, and blood pressure and will require considerable statistical study before validation will be achieved. Thus, the urgency lies in developing instrumentation and better sensors to answer today's needs--those that now limit intensive care capabilities in intensive care wards throughout the country.

G. MULTIPHASIC SCREENING

The primary purpose of multiphasic screening is to discover unsuspected diseases in people. At several clinical centers throughout the country (e.g., Permanente Medical Group, Oakland, California) multiphasic screening is performed routinely by subjecting large numbers of persons to x rays, blood pressure readings, blood and urine analyses, height and weight recordings, visual acuity measurements, tonometry, electrocardiography, mammography, Papanicolaou cervical smear analyses, spirometry, audiometry, and so forth, as part of a comprehensive health care program.

Test records are entered, as automatically as possible, into a person's computer memory record, along with information (usually on punched cards) on his medical history and present physical condition. The computer then compares the test results with the normal ranges for age and sex to determine if an abnormality exists. If an abnormal condition is identified, the person is referred to a physician for a more thorough diagnosis and treatment.

Today the great advantage of screening centers is in economy of performing large numbers of patient tests in short time periods. The same tests, if performed in the traditional manner rather than by the automated screening center, would cost four times as much and take much longer.[22]

A future possibility may be the integration of the screening center into a community, regional, and national disease-prevention program to eradicate such major health problems as venereal disease. Disease prevention rather than disease treatment may become the mode of health care in the future when health centers will screen a greater part of the population. The development of tests designed to identify the early stages of specific diseases (e.g., Papanicolaou smear for cervical cancer), will allow physicians to treat the early stages rather than the late severe conditions where changes are already irreversible.

The contribution that the engineering disciplines can make for detecting disease in its earliest stages is the development of improved diagnostic instrumentation which can be automated and operated with a minimum of medical and technical supervision.

For some diseases, early detection and prevention seem the only logical way to achieve better health care. In particular, cerebrovascular disease seems to require the preventive approach because there is little hope of reversing established brain damage. The potential for salvage is particularly important in the case of stroke, which has a high incidence of permanent disability for survivors. The fatality rate is only 15% but, of the survivors, 50% suffer some permanent disability, often leaving them unemployable. The estimated annual cost of care for stroke disability, excluding the cost of care in the hospital during the acute stage, is $3 billion.[23]

RAND Corporation, Santa Monica, and the Cedars-Sinai Medical Centers, Los Angeles, have set the goal of improved stroke detection and prevention by developing screening units for the early detection of the potential stroke victim, thereby allowing preventive medical or surgical therapy to be applied.[24] This interdisciplinary project requires the collaborative efforts of the bioengineer, computer specialist, biostatistician, systems specialist, diagnostician, ophthalmologist, internist, neruologist, neurosurgeon, and neuroradiologist.

Clinical research indicates that most strokes are due to occlusive lesions in the vessels supplying blood to the brain. If the disease is detected in the stenotic or narrowing stage, before complete occlusion occurs, then treatment and prevention of stroke are possible. Several well-known diagnostic techniques for determining anomalies of blood flow to the head are being included in the pilot Potential-Stroke-Screening Unit (PSU): determination of blood flow and pressure in the eye (funduscopy, mediate auscultation, ophthalmodynomometry, tonometry), comparison with blood pressure in the arm (brachial sphygmomanometry), and thermal mapping of the forehead (thermography). These practices are being integrated into a semiautomated screening environment, with data reduction and analysis by computer. Of particular importance to the diagnosis in addition to the above measurements will be a study of the patient history.

Technical support to the RAND study is required in the design of practical (noninvasive) clinical instruments, analysis of the interactions of pulsatile ocular blood flow with ocular structural characteristics, research in methods for clinical data analysis and processing, as well as the improvement of diagnostic procedures and the establishment of a prototype clinic.

H. PROSTHETICS, SENSORY AIDS, AND REHABILITATION

No reliable statistics exist on the number of persons who would benefit from better prosthetics, sensory aids, and rehabilitation. Some indication of the need is possible from the estimated increase of 30,000 amputees and 50,000 blind people in the U.S. each year, adding to the existing several million who are currently in need of aid.

For decades engineers and physicians in these areas of medicine have worked in close association to provide artificial limbs for amputees, sensory aids for the near blind and deaf, and rehabilitation devices for the physically handicapped. However, progress has been limited; private enterprise has been reluctant to enter the field because the market is small, research and development costs are high, and risks are great. The support available in the past has come mainly from the Vocational Rehabilitation Administration, the Veterans Administration, the Children's Bureau, and a few private foundations and insurance companies. The total nationwide support for prosthetic device development has been less than $4 million per year.

The hope exists that much of the research and development needed to support a strong prosthetics and sensory aids program can be drawn from other national efforts, such as that conducted by NASA. Although the past has seen little spin-off in the way of useful hardware, the potential for technology transfer remains high if proper guidelines are followed, guidelines which call for simple devices which are economical, reliable, and have a high degree of user acceptance. Two examples of the successful application of these guidelines follow.

1. Closed-Circuit Television Systems for the Visually Handicapped

Of those persons classified as legally blind in the U.S. (those whose vision is less than 20/200), 60% have some degree of useful vision which can be aided by optical systems. These visually handicapped persons, if assisted by well-designed closed-circuit television systems, could view an illustrated lecture; read plans, books, and papers; study diagrams; make notes; type and see what they are typing; write reports; and sort, manipulate, and assemble small parts.

A prototype closed-circuit television system, designed and fabricated by RAND Corporation researchers,[25,26] is now being used daily by several visually handicapped persons to facilitate reading and writing. The system primarily consists of (1) a television monitor which permits close observation by the handicapped person, (2) a television camera that is positioned by means of an electrically operated servomechanism, and (3) a working surface to support reading and writing material.

The success which this prototype has achieved can be expanded to other uses if the equipment is made portable, miniaturized, and reduced in cost. These changes are now within the state-of-the art, partly through NASA research and development efforts.

2. Myotron for Neuromuscular Rehabilitation

The Myotron[27] is a new type of instrument for the dynamic measurement of skeletal muscle forces and for neuromuscular rehabilitation. It is an illustration of technology transfer from a nonmedical research effort to physical medicine and rehabilitation through interdisciplinary cooperation.

Basically, the Myotron is an external mechanized structure, or exoskeleton, worn around the human arm. It utilizes servomechanisms controlled by arm-force and position transducers to monitor and interact with the motion of the arm. The device was developed by Cornell Aeronautical Laboratory (CAL) and the Veterans Administration Hospital in Buffalo, N. Y. It is a spin-off of an earlier CAL research effort that was directed toward the problem of amplifying man's natural strength by an external mechanized structure, in order to permit a person with average strength to perform heavy work with ease.

The recognition of the potentially useful application of a low-power version of CAL's man-amplifier to medical research and rehabilitation, followed by close cooperation between CAL's engineers and scientists and the VA's research staff, has yielded this new research tool and therapeutic device.

III. CONCLUDING REMARKS

Technology can contribute significantly to the solution of major medical problems hindering the advancement of health care today. To achieve success, however, there must be a close interplay of ideas among diverse disciplines of science, engineering, and medicine, fostered by continuing personal contact and professional understanding.

In methodology, the technical disciplines offer to medicine and biological research the powerful tools of mathematics, systems analysis, and the physical laws. Application of these tools can promote a better understanding of the fundamental behavior of biological systems. This understanding may allow the prediction of biological response to a variety of imposed conditions, measurements, and treatments, thereby making possible the development of new therapies and new diagnostic devices.

In instrumentation, technology can answer the great need for reliable, economical, and practical medical devices. Noninvasive monitoring, automated life-support, and remote telemetry are important instrumentation areas deserving study. In addition, the medical community has need for specific devices (e.g., to locate gastrointestinal bleeding) which should be sought from modern technology.

For both methodology and instrumentation, the areas of mass screening, hospital information processing, and clinical automation present a clear challenge to technology. Mass screening offers the opportunity to play a part in the profound change to modern medicine, a change from the treatment of acute, often irreversible symptoms found in late stages of disease to the earlier detection and prevention of disease. Here the "systems approach" can determine the optimum method for screening many people and may identify hidden interrelationships among test results to detect the earliest stage of disease. Efficient hospital information processing, coupled with extensive clinical automation, can help reduce today's excessive hospital costs.

Technologists should follow certain guidelines if they are to make an impact on today's medical problems. First, an established working relationship with the medical community is essential. Second, the establishment of priorities is important. These priorities should concentrate effort in areas where the potential for technological contribution is high and the impact on health care great. Third, some estimate of cost/benefit must be made to insure that costs do not outweigh benefits to be derived. The upward cost spiral of medical care must be stopped.

There is a genesis of concern today that the rising cost of medicine, crowding in urban clinics, and the lack of rural medical facilities are causing this country's health care to deteriorate. The United States, richest and most technically advanced country in the world, now lags behind 13 other countries in infant survivability and behind 17 others in life expectancy at birth.

What is needed most from technology is not more elaborate electronic gadgetry for the medical researcher and clinician, not more transistorized versions of equipment common to clinics for decades; it is, instead, a fundamental understanding of the problems hindering the availability and quality of health care today, and the application of scientific methods and instruments to these problems in order to bring at more reasonable cost the benefits of today's medicine to all the people, including those who are now out of its reach.

APPENDIX I

RESEARCH PERSONNEL VISITED

The numbers within the parentheses following the names of researchers indicates activity having potential impact on the following areas:

1. Artificial organs and assistive devices
2. Automation of clinical laboratories
3. Clinical instrumentation
4. Hospital information systems
5. Medical telecommunication
6. Monitoring patients under intensive care
7. Multiphasic screening
8. Prosthetics, sensory aids, and rehabilitation

A. H. Gott (2,3)
R. F. Janz (2,3)
Aerospace Corporation
San Bernardino, California

A. Lurie (2)
Biochemistry Laboratory
Boston City Hospital
Boston, Massachusetts

S. Berger (3)
G. Trezek (3)
Department of Mechanical Engineering
University of California
Berkeley, California

D. D. Colosimo (2)
J. W. Ford (3)
W. S. Holmes
R. E. Kell (6,7,8)
E. A. Kidd
J. L. Muerle (4)
R. J. Vidal (3)
Cornell Aeronautical Laboratory, Inc.
Buffalo, New York

B. Lipps (1)
Dow Chemical Research Laboratory
Walnut Creek, California

J. Stem (2,7)
J. Welsh (2,7)
Flow Laboratories, Inc.
Rockville, Maryland

R. Lees (2,3)
Clinical Research Center
Massachusetts Institute of Technology
Cambridge, Massachusetts

I. T. Young (2)
Department of Electrical Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

C. F. Dewey, Jr. (3)
Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

J. D. Fleming, Jr. (2,4,5)
R. F. Stengel (2,4,5)
Charles Stark Draper Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

A. Leroy (2)
Biomedical Engineering Division
National Institutes of Health
Bethesda, Maryland

R. C. Eberhard (1,6)
Institute of Medical Sciences
Pacific Medical Center
San Francisco, California

W. K. McEwen (3)
Francis I. Proctor Foundation for
Research in Opthalmology
and
Department of Opthalmology
University of California
San Francisco Medical Center
San Francisco, California

C. Gazley, Jr. (3,4,7)
S. M. Genensky (8)
J. J. Sheppard, Jr. (3,4,7)
The RAND Corporation
Santa Monica, California

J. Clements (3)
J. Goerke
Cardiovascular Research
San Francisco Medical Center
San Francisco, California

I. M. Levine (5)
Department of Neurology
Veterans Administration Outpatient Clinic
Boston, Massachusetts

APPENDIX II

THE NASA TECHNOLOGY UTILIZATION PROGRAM

The National Aeronautics and Space Administration is the first major science procurement agency to establish an agency wide program to promote the transfer and application of its technology to problems beyond aerospace, for the benefit of the American public. This program was established by NASA following the Space Act of 1958 when it was recognized that the broad and carefully developed technological base NASA had created for the space program might contribute to the solution of other problems facing the nation. The intent of this program is to reap the maximum return of investment in NASA programs by promoting secondary use of space science and technology; or, in the words of Melvin S. Day, Acting Assistant Administrator for Technology Utilization (TU),[28]

> . . . to make available to the American public, including industry, small business, education, medicine, and those concerned with environmental quality, the new technology developed [by the elements of NASA] across many scientific and technical disciplinary areas.

As one part of this program, NASA has sponsored a project which has at its core multidisciplinary teams of scientists and engineers at three not-for-profit research institutes. The teams, called Biomedical Application Teams (Table 6), seek to provide an interface between the diverse fields of aerospace engineering and medicine, thereby increasing the flow of information, ideas, and technology between them.

TABLE 6

NASA BIOMEDICAL APPLICATION TEAMS

Midwest Research Institute 425 Volker Boulevard Kansas City, Missouri 64110	Research Triangle Institute Post Office Box 12194 Durham, North Carolina 27709

Southwest Research Institute
8500 Culebra Road
San Antonio, Texas 78206

The effectiveness of the Biomedical Application Teams' efforts depends considerably on their ability to bridge the gap in methodology and terminology between engineering and medicine. The manner in which this is done was described recently by one of the team's members, and is cited below.[29]

> . . . Technology utilization is the term applied to the task of finding second applications for technology. Many of the methods for implementing the concept of technology utilization are largely passive in nature; passive in this case means the information is provided to those who seek it and thus, the physician must understand the information system in order to use it. One of the unique features of the Biomedical Application Team program is that the method is active. Active, in this sense, means that the problems and solutions are actively sought.
>
> This search for problems is carried out by the members of the multidisciplinary team. Team members visit major medical centers (the National Institutes of Health and medical schools) where suitable medical problems are identified with the aid of a consultant. The consultant, a medical center staff member, helps to insure that the problems selected meet certain minimum requirements. In general our team accepts only those problems which (1) have no solutions available on the

commercial market, (2) are discrete and can be defined in specific terms, (3) impede the progress of priority efforts of the physician, and (4) appear amenable to solution by aerospace related technology. We impose these requirements because this program is designed for problem solving, not just information searching.

If a problem meets these requirements, it is defined by the physician and team member during one or more meetings. Personal interaction has been found to play a vital role in many aspects of the program, and problem definition is no exception. During problem definition, the team member determines the physical science or engineering requirement which is impeding the medical research . . .

After a problem is defined, a solution is sought using several approaches. First, a computer search of the NASA document bank is performed which covers the documents identified in Scientific and Technical Aerospace Abstracts (STAR) and International Aerospace Abstracts (IAA). The bibliography and related documents are analyzed by the physician and the team member to determine whether an adequate solution is available.

A second approach used in finding solutions is to request suggestions from NASA personnel by circulating concise written problem statements to the NASA field centers. These documents are circulated by the Technology Utilization Officers (TUO) who are located at each center and who have a detailed knowledge of the research activities at their centers. The TUO provides a vital link between the teams and key NASA personnel.

A third approach is to contact field center personnel or NASA contractor personnel directly when the teams are aware that these personnel have knowledge about particular problems. These contacts, coordinated with each TUO, allow the teams to rapidly obtain advanced technological information.

After an idea or individual has been identified by these searching procedures, both direct and indirect contacts between physicians and NASA personnel are arranged. In the former case, physicians have visited NASA centers for discussions; in the latter case, the team members have provided the contact by visits and correspondence. Always the idea is to provide the physician with fresh insight into his problem from a discipline he does not normally encounter.

The team then acts as a catalyst to provide implementation of the ideas. Although the primary responsibility for implementation of the technology lies with the physician, the team assists in engineering consultation and in recommendations for ways of applying the technology. In addition, in a few instances NASA has implemented the technology directly when it is clear that no other avenues are open to the physician and when the necessary expertise is available only within NASA. At all times, the team feels that success comes only when utilization has occurred . . .

A variety of applications of aerospace technology to medical research and clinical needs has occurred. Some are adaptation of aerospace instrumentation: (1) a cardiac catheter with a miniature pressure transducer (originally designed for wind-tunnel studies), (2) a muscle accelerometer (from a micrometeorite detector) for measuring neuromuscular disorders, and (3) a breathing monitor (based on automatic air surveillance system) for critically ill patients. Others, such as image processing techniques like those used to enhance television pictures received from spacecraft are being used to bring out details of an x ray picture to aid the doctor making a diagnosis, showing that the more sophisticated and complex aerospace techniques may also contribute to the advancement of medicine.

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