ENGINEERING IN MEDICINE [a]

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INTRODUCTION

We are living at a time when the role of the engineer is taking a number of new directions. New disciplines have emerged—geophysics, meteorology, and oceanography which are identified as engineering sciences. And more revolutionary than this, is the closer association of the engineer with problems in the behavioral and life sciences. We have seen develop within the last generation, disciplines identified as human engineering and human factors engineering and others more closely identified with physiology and medicine.

What has occurred is a change in attitude on the part of many engineers, an increased concern for the well-being of man, an increased awareness of the areas in which the engineer can contribute to this well-being, and an advanced technology which is making these contributions possible.

This change in attitude runs counter to the traditional role of the engineer. In order to appreciate better the magnitude of the transition it is perhaps desirable to trace the history of engineering from its origin.

HISTORY OF ENGINEERING

The prototype of the engineer appears in the earliest historical records. In the lands east of the Mediterranean Sea, in Mesopotamia and Egypt, there were master builders whose knowledge was applied to planning irrigation ditches for agricultural needs, canals for navigation and transportation, aqueducts for water supply, and to the construction of temples, palaces, and pyramids. They also helped develop the arts and implements of war.

In ancient Greece the work was carried on by the "architectron," arch technician, the master of the practical arts. The realm of engineering was extended to include the design and construction of harbors and tunnels and of the first simple mechanical devices using power other than that of man or animal.

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[a] This paper was originally presented at Iowa and Iowa State Universities on May 8 and 9, 1967, as part of a distinguished lecture series given by the engineering departments of both schools. The audiences consisted of medical students and practitioners, engineering students and faculty, and industrial representatives.

The master builder achieved a maximum status during the period of the Roman Empire. The "architectus," as he was then called, was expected to have knowledge of many fields useful to his role. He needed to know astronomy, so that he could better survey land; to know history so that he could better appreciate architectural design and ornamentation; to have a knowledge of law for the preparation of contracts; and to have knowledge of the elements of sanitation and medicine for the better planning of cities and water supplies. In fact, the role of the architectus was so well defined, that a treatise entitled "De Architectura," written by Marcus Vitruvius Pollio about 15 B.C., was regarded an engineering classic and standard reference work 15 centuries later, during the Renaissance.

THE MILITARY ENGINEER

Much of the effort of these early builders was directed to improving techniques and implements of war. We may include the "Trojan Horse" among them, since most of these devices were developed for assault or defense of fortresses or walled cities. Battering rams, catapults and scaling towers, and ingenious defenses against these were their products.

The constant conflict between attack and defense in a period of continuing wars required more and more ingenious devices and defenses. Because these devices were ingenious their inventors were called "ingeniators." Eventually the devices came to be called engines and their creators, engineers. The implication was still the clever planner or contriver.

THE CIVIL ENGINEER

Till the latter part of the 18th century the military engineer applied his skills to civil as well as military needs. As civilian needs increased in relation to military needs during the latter part of the 18th and early in the 19th century, the civilian engineer came into being.

In 1828, the Institution of Civil Engineers, London, was chartered, and in the charter there was stated what may be the first definition of engineering. It said in part, *"Civil Engineering is the art of directing the great sources of power in nature for the use and convenience of man."*

The discovery of oil, the increased use of steam power for moving machinery, the increased utilization of iron and other metals, and the increasing potential of electrical power so increased the scope of the civilian engineer that new areas of engineering developed. In quick succession as scientific discoveries and areas of application occurred, there emerged the mechanical, mining, electrical, chemical, materials, and other new disciplines.

The proliferation did not stop. As new specific areas of technology develop, engineers wish to be identified with them. Within the A.S.M.E., there are probably in excess of 20 groups, each being identified as some distinct pro-

fessional group, such as Solar Energy or Underwater Technology, and yet all coming under the umbrella of mechanical engineering.

In fact, identification with the term engineer was to become so popular, that about 25 years ago, a list was published which included more than 2000 titles with the word engineer. By far the majority of these occupations required no engineering knowledge, and the application of the term engineer was inappropriate.

ENGINEERING DEFINED

Since the inception of professional engineering societies, there has been a constant review and reappraisal of the responsibilities of the engineer. In the latter part of the 1950's, the Recognition Committee of the Engineers Council for Professional Development proposed the following definition:

> "Engineering is the profession in which a knowledge of the mathematical and physical sciences gained by study, experience and practice, is applied with judgment to develop ways to utilize economically, the materials and forces of nature for the progressive well-being of mankind."

This definition expands upon but does not materially change the role conceived for the engineer in the 1828 Charter of Civil Engineers. In elaborating on the later definition the Recognition Committee further stated: "the scope of knowledge peculiar to engineering has been limited to the realms of the mathematical and physical sciences to *distinguish it from the medical and psychological sciences.*"

There is a seeming contradiction between the definition and its elaboration. If knowledge is to be applied for the progressive well-being of mankind, knowledge is necessary as to what constitutes this well-being. This implies knowledge of what affects the physiological and psychological states of man.

And in fact this is so and has been so throughout history, even if this awareness has been limited to a small minority of those who have practiced engineering.

ENGINEERING-MEDICINE RELATIONS

Five thousand years ago, Imhotep was both engineer and physician. He was credited with having conceived and built some of the first pyramids, and being the originator of cut stone masonry. He was also the court magician and physician, remembered in Egyptian mythology as the God of Healing. It may well have been he, or some similarly oriented physician, who performed the first trepanning or trephining procedure, the surgical removal of part of the skull (Fig. 1) to relieve pressure or perhaps in those times, to exorcise demons. Similar procedures must have been followed by Inca and pre-Inca cultures in Peru, since similarly trephined skulls were found in excavations there.

The Romans associated engineering and medicine when they were con-

FIGURE 1.—Frontal bone trephined from famous Squier's Skull, Yucary Valley located 24 miles east of Cuzoo, Peru.

cerned with the draining of marshes and the availability of potable water, the first sanitary engineers.

At the Museum in Naples, Italy, there is an exhibit of surgical instruments used in Rome and Pompeii. These instruments do not vary significantly from present instruments and indicate a close working relationship between the medical practitioner and the tool and instrument maker.

Leonardo da Vinci (1452–1519), a great artist, was not only an engineering genius, but and outstanding anatomist and physiologist, and applied his knowledge of physical law to explain physiological phenomena, even to attempting to describe the circulation system. Giovanni Borelli (1609–79), pupil of Galileo, applied the laws of mechanics to the movements of animals and wrote the first treatise on biomechanics.

This cross-disciplinary curiosity was evidenced with increasing frequency by scholars during the 17th, 18th, and 19th centuries. Sanctorius (1561–1636), a professor of medicine, was the first to use the thermometer as a clinical tool. Marcello Malpighi (1629–94), an anatomist, was the first to apply the microscope to study living tissue. Charles Babbage (1792–1871), a mathematician and physicist, developed a form of ophthalmoscope, and Willem Einthoven (1860–1927), a physiologist, developed a string galvanometer as a tool to record cardiac electric outputs.

Bernoulli, Euler, and Coulomb (18th century) tried to develop mathematically a rational formula for the determination of the optimum and maximum of human work capacity in terms of force, velocity, and duration of activity.

As a result of the Franco-Prussian War and the Italian efforts in North Africa, towards the end of the 19th century, considerable interest developed

in prosthetic devices to help the large number of amputees. New techniques involving engineering and medical efforts were tried.

In Europe also, this was a period of great concern for the proper utilization of the manual worker and operator. Extensive research was conducted then in work physiology, now known as Ergonomics.

POST-WORLD WAR II PERIOD

But it was not until World War II when communication devices, transportation equipments, and weapons of war were often beyond the capacities of their human operators that a substantial segment of the engineering population came to realize their interdependence with the behavioral and life scientists. It was the Space Age, on the other hand, with its sophisticated scientific achievements, particularly for the support of life in an unfavorable environment and the monitoring of life processes remotely that raised the status of the engineer in the opinion of the medical counterpart.

It was during this period between World War II and the Space Age and beyond that this new discipline emerged. It has been called by many names—biotechnology, bioengineering, medical engineering, and biomedical engineering. And it has had as many definitions.

To avoid the dilemma of what title and which definition may be most appropriate, let us simply think of this as an association of the engineer and engineering scientist with the physician and medical scientist or Engineering in Medicine.

MEDICINE DEFINED

Medicine is defined in the dictionary as "the art or science of preserving or restoring health or due physical condition as by means of drugs, surgical operations or appliances." Medicine therefore has the responsibility, 1. to prevent disease where possible, 2. to diagnose the nature of the disease at its onset, 3. to cure where it cannot be prevented, and finally 4. to restore some function where damage has occurred.

ENGINEERING PARTICIPATION

Engineering participation takes place along this continuum. At each of these stages the engineer may perform at different levels of sophistication. He may, for example, satisfy the need expressed by some physician by designing for him some particular instrument or device. He may participate jointly with the medical scientist in some such development or research. He may, finally, proceed on his own with the advice or consultation of the medical scientist.

PREVENTIVE STAGE

There is a role for the engineer even as there is for the physician in the prevention of disease. This is the oldest continuing area of association

between physician and engineer, and is exemplified by their joint efforts in the Public Health Service. This joint service covers the drainage of marshlands, the disposal of sewage, the reduction of airborne and water-borne pollutants, the transportation of potable water, and the creation of habitable environments (radiation and other hazards).

The recent furor about safety in automotive design highlights another area which is akin to preventive medicine. When the engineer considers the harmful and dangerous elements existing in a developing design, and proceeds in a manner so as to minimize these elements, he is acting to prevent injury or trauma.

Recent work in sterile environments is another such contribution. The impetus for this was derived from the experience obtained on space vehicles and its successful adaptation to hospital environments will definitely result in reducing infections and their transmission.

DIAGNOSTIC STAGE

For a long while the engineer assisted the physician by the design or invention of diagnostic tools. New techniques and improvements in older techniques developed by the physical scientists for whatever purpose have been adapted to medical purposes. X-ray photography has been improved so that better results can be obtained with less harmful effect on the subject.

Infrared photography has been adapted for diagnostic purposes, since the parts of the body with increased blood flow, as in a rheumatoid condition, will photograph differently than parts with a normal blood supply, and even more so than for an area with a diminished blood supply. Ultrasonics also has been used as a diagnostic technique, in ophthalmology and in the location of breast tumors, as two instances.

The fiber optic endoscope is a comparatively recent tool which has made it possible to examine relatively inaccessible interiors—the esophagus, stomach, urethra, and rectum. Based on devices developed for examining the interior surface of hollow castings, these endoscopes consist of flexible light-conducting, plastic fibers arranged in geometric bundles. Images viewed internally are conducted around the fiber bends by multiple reflections until they are received at some external viewing piece.

Improvements in electronic and optical techniques have been used for measuring and recording physical or physiological deviations from the normal. By fixing on permanent records, events which occur in time, more accurate clinical observations are being made.

Subjective impressions which the physician obtains from personal observation may be reinforced or corrected by such records.

The computer has become potentially powerful as a diagnostic tool. Programs have been and can be established in which the various symptoms associated with some family of diseases may be organized in an appropriate

fashion to relate symptoms with disease. One such program recently completed at N.Y.U. relates blood disease symptoms to certain blood diseases, the symptoms weighted according to some order agreed upon by a group of medical experts. In trial runs in which the symptoms associated with a number of patients were fed into the computer, the diagnoses made by the computer agreed with those of the experts in over 80 percent of the cases.

CURATIVE, REMEDIAL STAGE

Those of you who have read Newsweek of April 24, 1967, will have seen the article entitled, "New Medicine." The article dealt with many of the recent engineering contributions to the healing arts. It described in much greater detail than would have warranted here, many of the dramatic devices that have resulted from the combined efforts of engineers and physicians.

Foremost, of course, have been the mechanical heart, heart and lung machine, and dialysis machines which maintain vital functions at a time when the patient's own organs are malfunctioning, and while the body's own restorative processes require assistance.

There are also the techniques which are facilitating the more daring surgical procedures. Hyperbaric chambers permit super-saturating the patient's blood with oxygen, extending the available operation time. Cryosurgery (super cooling) and lasers (coherent light) have been used as surgical knives. The former has been used principally for brain surgery and the latter for "spot welding" detached retina and for certain skin cancers.

Techniques adapted from surveying triangulation techniques have been used to concentrate beams of radiant energy on some source of infection or malignancy. By directing a series of beams, each of which is in itself not intense enough to damage living tissue, to a particular point, enough energy may be concentrated at that point to destroy infected or cancerous tissue. Ultrasonic energy has been directed by appropriate devices to destroy interior tissues and formations such as kidney stones.

Less glamorous, but equally effective, are interior prostheses or endoprostheses—pins, plates, and screws of various sizes which are used to stabilize bone fractures while the healing is in progress.

PROSTHETIC OR REHABILITATIVE STAGE

This area, perhaps, is the one in which engineering has had the widest scope till now. The extensive financial support made available through the Prosthetic and Sensory Aids Service of the Veterans Administration since 1948, and later the even more extensive support from the Vocational Rehabilitation Administration for all types of rehabilitative devices have prompted many engineers into this area of engineering in medicine.

A prosthesis is the extension of any human organ to restore or improve its function when such function has been totally or partially lost through deterioration, disease, or trauma. In this sense, spectacles or eyeglasses are prostheses, as are hearing aids, though more appropriately they may be called sensory aids.

The modern hearing aid is a distantly removed relative of the old hearing trumpet, or even of the hearing aids of the thirties and forties. Even though some engineers insist that modern hearing aids are not as effective as some earlier models, there is no question that cosmetically they are much more acceptable. And who is to say how much psychological acceptance may affect the attitude of the one needing aid, so that he may hear better though the device is no better?

A major area of concentration in recent years has been that of aids to the blind. The conventional cane, which was used by the blind to sense the ground surface ahead of them, may soon be replaced. This one (developed under VA auspices) uses laser beams to sense obstacles, above, directly forward, and forward at ground level (pp. 253–254, BPR 10–7). The high obstacle results in a high beep tone in the sensing device, the low obstacle will produce a low tone, and anything affecting the intermediate sensor will produce a tactual stimulus. Each of these will advise the blind person of the conditions existing in the space before him.

For the blind also, devices are being developed which will enable them to read books in conventional type. Some rather elaborate attempts are being made in which the device will read printed syllables and will produce intelligible sounds. Less pretentious but currently more effective are devices such as the "Visotactor" from the laboratory of Hans Mauch which senses the letter as the blind person moves the sensing device along the printed line. It then actuates the number of tactile stimuli (six) at each of the fingers in such a fashion as to simulate the shape of the letter. The operator senses the letter as if it were in raised type. Another version, the "Visotoner," produces a series of tones, which are interpreted by the blind person.

ARTIFICIAL EXTREMITIES—LEGS

Remarkable progress in artificial arms and legs, upper- and lower-extremity prostheses, has been made since 1946, if not always in improved function, at least always in cosmetic appearance, comfort, and ease in performance of the required functions.

Better materials, particularly plastics, have improved appearance, reduced fabrication time, and together with improved fitting techniques, reduced discomfort. But beyond this, advanced engineering design has made possible certain improvements not previously available to the amputee.

In the design of lower extremity above-knee prostheses, the introduction

of the "suction socket," in effect a better fit to the amputee's musculature, has removed the need for suspenders or other means of supporting the prostheses, and permitted the amputee greater freedom of movement. Several hydraulic knee devices have improved the amputee's sense of balance on the artificial leg. Taking advantage of the variable resistance of a fluid through an orifice, the engineers have devised combinations which decelerate at the termination of forward and rearward swings. This has not only improved the appearance of the gait of the amputee, but also reduced terminal impact and the energy cost.

For the below-knee amputee also, major improvements have been made. The human knee does not operate as a simple hinge. It has a constantly shifting instantaneous center of rotation as the shank is fully flexed. The prosthesis, however, has a single-axis hinge. Before the lower-extremity prosthesis was improved, the discrepancy between the knee flexion and the prosthesis hinge resulted in longitudinal movement between the stump and the socket. This produced discomfort and abrasion. The improvement has been accomplished by applying the principle of the suction socket, and depending on a flexible hinge system between below-knee prostheses and above-knee cuff.

Within the last ten years, lower-extremity prostheses have been designed and applied successfully in cases where the leg has been amputated at the hip joint, and even in cases where half of the pelvis has been removed.

ARTIFICIAL EXTREMITIES—ARMS

As great as have been the advances in lower-extremity prostheses, those for the upper extremity have been greater. First, there was a difference in amputee attitude to be overcome. While the leg was almost a necessity, the artificial arm was not. A majority of amputees had learned to function quite adequately with one hand, in preference to wearing the rather ghastly pre-World War II devices.

Among the improvements was the appearance. New plastics and casting techniques permitted fabrication of cosmetic gloves which are more lifelike in appearance, and better arm segments. New combinations of springs or tension devices made for easier hook operation. New elbow locks facilitated positioning the arm, new control cable arrangements increased the overall efficiency, and the new plastics facilitated fabrication. As in the case of lower-extremity prostheses, more difficult amputations as forequarter disarticulations have been successfully fitted with prostheses.

Improvements in electromyography, the pickup and recording of voltages generated within the muscle, and miniaturization of electronic electromechanical components have suggested the possibility of more sophisticated control systems for upper-extremity prostheses, the ultimate goal of such a prosthesis responsive to the "thought" or willed movement of the wearer

(Fig. 2). Simpler versions are already operating in a variety of experimental combinations.

SPLINTS-BRACES

Perhaps even more difficult is to restore some measure of upper-extremity function to the hemiplegic or quadriplegic patient. The operation of even the simplest device is a major achievement for the paralyzed person. Many engineering groups have attempted to arrange multiple linkage systems which simulate the arm motion, and power them to perform some necessary function. The feeder has been a subject of much study. In principle, such devices compare with some of the Armed Services Studies of man-amplifiers, but in practice these may prove even more difficult of achievement. The greater challenge results from the fact that the inert arm is an impediment, but must be maintained and given the semblance of a functioning extremity.

Wheelchairs and walkers are other assistive services receiving much attention.

Endoprostheses, discussed previously, to maintain parts together during healing, are also conceived of as permanent replacements for certain damaged skeletal parts. In one dramatic instance reported recently, the whole femur was removed and replaced by a metal replica. The unusual feature was that the endoprostheses included the knee hinge and a lower

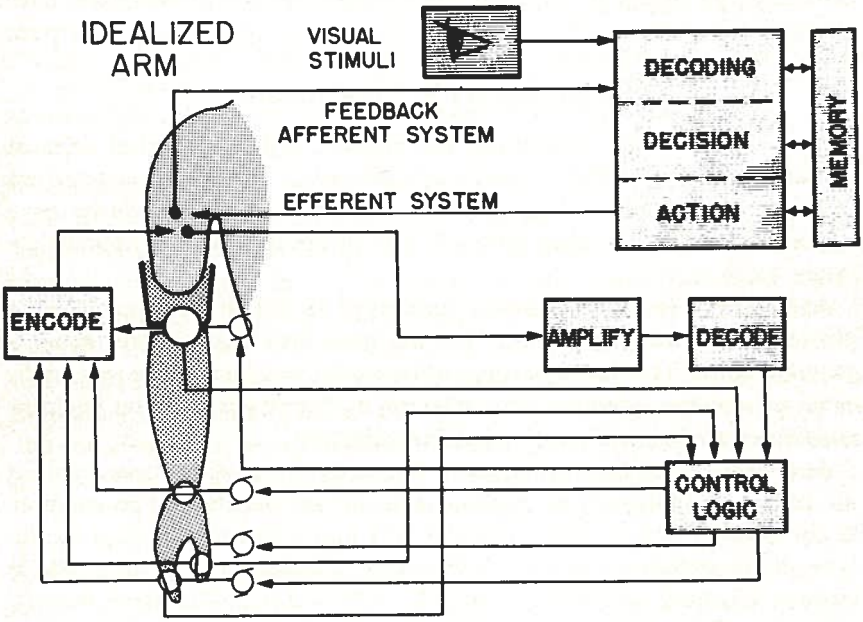

FIGURE 2.—Idealized schematic presentation of the components of a completely controlled arm prosthesis.

segment that was inserted into and attached to the tibia. Apparently this has proven to be a successful replacement.

REHABILITATION SURGERY

The engineer is even participating in plastic surgery, also within the area of rehabilitation or restoration. In Glasgow, Scotland, a team of engineers under Robert Kenedi, University of Strathclyde, has cooperated with a surgical group under Thomas Gibson, Royal College of Surgeons, to improve plastic surgery where skin grafts and cartilage implants are being made.

A tensiometer measures the extent to which the skin may be extended without undue loss of circulation in the capillaries which feed it. They have also separately determined built-in stresses in rib cartilage, so that when this is used as a replacement in damaged noses, for example, there will not be deformation due to the effect of stress relief.

ENGINEERING DIVISIONS

From the foregoing, it can be surmised that engineers with a variety of backgrounds are entering the field of medicine. The civil, sanitary, or environmental engineer carved out his role some decades ago, and is constantly expanding it. Now, however, other engineering disciplines have assumed initiative on their own, and are playing increasingly important parts.

ENGINEER-DOCTOR RELATIONSHIPS

As I have already mentioned, the engineer and the physical scientist operate at several different levels of relationship with their counterpart in the medical sciences (Fig. 3). Since we at New York University have functioned at many of these levels, I may illustrate this with appropriate examples.

At the lower level, the engineer has served as technical support for the physician and medical scientist. This has been the situation until about a generation ago. The design of such equipment as was then in use was predicated on the specifications recommended by the physician. The engineer designed, perfected, and maintained the equipment.

At the next level, the engineer is consulted by the physician who suggests the need for equipment to perform some specific function. The engineer in this instance has a wider latitude, and may proceed to design to the limit of his experience and ingenuity. Such an instance was the multiple purpose iron lung, which we developed in 1952–53 with Dr. Alvan Barach, a member of the College of Physicians and Surgeons, Columbia University.

At a still higher level, the engineer and physician work as a team to develop knowledge about some physiologic state, or perhaps to come to a bet-

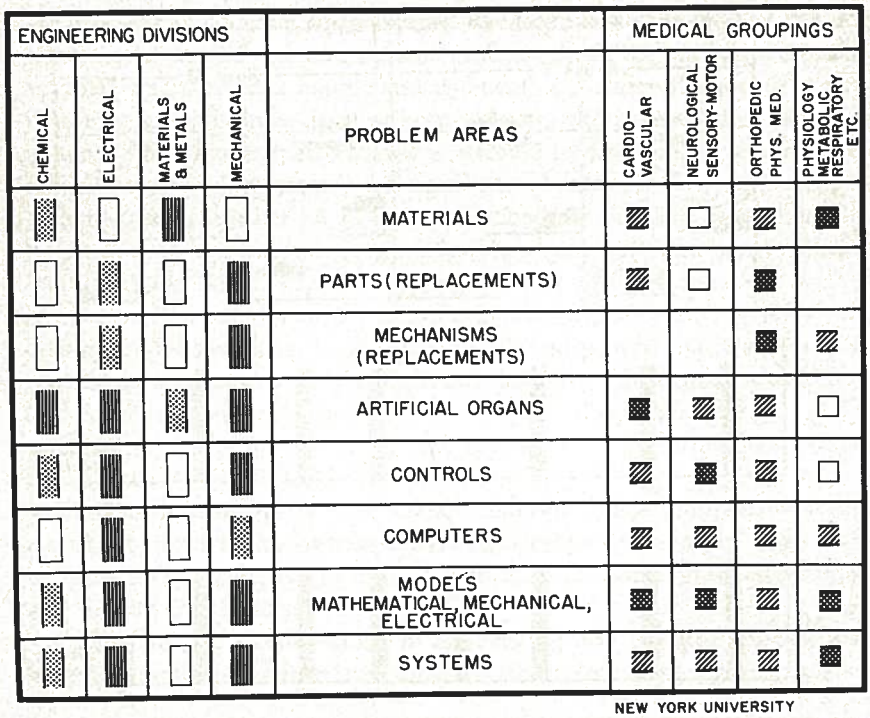

FIGURE 3.—Suggested relationships between areas of engineering and medicine and where problems are likely to occur. The density of the square indicates the intensity of involvement (after Robert Rushmer, University of Washington).

ter solution to a design or equipment problem. The engineer may perceive some physical phenomenon relating to a physiological event, and this may suggest some diagnostic, therapeutic, or rehabilitative device. An instance of such cooperation, in our experience, is the system we have called the "Pedograph." (Fig. 4.) This system, which utilizes a specially designed shoe or sandal worn by the subject, indicates the relative states of the feet in pathological locomotion, as a departure from normal locomotion, in position and time. This is an engineering concept, originating from close observation of locomotion in another study, but depends on its ultimate use on a good understanding of the physiological correlates.

In a similar category, we place our study on the pressures within the socket of the amputee. A number of fitting techniques have been developed on the basis of different hypotheses as to what occurs at the stump-socket interface. This study was conceived to evaluate a variety of these techniques to investigate pressures, and changes in pressure within the step cycle during the day and diurnally. Consultation with the physician for the possible causes of the observed variations may eventually result in a

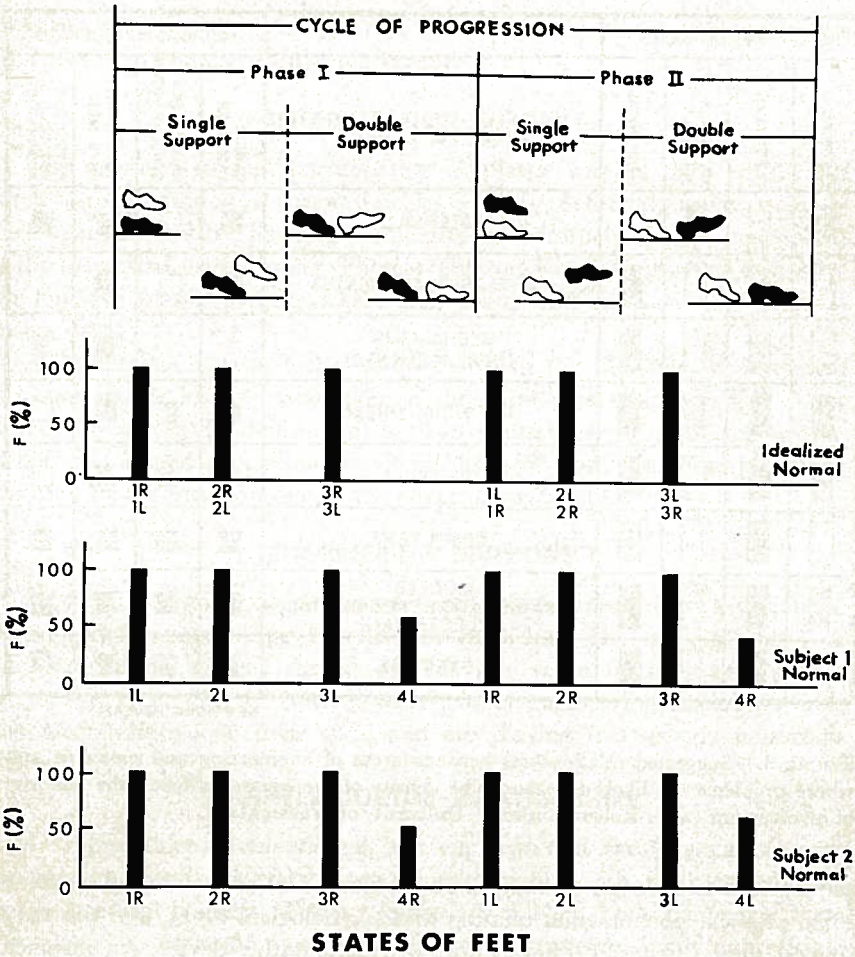

FIGURE 4.—Frequency diagram denoting the percentage of time in a given number of steps in which certain foot positions occur for different subjects (normal locomotion).

better understanding of socket shape, and the effect of fitting and of alignment.

At the highest level of participation, the engineering scientist may often initiate the research and as often act as project director. This does not imply the absence of the life scientist. It does suggest that the nature of the program is such as to place a premium on knowledge of the physical sciences in order to obtain better understanding of some particular physiological phenomenon.

Such a situation exists currently in our Research Group wherein Dr. Nubar and Mr. Bennett are attempting to explain the presence or absence of "slip" among plasma and red cells and the intima. Nubar has approached

the problem analytically, assuming slip to exist, and on the basis of this and other certain simplifying assumptions (so as to make the mathematics manageable) has derived a mathematical model of a slurry flowing in a nonpulsating, straight tube. He has been able, on the basis of this model, to obtain a flow velocity pattern as it is affected by pressure, vessel diameter, and hematocrit in agreement with experimental data.

Bennett, on the other hand, has approached the problem experimentally, with equipment of his own design (Fig. 5), which permitted him to observe individual red blood cells, and determine their distance from the wall at limits from 0.4 micron to 1.4 micron. In this experiment, "in vitro" the cells appeared somewhat as shown (Fig. 6) and proved that these cells do slip along the container surface. He is now hopeful of developing a technique to determine whether the plasma too is slipping along the surface.

There are some controversial thoughts about engineering in medicine which I should like to leave with you.

The first is in regard to educational programs. There are those who now consider bioengineering or biomedical engineering as a separate distinct discipline with its own quota of courses in addition to courses in the life sciences and the physical sciences.

Others suggest a combination of engineering and physical sciences with a limited number of courses from the life sciences, courses such as mammalian

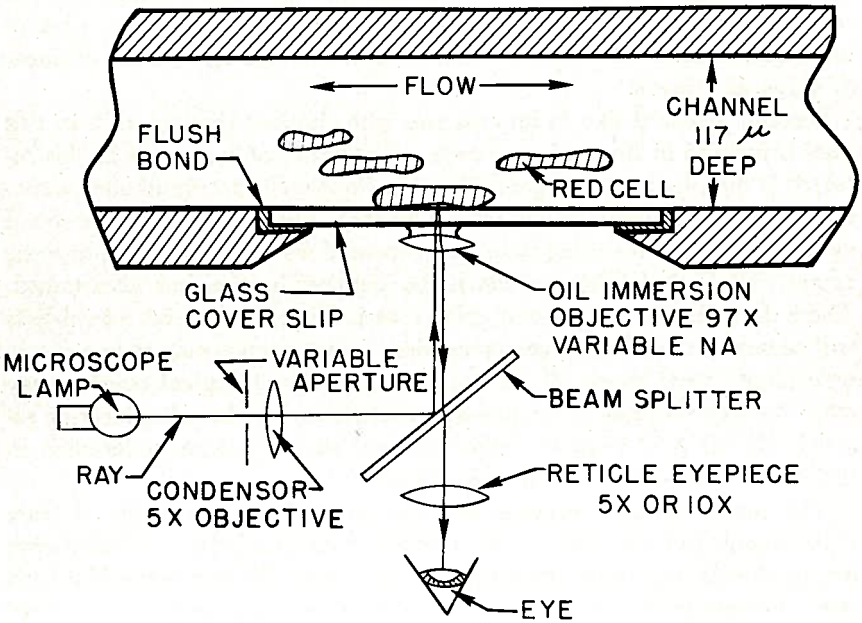

FIGURE 5.—Schematic diagram of an optical system for viewing a red blood cell as it passes over a glass plate.

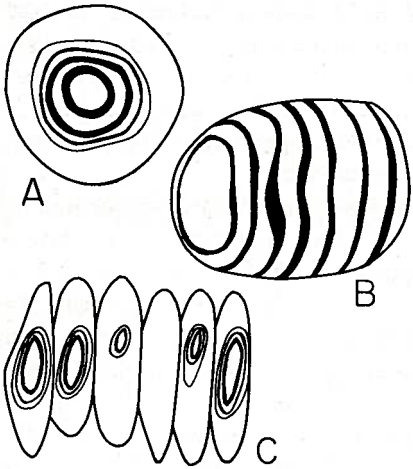

FIGURE 6.—Graphic representations of how blood corpuscles and groups of blood corpuscles appear when seen through the scanning device. The alternate light and dark lines are caused by the interference between the direct and reflected light waves.

anatomy, physiology, and organic chemistry. Still others suggest only the best possible training in the engineering and physical sciences.

I personally would favor the last. I believe the truly interested person will develop his interests in one major area of the life sciences, and eventually will concentrate on some limited aspect of his general area of interest. He then can review the literature, consult with the experienced counterparts in the life sciences, and conduct his research accordingly. What he brings of importance to the life sciences research is his competence as an engineer or physical scientist.

Second, I should like to impress you with the fact that research in this area is not full of dramatic successes. As a matter of fact, most of this research is dull, tedious, and painstaking. It implies the accumulation, reduction, and interpretation of mountains of data. The human organism is not as compliant, nor as willing to be experimented with, for research purposes, as are the physical things to which the engineer has become accustomed. These data usually will have a greater variability, the number of subjects will be more limited; and even more when the research is such as to measure or evaluate some aspect of human effort, the psychological overlay may mask the true meaning of the physical or physiological data. Engineering research in this field requires dedication and should not be undertaken in the search for glamour or instant reputation.

The engineer should consider not only research for the design of body replacements but also that research which leads to a better understanding of the physical conditions which govern or modify life processes. This with the hope that understanding may eventually lead to a diminution or control of processes which result in disease and incapacitation. Control of heart damage, for example, is to be preferred to the best artificial heart replace-

ment. When control cannot be achieved, and rehabilitation is required, however, the engineer should strive to provide rehabilitation and assistive devices which are possible, at the minimum cost, with the minimum of encumbrance, for the greatest number.

And last, I am concerned that the developing teams of engineers and doctors may not seriously evaluate their accomplishments in terms of the true meaning of life, of adequate living. In the article in Newsweek, to which I previously referred, a member of one of the more publicized medical engineering teams was quoted as saying: "We cannot duplicate God's work, but we can come very close." I am worried by this presumptuous attitude. We may in many instances prolong life, a life however, limited to the radius permitted by the length of tube or cable connecting the patient to his machine. We may indeed provide excellent artificial organs, but then we may have something half-man, half-robot. Truly let us hope that the efforts of this new discipline or cooperative effort will be directed to something more worthwhile.

It will be up to the present and future generations of engineers and engineering scientists to work with life scientists for the "progressive well-being of mankind."