Autumn 1963

Artificial Limbs

A Review of Current Developments

COMMITTEE ON PROSTHETICS RESEARCH AND DEVELOPMENT

COMMITTEE ON PROSTHETICS EDUCATION AND INFORMATION

National Academy of Sciences
National Research Council

NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

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COMMITTEE ON PROSTHETICS RESEARCH AND DEVELOPMENT
COMMITTEE ON PROSTHETICS EDUCATION AND INFORMATION

The *Committee on Prosthetics Research and Development* and the *Committee on Prosthetics Education and Information*, units of the Division of Engineering and Industrial Research and the Division of Medical Sciences, respectively, advise the Veterans Administration and the Department of Health, Education, and Welfare in the conduct of research and education activities in the fields of prosthetics and orthotics; they provide means for correlating Government- and privately sponsored research in those fields.

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Variety

WILLIAM J. ERDMAN, II, M.D.[1]

In virtually every area of knowledge, be it anthropology, engineering, psychology, or zoology, there is a need for dissemination of information at various levels of sophistication. Information in the form contained in research reports is necessary for further progress by other research groups but is seldom found to be directly useful by practitioners. Technical documents intended to assist the practitioner in carrying out his day-to-day responsibilities are of little value to the lay people or nonspecialists who, for one reason or another, have an interest in the subject. Limb prosthetics is no exception to this rule.

For example, a detailed report on the physical constants of various segments of the human body is of little interest to the chief of a prosthetics clinic team or to the practicing prosthetist, but is indispensable to the designer of artificial limbs. Definitive manuals on fabrication procedure, so essential to the prosthetist, are of little or no concern to the physician, patient, or rehabilitation counselor. Thus, information in a variety of forms is needed if all concerned with problems of amputation, including the amputee, are to carry out their responsibilities effectively and efficiently.

In the early days of the Artificial Limb Program, a lady amputee once wrote to the Mellon Institute complaining that, whereas she could obtain a four-page pamphlet on a new can opener, there were no printed instructions available concerning proper use of an expensive artificial leg. Similar observations have been made by other amputees in their desire to overcome their disabilities. Though in recent years there has been a great increase in the specialized literature pertaining to amputees, little information and no truly comprehensive documents have been prepared especially for the amputee, his family, or other nonspecialists. Accordingly, the Editorial Board of ARTIFICIAL LIMBS decided to devote the major portion of this issue to an article that might be of value to nontechnical personnel concerned with rehabilitation of the amputee.

Quite naturally, a patient has an avid interest in his condition which is not satisfied by his physician's sometimes cursory or too-technical explanation, or the patient may be embarrassed to ask questions that seem simple to others. There will be many areas about which he will not have the intellectual ability to raise questions until he has experienced the need to know. He may not quickly gain psychological insight adequate to ask realistic questions. It is hoped that *Limb Prosthetics Today*, by providing the patient and his family with early and ready access to correct, up-to-date information, will prevent them from arriving at erroneous conclusions or oscillating

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between unrealistic hopes and unwarranted fears, and thus will materially assist them all to meet their problems.

Though prepared primarily for use by amputees and their families, *Limb Prosthetics Today* may also prove valuable to others. The nontechnical approach should make it useful as an introductory text to future practitioners: undergraduate medical students, residents, students in physical and occupational therapy, and apprentice prosthetists. Rehabilitation counselors and administrative personnel responsible for the welfare of amputees might gain a more accurate picture of the problems and potentialities of the patients they serve. Where more technical information is desired, the documents cited in the bibliography accompanying *Limb Prosthetics Today* may be studied.

It is not anticipated that regular readers of ARTIFICIAL LIMBS will necessarily learn any new information from *Limb Prosthetics Today,* though some may appreciate a review or the updating of previous information. Present readers, however, are in a position to make a critical analysis of the level of the presentation, its clarity, and the appropriateness of various items for amputees and for the nonspecialist professional persons concerned with amputees; and the Editorial Board invites any comments that will assist in future revisions.

For the more sophisticated reader, this issue of ARTIFICIAL LIMBS contains an article by Edward Peizer concerning the effects of socket attitude on the gait of a bilateral, above-knee amputee. In addition to emphasizing the necessity for accurate alignment, this research report demonstrates how certain instrumentation can be employed to uncover facts previously hidden.

Both the specialist and the general practitioner in any field will always appreciate a thoughtful book review by a world-famous authority. Such reviews may well point out the many excellent features justifying purchase of a new book, yet note any aspect considered controversial or potentially misleading. For all readers, thus, we are happy to inaugurate signed book reviews as a new feature. As a first step, Charles Frantz has provided a thoughtful analysis of an important new book, *The Limb-Deficient Child.*

It is hoped a wide variety of readers will find this issue of ARTIFICIAL LIMBS interesting and useful.

Limb Prosthetics Today

A. BENNETT WILSON, Jr., B.S.M.E.[1]

Loss of limb has been a problem as long as man has been in existence. Even some prehistoric men must have survived crushing injuries resulting in amputation, and certainly some children were born with congenitally deformed limbs with effects equivalent to those of amputation. In 1958 the Smithsonian Institution reported the discovery of a skull dating back about 45,000 years of a person who, it was deduced, must have been an arm amputee, because of the way his teeth had been used to compensate for lack of limb. Leg amputees must have compensated partly for their loss by the use of crude crutches and, in some instances, by the use of peg legs fashioned from forked sticks or tree branches (Figs. 1 and 2).

Fig. 1. Mosaic from the Cathedral of Lescar, France, depicts an amputee supported at the knee by a wooden pylon. Some authorities place this in the Gallo-Roman era. From Putti, V., *Historic Artificial Limbs*, 1930.

Fig. 2. Pen drawing of a fragment of antique vase unearthed near Paris in 1862 which shows a figure whose missing limb is replaced by a pylon with a forked end.

The earliest known record of a prosthesis being used by man was made by the famous Greek historian, Herodotus. His classic "History," written about 484 B.C., contains the story of the Persian soldier, Hegistratus, who, when imprisoned in stocks by the enemy, escaped by cutting off part of his foot, and replaced it later with a wooden version.

A number of ancient prostheses have been displayed in museums in various parts of the world. The oldest known is an artificial leg unearthed from a tomb in Capua in 1858, thought to have been made about 300 B.C., the period of the Samnite Wars. Constructed of copper and wood, the Capua leg was destroyed when the Museum of the Royal College of Surgeons was bombed during World War II. The Alt-Ruppin hand (Fig. 3), recovered along the Rhine River in 1863,

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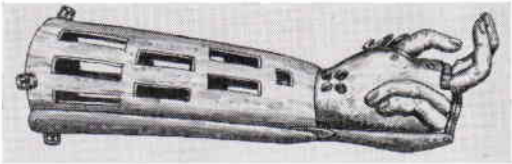

Fig. 3. Alt-Ruppin Hand (Circa 1400). The thumb is rigid; the fingers move in pairs and are sprung by the buttons at the base of the palm; the wrist is hinged. Putti, V., *Chir. d. org. di movimento*, 1924–25.

and other artificial limbs of the 15th century are on display at the Stibbert Museum in Florence. Most of these ancient devices were the work of armorers. Made of iron, these early prostheses were used by knights to conceal loss of limbs as a result of battle, and a number of the warriors are reported to have returned successfully to their former occupation. Effective as they were for their intended use, these specialized devices could not have been of much use to any group other than the knights, and the civilian amputees for the most part must have had to rely upon the pylon and other makeshift prostheses.

Although the use of ligatures was set forth by Hippocrates, the practice was lost during the Dark Ages, and surgeons during that period and for centuries after stopped bleeding by either crushing the stump or dipping it in boiling oil. When Ambroise Paré, a surgeon in the French Army, reintroduced the use of ligatures in 1529, a new era for amputation surgery and prostheses began. Armed with a more successful technique, surgeons were more willing to employ amputation as a lifesaving measure and, indeed, the rate of survival must have been much higher. The practice of amputation received another impetus with the introduction of the tourniquet by Morel in 1674, and removal of limbs is said to have become the most common surgical procedure in Europe. This in turn led to an increase in interest in artificial limbs. Paré, as well as contributing much in the way of surgical procedures, devised a number of limb designs for his patients. His leg (Fig. 4) for amputation through the thigh is the first known to employ articulated joints. Another surgeon, Verduin, introduced in 1696 the first known limb for below-knee amputees that permitted freedom of the knee joint (Fig. 5), in concept much like the thigh-corset type of below-knee limb still used by many today. Yet, for reasons unknown, the Verduin prosthesis dropped from sight until it was reintroduced by Serre in 1826 and, until recently, was the most popular type of below-knee prosthesis used.

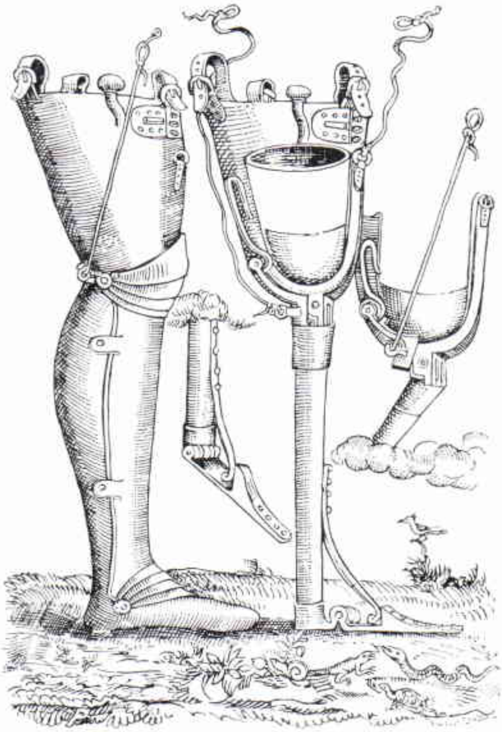

Fig. 4. Artificial leg invented by Ambroise Paré (middle sixteenth century). From Paré, A., *Oeuvres Completes*, Paris, 1840. From the copy in the National Library of Medicine.

After Paré's above-knee prosthesis, which was constructed of heavy metals, the next real advance seems to be the use of wood, introduced in 1800 by James Potts of London. Consisting of a wooden shank and socket, a steel knee joint, and an articulated foot, the Potts invention (Fig. 6) was equipped with artificial tendons connecting the knee and the ankle, thereby coordinating toe lift with knee flexion. It was made famous partly because it was used by the Marquis of Anglesea after

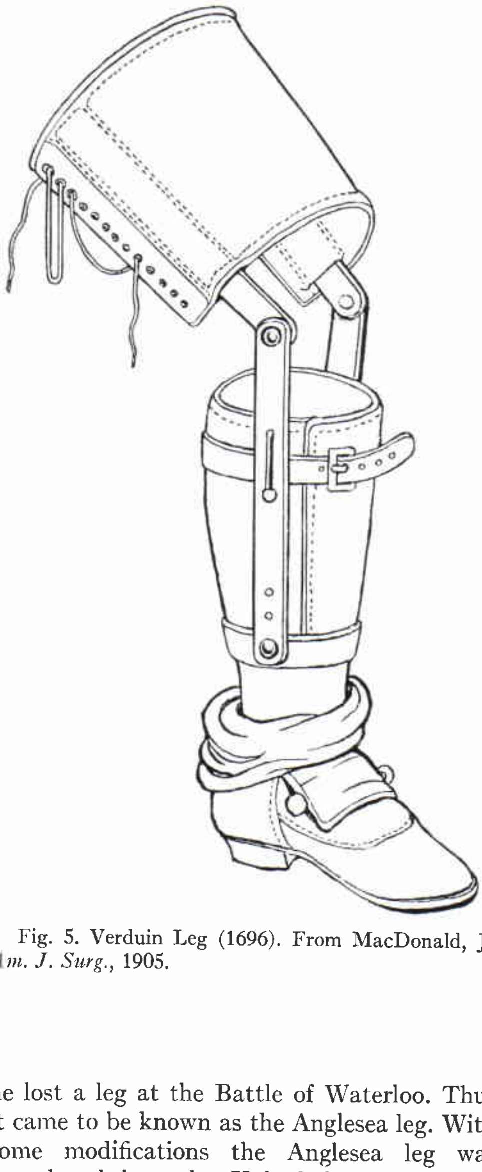

Fig. 5. Verduin Leg (1696). From MacDonald, J., *Am. J. Surg.*, 1905.

he lost a leg at the Battle of Waterloo. Thus it came to be known as the Anglesea leg. With some modifications the Anglesea leg was introduced into the United States in 1839. Many refinements to the original design were incorporated by American limb fitters and in time the wooden above-knee leg became known as the "American leg."

The Civil War produced large numbers of amputees and consequently created a great interest in artificial limbs, no doubt inspired partly by the fact that the federal and state governments paid for limbs for amputees who had seen war service.

J. E. Hanger, one of the first Southerners to lose a leg in the Civil War, replaced the cords in the so-called American leg with rubber bumpers about the ankle joint, a design used almost universally until rather recently. Many patents on artificial limbs were issued between the time of the Civil War and the turn of the century, but few of the designs seem to have had much lasting impact.

During this period, with the availability of chloroform and ether as anesthetics, surgical procedures were greatly improved and more functional amputation stumps were produced by design rather than by fortuity.

World War I stirred some interest in artificial limbs and amputation surgery but, because the American casualty list was

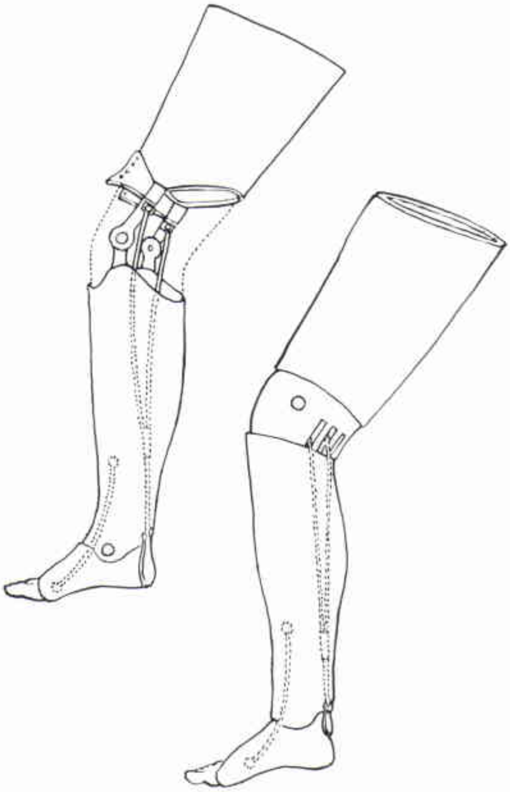

Fig. 6. Anglesea Leg (1800). Below knee at left above knee at right. Knee, ankle, and foot are articulated. From Bigg, H. H., *Orthopraxy*, 1877.

relatively small, this interest soon waned and, because of the economic depression of the Thirties, some observers think, very little progress was made in the field of limb prosthetics between the two World Wars. Perhaps the most significant contributions were the doctrines set forth and emphasized by Haddan and Thomas, a prosthetist-surgeon team from Denver, that fit and alignment of the prosthesis were the most critical factors in the success of any limb and that much better end-results could be expected if prosthetists and physicians worked together.

Early in 1945, the National Academy of Sciences, at the request of the Surgeon General of the Army, initiated a research program in prosthetics. The initial reaction of the research personnel was that the development of a few mechanical contrivances would solve the problem. However, it soon became evident that much more must be known about biomechanics and other matters before real progress could be made. Devices and techniques based on fundamental data have materially changed the practice of prosthetics during the past dozen years. However, the best conceivable prosthesis is but a poor substitute for a live limb of flesh and blood, and so the research program is still continuing. Fiscal support for research and development by some 20 laboratories is provided by the Veterans Administration, the Vocational Rehabilitation Administration, the National Institutes of Health, the Children's Bureau, the Army, and the Navy. The over-all program is coordinated by the Committee on Prosthetics Research and Development of the National Academy of Sciences—National Research Council.

Soon after the close of World War II, the Artificial Limb Manufacturers Association, which had been formed during World War I, engaged the services of a professional staff to coordinate more effectively the efforts of individual prosthetists. Known today as the American Orthotics and Prosthetics Association, this organization consists of some 415 limb and brace shops, and plays a large part in keeping individual prosthetists and orthotists advised of the latest trends and developments in prosthetics and orthotics.

In 1949, upon the recommendation of the Association, the American Board for Certification of Prosthetists and Orthotists was established to ensure that prosthetists and orthotists met certain standards of excellence, much in the manner that certain physicians' specialty associations are conducted. Examinations are held annually for those desiring to be certified. In addition to certifying individuals as being qualified to practice, the American Board for Certification approves individual shops, or facilities, as being satisfactory to serve the needs of amputees and other categories of the disabled requiring mechanical aids. Certified prosthetists wear badges and shops display the symbol of certification (Fig. 7).

Fig. 7. Symbol of certification by the American Board for Certification in Orthotics and Prosthetics.

The research program, with the cooperation of the prosthetists, has introduced a sufficient number of new devices and techniques to modify virtually every aspect of the practice of prosthetics. To reduce the time lag between research and widespread application, facilities have been established within the medical schools of three universities for short-term courses in special aspects of prosthetics. Courses are offered to each member of the prosthetics-clinic team—the physician, the therapist, and the prosthetist. Also, special courses are offered to vocational rehabilitation counselors and administrative personnel concerned with the welfare of amputees. Approximately 2,100 physicians, 1,900 therapists, and 1,400 prosthetists have been enrolled in these courses during the period 1953 through 1962.

Prior to 1957 medical schools offered little in the way of training in prosthetics to doctors and therapists. To encourage the inclusion of prosthetics into medical and paramedical curricula, the National Academy of Sciences organized the Committee on Prosthetics Education and Information, and as a result of the efforts of this group many schools have adopted courses in prosthetics at both undergraduate and graduate levels.

Today there are approximately 200 amputee-clinic teams in operation throughout the United States. Each state, with assistance from the Vocational Rehabilitation Administration, carries out programs that provide the devices and training required to return the amputee to gainful employment. The Children's Bureau, working through a number of states, has made it possible for child amputees to receive the benefit of the latest advances in prosthetics. The Veterans Administration provides all eligible veterans with artificial limbs. If the amputation is related to his military service, the beneficiary receives medical care and prostheses for the remainder of his life. The Public Health Service, through its hospitals, provides limbs and care to members of the Coast Guard and to qualified persons who have been engaged in the Maritime Service.

In addition to these Government agencies that are concerned with the amputee, there are several hundred rehabilitation centers throughout the United States that assist amputees, especially those advanced in age, in obtaining the services needed for them to return to a more normal life.

Thus, through the cooperative efforts of Government and private groups, considerable progress has been made in the practice of prosthetics and there is little need for an amputee to go without a prosthesis.

Reasons For Amputation

Amputation may be the result of an accident, or may be necessary as a lifesaving measure to arrest a disease. A small but significant percentage of individuals are born without a limb or limbs, or with defective limbs that require amputation or fitting (like that of an amputee).

In some accidents a part or all of the limb may be completely removed; in other cases, the limb may be crushed to such an extent that it is impossible to restore sufficient blood supply necessary for healing. Sometimes broken bones cannot be made to heal, and amputation is necessary. Accidents that cause a disruption in the nervous system and paralysis in a limb may also be cause for amputation even though the limb itself is not injured. The object of amputation in such a case is to improve function by substituting an artificial limb for a completely useless though otherwise healthy member. Amputation of paralyzed limbs is not performed very often but has in some cases proven to be very beneficial. Accidents involving automobiles, farm machinery, and firearms seem to account for most traumatic amputations. Freezing, electrical burns, and power tools also account for many amputations.

Diseases that may make amputation necessary fall into one of three main categories—vascular, or circulatory, disorders; cancer; and infection. The diseases that cause circulatory problems most often are arteriosclerosis, or hardening of the arteries, diabetes, and Buerger's disease. In these cases not enough blood circulates through the limb to permit body cells to replace themselves, and unless the limb, or part of it, is removed the patient cannot be expected to live very long. In nearly all these cases the leg is affected because it is the member of the body farthest from the heart and, in accordance with the principles of hydraulics, blood pressure in the leg is lower than in any other part of the body. Vascular disorders are, of course, much more prevalent among older persons. Considerable research is being undertaken to determine the cause of vascular disorders so that amputation for these reasons may at least be reduced if not eliminated, but at the present time vascular disorders are the cause of a large number of lower-extremity amputations.

In many cases amputation of part or all of a limb has arrested a malignant or cancerous condition. In view of present knowledge, the entire limb is usually removed. Malignancy may affect either the arms or legs. Much time and effort are being spent to develop cures for the various types of cancer.

Since the introduction of antibiotic drugs, infection has been less and less the cause for amputation. Moreover, even though amputation may be necessary, control of the infection may allow the amputation to be performed at a lower level than would be the case otherwise.

Recently, "thalidomide babies" have been given extensive press coverage; however, thalidomide is by no means the sole cause of congenital malformations. Absence of all or part of a limb at birth is not an uncommon occurrence. Many factors seem to be involved in such occurrences, but what these factors are is not clear. The most frequent case is absence of most of the left forearm, which occurs slightly more often in girls than in boys. However, all sorts of combinations occur, including complete absence of all four extremities. Sometimes intermediate parts such as the thigh or upper arm are missing but the other parts of the extremity are present, usually somewhat malformed. In such cases amputation may be indicated; however, even a weak, malformed part is sometimes worth preserving if sensation is present and the partial member is capable of controlling some part of the prosthesis. Extensive studies are being carried out to determine the reasons for congenital malformations.

Losses Incurred

Many of the limitations resulting from amputation are obvious; others less so. An amputation through the lower extremity makes standing and locomotion without the use of an artificial leg or crutches difficult and impracticable except for very short periods. Even when an artificial leg is used, the loss of joints and the surrounding tissues, and consequently loss of the ability to sense position, is felt keenly. The sense of touch of the absent portion is also lost, but in the case of the lower-extremity amputee this is not quite as important as it might seem because the varying pressure occurring between the stump and the socket indicates external loading. In the upper-extremity amputee, sense of touch is more important.

Most lower-extremity amputees cannot bear the total weight of the body on the end of the stump, and other parts of the anatomy must be found for support.

Muscles attached at each end to bones are responsible for movement of the arms and legs. Upon a signal from the nervous system muscle tissue will contract, thus producing a force which can move a bone about its joint (Fig. 8). Because muscle force can be produced only by contraction, each muscle group has an opposing muscle group so that movement in two directions can take place. This arrangement also permits a joint to be held stable in any one of a vast number of positions for relatively long periods of time. How much a muscle can contract is dependent upon its length, and the amount of force that can be generated is dependent upon its circumference.

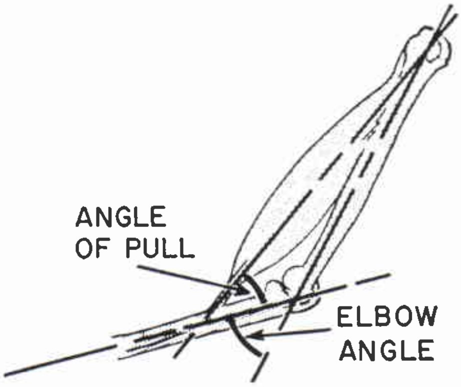

Fig. 8. Schematic drawing of muscular action on skeletal system. The motion shown here is flexion, or bending, of the elbow.

Muscles that activate the limbs must of course pass over at least one joint to provide a sort of pulley action; some pass over two. Thus, some muscles are known as one-joint muscles, others as two-joint muscles. When muscles are severed completely, they can no longer transmit force to the bone and, when not used, wither away or atrophy. It will be seen later that these facts are very important in the rehabilitation of amputees.