Artificial Limbs, Vol 14, No 1, pp 1-52, Spring 1970

Limb Prosthetics —1970

A. BENNETT WILSON, JR.

In order to meet the many requests for reprints of "Limb Prosthetics—1967" *(Artificial Limbs,* Spring 1967), the supply of which has been exhausted, the article is offered again, with revisions to reflect the recent advances in prosthetics technology.

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).

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, Hegesistratus, 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, 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

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.

[1] Executive Director, Committee on Prosthetics Research and Development, National Academy of Sciences—National Research Council, 2101 Constitution Ave., N.W., Washington, D.C. 20418.

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.

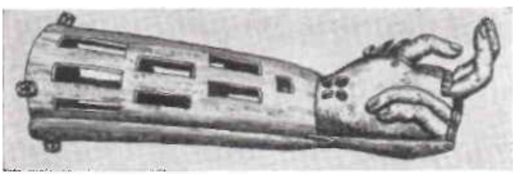


Fig. 3. Alt-Ruppin Hand (circa 1400). The thumb is rigid; the fingers move in pairs and are sprung by the buttons at the base of the palm; the wrist is hinged. From Putti, V., *Chir. d. org di movimento,* 1924-25.

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 Pare, 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 life-saving 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. Pare, 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

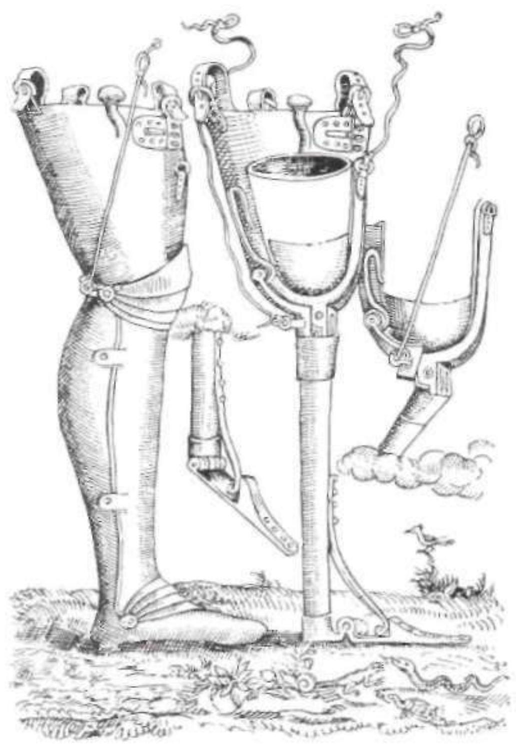


Fig. 4. Artificial leg invented by Ambroise Pare (middle sixteenth century). From Pare A., *Oeuvres Completes,* Paris, 1840. From the copy in the National Library of Medicine.

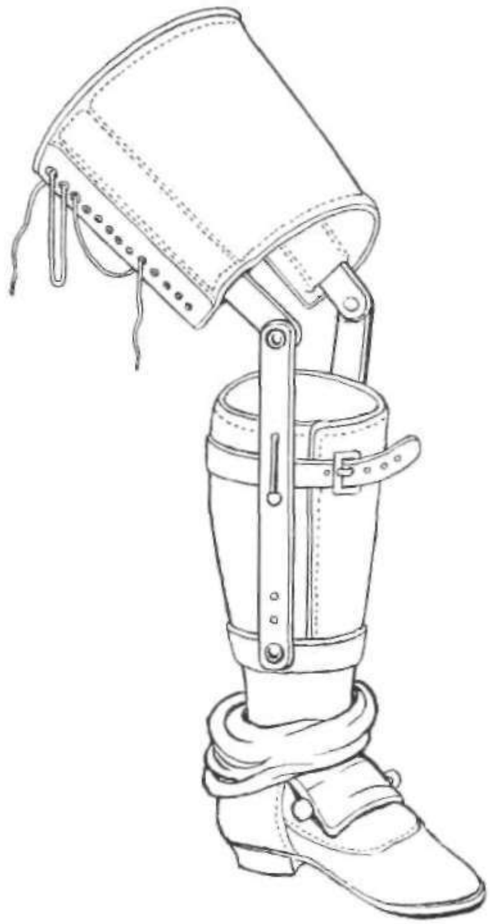


Fig. 5. Verduin Leg (1696). From MacDonald, J., *Amer.J. Surg.,* 1905.

most popular type of below-knee prosthesis used.

After Pare'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 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 American 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

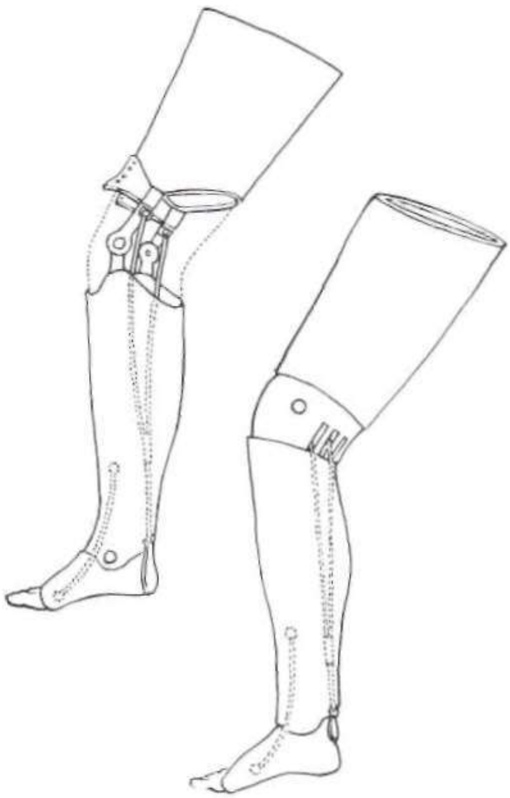


Fig. 6. Anglesea Leg (1800). Below knee at left, above knee at right. Knee, ankle, and foot are articulated. From Bigg, H., *Orthopraxy,* 1877.

time of the Civil War and the turn of the century, but few of the designs seem to have had must 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 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 Thomas and Haddan *(18),* 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 (7). 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 *(12).* Devices and techniques based on fundamental data have materially changed the practice of prosthetics during the past 15 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 30 laboratories is provided by the Veterans Administration, the Social and Rehabilitation Service, the National Institutes of Health, the Children's Bureau, the Department of the Army, and the Navy Department. The overall program is coordinated by the Committee on Prosthetics Research and Development of the National Academy of Sciences. The committee publishes twice a year the journal *Artificial Limbs* and serves as an information center, not only in limb prosthetics but for orthotics as well.

In England and Europe, research in artificial limbs was resumed after World War II at Queen Mary's Hospital, Roehampton, London, by the Ministry of Health, and a new program was started in Russia. The "thalidomide tragedy" of 1959-60 gave incentive for governments to support research, and now there are effective programs in Canada, Denmark, Holland, Scotland, and Sweden, and the studies in England and Germany have been greatly expanded. Under Public Law 480, the United States supports prosthetics research in a number of foreign countries.

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 Orthotic and Prosthetic Association,[2] this organization consists of some 500 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 in Orthotics and Prosthetics, Inc.,[2] 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

[2] 1440 N St., N.W., Washington. D.C. 20005.

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

categories of the disabled requiring mechanical aids. Certified prosthetists wear badges and shops display the symbol of certification (Fig. 7).

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.

Short-term, continuing-education courses are offered by the University of California, Los Angeles, Northwestern University, and New York University. Two-year courses in prosthetics are offered by Cerritos Junior College (Norwalk, Calif.) and Chicago City College, and a four-year course is available at New York University.

Prior to 1957, medical schools offered little in the way of training in prosthetics to doctors and therapists. To encourage the inclusion of prosthetics in 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 more than 400 amputee-clinic teams in operation throughout the United States. Each state, with assistance from the Social and Rehabilitation Service, 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 July 1965, the 89th Congress passed Public Law 89-97, the Medicare bill, which includes provision for artificial limbs at essentially no cost for persons 65 years of age and over. The bill also assists individual states in providing artificial limbs for persons who are medically indigent at any age. A number of states have enacted legislation to take advantage of the offer by the federal government.

In addition to the 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 the misuse of power tools also account for many amputations.

Improved medical and surgical procedures introduced in recent years have resulted in the preservation of many limbs that would have been amputated. Infection, once a cause of a high fraction of amputations, can usually be controlled with antibiotics. Newer methods of vessel and nerve suturing make it possible to save limbs that would have had to be amputated some years ago. Highly qualified surgical teams have demonstrated during the last few years that it is possible to replace a completely severed limb.

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 mellitus, 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 otherwise be the case.

"Thalidomide babies" born between 1958 and 1961 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.

As far as it can be determined, there are approximately 311,000 amputees in the United States, exclusive of those patients residing in institutions. There are about six lower-extremity amputees for every upper-extremity amputee.

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.

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

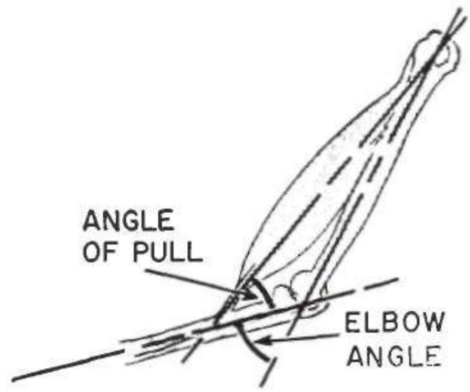


Fig. 8. Schematic drawing of muscular action on skeletal system. The motion shown here is flexion, or bending, of the elbow.

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.

TYPES OF AMPUTATION

Amputations are generally classified according to the level at which they are performed (Fig. 9). Some amputations levels are referred to by the name of the surgeon credited with developing the amputation technique used. The general rule in selecting the site of amputation is to save all length that is medically possible.

LOWER-EXTREMITY AMPUTATIONS

Syme's Amputation

Developed about 1842 by James Syme, a leading Scottish surgeon, the Syme amputation leaves the long bones of the shank (the tibia and fibula) virtually intact, only a small portion at the very end being removed (Fig. 10) (*2, 14*). The tissues of the heel, which are ideally suited to withstand high pressures, are preserved, and this, in combination with the long bones, usually permits the patient to bear the full weight of his body on the end of the stump. Because the amputation stump is nearly as long as the unaffected limb, a person with Syme's amputation can usually get about the house without a pros-

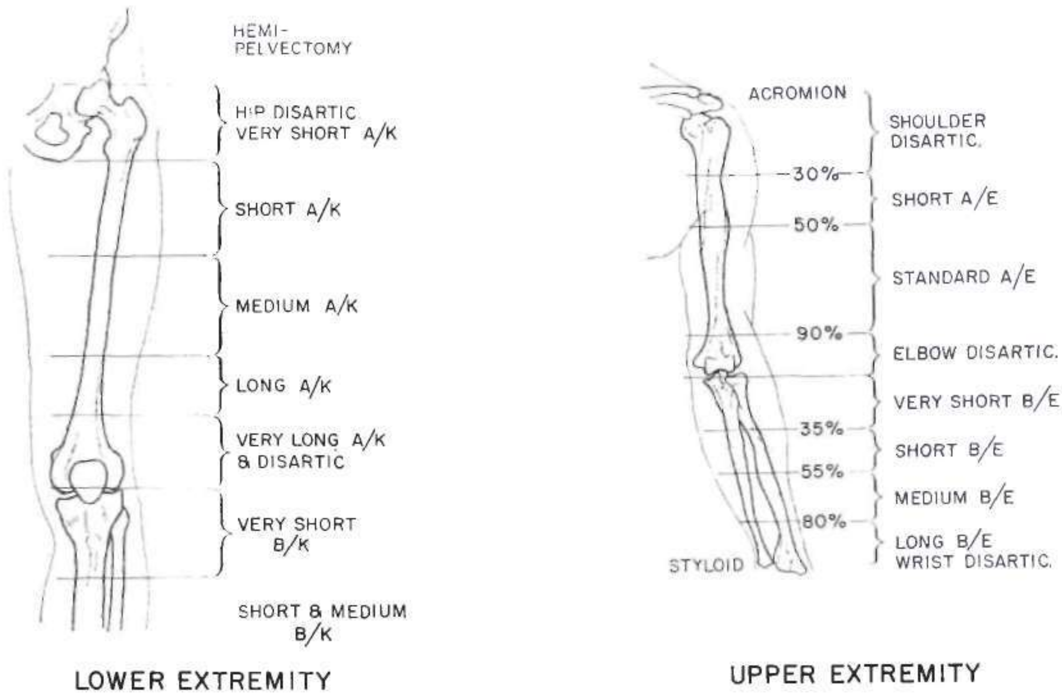


Fig. 9. Classification of amputation by level.

thesis, even though normal foot and ankle action has been lost. Atrophy of the severed muscles that were formerly attached to bones in the foot to provide ankle action results in a stump with a bulbous end which, though not of the most pleasing appearance, is quite an advantage in holding the prosthesis in place.

Since its introduction, Syme's operation has been looked upon with both favor and disfavor by surgeons. It seems to be the consensus now that "the Syme" should be performed in preference to an amputation at a higher level, if possible. In the case of most women, though, "the Syme" is undesirable because of the difficulty of providing a prosthesis that matches the shape of the other leg.

Below-Knee Amputations

Any amputation above the Syme level and below the knee joint is known as a below-knee amputation. Because circulatory troubles have often developed in long below-knee stumps, and because the muscles that activate the shank are attached at a level close to the knee joint, the below-knee amputation is usually performed at the junction of the upper and middle third sections (Fig. 11). Thus, nearly full use of the knee is retained—an important factor in obtaining a gait of nearly normal appearance. However, it is rare for a below-knee amputee to bear a significant amount of weight on the end of the stump; therefore, the design of prostheses must provide for weight-bearing through other areas. Several types of surgical procedures have been employed to obtain weight-bearing through the end of the below-knee stump, but none has found widespread use.

Knee-Bearing Amputations

Complete removal of the lower leg, or shank, is known as a knee disarticulation. When the operation is performed properly, the result is an efficient, though bulbous, stump (Fig. 12), capable of carrying the weight-bearing forces through the end.

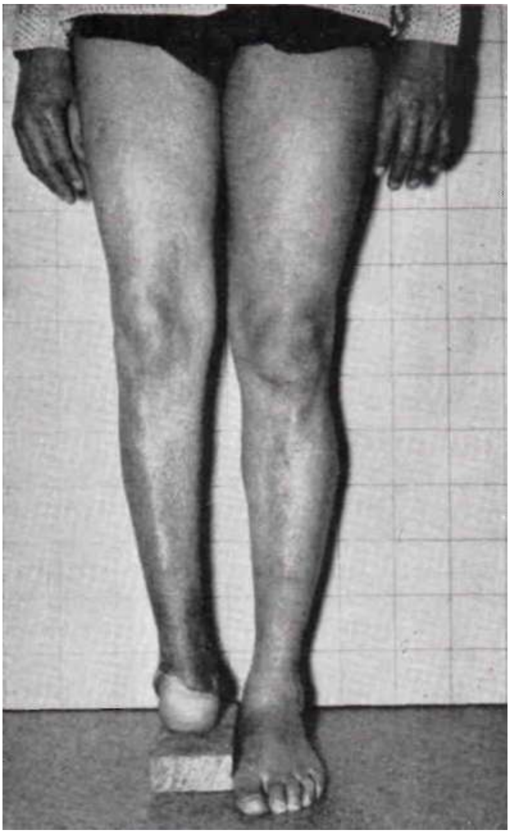


Fig. 10. Excellent Syme stump.

Unfortunately, the length causes some problems in providing an efficient prosthesis because the space used normally to house the mechanism needed to control the artificial shank properly is occupied by the end of the stump. Nevertheless, excellent prostheses can be provided the knee-disarticulation case.

Several amputation techniques have been devised in an attempt to overcome the problems posed by the length and shape of the true knee-disarticulation stump. The Gritti-Stokes procedure entails placing the kneecap, or patella, directly over the end of the femur after it has been cut off about two inches above the end. When the operation is performed properly, excellent results are obtained, but extreme skill and expert postsurgical care are required. Variations of the Gritti-Stokes amputation have been introduced from time to time but have never been used widely.

Above-Knee Amputations

Amputations through the thigh are among the most common (Fig. 13). Because of the high pressures exerted on the soft tissues by the cut end of the bone, total body weight cannot be taken through the end of the stump but can be accom-

Fig. 11. Typical, well-formed, right below-knee stump. *Courtesy Veterans Administration Prosthetics Center.*

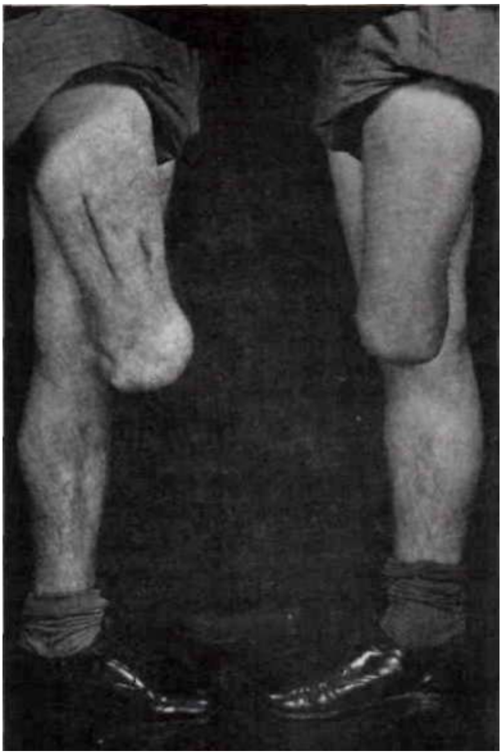


Fig. 12. Typical knee-disarticulation stumps.

modated through the ischium, that part of the pelvis upon which a person normally sits.

Hip Disarticulation and Hemipelvectomy

A true hip disarticulation (Fig. 14) involves removal of the entire femur, but, whenever feasible, the surgeon leaves as much of the upper portion of the femur as possible, in order to provide additional stabilization between the prosthesis and the wearer, even though no additional function can be expected over the true hip disarticulation *(1).* Both types of stump are provided with the same type of prosthesis. With slight modification, the same type of prosthesis can be used by the hemipelvectomy patient, that is, when half of the pelvis has been removed. It is surprising how well hip-disarticulation and hemipelvectomy patients have been able to function when fitted with the newer type of prosthesis.

UPPER-EXTREMITY AMPUTATIONS

Partial-Hand Amputations

If sensation is present, the surgeon will save any functional part of the hand in lieu of disarticulation at the wrist. Any method of obtaining some form of grasp,

Fig. 13. Typical well-formed above-knee stump. *Courtesy Veterans Administration Prosthetics Center.*

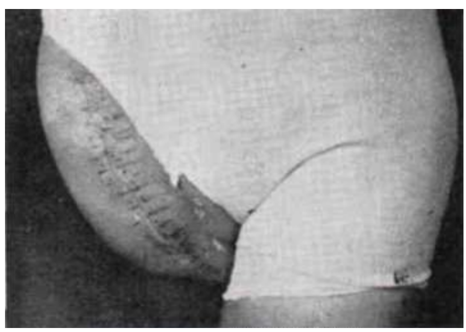


Fig. 14. Patient with true hip-disarticulation amputation.

or prehension, is preferable to the best prosthesis. If the result is unsightly, the stump can be covered with a plastic glove, lifelike in appearance, for those occasions when the wearer is willing to sacrifice function for appearance. Many prosthetists have developed special appliances for partial-hand amputations that permit more function than any of the artificial hands and hooks yet devised and, at the same time, permit the patient to make full use of the sensation remaining in the stump. Such devices are usually individually designed and fitted.

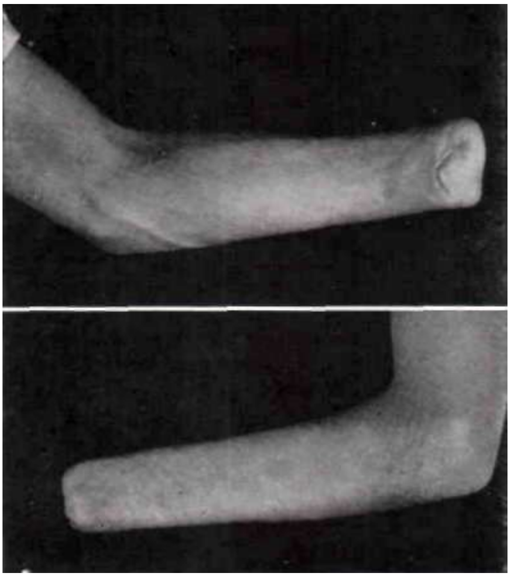


Fig. 15. A good wrist-disarticulation stump.

Wrist Disarticulation

Removal of the hand at the wrist joint was once condemned because it was thought to be too difficult to fit so as to yield more function than a shorter forearm stump. However, with plastic sockets based on anatomical and physiological principles, the wrist-disarticulation case can now be fitted so that most of the pronation-supination of the forearm—an important function of the upper extremity—can be used. In the case of the wrist disarticulation (Fig. 15), nearly all the normal forearm pronation-supination is present. Range of pronation-supination decreases rapidly as length of stump decreases; when 60 per cent of the forearm is lost, no pronation-supination is possible.

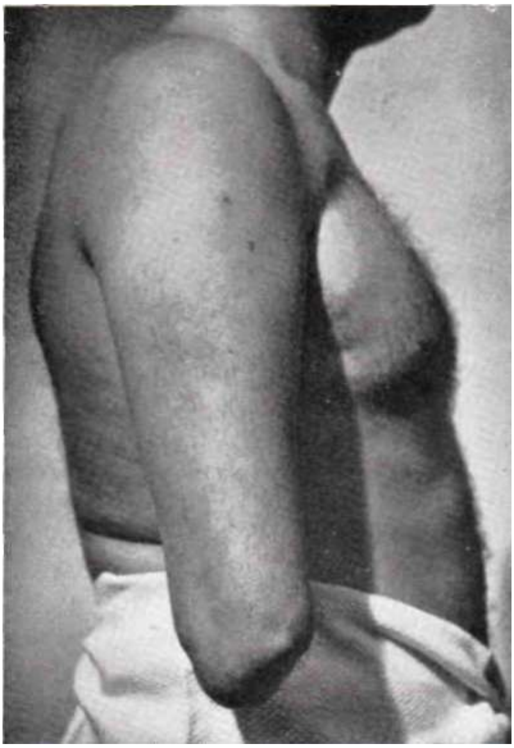


Fig. 16. Amputation through the elbow.

Amputations Through the Forearm

Amputations through the forearm are commonly referred to as below-elbow amputations, and are classified as long, short, and very short, depending upon the length of stump (Fig. 9). Stumps longer than 55 per cent of total forearm length are considered long, between 35 and 55 per cent as short, and less than 35 per cent as very short.

Long stumps retain the rotation function in proportion to length; long and short stumps without complications possess full range of elbow motion and full power about the elbow, but often very short stumps are limited in both power and motion about the elbow. Devices and techniques have been developed to make full use of all functions remaining in the stump.

Disarticulation at the Elbow

Disarticulation at the elbow consists of removal of the forearm, resulting in a slightly bulbous stump (Fig. 16), but usually one with good end-weight-bearing characteristics. The long bulbous end, while presenting some fitting problems, permits good stability between socket and stump and thus allows use of nearly all the rotation normally present in the upper arm—a function much appreciated by the amputee.

Above-Elbow Amputation

Any amputation through the upper arm is generally referred to as an above-elbow amputation (Fig. 9). In practice, stumps in which less that 30 per cent of the humerus remains are treated as shoulder-disarticulation cases; those with more than 90 per cent of the humerus remaining are fitted as elbow-disarticulation cases.

Shoulder Disarticulation and Forequarter Amputation

Removal of the entire arm is known as shoulder disarticulation, but, whenever feasible, the surgeon will leave intact as much of the humerus as possible, to provide stability between the stump and the socket (Fig. 17). When it becomes necessary to remove the clavicle and scapula, the operation is known as a forequarter, or interscapulothoracic, amputation. The very short above-elbow, the shoulder-disarticulation, and the forequarter cases are all provided with essentially the same type of prosthesis.

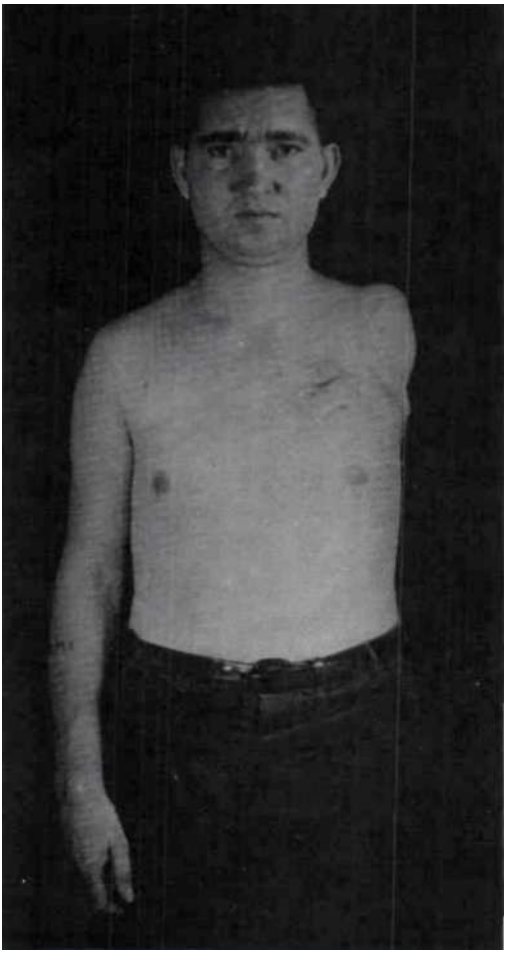


Fig. 17. A true shoulder disarticulation.

THE POSTSURGICAL PERIOD

The period between the time of surgery and time of fitting the prosthesis is an important one if a good functional stump, and thus the most efficient use of a prosthesis, is to be obtained. The surgeon and others on his hospital staff will do everything possible to ensure the best results, but ideal results require the wholehearted cooperation of the patient.

It is not unnatural for the patient to feel extremely depressed during the first few days after surgery, but after he becomes aware of the possibilities of recovery, the outlook becomes brighter, and he generally enters cooperatively into the rehabilitation phase.

It has been generally agreed through the years that the earlier a patient could be fitted, the easier would be the rehabilitation process. However, until a few years ago, virtually no patients were provided with a prosthesis before six weeks after amputation, and such cases were rare—

the average time probably being closer to four months.

With the advent of improved cast-taking methods, and temporary legs in which alignment can be easily adjusted, Duke University, about 1960, began an experiment to determine the earliest practical time after surgery for providing amputees with limbs. By 1963, it had been shown clearly that it was not only practical but desirable to fit a temporary, but well-fitted, limb as soon as the sutures were re-

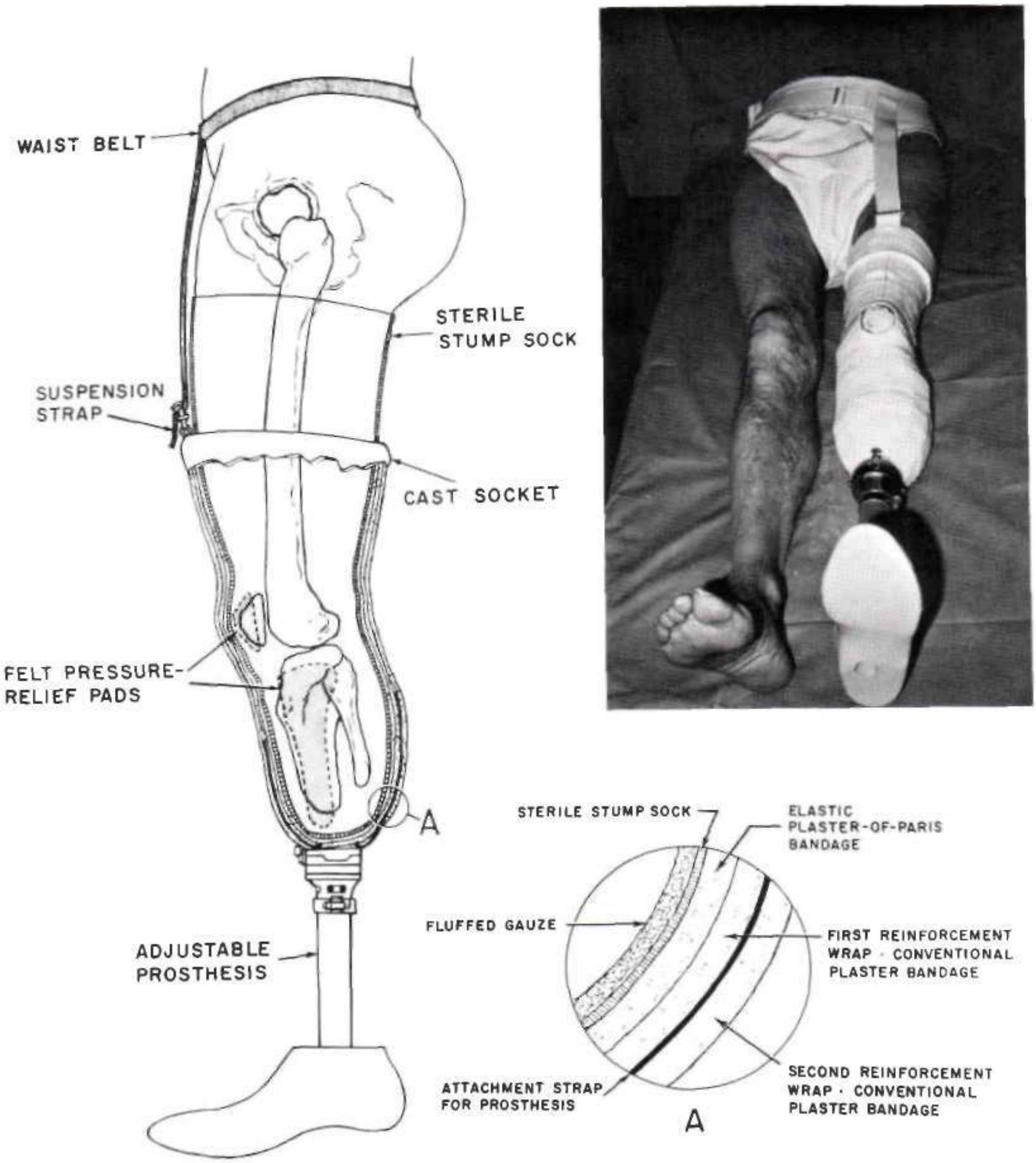


Fig. 18. Schematic cross section showing the major elements of a prosthesis as applied immediately following surgery to a below-knee amputee. The suture line, silk dressing, and drain are not shown. The fluffed gauze does not extend beyond the area indicated in "A." *Inset:* A below-knee amputee fitted with the immediate postsurgical prosthesis.

moved, some two to three weeks after surgery. In 1963, Dr. Marian Weiss of Poland, in an address in Copenhagen, reported success with fitting amputees immediately after surgery while the patient was still anesthetized, and beginning ambulation training the day afterward *(20).* Dr. Weiss's work stimulated similar work in this country, notably at the University of California, San Francisco; the Oakland Naval Hospital; the Prosthetics Research Study, Seattle, Washington; Duke University; the University of Miami; Marquette University; and New York University. Records on several thousand patients of all types have shown immediate postsurgical fitting of prostheses to be the method of choice when possible. Healing seems to be accelerated; postsurgical pain is greatly alleviated; contractures are prevented from developing; phantom pain seems to be virtually nonexistent; fewer psychological problems seem to ensue; and patients are returned to work or home at a much earlier date than seemed possible only a few years ago.

The procedure consists essentially of providing a rigid plaster dressing over the stump which serves as a socket, and the use of an adjustable leg which can be removed and reinstalled easily (Fig. 18) *(6).* The cast-socket is left in place for 10 to 12 days, during which ambulation is encouraged. At the end of this time, the cast-socket is removed, the stitches are usually taken out, and a new cast-socket is provided immediately. The original prosthetic unit is replaced and realigned. The second cast-socket is left in place for eight to ten days, at which time a new cast can be taken for the permanent, or definitive, prosthesis.

Special courses in immediate postsurgical fitting and early fitting are being offered to qualified prosthetics clinic teams by Northwestern University, the University of California at Los Angeles, and New York University.

CONTRACTURES

When immediate postsurgical fitting is employed, there is little opportunity for contractures to develop. When these procedures are not used, it is most important to avoid the development of muscle contractures. They can be prevented easily, but it is most difficult, and sometimes impossible, to correct them. At first, exercises are administered by a therapist or nurse; later, the patient is instructed concerning the type and amount of exercise that should be undertaken. The patient is also instructed in the methods and amount of massage that should be given

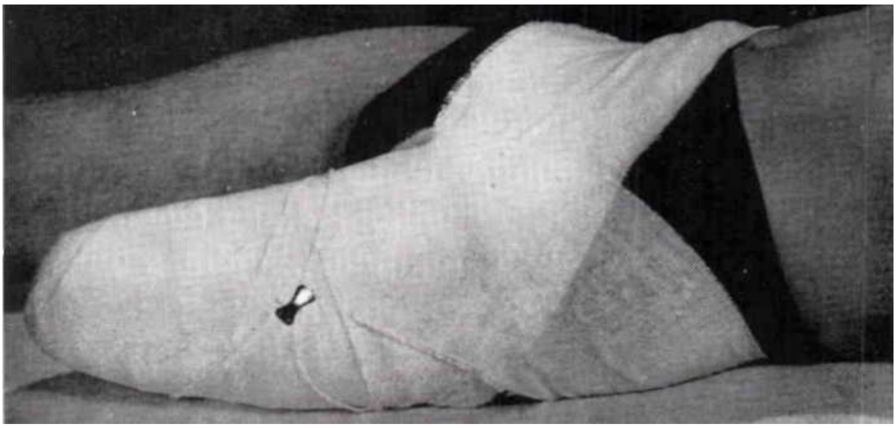


Fig. 19. Compression wrap for above-knee amputation. The wrap of elastic bandage aids in shrinking the stump.

Fig. 20. Actions to be avoided by lower-extremity amputees during the immediate postoperative period.

the stump to aid in the reduction of the stump size. Further, to aid shrinkage, cotton-elastic bandages are wrapped around the stump (Fig. 19) and worn continuously until a prosthesis is fitted. The bandage is removed and reapplied at regular intervals—four times during the day and at bedtime. It is most important that a clean bandage is available for use each day.

The amputee is taught to apply the bandage unless it is physically impossible for him to do so, in which case some member of his family must be taught the proper method for use at home.

To reduce the possibility of contractures, the lower-extremity stump must not be propped upon pillows. Wheelchairs should be used as little as possible; crutch walking is preferred, but the above-knee stump must not be allowed to rest on the crutch handle (Fig. 20).

THE PHANTOM SENSATION

After amputation, the patient almost always has the sensation that the missing part is still present. The exact cause of this is as yet unknown. The phantom sensation usually recedes to the point where it occurs only infrequently or disappears entirely, especially if a prosthesis is used. In a large percentage of cases, moderate pain may accompany the phantom sensation, but in general this too eventually disappears entirely or occurs only infrequently. In a small percentage of cases, severe phantom pain persists to the point where medical treatment is necessary *(8).*

PROSTHESES FOR VARIOUS TYPES OF AMPUTATION

Much time and attention have been devoted to the development of mechanical components, such as knee and ankle units, for artificial limbs, yet by far the most important factors affecting the successful use of a prosthesis are the fit of the socket to the stump and the alignment of the various parts of the limb in relation to the stump and other parts of the body.

DEFINITIONS

Preparatory Prosthesis

A cosmetically unfinished functional replacement for an amputated extremity, fitted and aligned in accordance with sound biomechanical principles, which is worn for a limited period of time to expedite prosthetic wear and use and to aid in the evaluation of amputee adjustment.

Pylon

A rigid supporting member, usually tubular, that is attached to the socket or knee unit of a prosthesis. The lower end of the pylon should be connected to a foot-ankle assembly.

Rigid Dressing

A plaster stump wrap, usually applied in the operating or recovery room immediately following operation for the purpose of controlling edema and pain. It is preferably shaped in accordance with the basic patellar-tendon-bearing (PTB) or quadrilateral designs, but is not necessarily so.

Immediate Postsurgical Prosthetic Fitting

A procedure wherein a functional socket, designed for weight-bearing and walking, is fitted to the patient immediately after operation in the operating or recovery room, or at some time prior to removal of sutures. As distinct from the rigid dressing, referred to above, this socket should be shaped in accordance with the basic PTB or quadrilateral design; it incorporates provision for easy attachment and detachment of a pylon and foot-ankle assembly.

Early Prosthetic Fitting

A procedure wherein a preparatory prosthesis, as defined above, is provided for the amputee immediately following removal of sutures.

Permanent Prosthesis

A replacement for a missing limb, which meets accepted checkout standards for comfort, fit, alignment, function, appearance, and durability.

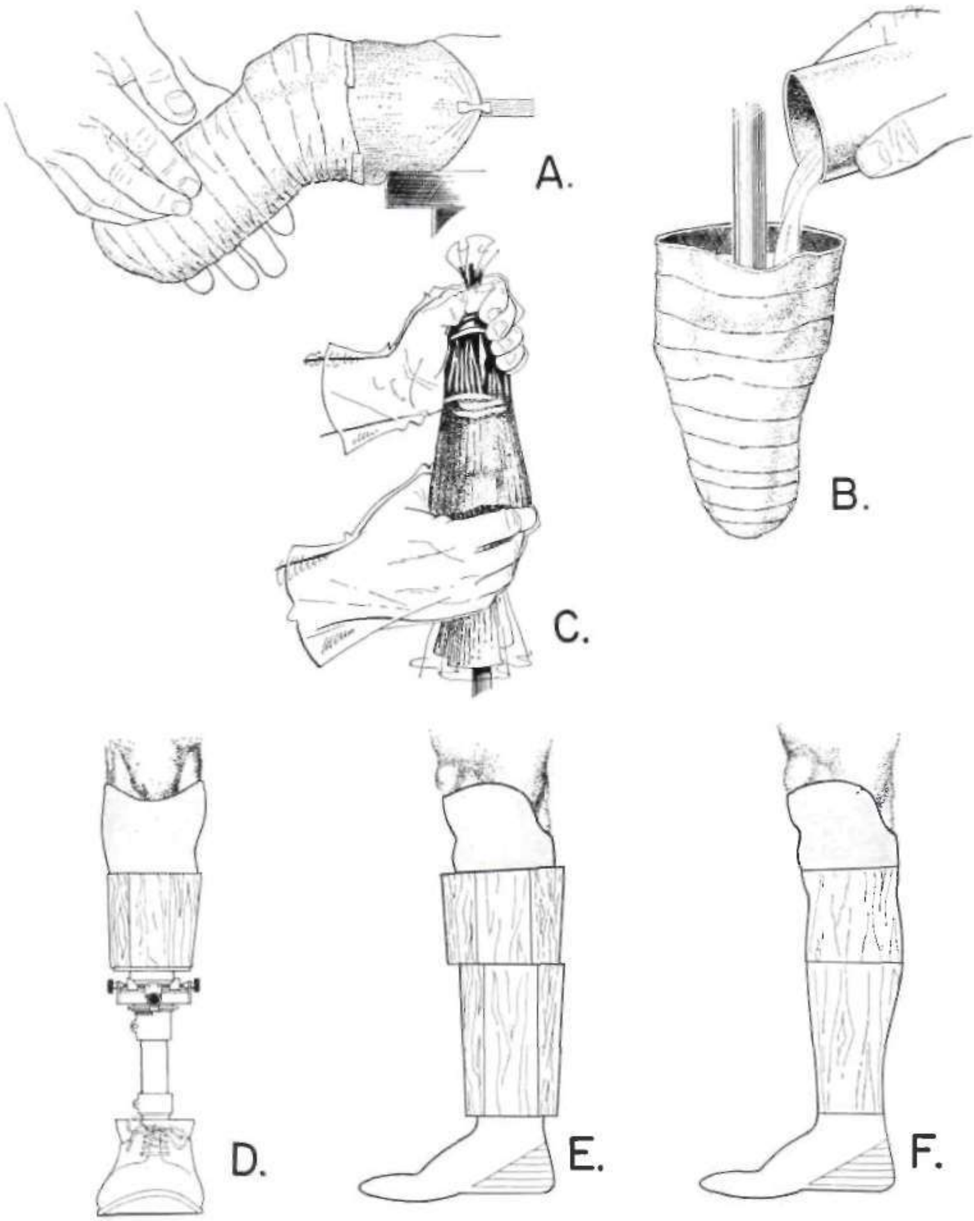
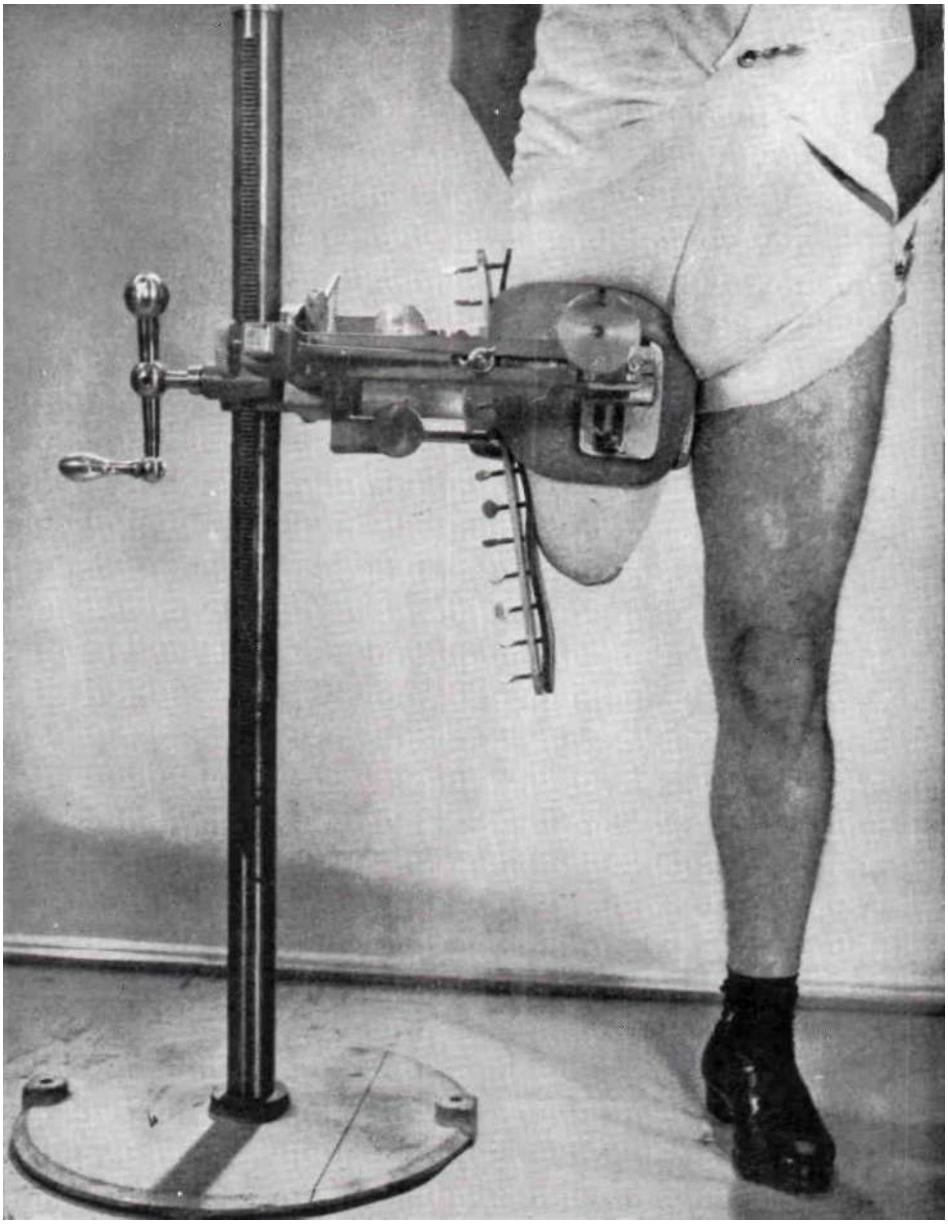


Fig. 21. Steps in the fabrication of a plastic prosthesis for a below-knee amputation: *A*, taking the plaster cast of the stump; *B*, pouring plaster in the cast to obtain model of the stump; C, introducing plastic resin into fabric pulled over the model to form the plastic-laminate socket; *D*, the plastic-laminate socket mounted on an adjustable shank for walking trials; *E*, a wooden shank block inserted in place of the adjustable shank after proper alignment has been obtained; *F*, the prosthesis after the shank has been shaped. To reduce weight to a minimum, the shank is hollowed out and the exterior covered with a plastic laminate.

Thus, though many parts of a prosthesis may be mass-produced, it is necessary for each limb to be assembled in correct alignment and fitted to the stump to meet the individual requirements of the intended user. To make and fit artificial limbs properly requires a complete understanding of anatomical and physiological



Fig, 22. Special jig developed by the Veterans Administration Prosthetics Center to facilitate casting above-knee stumps.

principles and of mechanics; craftsmanship and artistic ability are also required.

In general, an artificial limb should be as light as possible and still withstand the loads imposed upon it. In the United States, willow and woods of similar characteristics have formed the basis of construction for more limbs than any other material, although aluminum, leather-and-steel combinations, and fiber have been used widely. Today, plastic laminates so popular in small-boat construction form the basis for construction of most artificial limbs. Some artificial legs are made of wood, and occasionally leather is used for sockets, but the trend is toward the plastic laminates. They are light in weight, easy to keep clean, and do not absorb perspiration. They may be molded easily and rapidly over contours such as those found on a plaster model of a stump. Plastic laminates can be made extremely rigid or with any degree of flexibility required in artificial-limb construction.

A procedure for making a porous plastic laminate has been developed for use when perspiration presents a difficult problem. A new material, synthetic balata, which can be molded directly over the stump, is now being used in some clinics, primarily to form temporary prostheses.

As in the case of the tailor making a suit, the first step in fabrication of a prosthesis is to take the necessary measurements for a good fit. If the socket is to be fabricated of a plastic laminate, an impression of the stump is made. Most often this is accomplished by wrapping the stump with a wet plaster-of-paris bandage and allowing it to dry, as a physician does in applying a cast when a bone is broken (Fig. 21).

A number of devices have been introduced in recent years to aid the prosthetist in obtaining accurate casts rapidly *(11).* Most use an apparatus that permits the patient to absorb some of the weight-bearing load through the affected side while the cast is being formed (Fig. 22).

The cast, or wrap, is removed from the stump and filled with a plaster-of-paris solution to form an exact model of the stump which—after being modified to provide relief for any tender spots, to ensure that weight will be taken in the proper places, and to take full advantage of the remaining musculature—can be used for molding a plastic-laminate socket. Often a "check" socket of cloth impregnated with beeswax is made over the

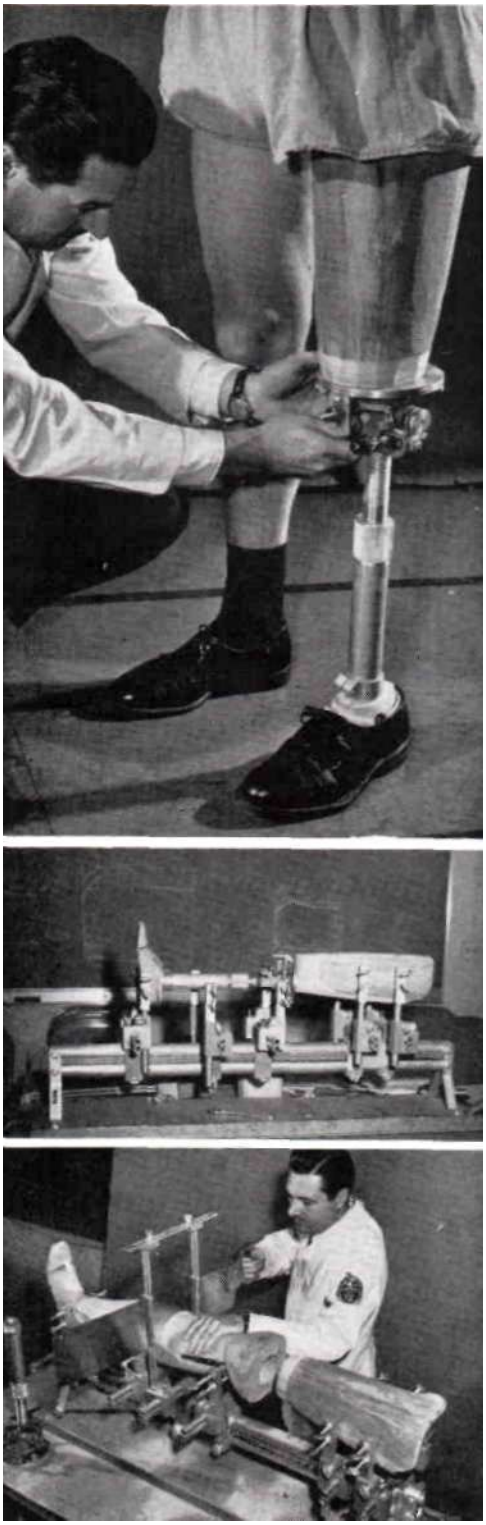


Fig. 23. Using the above-knee adjustable leg and alignment duplication jig. *Top,* adjusting the adjustable leg during walking trials; *center,* the socket and adjustable leg in the alignment duplication jig; *bottom,* replacement of the adjustable leg with a permanent knee and shank.

Fig. 24. Adjustable coupling used for alignment of artificial legs. This unit was designed by the Veterans Administration Prosthetics Center and is suitable for below-knee as well as above-knee legs.

model and tried on the stump to determine the correctness of the modifications.

For upper-extremity cases, the socket is attached to the rest of the prosthesis, and a harness is fabricated and installed for operation of the various parts of the artificial arm. For the lower-extremity case, the socket is fastened temporarily to an adjustable, or temporary, leg for walking trials (Fig. 23). With this device, the prosthetist can easily adjust the alignment until both he and the amputee are satisfied that the optimum arrangement has been reached. A prosthesis can now be made, incorporating the same alignment achieved with the adjustable leg.

A more refined procedure uses the "Staros-Gardner" coupling (Fig. 24) *(16)*. Not only is the need for the alignment jig eliminated, but in the case of above-knee fittings the alignment adjustments can be made with the knee unit that is to be used permanently, an important factor when sophisticated knee units are used because the present adjustable leg is available with only a single-axis, constant-friction joint.

An even more refined procedure consists of using one of the adjustable pylon types of prostheses that were originally designed for use in immediate postsurgical fitting. These units are strong enough and sufficiently inexpensive so they can form part of the permanent, or definitive, prosthesis (Figs. 25 and 26). A light, removable, cosmetic cover is used over the pylon. This

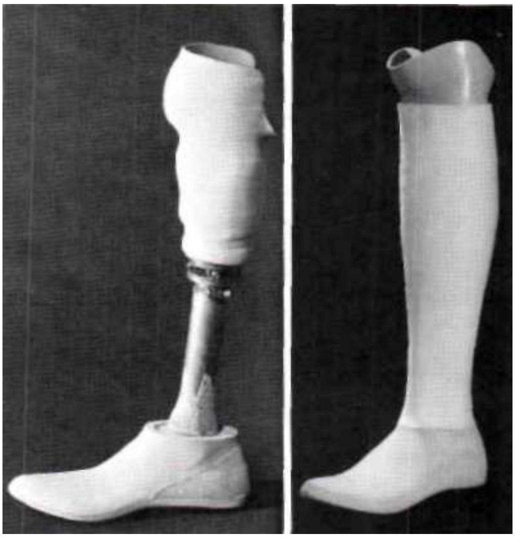


Fig. 25. An adjustable below-knee pylon with cosmetic cover.

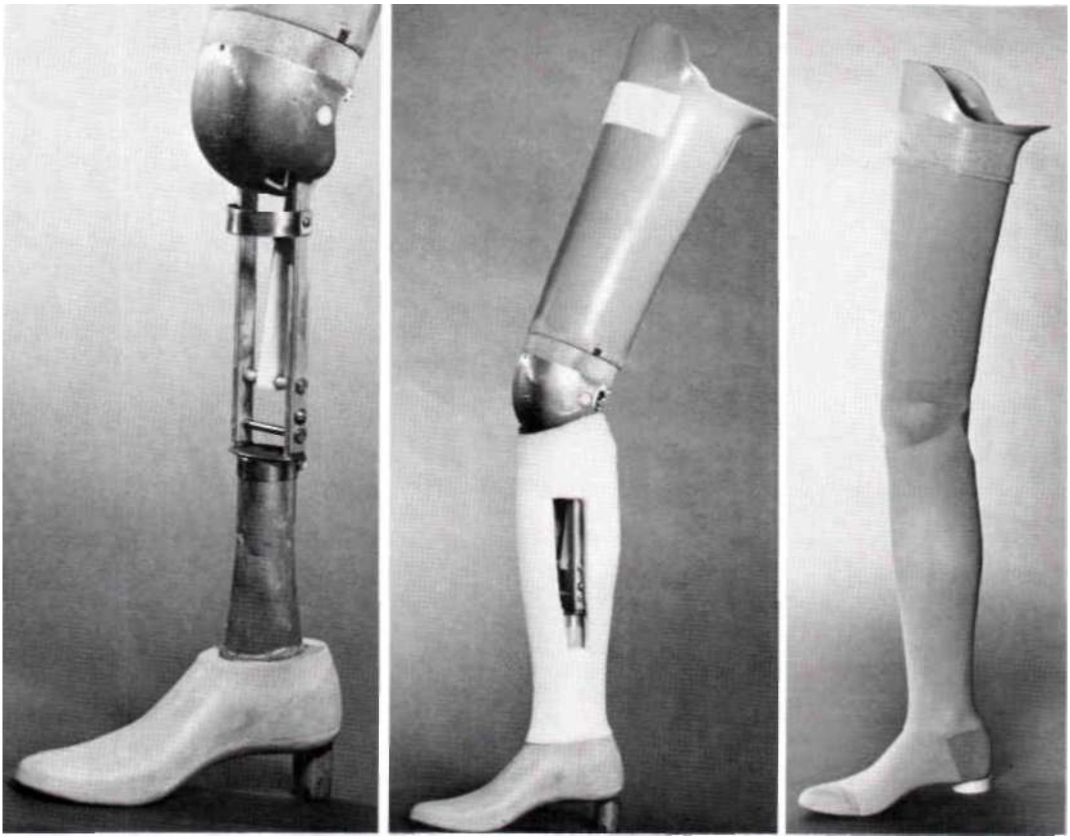


Fig. 26. An adjustable above-knee prosthesis.

arrangement permits the prosthetist to change alignment easily at any time. An added feature of the VAPC above-knee "standard" pylon is provision for interchangeability of a number of knee units, ranging from the simple constant-friction unit to complex hydraulic units. Thus, the patient may try a number of different methods of knee control, at little expense, in order to determine which meets his needs the best.

There are many kinds of artificial limbs available for each type of amputation, and much has been written concerning the necessity for prescribing limbs to meet the needs of each individual. This of course is particularly true in the case of persons in special or arduous occupations, or with certain medical problems, but limbs for a given type of amputation actually vary to only a small degree. Following are descriptions of the artificial limbs most commonly used in the United States today.

LOWER-EXTREMITY PROSTHESES

Prostheses for Syme's Amputation

Perhaps the major reason Syme's amputation was held in such disfavor in some quarters was the difficulty in providing a comfortable, sufficiently strong prosthesis with a neat appearance. The short distance between the end of the stump and the floor made it extremely difficult to provide for ankle motion needed. Most Syme prostheses were made of leather reinforced with steel side bars, resulting in an ungainly appearance. Research workers at the Prosthetic Services Centre at the Department of Veterans Affairs of Canada

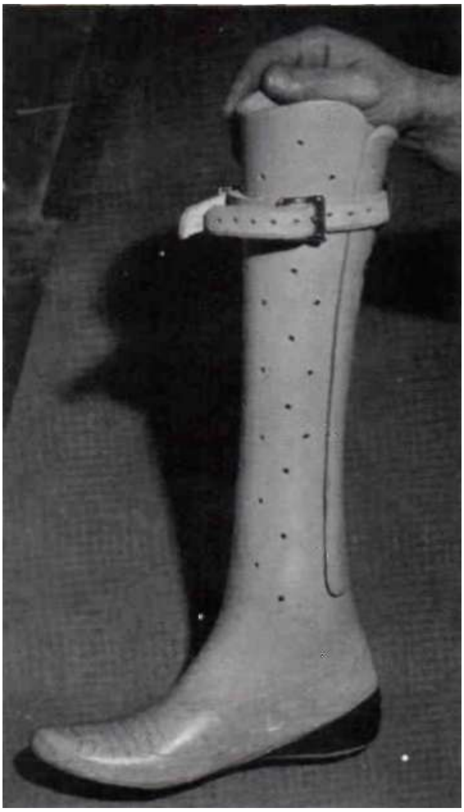


Fig. 27. The Syme prosthesis adopted by the Canadian Department of Veterans Affairs. The posterior opening extends the length of the shank.

were quick to realize that the use of the proper plastic laminate might solve many of the problems long associated with the Syme prosthesis. After a good deal of experimentation, the Canadians developed a model in 1955 which, with a few variations, is used almost universally in both Canada and the United States today (Fig. 27) (2).

Necessary ankle action is provided by making the heel of the foot of sponge rubber. The socket is made entirely of a plastic laminate. A full-length cutout in the rear permits entry of the bulbous stump. When the cutout is replaced and held in place by straps, the bulbous stump holds the prosthesis in place. In the American version (Fig. 28), a window-type cutout is used on the side because calculations show that smaller stress concentrations are present with such an arrangement. An increasing number of prosthetists have been using a double-wall socket with an expandable inner wall in order to eliminate the need for the window.

In those cases where, for poor surgery or other reasons, full body weight cannot be tolerated on the end of the stump, provisions can be made to transfer all or part of the load to the area just below the kneecap *(14).*

Prostheses for Below-Knee Amputations

Until recently, most below-knee amputees were fitted with wooden prostheses carved out by hand (Fig. 29). A good portion of the body weight was carried on a leather thigh corset, or lacer, attached to the shank and socket by means of steel hinges. The shape of the corset and upper hinges also held the prosthesis to the stump. The distal, or lower, end of the socket was invariably left open. Other ver-

Fig. 28. Two views of the Canadian-type Syme prosthesis as modified by the Veterans Administration Prosthetics Center.

sions of this prosthesis used aluminum, fiber, or molded leather as the materials for construction of the shank and socket, but the basic principle was the same. Many thousands of below-knee amputees have gotten along well with this type of prosthesis, but there are many disadvantages. Because the human knee joint is not a simple, single-axis hinge joint (Fig. 30), relative motion is bound to occur between the prosthesis and the stump and thigh during knee motion when single-jointed side hinges are used, resulting in some chafing and irritation. To date it has not been possible to devise a hinge to overcome this difficulty. Edema, or accumulation of fluid, was often present at the lower end of the stump. Most of these prostheses were exceedingly heavy, especially those made of wood.

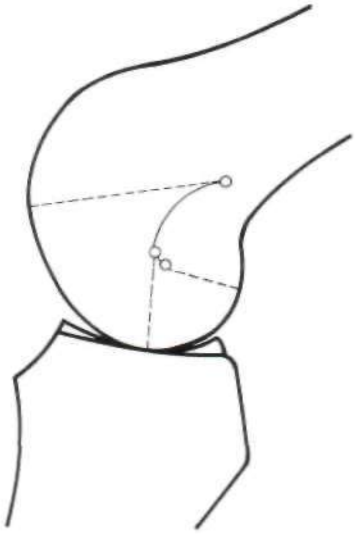


Fig. 30. Section through the medial condyles of the femur and tibia. The center of curvature is shown for three parts of the articular surface. As gliding occurs in the joint, the instant center moves along the curve connecting these three centers.

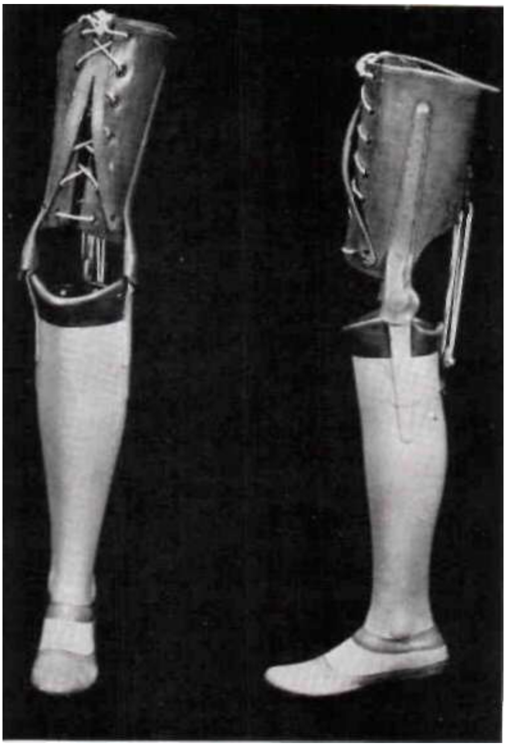


Fig. 29. Below-knee prosthesis with wood socket-shank, thigh corset, and steel side bars. *Courtesy Veterans Administration Prosthetics Center.*

In an attempt to overcome these difficulties, the Biomechanics Laboratory of the University of California, in 1958, designed what is known as the patellar-tendon-bearing (PTB) below-knee prosthesis (Fig. 31). In the PTB prosthesis no lacer and side hinges are used, all of the weight being taken through the stump by making the socket high enough to cover all the tendon below the patella, or kneecap *(3,10).* The patellar tendon is an unusually inelastic tissue which is not unduly affected by pressure. The sides of the socket are also made much higher than has usually been the practice in the past, in order to give stability against side loads. The socket is made of molded plastic laminate that provides an intimate fit over the entire area of the socket, and is lined with a thin layer of sponge rubber and leather. Because it is rare for a below-knee stump to bear much pressure on its lower end, care is taken to see that only a very slight amount is present in that area. This feature has been a big factor in eliminating

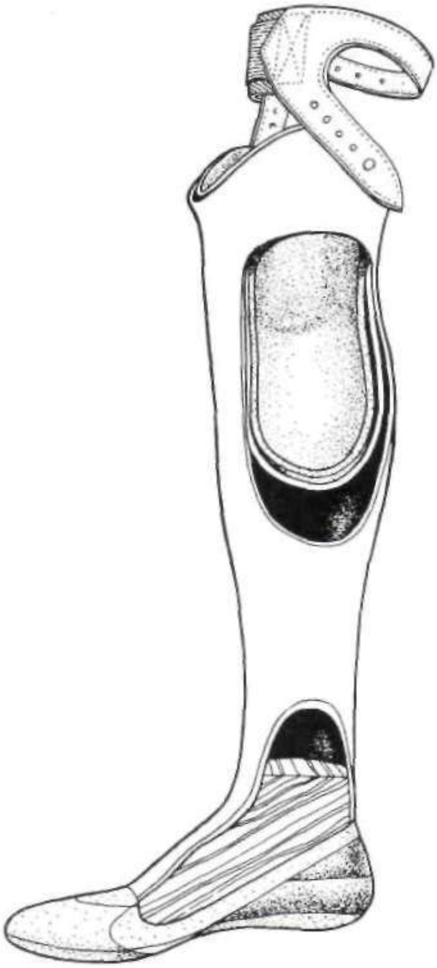


Fig. 31. Cutaway view of the patellar-tendon-bearing leg for below-knee amputees.

the edema problem in many instances. The PTB prosthesis is generally suspended by means of a simple cuff, or strap, around the thigh just above the kneecap, but sometimes a strap from the prosthesis to a belt around the waist is used.

A number of variations have been introduced during the past few years which make the PTB even more versatile. Many prosthetists feel that not only can many of the problems associated with perspiration be ameliorated by elimination of the soft inner liner, but that a better physiological fit can be obtained with the "hard socket" PTB. Two methods of eliminating the suspension have been introduced from Europe. From France, there is the "prothese tibiale a emboitage supracon-

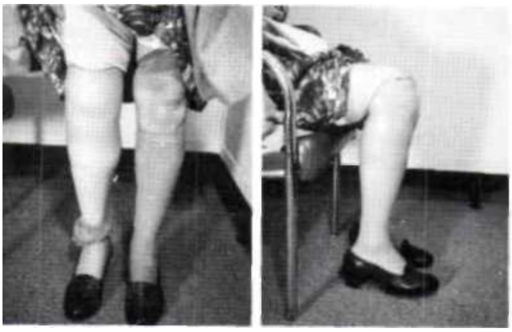


Fig. 32. A below-knee amputee wearing a PTS-socket prosthesis.

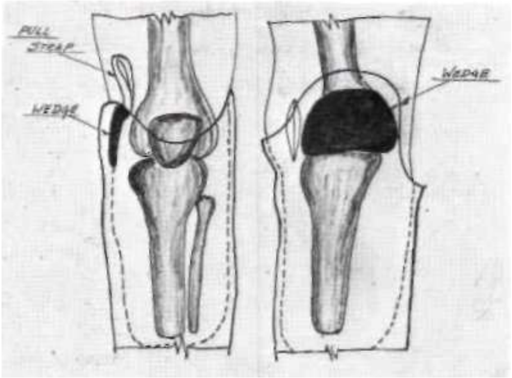


Fig. 33. The supracondylar-wedge suspension method.

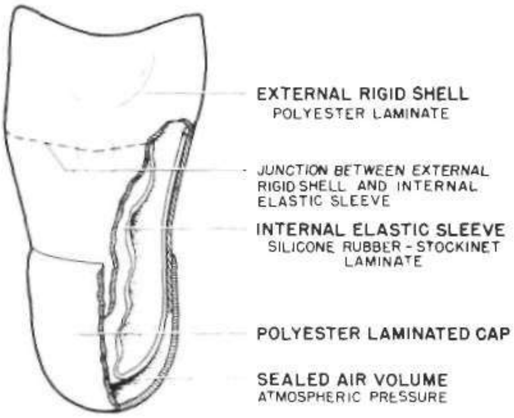


Fig. 34. Cutaway view of the air-cushion socket.

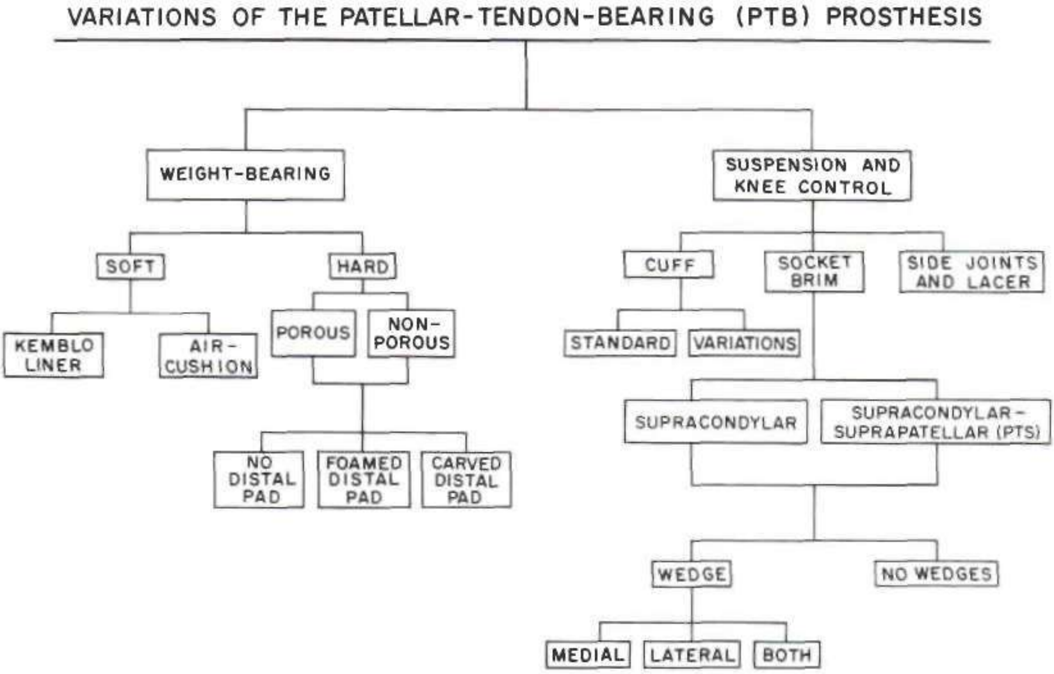


Fig. 35

dylien," popularly known as the PTS, in which the proximal border extends above the patella anteriorally and the femoral condyles medially and laterally (Fig. 32). Not only does this arrangement eliminate the need for other means of suspension, but it also provides a certain amount of mediolateral stability when required. Another means for eliminating the need for suspension straps was introduced from Germany, known as the wedge-suspension system. In this variation, a molded removable plastisol wedge is inserted between the wall of the proximal area of the socket and the area of the stump along the medial condyles of the femur (Fig. 33).

In an effort to develop a socket that would permit the stump to bear the optimum amount of the weight load over its distal end, the University of California designed the air-cushion socket, consisting of a rigid outer socket and an elastic inner sleeve (Fig. 34). Stump support is provided by the tension of the sleeve and by compression of the air between the sleeve and socket. Nearly all of these innovations are compatible with each other, and the Committee on Prosthetics Research and Development has prepared a chart for use by clinical teams in prescribing for the below-knee amputee (Fig. 35).

After the PTB socket has been made, it is installed on a special adjustable leg (Fig. 36) or one of the newer pylons (Fig. 37) so that the prosthetist can try various alignment combinations with ease. When both prosthetist and patient are satisfied, the leg is completed, utilizing the alignment determined with the adjustable unit.

The shank for the definitive prosthesis is usually made of wood reinforced with plastic laminate. When the new light pylons are used, a cosmetic cover is often provided. The foot prescribed in most instances is the SACH (solid-ankle, cushion-heel) design, but any other type may be used.

It is now general practice in many areas to prescribe the PTB prosthesis in most new cases and in many old ones, and if side hinges and a corset are indicated later, these can be added.

Stumps as short as two and one-half inches have been fitted successfully with the PTB prosthesis.

In special cases such as extreme flexion contracture, the so-called kneeling-knee, or bent-knee, prosthesis may be indicated. The prosthesis used is similar to that used for the knee-disarticulation case.

Prostheses for the Knee-Disarticulation and Other Knee-Bearing Cases

Because of the bulbous shape of the true knee-disarticulation stump, it is not possible to use a wooden socket of the type used on the tapered above-knee stump. To allow entry of the bulbous end, a socket is molded of leather to conform to the stump, and is provided with a lengthwise anterior cutout that can be laced to hold the socket in position (Fig. 38). The length of the knee-disarticulation and supracondylar stump makes it difficult to install any of the present knee units designed for above-knee prostheses; therefore, heavy-duty below-knee joints are generally used. Most prosthetists try to provide some control of the shank during the swing phase of walking by inserting nylon washers between the mating surfaces of the joint to provide friction and by using checkstraps. Some prosthetists in the past have installed commercially available piston-type hydraulic swing-phase control units (Fig. 39), a procedure that requires extreme care to achieve the proper result. To make this task easier, the Hosmer Corporation has recently made available a special boring fixture for use in installing the Hosmer-DuPaCo hydraulic knee unit.

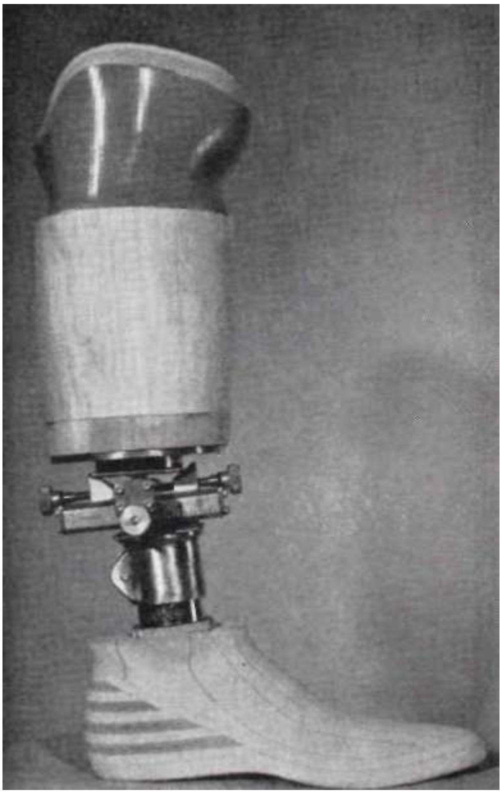


Fig. 36. Trial below-knee adjustable leg.

Prostheses for Above-Knee Cases

The articulated above-knee leg is in effect a compound pendulum actuated by the thigh stump. If the knee joint is perfectly free to rotate when force is applied, the effects of inertia and gravity tend to make the shank rotate too far backward and slam into extension as it rotates forward, except at a very slow rate of walking. The method most used today to permit an increase in walking speed is the introduction of some restraint in the form of mechanical friction about the knee joint. The limitation imposed by constant mechanical friction is that for each setting there is only one speed that produces a natural-appearing gait. When restraint is provided in the form of hydraulic resistance, a much wider range of cadence can be obtained, without introducing into the gait pattern awkward and unnatural motions.

In recent years, a number of hydraulic units have been made available for control of the shank during the swing phase.

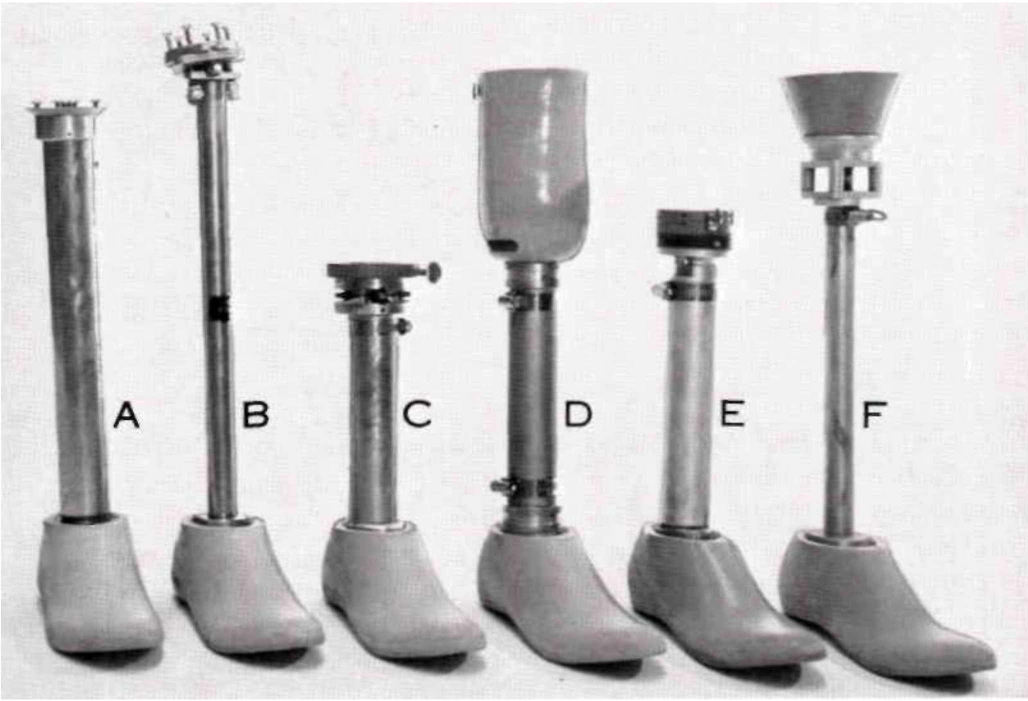


Fig. 37. Below-knee pylon-type prostheses that can be used for fitting immediately after surgery. *A,* Hosmer Postoperative Pylon; *B,* Northwestern Pylon (Hosmer); C, Veterans Administration Prosthetics Center (VAPC) "Standard" Pylon; *D,* Canadian "Instant" Prosthesis (Hosmer); *E,* U.S. Manufacturing Co. Pylon; *F,* Finnie-Jig (Arthur Finnieston Co.), *Courtesy of Veterans Administration Prosthetics Center.*

Among them are the DuPaCo, the Henschke-Mauch Type S[3] (Fig. 40), and the Hydra-Knee. These units are all of the piston-cylinder type, provide for swing-phase control only, and are designed so that they can be incorporated into the more conventional leg structures. The Hydra-Cadence leg (Fig. 41), a complete knee-shin-foot unit, in addition to providing swing-phase control hydraulically, uses the hydraulic system to control ankle action in concert with knee motion. After the knee is flexed 20 degrees, the toe of the foot is lifted as the knee is flexed further, thereby giving more clearance between the foot and the floor as the leg swings through.

[3] The Type S replaces Model B. It provides the same function but is shorter and lighter.

Throughout the past century, much time and effort have been spent in providing an automatic brake or lock at the knee in order to provide stability during the stance phase and to reduce the possibility of stumbling. Stability during the stance phase can be obtained by aligning the leg so that the axis of the knee is behind the hip and ankle axes. For most above-knee amputees in good health, such an arrangement has been quite satisfactory, but an automatic knee brake is indicated for the weaker or infirm patients.

When an automatic brake is indicated, the Bock, the "Vari-Gait" 100, and the Mortensen knee units (Fig. 42) are the ones most generally used. All are actuated upon contact of the heel with the ground. The Bock and Vari-Gait units can be used with almost any type of foot, while a foot

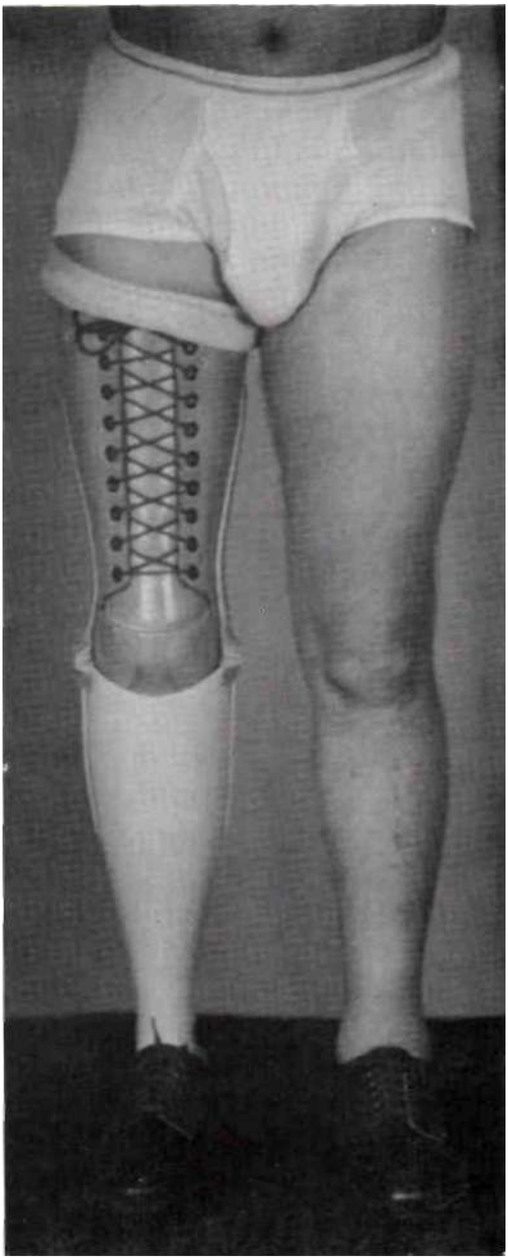


Fig. 38. Typical knee-disarticulation prosthesis.

of special design is necessary when the Mortensen mechanism is used.

The most sophisticated stance-phase control unit is the Henschke-Mauch Type S-N-S hydraulic unit. It has been thoroughly evaluated by the Veterans Administration and is now available commercially. The Type S-N-S unit contains the same swing-phase control device as the Type S and in addition provides a braking action about the knee when there is a tendency to buckle. The braking action is brought about by the attitude of a pendulum which in turn is controlled by the inertia forces in the shank. The "S" and "S-N-S" units are interchangeable.

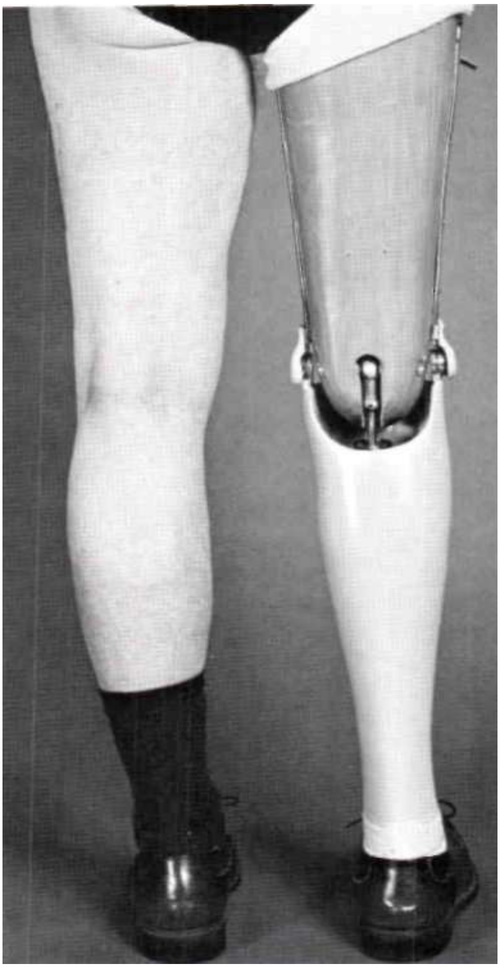


Fig. 39. DuPaCo swing-phase control unit installed in a knee-bearing prosthesis.

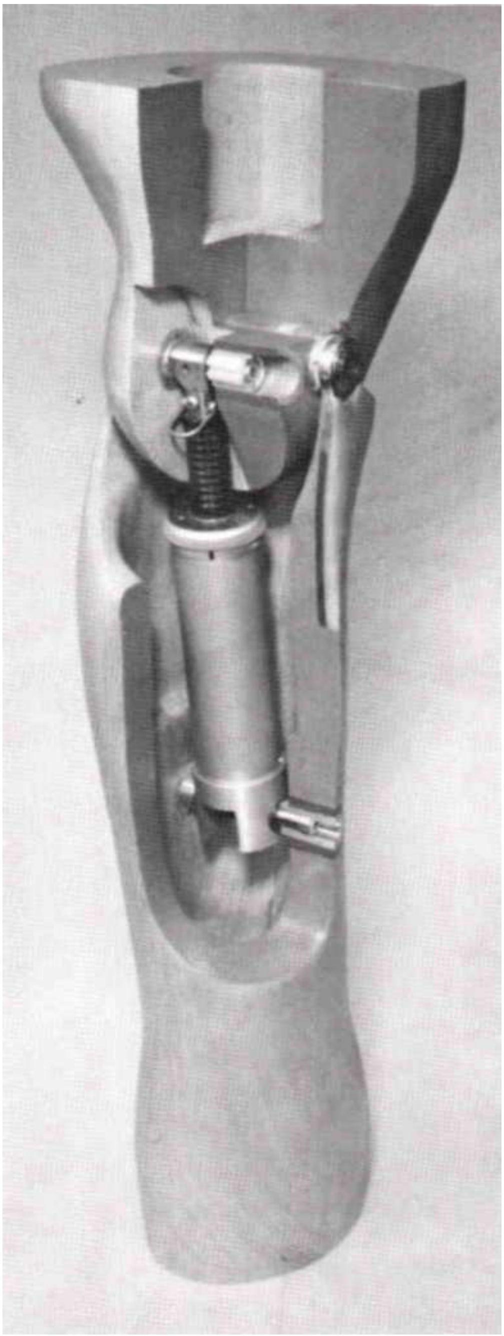


Fig. 40. The Henschke-Mauch Type S hydraulic unit.

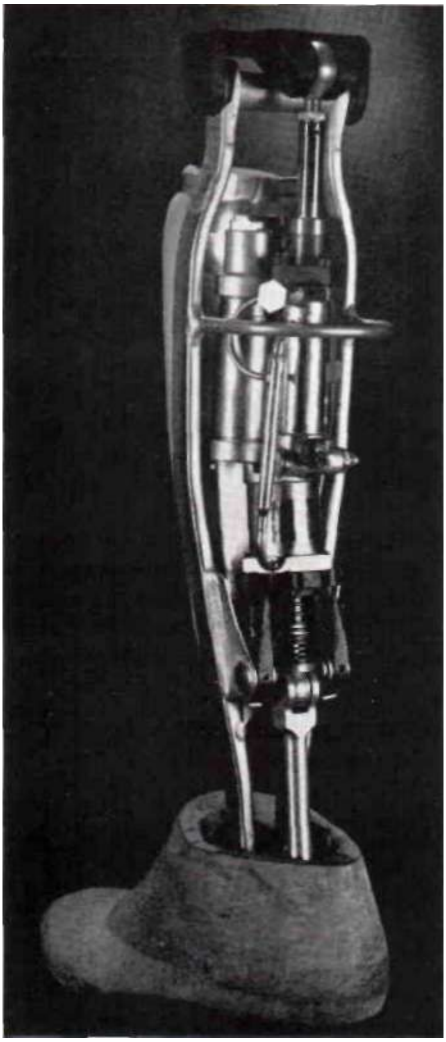


Fig. 41. The Hydra-Cadence leg without cosmetic cover.

A number of methods for suspending the above-knee leg are available. For younger, healthy patients, the suction socket (Fig. 43A) has generally been the method of choice. In this design, the socket is simply fitted tightly enough to retain sufficient negative pressure, or suction, between the stump and the bottom of the socket when the leg is off the ground. Special air valves are used to control the amount of negative pressure

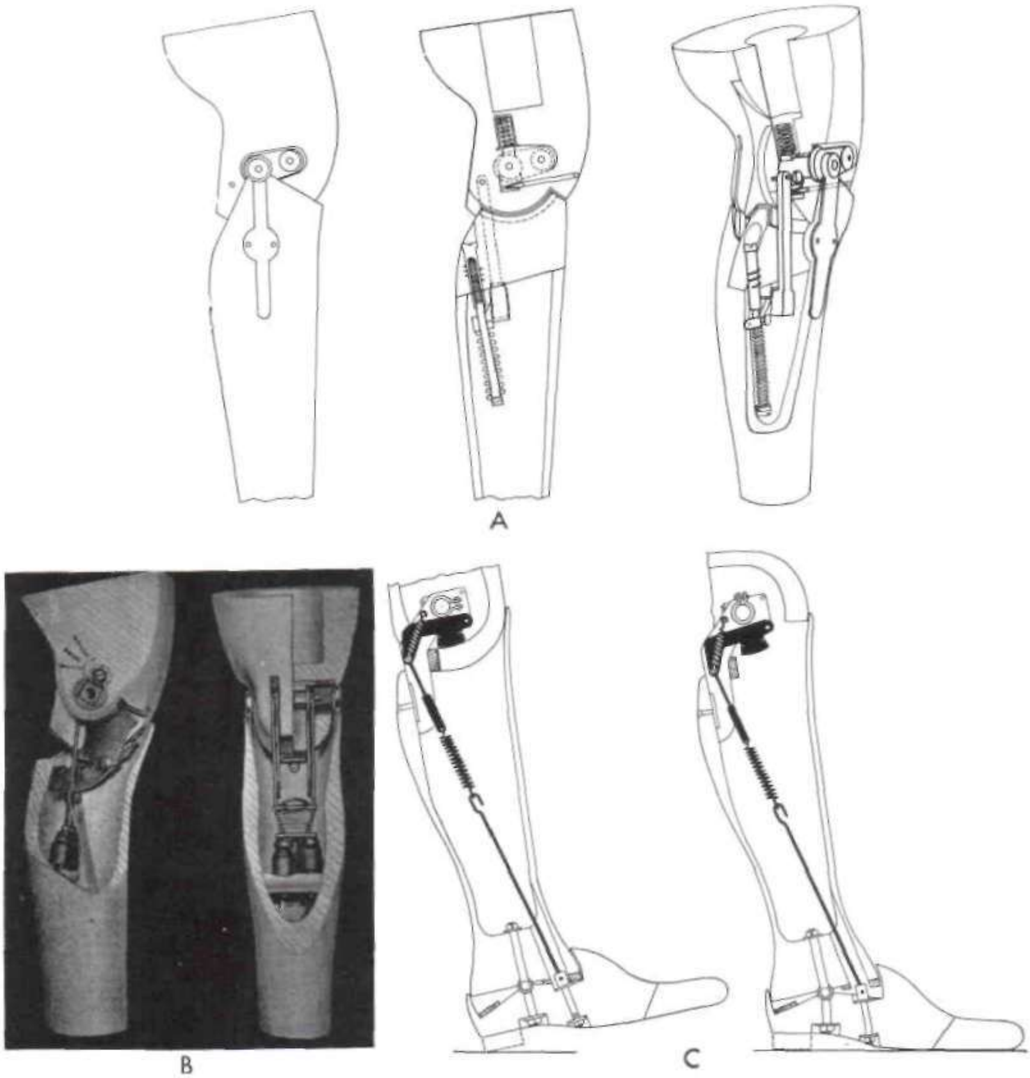


Fig. 42. Some examples of weight-actuated knee units. *A,* Bock "Safety-knee"; *B,* Vari-Gait knee; C, Mortensen leg.

created so as not to cause discomfort. No stump sock is worn with the suction socket. A major advantage of this type of suspension is the freedom of motion permitted the wearer, thus allowing the use of all the remaining musculature of the stump. Another important advantage is the decreased amount of piston action between stump and socket. Additional comfort is also obtained by elimination of all straps and belts.

In some cases, additional suspension is provided by adding a Silesian bandage (Fig. 43B), a light belt attached to the socket in such a way that there is very little restriction of motion of the various parts of the body.

Patients with weak stumps and most of those with very short stumps often will require a pelvic belt connected to the socket by means of a "hip" joint (Fig. 43C). Because the connecting joint cannot be placed to coincide with the normal joint, certain motions are restricted. Pelvic-belt suspension is generally indicated for the older patient because of the problems encountered in donning the suction socket, especially that of bending over to remove the donning sock.

Shoulder straps, at one time the standard method of suspending above-knee prostheses are still sometimes indicated for the elderly patient.

Prior to the introduction of the suction socket into the United States soon after the close of World War II, virtually all above-knee sockets had a conical-shaped interior and were known as plug fits, most of the weight being borne along the sides of the stump. Such a design does not permit the remaining musculature to perform to its full capabilities. In the development of the suction socket, a design known as the quadrilateral socket (see Fig. 43) evolved, and it now is virtually the standard for above-knee sockets, regardless of the type of suspension used. When the pelvic belt or suspender straps are used, the socket is fitted somewhat looser than in the case of the suction socket, and the stump sock is generally worn to reduce skin irritation from the pumping action of the loose

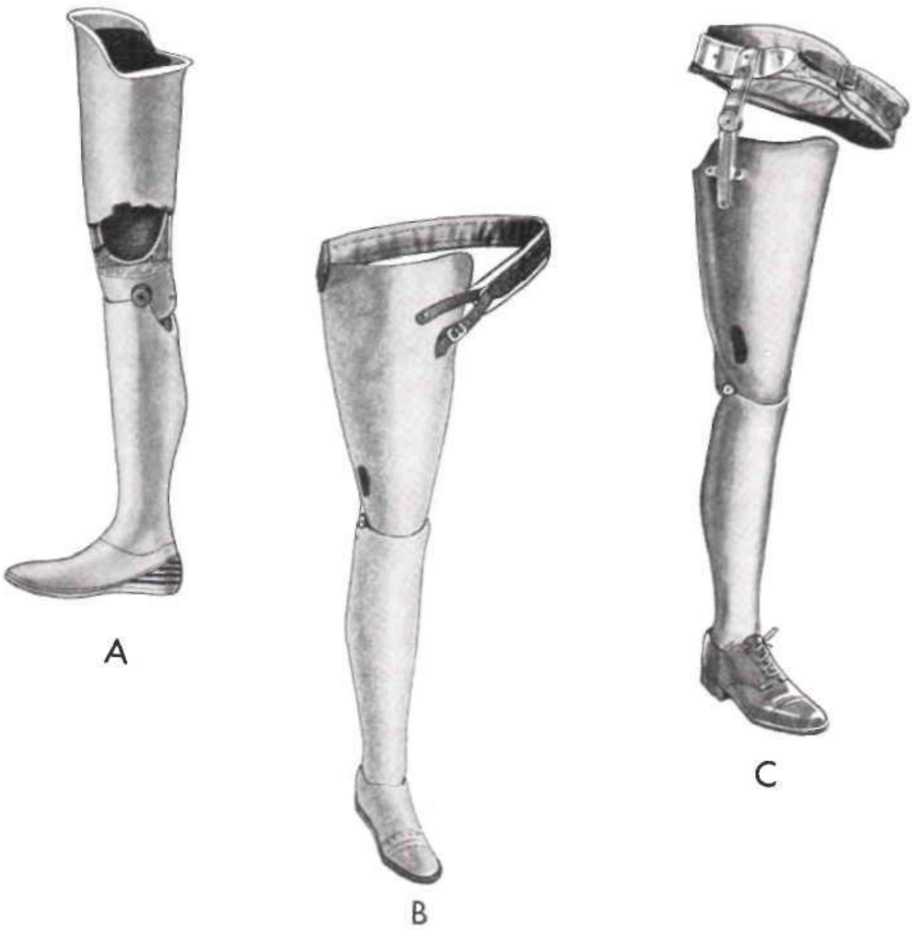


Fig. 43. Above-knee sockets and methods of suspension: *A*, total-contact suction socket; *B*, above-knee leg with Silesian bandage for suspension; C, above-knee leg with pelvic belt for suspension. Most above-knee sockets have a quadrilateral-shaped upper portion as shown.

socket. A good part of the body weight is taken on the ischium, that part which assumes the load when an individual is sitting.

The quadrilateral socket, because of the method employed to permit full use of the remaining muscles, does not resemble the shape of the stump, but, as the name implies, is more rectangular in shape. Until recently, the standard method of fitting a quadrilateral socket called for no contact over the lower end of the stump, a hollow space being left in this area. Although this method was quite successful, there remained a number of cases that persistently developed ulcers or edema over the end of the stump. Experiments involving the use of slight pressure over the stump end led to the development of what is known as the plastic total-contact socket (9) (Fig. 43A). As the name implies, the socket is in contact with the entire surface of the stump. In taking some pressure over the end of the stump, the pressure on the ischial area is reduced, thereby providing more comfort to the patient. It also appears that the pressure over the end of the stump helps circulation and improves proprioception. Today the total-contact socket is the method of choice for use by above-knee amputees.

In fitting the wooden above-knee prosthesis, the prosthetist carves the interior of the socket, using measurements of the stump as a guide. When a satisfactory fit has been achieved the socket is usually mounted on an adjustable leg for alignment trial, after which the wooden shank and the knee are substituted for the adjustable unit, and the leg is finished by applying a thin layer of plastic laminate over the shank and the thigh piece.

In the case of the total-contact socket, the prosthetist obtains a plaster cast of the stump, usually with the aid of a special casting jig (see Fig. 22), and thus obtains a model of the stump over which the plastic socket can be formed.

Special adjustable pylon-type legs are available for fitting immediately after surgery, or use as a temporary leg. Provisions are made for all necessary adjustments, and a manually operated knee lock is provided for use by infirm patients.

Prostheses for Hip-Disarticulation and Hemipeluectomy Cases

A prosthesis (Fig. 44) developed by the Canadian Department of Veterans Affairs in 1954, and modified slightly through the years, is used almost universally. In the Canadian design, a plastic-laminate socket is used, and the "hip" joint is placed on the front surface in such a position that, when used with an elastic strap connecting the rear end of the socket to a point on the shank ahead of the femur, stability during standing and walking can be achieved without the use of a lock at the hip joint. The location of the hip joint in the Canadian design also facilitates sitting, a real problem in earlier designs.

A constant-friction knee unit is most often used with the hip-disarticulation prosthesis, but some prosthetists have reported successful use of hydraulic knee units.

The hemipelvectomy patient is provided with the same type of prosthesis, but the socket design is altered to allow for the loss of part of the pelvis.

UPPER-EXTREMITY PROSTHESES *(17)*

The major role of the human arm is to place the hand where it can function and to transport objects held in the hand. The energy for operation of the hand-substitute in upper-extremity prostheses is generally derived from relative motion between two parts of the body. Energy for operation of the elbow joint, when necessary, can be obtained in the same way. The stump, of course, is also a source of energy for control of the prosthesis in all except the shoulder-disarticulation and forequarter cases. Force and motion can be obtained through a cable connected between the device to be operated and a harness across the chest or shoulders.

In recent years artificial arms powered by electricity and by compressed gas have received considerable publicity. An arti-

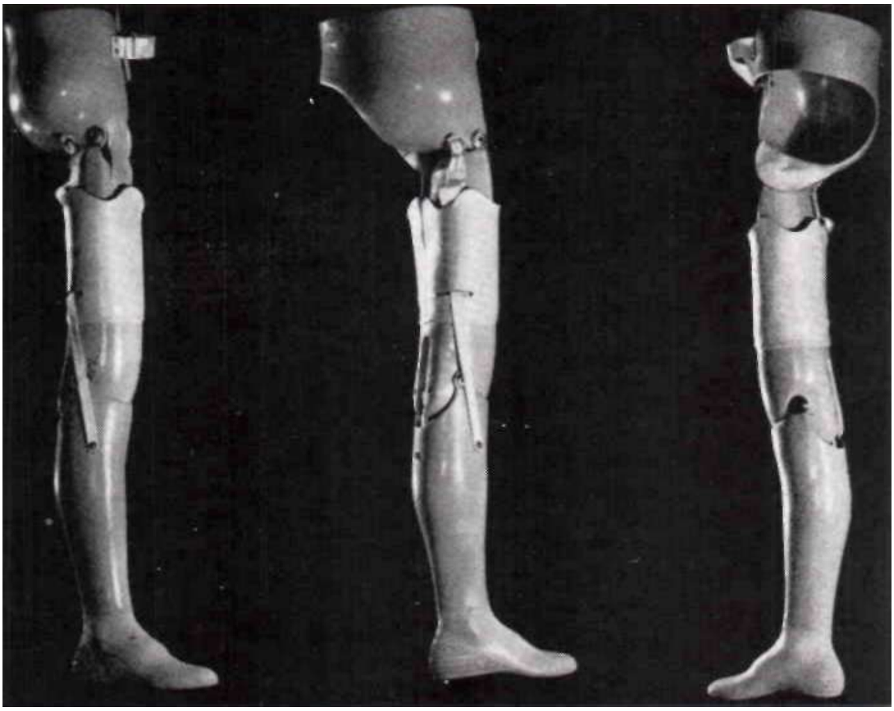


Fig. 44. Hip-disarticulation prosthesis, known as the Canadian type because its principle was originally conceived by workers at the Department of Veterans Affairs of Canada.

ficial hand powered by electricity and controlled by electrical signals from muscles was developed first in Russia for below-elbow amputees. Versions of the Russian design are manufactured in England, Canada, Germany, and elsewhere. However, the below-elbow patient, of all the types of upper-extremity amputees, is the least handicapped and therefore is less in need of sophisticated devices. The devices are expensive, and in their present state of development seem to offer no real advantage over the simpler conventional devices. The real need is for powered devices for patients with amputations above the elbow and higher.

A number of electrically powered elbow units are now being tested, including the so-called Boston Arm, but none are available for general clinical use. To date, no truly satisfactory method of controlling externally powered prostheses has been developed. A good deal of effort is being made both in the United States and abroad to overcome the control problem (73).

Sockets for artificial arms are usually made of plastic laminate formed over a modified plaster model of the stump. Synthetic balata, which is molded directly over the stump, is now being used in a few centers.

Hand Substitutes—Terminal Devices

All upper-extremity prostheses for amputation at the wrist level and above have in common the problem of selection of the terminal device, a term applied to artificial hands and substitute devices such as hooks. In some areas of the world, there is a tendency to supply the arm amputee with a number of devices, each designed for a specific task such as eating, shaving, hair grooming, etc. In the United States, such an approach has been considered too clumsy, and opinion has been that the terminal device should be designed so that most upper-extremity amputees can perform the activities of daily living with a single device, or at most with two devices.

The so-called split hooks are much more functional than any artificial hand devised to date. The arm amputee must rely heavily upon visual cues in handling objects, and the hook offers more visibility. The hook also offers more prehension facility and can be more easily introduced into and withdrawn from pockets than a device in the form of a hand. Therefore, the hook is used in manual occupations and those avocations requiring manual dexterity. When extensive contact with the public is necessary and for social occasions, the hand is of course generally preferred. Many amputees have both types of devices, using each as the occasion warrants.

Two basic types of mechanisms have been developed for terminal-device operation—voluntary-opening and voluntary-closing. In the former, tension on the control cable opens the fingers against an elastic force; in the latter, tension in the control cable closes the fingers against an elastic force. Each type of mechanism has its advantages and disadvantages, neither being superior to the other when used in a wide range of activities. Both hands and hooks are available with either type of mechanism.

The major types of terminal devices are shown in Figures 45 and 46.

Prostheses for the Wrist-Disarticulation Case

One of the problems in fitting the wrist disarticulation in the past has been to keep the overall length of the prosthesis commensurate with the normal arm. The development of very short wrist units, especially for wrist-disarticulation cases, has materially reduced this problem. However, these units are available in only the screw, or thread, type and cannot be obtained in the bayonet type which lends itself to quick interchange of terminal devices.

The socket for the wrist-disarticulation case need not extend the full length of the forearm, and is fitted somewhat loosely at the upper, or proximal, end to permit the wrist to rotate. A simple figure-eight harness and Bowden cable are used to operate the terminal device (Fig. 47).

Prostheses for the Long Below-Elbow Case

The prosthesis for the long below-elbow case is essentially the same as that for the wrist-disarticulation patient except that the quick-disconnect wrist unit can be used when desired.

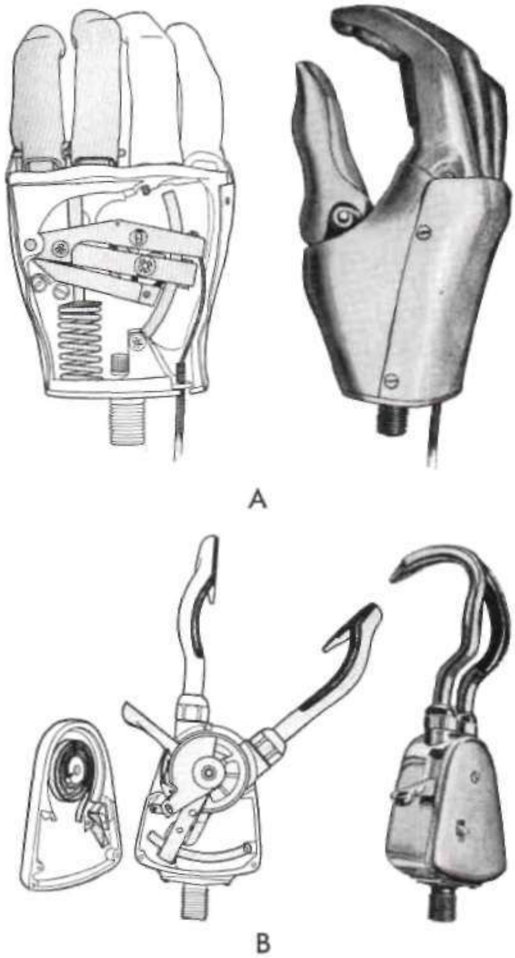


Fig. 45. Voluntary-closing terminal devices. *A*, APRL-Sierra Hand; *left*, cutaway view showing mechanism; *right*, assembled hand without cosmetic glove; *B*, APRL-Sierra Hook.

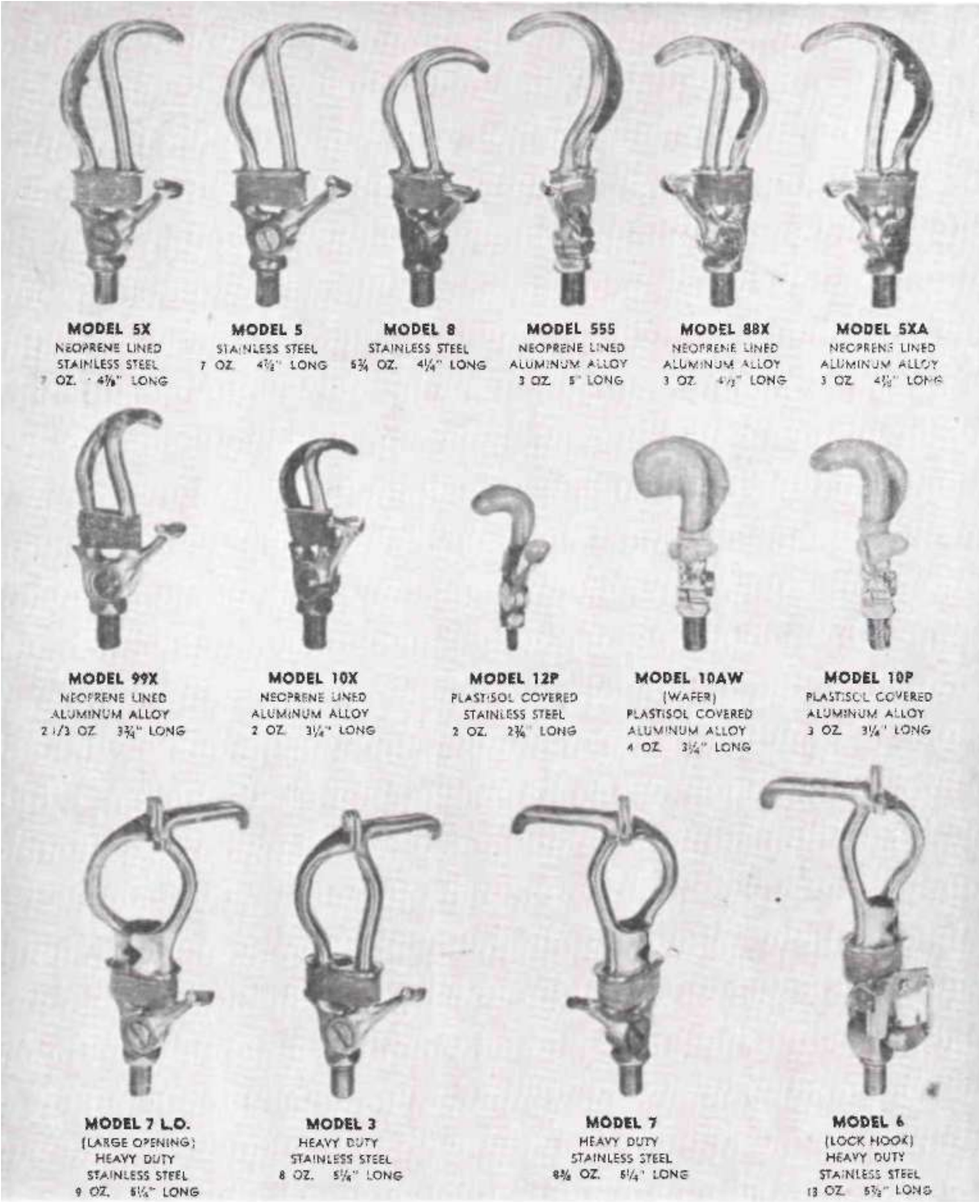


Fig. 46. Voluntary-opening terminal devices. The wide range of models offered by the D. W. Dorrance Company includes sizes and designs for all ages.

Prostheses for the Short Below-Elbow Case

The socket for the short below-elbow stump, where there is no residual rotation of the forearm, is usually fitted snugly to the entire stump, and rigid hinges connecting the socket to a cuff about the upper arm are often used to provide additional stability. Either the figure-eight harness or the chest-strap harness may be used, the latter being preferred when heavy-duty work is required, since it tends to spread the loads involved in lift-

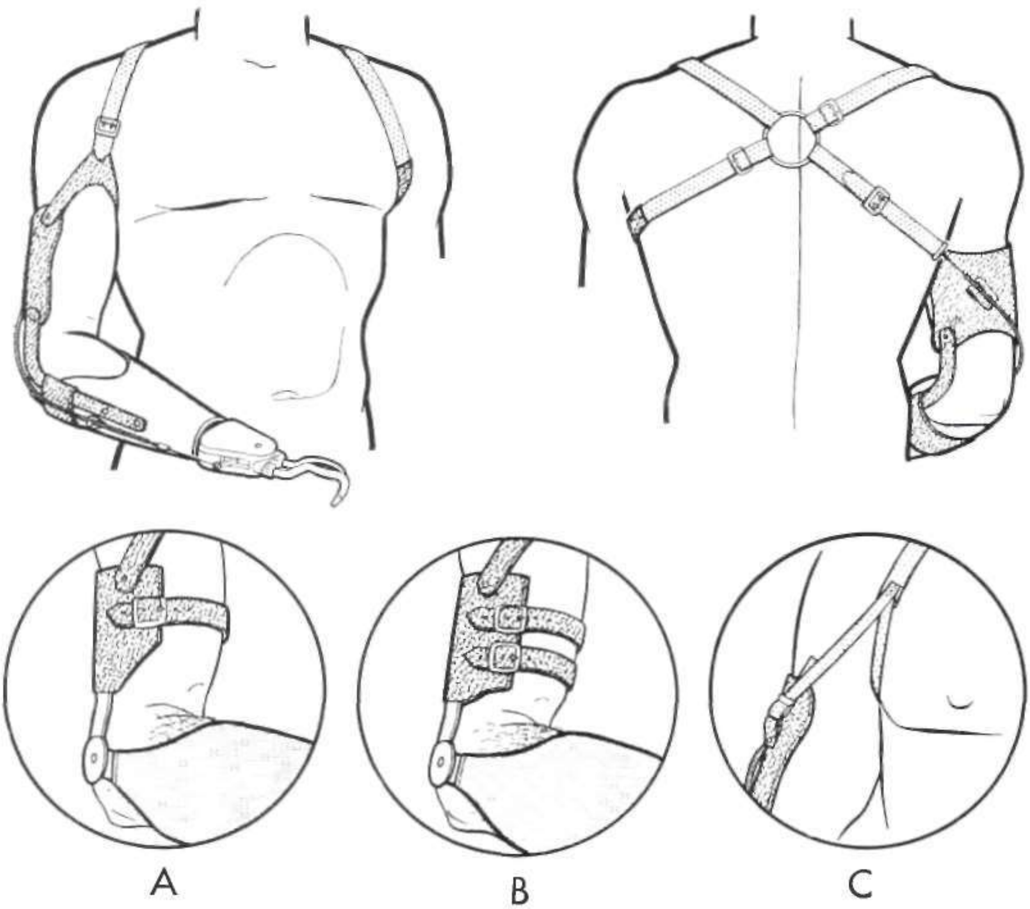


Fig. 47. Typical methods of fitting below-elbow amputees with medium to long stumps. *Top,* the figure-eight, ring-type harness is most generally used. Where possible, flexible leather hinges and open biceps cuff or pad are used. When more stability between socket and stump is required, rigid (metal) hinges and closed cuffs can be used *(A* and *B). C* shows fabric straps that are used for suspension in lieu of a leather billet.

ing over a broader area than is the case with the figure-eight design.

A wrist-flexion unit, which permits the terminal device to be tilted in toward the body for more effective use, can be provided in the short below-elbow prosthesis, but it is seldom prescribed for unilateral cases.

Prostheses for the Very Short Below-Elbow Case

Often the very short below-elbow amputee cannot control the prosthesis of the short below-elbow type through the full range of motion, either because of a muscle contracture or because the stump is too short to provide the necessary leverage.

When a contracture is present that limits the range of motion of the stump, a "split-socket" and "step-up" hinge may be used. With this arrangement of levers and gears, movement of the stump through one degree causes the prosthetic forearm to move through two degrees; thus, a stump that has only about half the normal range of motion can drive the forearm through the desired 135 degrees. However, when the step-up hinge is used, twice the normal force is required. When the stump

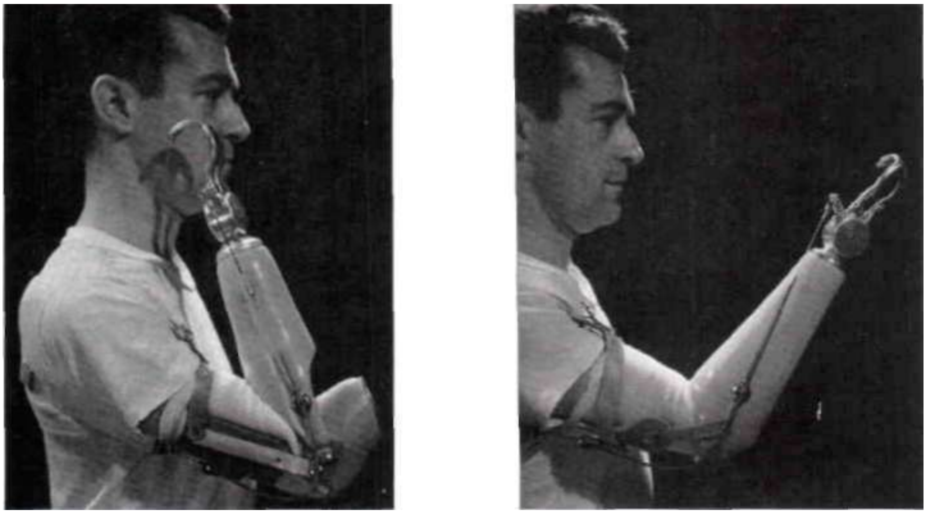


Fig. 48. Comparison of split socket and Miinster-type fitting of short below-elbow case. *A,* split socket and step-up hinge provides 140 deg of forearm flexion; *B,* Miinster-type fitting permits less forearm flexion but enables the amputee to carry considerably greater weight with flexed prosthesis unsupported by harness. *Courtesy New York University College of Engineering Prosthetic and Orthotic Research.*

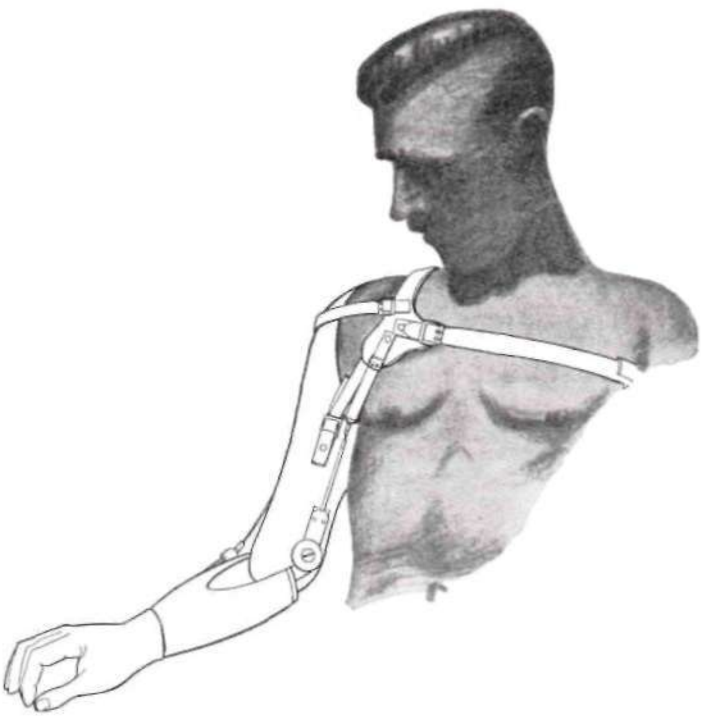


Fig. 49. Typical prosthesis for the elbow-disarticulation case. The chest-strap harness with shoulder saddle is shown here, but the above-elbow figure-eight is also used. See Figure 50.

is incapable of supplying the force required, it can be assisted by employing the "dual-control" harness, wherein force in the terminal-device control cable is diverted to help lift the forearm. When the elbow stump is very short or has a very limited range of motion, an elbow lock operated by stump motion is employed to obtain elbow function.

Recently, a number of prosthetists have reported success in fitting very short below-elbow cases with an arm which is bent to give a certain amount of preflexion. This type of fitting, which was developed in Minister, West Germany, eliminates the necessity for using the rather clumsy step-up hinges and split socket, thus providing improved prosthetic control without a disadvantageous force feedback. Furthermore, the harness is not necessary for suspension of the prosthesis. The maximum forearm flexion may be limited to about 100 degrees, but this does not appear to be a significant disadvantage to unilateral amputees (Fig. 48).

Prostheses for the Elbow-Disarticulation Case

Because of the length of the elbow-disarticulation stump, the elbow-locking mechanism is installed on the outside of the socket. Otherwise the prosthesis and harnessing methods (Fig. 49) are identical to those applied to the above-elbow case.

Prostheses for the Above-Elbow Case

For the above-elbow prosthesis to operate efficiently, it is necessary that a lock be provided in the elbow joint, and it is, of course, preferable that the lock is engaged and disengaged without resorting to the use of the other hand or pressing the locking actuator against an external object such as a table or chair.

Several elbow units that can be locked and unlocked alternately by the same motion are available. This action is usually accomplished by the relative motion between the prosthesis and the body when the shoulder is depressed slightly and the arm is extended somewhat. The motion required is so slight that with practice the amputee can accomplish the action without being noticed. These elbow units contain a turntable above the elbow axis that permits the forearm to be positioned with respect to the humerus, supplementing the normal rotation remaining in the upper arm and thus allowing the prosthesis to be used more easily close to the midline of the body.

The elbow units described above are available with an adjustable coil spring to assist in flexing the elbow when this is desired. The flexion-assist device may be added or removed without affecting the other operating characteristics.

The socket of the above-elbow prosthesis covers the entire surface of the stump. The most popular harness used is the figure-eight dual-control design,

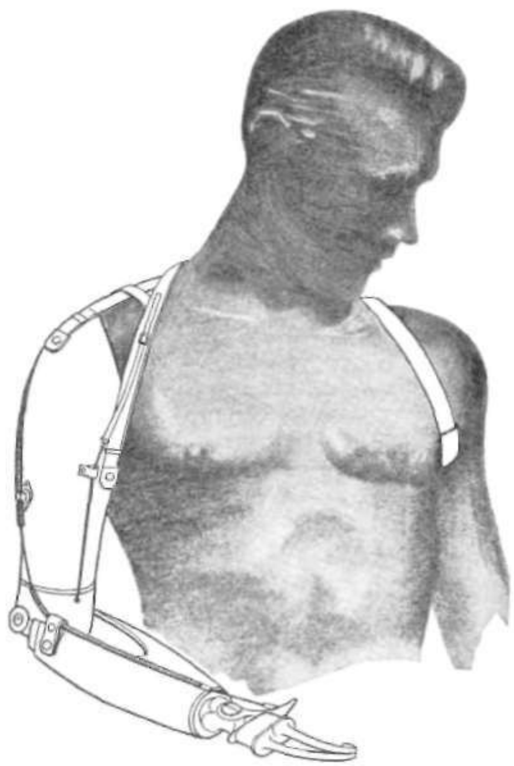


Fig. 50. Typical prosthesis for the above-elbow case. The figure-eight harness is shown here but the chest-strap harness with shoulder saddle may also be used. See Figure 49.

Fig. 51. Typical prosthesis for the shoulder-disarticulation case.

wherein the terminal-device control cable is also attached to a lever on the forearm so that when the elbow is unlocked, tension in the control cable produces elbow flexion, and when the elbow is locked, the control force is diverted to the terminal device (Fig. 50).

The chest-strap harness may also be used in the dual-control configuration.

Prostheses for the Shoulder-Disarticulation and Forequarter Cases

Because of the loss of the upper-arm motion as a source of energy for control and operation of the prosthesis, restoration of the most vital functions in the shoulder-disarticulation case presents a formidable problem; for many years, a prosthesis was provided for this type of amputation only for the sake of appearance. In recent years, however, it has been possible to make available prostheses which provide a limited amount of function (Fig. 51). To date it has not been possible to devise a shoulder joint that can be activated from a harness, but a number of manually operated joints are available. Various harness designs have been employed, but because of the wide variation in the individual cases and the marginal amount of energy available, no standard pattern has developed, each design being made to take full advantage of the remaining potential of the particular patient.

Prostheses for Bilateral Upper-Extremity Amputees

Except for the bilateral, shoulder-disarticulation case, fitting the bilateral case offers few problems not encountered with the unilateral case. The prostheses provided are generally the same as those prescribed for corresponding levels in unilateral cases. Artificial hands are rarely used by bilateral amputees, because hooks afford so much more function. Many bilateral cases find that the wrist-flexion unit, at least on one side, is of value. The harness for each prosthesis may be separated, but it is the general practice to combine the two (Fig. 52). In addition to being neater, this arrangement makes the harness easier for the patient to don unassisted.

Some prosthetists have claimed success in fitting bilateral shoulder-disarticulation cases with two prostheses. Because of the lack of sufficient sources of energy for control, most cases of this type are provided with a single, functional prosthesis and with a plastic cap over the opposite shoulder, which provides an anchor for the harness and also fills this area to present a better appearance (Fig. 53).

LEARNING TO USE THE PROSTHESIS

To derive maximum benefit from his prosthesis, the amputee must understand how it functions and learn the best means of controlling it. A patient may be of the opinion that he is getting along very well when, in reality, he could do much better.

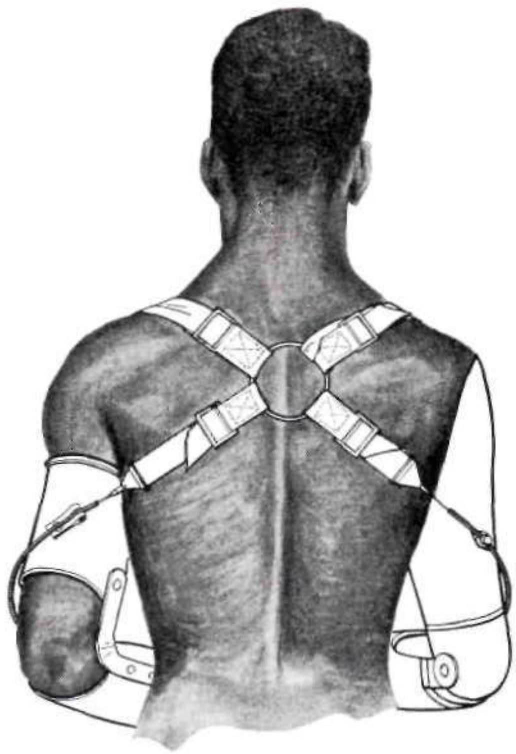


Fig. 52. Harness for the bilateral below-elbow/above-elbow case.

Use of the prosthesis can best be learned under the supervision of an instructor who has had special training.

All amputees using an artificial limb for the first time will need some instruction. In some instances, when a prosthesis is replaced with one of a different design, special instruction will be required. The time required for training depends upon the complexity of the device and the physical condition and degree of coordination of the patient. The time required will vary from a few hours to several weeks. In many instances, amputees themselves have become excellent trainers, but more often such training is given by physical or occupational therapists. Usually, physical therapists instruct lower-extremity patients, and occupational therapists teach upper-extremity cases.

During the period of instruction, the trainer is careful to observe any effects the use of the prosthesis has on the patient, especially at points where the prosthesis is in contact with the body. Any changes are reported immediately to the physician in charge.

LOWER-EXTREMITY CASES

One of the major goals in training the leg amputee *(19)* is to enable him to walk as gracefully as possible. Training is begun as soon as the amputee is provided with a comfortable prosthesis. In the case of immediate postsurgical fitting *(6)*, training is often begun on the day following surgery and an adjustable leg is used. There is a growing tendency to train lower-extremity amputees on legs with adjustable features, even though they have not been fitted immediately after surgery. Some other goals of training are to teach the patient proper methods of donning the prosthesis, caring for the stump, arising after a fall, and using canes and crutches when necessary. The type of training will, of course, depend upon the level of amputation.

A patient with a Syme amputation needs a minimum of training. The average below-knee case will require somewhat more, though usually not a great deal unless other medical problems are present. The training required is usually considerable for patients who have lost the knee joint.

The ability to balance oneself is the first prerequisite in learning to walk, and so it is balance that is taught first to the above-knee amputee. Two parallel railings are used to give the patient confidence and to reduce the possibility of falling (Fig. 54). Balancing on both legs is practiced first, then on each leg. Walking in a straight line between the parallel bars is repeated until the patient no longer requires use of the hands for support. Walking in a straight line is practiced until the gait is even and smooth.

When a rhythmic gait has been accomplished, more difficult tasks are learned, such as pivoting, turning, negotiating stairs and ramps, and sitting on and arising from the floor.

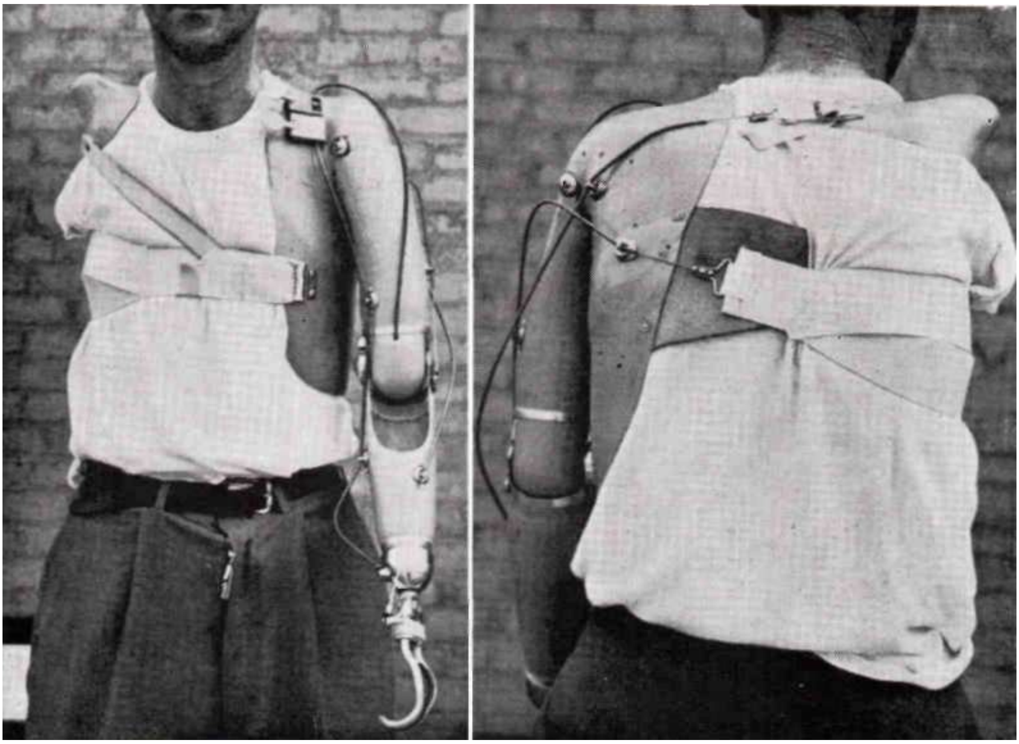


Fig. 53. Special harness arrangement for the bilateral shoulder-disarticulation case.

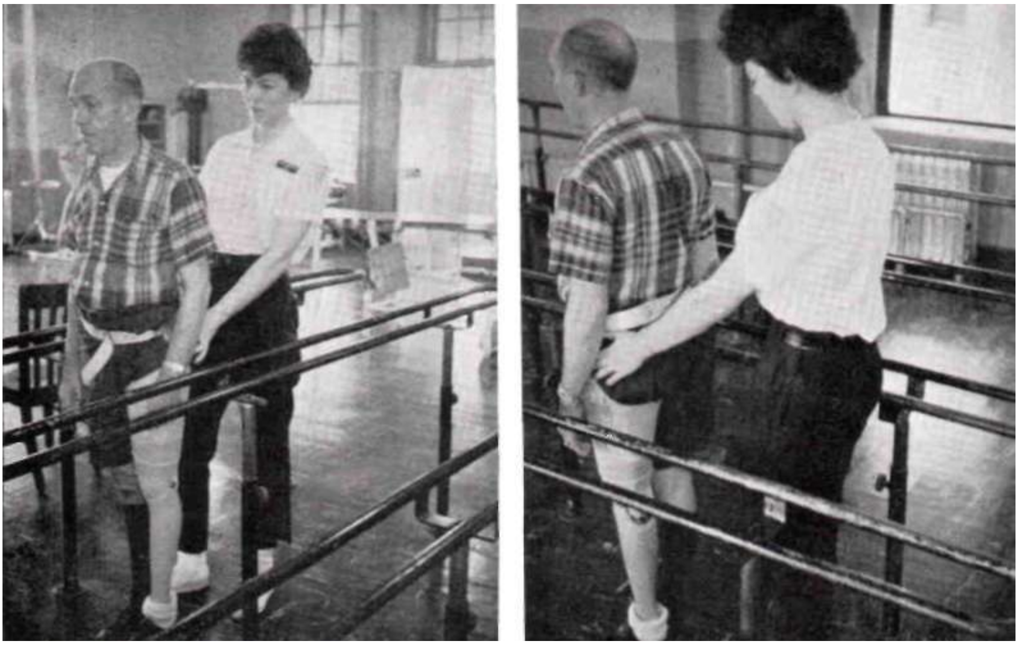


Fig. 54. Above-knee patient being trained to walk by a physical therapist.

Most unilateral above-knee patients can use their prostheses quite well without the necessity for a cane. However, in the case of short, weak stumps, it may be advisable to employ a cane for additional support and stability. If a cane is necessary, it should be selected to meet the needs of the patient, and it must be used properly if ungainly walking patterns are to be avoided. Canes with curved handles and made from a single piece of wood should be used. The shaft should not show any signs of buckling under the full load of the body weight, and should be just long enough so that the elbow is bent slightly when the bottom of the cane rests near the foot. The cane is used on the side opposite the amputation to help maintain balance, but it is not used to the extent that body weight is centered between the good leg and the cane (Fig. 55). Continued use of the cane in this manner usually results in a limp that is difficult to overcome. It has been found that, for biomechanical reasons, it is helpful for the amputee to carry a briefcase or purse on the side of the amputation.

Fig. 55. Above-knee patient being taught correct use of cane.

Training The Hip-Disarticulation Cases

The training of hip-disarticulation cases follows much the same pattern as that of above-knee cases. With the advent of the Canadian-type prosthesis, the training procedure has been considerably simplified. Some special precautions must be taken to avoid stumbling while ascending stairs.

Special Considerations for Bilateral-Leg Cases

As would be expected, bilateral-leg cases pose special problems in addition to those of the unilateral cases, and therefore a good deal of time will usually be required in training. Patients with two good below-knee stumps will seldom require canes. Some bilateral above-knee amputees can get along without canes, but as a general rule, at least one cane is required.

UPPER-EXTREMITY CASES

The first objective in the training program for upper-extremity amputees is to ensure that the patient can perform the activities encountered in daily living, such as eating, grooming, and toilet care. When this goal has been attained, attention is devoted to any special training that might be required in vocational pursuits (Fig. 56).

Before the prosthesis is put to useful purposes, the patient is shown how the various mechanisms are controlled, and is made to practice these motions until they can be performed in a graceful manner and without undue exertion. In general, the arm amputee soon becomes so adept in these procedures that they are carried out without conscious thought. During this period, the functioning of the pros-

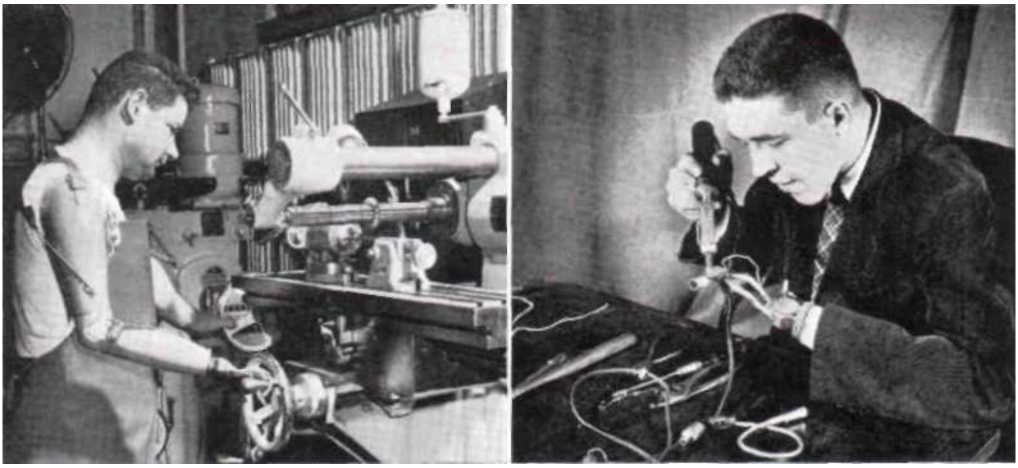


Fig. 56. Upper-extremity amputees performing vocational tasks.

thesis, especially of the harness and control cables, is watched carefully by the instructor and constantly rechecked to ensure maximum performance.

Only when the patient has mastered use of the various controls is practice in handling objects and performing activities of daily living undertaken.

CARE OF THE STUMP

Even under the most ideal circumstances, the amputation stump, when called upon to operate a prosthesis, is subjected to certain abnormal conditions which, if not compensated for, may lead to physical disorders which make the use of a prosthesis impossible.

Lack of ventilation as a result of encasing the stump in a socket with impervious walls causes an accumulation of perspiration and other secretions of glands found in the skin. In addition to the solid matter in the secretions, bacteria will accumulate in the course of a day. Both the solid matter and bacteria can lead to infection, and the solid matter, though it may appear to be insignificant, may result in abrasions and the formation of cysts. For these reasons, cleanliness of the stump and anything that comes in contact with it for any length of time is of the utmost importance, even when sockets of the newer porous plastic laminate are used.

Therefore, the stump should be washed thoroughly each day, preferably just before retiring. A soap or detergent containing hexachlorophene, a bacteriostatic agent, is recommended, but strong disinfectants are to be avoided. To be fully effective, the bacteriostatic agent must be used daily. Some six or seven daily applications are necessary before full effectiveness is obtained, and any cessation of this routine lowers the agent's ability to combat the bacteria. A physician who is himself an amputee has suggested that, after an amputee takes a bath, the stump should be dried first, in order to minimize the risk of introducing infection to it by the towel.

When the prosthesis is used without a stump sock, the stump should be thoroughly dry, as moisture may cause swelling that will result in rubbing and irritation. For such cases, it is especially desirable for the stump to be cleansed in the evening.

The stump sock should receive the same meticulous care as the stump. The socks should be changed daily and washed as soon as they are taken off. In this way, the perspiration salts and other residue are easier to remove. A mild soap and warm water are used to keep shrinkage to a minimum. Woolite (a cold-water soap) and cold water in recent trials have given excellent results. A rubber ball inserted in the "toe" during the drying process ensures retention of shape.

Elastic bandages should be washed daily in the same manner as stump socks, but should not be hung up to dry; rather, they should be laid out on a flat surface away from excessive heat and out of the direct rays of the sun. Hanging places unnecessary stresses on the elastic threads, and heat and sunlight accelerate deterioration.

It is of the utmost importance that any skin disorder of the stump—no matter how slight—receive prompt attention, because such disorders can rapidly worsen and become disabling. The amputee should see a physician for treatment. He should also see his prosthetist; it may be that adjustment of the prosthesis will eliminate the cause of the disorder. In no case should iodine or any other strong disinfectant be used on the skin of the stump.

Sometimes the skin of the stump is rubbed raw by socket friction. When this happens, the skin should be gently washed with a mild toilet soap. After the stump has been rinsed and dried, bacitracin ointment or some other antibacterial agent should be applied, and the area covered with sterile gauze. The prosthesis should be completely dry before it is put on. If such abrasions occur frequently, the prosthetist should be informed. If there is the slightest sign of infection, the amputee should see a physician.

Small painless blisters should not be opened; they should be washed gently with a mild soap and left alone. Large, painful blisters should be treated by a physician.

BANDAGING THE STUMP

The stump is usually kept wrapped in an elastic bandage from the time healing permits until the time the prosthesis is delivered. Also, bandaging is recommended when for some reason it is impracticable or impossible for the patient to wear his limb routinely. It is therefore highly desirable for the amputee, or at least one member of his family, to be able to apply the bandages. Many amputees can wrap their stumps unaided and, indeed, prefer to do so. Others prefer, and in some instances require, the help of another person.

Recommended methods for applying elastic bandages for below-knee, above-knee, below-elbow, and above-elbow patients are shown in Figures 57, 58, and 59. These illustrations first appeared in a booklet entitled *Industrial Amputee Rehabilitation,* prepared by Dr. C. 0. Bechtol under the sponsorship of Liberty Mutual Insurance Company of Boston.

CARE OF THE PROSTHESIS

In addition to the care required in keeping the inside of the socket clean, which has been stressed, best results can be obtained only if the prosthesis is maintained in the best operating condition. Like all mechanical devices, artificial limbs can be expected to receive wear and be discarded for a new device, but the length of useful life can be extended materially if reasonable care is taken in its use. An example often quoted is that of two identical automobiles. The car given the maintenance recommended by the manufacturer and operated with care will outlast many times the vehicle given spotty maintenance and operated with disregard for the heavy stresses imposed. So it is with artificial limbs. Some amputees require a new prosthesis every few years or even more often, while others who follow the manufacturer's instructions, apply preventive maintenance practices, and have minor problems corrected without delay have received satisfactory service from their limbs for periods as long as twenty years.

Manufacturers' instructions vary with the design of the device. They consist

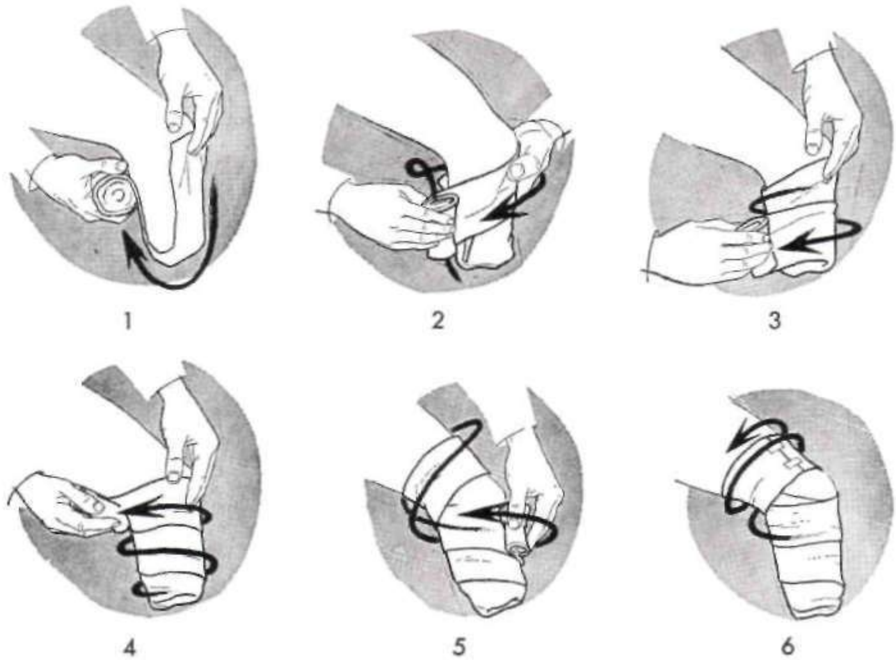


Fig. 57. Recommended method of applying elastic bandage to the below-knee stump. The bandage is wrapped tighter at the end of the stump than it is above.

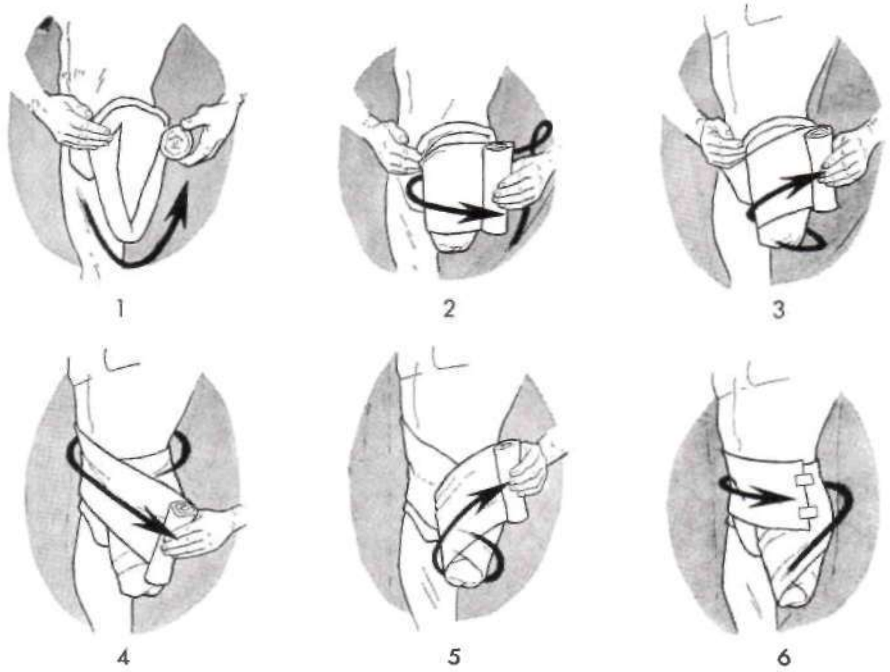


Fig. 58. Recommended method of applying elastic bandage to the above-knee stump. The stump is kept in a relaxed position, and the bandage is wrapped tighter at the end of the stump than it is above.

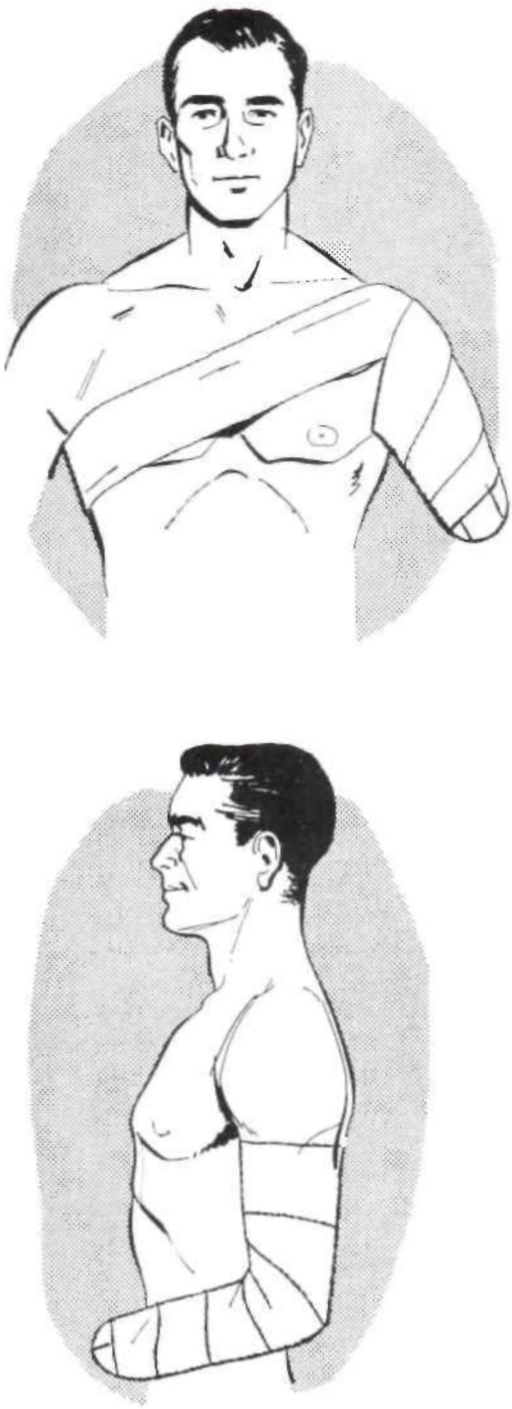


Fig. 59. Elastic bandages applied properly to upper-extremity stumps.

mainly of lubrication practices, and should be followed closely. Too much lubricant can sometimes produce conditions as troublesome as excessive wear. Looseness of joints and fastenings should be corrected as soon as it is detected, for the wear rate increases rapidly under such a condition. Any cracks that appear in supporting structures should be reinforced immediately, in order to avoid complete failure and the necessity for replacement. The foot should be examined weekly for signs of excessive wear.

A point often overlooked by leg amputees, but nevertheless one of the factors affecting optimum use of the artificial limb, is the condition of the shoe. Badly worn or improper shoes can alter alignment and therefore have adverse effects on the stability and gait of the wearer. This is a matter that requires especially close attention in the case of child amputees.

Hooks and artificial hands should be treated with the same care that the normal hand is given. Because the sensation of feeling is absent in the terminal device, the upper-extremity amputee is all too prone to use hooks to pry and hammer and to handle hot objects that are deleterious to the hook materials. Hands with cosmetic gloves should be washed daily, and of course hot objects and staining materials should be avoided.

SPECIAL CONSIDERATIONS IN TREATMENT OF CHILD AMPUTEES (5)

Only a few years ago, it was seldom that a child amputee was fitted with a prosthesis before school age, and often not until much later. In recent years, experience has shown that fitting at a much earlier age produces more effective results.

If there are no complicating factors, children with arm amputations usually should be provided with a passive type of prosthesis soon after they are able to sit alone, which is generally at about six months of age. Certain gross two-handed activities are thus made possible, crawling is facilitated, and the child becomes accustomed to using and wearing the prosthesis and moves easily into using a body-operated prosthesis as his coordination develops soon after his second birthday.

Lower-extremity child amputees should be fitted with prostheses as soon as they show signs of wanting to stand. The development of muscular coordination of child amputees is the same as for non-handicapped children, and therefore this phase may take place as early as eight months or as late as twenty or more months.

Children, especially when fitted at an early age, almost always adapt readily to prostheses. As the child grows, the artificial limb seems to become a part of him in a manner seldom seen in adults (Fig. 60).

Except for the very young, children's prostheses follow much the same design as those for the adult group. Special devices and techniques have been developed for initial fitting of infants and problem cases.

Regardless of where the child amputee resides, or the extent of his parents' financial resources, he need not go without the treatment and prostheses required to make full use of his potentials. To ensure that such services are available, the Children's Bureau of the Department of Health, Education, and Welfare has assisted a number of states in establishing well-organized child-amputee clinics, and the facilities of those states are available to residents of states where such specialized services are not to be had. There is an agency in each state that can advise the parents of the proper course of action.

Most children can be treated on an out-patient basis, but for the more severely handicapped, many of the clinics have facilities for in-patient treatment. The clinic team for children is often aug-

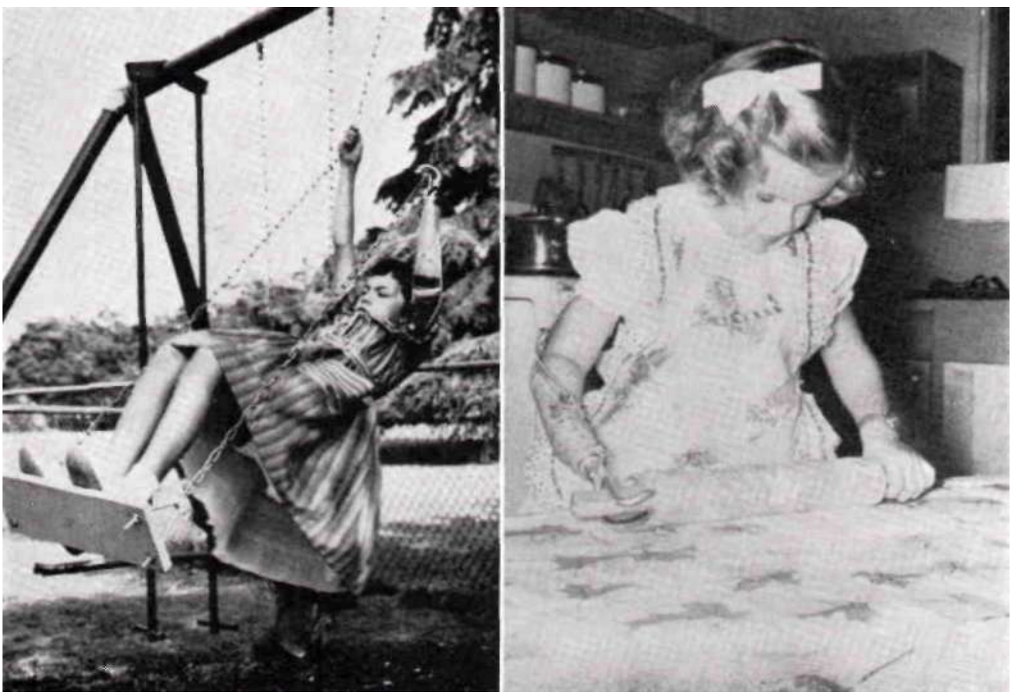


Fig. 60. Children with upper-extremity amputations performing two-handed activities.

mented by a pediatrician and a social worker, and sometimes by a psychologist.

Training very young children is one of the most difficult problems of the clinic team. Although the learning ability of young children may be rapid, their attention span is of such short duration that extreme patience is required. Regardless of the ability of the therapist, successful results cannot be achieved without complete cooperation of the parents. The mental attitude of the parents is reflected in the child, and all too often children have rejected prostheses because the parents, consciously or subconsciously, could not accept the fact that a prosthesis was needed. Parents of children born with a missing or deformed limb often experience a sense of guilt, a feeling that only adds to an already difficult problem. The guilt feeling is unwarranted, inasmuch as the knowledge of the causes of congenital defects—and appropriate preventive measures—is very limited. The recent discovery of the effects of thalidomide suggests that other causes may be found.

As a rule, lower-extremity amputees present fewer problems than the upper-extremity cases. It is natural for the child to walk, and almost invariably the lower-extremity patient adapts rather quickly. However, parents should keep close observation of the walking habits of the child, the condition of his stump, and the state of repair of his prosthesis, and above all they should present the child at the clinic at the recommended times. A gradual change in walking habit may indicate that the child has outgrown the prosthesis or that excessive wear of the prosthesis has taken place. Any unusual appearance of the stump should be reported to the physician immediately so that remedial steps may be taken, thereby avoiding more complicated medical problems at a later date. Children give a prosthesis more wear and tear than do adults, and it is important that the prosthesis be examined carefully at regular intervals and needed repairs made as soon as possible—not only to ensure the safety of the child but to avoid the necessity for major repairs at a later date.

Many upper-extremity child amputees adapt readily to artificial arms (some even want to sleep with the arm in place), but in many cases the child will need a great deal of encouragement before he will accept the device and make use of it. At first, the unilateral amputee may feel that the prosthesis is a deterrent rather than an aid, but with the proper encouragement, this feeling is reversed.

Parents can help by continuing the training given in the clinics. From the beginning, the artificial arm should be worn as much as possible. Young children should be given toys that require two hands for use, and older children should be given household chores that require two-handed activities. In the latter case, not only does the child learn to appreciate the usefulness of the prosthesis, but he also gains a feeling of being a useful member of the family and thus a better mental attitude is created.

The child amputee should not be sheltered from the outside world, but should be encouraged to associate with other children and, to the extent that he can, to take part in their activities. Of course there are certain limitations, but the number of activities that can be performed with presently available prostheses is amazing. It goes almost without saying that the child should receive no more special attention than is necessary and should be made to perform the activities of daily living of which he is capable.

It has been shown that it is preferable for the child amputee to attend a regular school, rather than one for the handicapped. Most child amputees can and do take their place in society, and the transition from school to work is much easier if they are not shown unnecessary special consideration. Nonhandicapped children soon accept the amputee and make little comment after the initial reaction.

Here again, the arm amputee is apt to be faced with the most problems. Some public school officials have hesitated to admit arm amputees wearing hooks, for fear the child may use them as weapons. This attitude is unrealistic. If such incidents have occurred, they are rare indeed. However, arm prostheses should be removed when the child is engaged in body-contact sports such as football.

Cleanliness of the stump, prosthesis, and stump sock is just as important for children as for adults. The same procedures as those outlined on pages 43-46 are recommended.

SPECIAL CONSIDERATIONS IN THE TREATMENT OF ELDERLY PATIENTS

Persons who have had amputations during youth or middle age seldom encounter additional problems in wearing their prostheses as they become older. However, for those patients who have an amputation in later life, many unusual problems are apt to be present. Most amputations in elderly patients are necessary because of circulatory problems, almost always affecting the lower extremity. For many years, the wisdom of fitting such patients with prostheses was debatable, the thought being that the remaining leg, which in most cases was subject to the same circulatory problems as the one removed, would be overtaxed and thus the need for its removal would be hastened. Energy studies in recent years have shown that crutch-walking is more taxing than use of an artificial limb. Experience with rather large numbers of elderly leg amputees has shown that failure of the remaining leg has not been accelerated by use of a prosthesis, and stumps that have been fitted properly have not been troublesome. As a result, more and more elderly patients are benefiting by the use of artificial limbs. A rule of thumb that is used in some clinics to decide whether or not to fit the elderly patient is that, if he can master crutch-walking, he should be fitted. This measure should be used with discretion because, in some instances, patients who could not meet the crutch-walking requirement have become successful wearers of prostheses.

The patient should be fitted as soon as possible, to avoid such complications as the development of contractures. The availability of adjustable pylon-type legs and the use of plaster or plastic sockets now makes early fitting practical, and this approach is being adopted by more and more centers. Many geriatric patients have benefited from the immediate post-surgical fitting procedures.

Most clinic teams feel that, if the patient can use the prosthesis to make him somewhat independent around the house, the effort is fully warranted.

Artificial legs for the older patients, as a rule, should be as light as possible. Except for the most active patients, only a small amount of friction is needed at the knee for control of the shank during the swing phase of walking because the gait is apt to be slow. Suction sockets have rarely been used, because of the effort required in donning them. A quadrilateral-shaped socket is often used with one stump sock and a pelvic belt. Silesian bandages have been used successfully, allowing more freedom of motion and increased comfort.

A new approach introduced recently by the University of Miami offers the geriatric amputee the possibility of using a suction socket by reducing the effort required in donning *(15)*. The flexible plastic inner liner, which contains a suction valve, is put on over the stump first, and then the stump and inner liner are inserted into the outer socket of rigid plastic and latched in place.

For the elderly below-knee cases, the patellar-tendon-bearing prosthesis is being used quite successfully.

CINEPLASTY *(4)*

In 1896, the Italian surgeon Vanghetti conceived the idea of connecting the control mechanism of a prosthesis directly to a muscle. Several ideas involving the formation of a club-like end or a loop of tendon in the end of a stump muscle were tried out in Italy. Just prior to World

War I, the German surgeon Sauerbruch devised a method of producing a skin-lined tunnel through the belly of the muscle. A pin through the tunnel was attached to a control cable, and thus energy for operation of the prosthesis was transferred directly from a muscle group to the control mechanism. With refinements, the Sauerbruch method is available for use today, but it must be used cautiously.

Although tunnels have been tried in many muscle groups, the below-elbow amputee is the only type who can be said to benefit truly from the cineplasty procedure. A tunnel properly constructed through the biceps can supply power for operation of a hand or hook, and there need be no harnessing above the level of the tunnel. Thus, the patient is not restricted by a harness, and the terminal device can be operated with the stump in any position. Training the tunneled muscle and care of the tunnel require a great deal of work by the patient; therefore if the cineplasty procedure is to be successful, the patient must be highly motivated.

Some female below-elbow amputees have been highly pleased with results from a biceps tunnel, but as a rule, cineplasty does not appeal to women.

Cineplasty is not indicated for children. Sufficient energy is not available for proper operation of the prosthesis, and the effects of growth on the tunnel are not known.

Tunnels have been tried in the forearm muscles, but the size of these muscles is such that the energy requirements for prosthesis operation are rarely met. While tunnels in the pectoral muscle are capable of developing great power, in the light of present knowledge the disadvantages tend to outweigh the advantages. It is extremely difficult to harness effectively the energy generated, and very little, if any, of the harness can be eliminated. It is true that an additional source of control can be created, but with the devices presently available, little use can be made of this feature.

No application for cineplasty has been found in lower-extremity amputation cases.

Still another type of cineplasty procedure is the Krukenberg operation, whereby the two bones in the forearm stump are separated and lined with skin to produce a lobster-like claw. The result, though unattractive in appearance, permits the patient to grasp and handle objects without the necessity of a prosthesis. Because sensation is present, the Krukenberg procedure has been found to be most useful for blind bilateral amputees. Although prostheses can be used with Krukenberg stumps when appearance is a factor, the operation has found little favor in the United States.

U.S. AGENCIES THAT ASSIST AMPUTEES

For several centuries at least, governments have traditionally cared for military personnel who received amputations in the course of their duties. But only in recent years, except in isolated cases, has the amputee in civilian life had much assistance in making a comeback. Today, there are available services to meet the needs of every category of amputee. Aside from the humanitarian aspects of such programs, it has been found to be good business to return the amputee to productive employment and, in the case of some of the more debilitated, to provide them with devices and training to take care of themselves.

The armed services provide limbs for military personnel who receive amputations while on active duty, and many of these cases are returned to active duty. After the patient has been discharged from military service, the Veterans Administration assumes responsibility for his medical care and prosthesis replacement for the remainder of his life. The U.S. Public Health Service, through its marine hospitals, cares for the prosthetics needs of members of the U.S. Maritime Service.

Each state provides some sort of service for child amputees. If sufficient facilities are not available within a state, provisions can be made for treatment in one of the regional centers set up in a number of states with the help and encouragement of the Children's Bureau of the Department of Health, Education, and Welfare. With assistance from the Social and Rehabilitation Service of the Department of Health, Education, and Welfare, every state operates a vocational rehabilitation program designed to help the amputee return to gainful employment. Some of these programs render assistance to housewives as well.

The Medicaid and Medicare programs sponsored by the federal government make it possible for the elderly and indigent to be supplied with artificial limbs.

Private rehabilitation centers, almost universally nonprofit and sponsored largely by voluntary organizations, greatly augment the state and federal programs.

Information concerning rehabilitation centers serving a particular area may be obtained from the International Association of Rehabilitation Facilities, 7979 Old Georgetown Rd., Bethesda, Md., 20014.

LITERATURE CITED

1. Artif. Limbs, 4:2, Autumn 1957.
2. Artif. Limbs, 6:1, April 1961.
3. Artif. Limbs, 6:2, June 1962.
4. Bechtol, Charles 0., and George T. Aitken, *Cineplasty,* in *Orthopaedic appliances atlas,* Vol. 2, J. W. Edwards, Ann Arbor, Mich., 1960.
5. Blakeslee, Berton, Ed., *The limb-deficient child,* University of California Press, Berkeley and Los Angeles, 1963.
6. Burgess, Ernest M., Joseph E. Traub, and A. Bennett Wilson, Jr., *Immediate postsurgical prosthetics in the management of lower-extremity amputees,* TR 10-5, Prosthetic and Sensory Aids Service, Veterans Administration, Washington, D.C., April 1967.
7. Committee on Artificial Limbs, National Research Council, Washington, D.C., *Terminal research reports on artificial limbs,* covering the period from 1 April 1945 through 30 June 1947.
8. Feinstein, Bertram, James C. Luce, and John N. K. Langton, *The influence of phantom limbs,* in Klopsteg, Wilson, *et al., Human limbs and their substitutes,* McGraw-Hill, New York, 1954.
9. Foort, J., *Adjustable-brim fitting of the total-contact above-knee socket,* No. 50, Biomechanics Laboratory, University of California, San Francisco and Berkeley, March 1963,
10. Foort, James, *The patellar-tendon-bearing prosthesis for below-knee amputees, a review of technique and criteria,* Artif. Limbs, 9:1:4-13, Spring 1965.
11. Hampton, Fred, *Suspension casting for below-knee, above-knee, and Syme's amputations,* Artif. Limbs, 10:2:5-26, Autumn 1966.
12. Klopsteg, P. E., *The functions and activities of the Committee on Artificial Limbs of the National Research Council,* J. Bone Joint Surg., 29:538-540, 1947.
13. National Academy of Sciences—National Research Council, *The control of external power in upper-extremity rehabilitation,* Publication 1352, 1966.
14. Sarmiento, Augusto, Raymond E. Gilmer, Jr., and Alan Finnieston, *A new surgical-prosthetic approach to the Syme's amputation, a preliminary report,* Artif. Limbs, 10:1:52 55, Spring 1966.
15. Sinclair, William F., *A suction socket for the geriatric above-knee amputee,* Artif. Limbs, 13:1:69-71, Spring 1969.
16. Staros, Anthony, *Dynamic alignment of artificial legs with the adjustable coupling,* Artif. Limbs, 7:1:31-43, Spring 1963.
17. Taylor, Craig L., *Control design and prosthetic adaptations to biceps and pectoral cineplasty,* in Klopsteg, Wilson, *et al., Human limbs and their substitutes,* McGraw-Hill, New York, 1954.
18. Thomas, Atha, and Chester C. Haddan, *Amputation prosthesis,* Lippincott, Philadelphia, 1945.
19. Vultee, Frederick E., *Physical treatment and training of amputees,* in *Orthopaedic appliances atlas,* Vol. 2, J. W. Edwards, Ann Arbor, Mich., 1960.
20. Weiss, Marian, *Neurological implications of fitting artificial limbs immediately after amputation surgery,* in Report of Fifth Workshop Panel on Lower-Extremity Prosthetics Fitting, Committee on Prosthetics Research and Development, National Academy of Sciences—National Research Council, February 1966.

ADDITIONAL BIBLIOGRAPHY

American Academy of Orthopaedic Surgeons, *Orthopaedic appliances atlas,* Vol. 2, J. W. Edwards, Ann Arbor, Mich., 1960.

Anderson, Miles H., and Raymond E. Sollars, Eds., *Manual of above knee prosthetics,* School of Medicine, University of California, Los Angeles, 1957.

Batch, Joseph W., August W. Spittler, and James G. McFaddin, *Advantages of the knee disarticulation over amputations through the thigh,* J. Bone Joint Surg., 36A:921-930, October 1954.

Brunnstrom, Signe, *The lower extremity amputee,* in Bierman, W., and S. H. Licht, Eds., *Physical medicine in general practice,* 3rd ed., Hoeber-Harper, New York, 1952.

De Lorme, Thomas Lanier, and A. L. Watkins, *Progressive resistance exercise, technic and medical application,* Appleton, New York, 1951.

Eisert, Otto, and O. W. Tester, *Dynamic exercises for lower extremity amputees,* Arch. Phys. Med., 35:695-704, November 1954.

Kerr, Donald, and Signe Brunnstrom, *Training of the lower extremity amputee,* Charles C Thomas, Springfield, El., 1956.

Klopsteg, Paul E., Philip D. Wilson, *et al., Human limbs and their substitutes,* McGraw-Hill, New York, 1954.

MacDonald, J., Jr., *History of artificial limbs,* Amer. J. Surg., 19:76-80, 1905.

Santschi, William R., Ed., *Manual of upper extremity prosthetics,* 2nd ed., Department of Engineering, University of California, Los Angeles, 1958.

SCHOOLS OFFERING TRAINING PROGRAMS

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Prosthetics-Orthotics Education Program
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Artificial Limbs: A Review of Current Developments, published twice yearly by the Committee on Prosthetics Research and Development, National Academy of Sciences, Washington, D.C. 20418. Free.

Bulletin of Prosthetics Research, published twice yearly by the Prosthetic and Sensory Aids Service, Veterans Administration. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Cost varies with each issue.

Inter-Clinic Information Bulletin, published monthly by the New York University Post-Graduate Medical School, 317 East 34th St., New York, N. Y. 10016. Subscriptions and single copies are available to organizations and individuals with a bona fide interest in prosthetics and orthotics.

Newsletter. . .Amputee Clinics, published every two months by the Committee on Prosthetic-Orthotic Education, Division of Medical Sciences, National Research Council, 2101 Constitution Ave., Washington, D.C. 20418.

Orthotics and Prosthetics, published quarterly by the American Orthotic and Prosthetic Association, 1440 N St , N.W., Washington, D.C. 20005, Yearly subscription: $6.50 in Western Hemisphere; $7.50 elsewhere.

Prosthetics International: Prosthetics, Orthotics and Allied Subjects, English edition published by the International Committee on Prosthetics and Orthotics of the International Society for Rehabilitation of the Disabled, 3 Hans Knudsens Plads, 2100 Copenhagen 0, Denmark.