KRUSEN STUDY

LIMB PROSTHETICS
for the
BUREAU OF MOTOR CARRIER SAFETY

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BUREAU OF MOTOR CARRIER SAFETY
WASHINGTON, D.C. 20590

APRIL 1977

LIMB PROSTHETICS

for the

BUREAU OF MOTOR CARRIER SAFETY

KRUSEN CENTER FOR RESEARCH AND ENGINEERING
of
MOSS REHABILITATION HOSPITAL
PHILADELPHIA, PENNSYLVANIA

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INTRODUCTION

In 1964, the Federal Motor Carrier Safety Regulations (FMCSR) were amended to allow handicapped individuals (i.e.: amputees) to operate commercial motor vehicles in interstate or foreign commerce. The intent of the waiver program is to provide an opportunity for individuals, who are otherwise qualified under the FMCSR except for their physical handicap, to drive commercial motor vehicles on the nation's highways. Prior to the initiation of the driver waiver program, and after extensive review and consideration, it was determined that only a controlled program would be acceptable to highway safety. Driver candidates are screened very closely as to their physical capability. To reduce the risk of catastrophic accidents, handicapped drivers are not allowed to transport passengers or hazardous materials.

Today there are over 150 drivers participating in the driver waiver program. Driver candidates may submit applications jointly with the motor carrier to the Director, Bureau of Motor Carrier Safety, Washington, D.C., for consideration, under the provisions of Section 391.49, waiver of certain physical defects, of the FMCSR.

FOCUS AND SCOPE OF "LIMB PROSTHETICS"

This booklet's primary focus is on informing the safety investigator, the medical examiner, the Bureau of Motor Carrier Safety's evaluator, and the motor carrier of the capabilities of the amputee waiver applicant to drive a commercial vehicle. This booklet also contains important background information about the amputee, his possible levels of amputations, and his recommended artificial limb (prosthesis) or limbs (prostheses).

The contents covered in "Limb Prosthetics" run a wide gamut; they include a collection of diverse material pertaining to the field of prosthetics. Perusal of the booklet will reveal a wealth of information covering the many prosthetic materials and components which are used in the construction and the operation of a specific artificial limb. Special emphasis is on the relationships between the amputation level, the recommended prosthetic device, and the specific tasks, both routine and emergency, involved in operating a commercial vehicle.

ORGANIZATION OF "LIMB PROSTHETICS"

The booklet's contents have been organized into four sections. Each section is written to stand alone, as a self-contained unit with its own figures, tables, and references. Writing for this kind of flexibility has necessitated a certain amount of redundancy among certain entries of several of the sections.

The first section contains general information about the amputee, his levels of amputations, and his prosthetic device. Sections II and III refer to the upper and lower limbs of the human body. Each limb has been designated as a zone. The upper left limb is Zone I; the upper right limb is Zone II; the lower left limb is Zone III; and the lower right limb is Zone IV. Section II contains specific information of Zones I and II or both upper limbs. Section III contains specific information of Zones III and IV or both lower limbs. Since some amputees have amputations in more than one zone, Section IV relates those combinations of amputations.

A special feature found in Sections II-IV is the Amputee Driver Functional Matrix Chart. Listed in the chart are the capabilities expected at various limb amputation levels when the amputee is performing the designated functional activities necessary in operating a tractor-trailer. Each section contains two charts. In Section II the charts (Tables II-1 and II-2) relate those designated functional activities performed at various amputation levels of the upper left limb (Zone I) and of the upper right limb (Zone II). Section III charts (Tables III-1 and III-2) relate those designated functional activities performed at various amputation levels of the lower left limb (Zone III) and of the lower right limb (Zone IV). Finally, Section IV charts (Tables IV-1 and IV-2) relate those designated functional activities performed at identical amputation levels of both upper limbs and of both lower limbs.

Once the user has become familiar with the general information of Section I, he needs only to turn to the appropriate section and zone to guide him in responding appropriately to the waiver application.

LIMITATIONS OF "LIMB PROSTHETICS"

It is important that the user understand clearly what this booklet can and cannot do. The booklet is a reference or aid but not a "bible." Most of the information, while specific in many ways, is based on generalities and common characteristics of the amputee population. Since each amputee is a unique individual it is important to remember that he may deviate from the statements made within this booklet.

The material contained between the covers of the booklet are not simple to comprehend. The new terminology may provide some difficulty since it is medical in nature. However, an attempt has been made to make the information interesting and clear as possible for the user. In order to more fully utilize this booklet in appraising the amputee's limitations in operating a commercial vehicle, it may be necessary to review the anatomy of the human motor system found in Appendix A.

DEVELOPMENT OF THE AMPUTEE DRIVER FUNCTIONAL MATRIX CHARTS

The functional activities for each of the functional matrix charts were essentially obtained from 135 task descriptions developed by Human Resources Research Organization (HumRRO) for truck drivers.[1] The HumRRO

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[1]Moe, G.L., Kelley, G.R., and Farlow, D.E. Truck and Bus Driver Task Analysis. Final Report, May 1973, Human Factors Research, Incorporated, Contract No. FH-11-7616, Subcontract No. 1, U.S. Department of Transportation, National Highway Traffic Safety Administration.

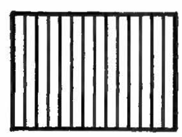
task description list was reviewed with the assistance of the Bureau of Motor Carrier Safety. The list was then shortened to 27 routine and emergency tasks descriptions found by HumRRO to be highly critical. This shortened list also reflected task descriptions considered critical for the amputee driver to safely perform. The task descriptions were reorganized and rewritten in their present form to include the current terminology used by truck drivers.

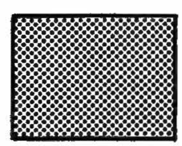
With the assistance of the ad hoc committee each of the 27 functional activities and their subdivisions were ranked within three categories. The categories were defined as follows:

Without Difficulty:	The driver at this amputation level can safely perform this activity.
Difficult:	The driver at this amputation level can perform this activity but has difficulty.
Extremely Difficult:	The driver at this amputation level has extreme difficulty performing this activity safely.

These categories have been designated on each chart by the following symbols to provide contrast for easy reading. The symbols for each category are:

Without Difficulty . . . . . . 

Difficult. . . . . 

Extremely Difficult . . . . . . 

The charts were formulated with the assumption that a prosthetic device was being worn by each type of amputee while performing a specific functional activity.

ACKNOWLEDGMENTS

An ad hoc committee of advisors provided guidance to this project. Most members were invited because of their expertise in various aspects of prosthetics. The advisors reviewed the project plan and earlier drafts, helped to identify problem areas, and recommended solutions.

We gratefully acknowledge their help and would like to call attention to all of the members:

Robert Bleakley, Contract Manager, Bureau of Motor Carrier Safety, Department of Transportation, Washington, D.C.

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Frank York, Safety Investigator, Federal Highway Administration, Boise, Idaho.

Section I. GENERAL INFORMATION

THE AMPUTEE

With proper care the individual who has undergone an amputation (loss of all or part of a limb) can return successfully to society. Indeed, amputation has given many the cause and inspiration to change their course of life for the better. Amputees can be found in nearly every occupation. This is not to say that every amputee enjoys unlimited opportunity, but when the proper surgical technique is employed, and when the best methods and devices are used in providing the artificial limb or prosthesis, the amputee without other complicating disabilities can return to a useful and virtually normal life.

The key to successful rehabilitation is in the hands of the surgeon, the physiatrist (doctor of physical medicine and rehabilitation), the therapists, and the prosthetist (artificial limb maker) but the degree of success is limited necessarily by the characteristics of the amputation stump. Much has been done in recent years to make available to surgeons improved techniques in amputation. Today every healthy stump, regardless of the level of amputation, can be fitted successfully, and in general the lower the level of the amputation, the more functional is the stump and thus the individual.

CAUSES OF 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 either require amputation or prosthesis as if they were amputees.

ACCIDENTS

In some accidents, a part or all of the limb may be removed completely because of the accident itself; 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. 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 when ideal circumstances are present.

DISEASE

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 (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 the blood pressure in the leg is less 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-limb amputations.

In many cases, amputation of part or all of a limb has arrested a malignant or cancerous condition. Cancer is the cause for amputation in many teenage youths.

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.

CONGENITAL AMPUTATIONS AND MALFORMATIONS

"Thalidomide babies" born between 1958 and 1961 have been given extensive press coverage; however, the drug thalidomide is by no means the sole cause of congenital (at birth) amputations and malformations. Absence of all or part of a limb at birth for no apparent reason 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 limbs. Sometimes intermediate parts such as the thigh or the upper arm are missing, but the other parts of the extremity are present, usually somewhat malformed. In many cases, amputation is 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.

THE AMPUTEE POPULATION

Because of the method of delivery of health services in the United States, it is not practical to conduct a true census of the amputee population. However, random polls conducted by the U.S. Public Health Service indicate that there are about 1.53 amputees per 1,000 population, not including patients in institutions. This agrees quite well with the figure in Great Britain, 1.58, where the culture and medical care are similar to that of the United States. Using the estimated 1975 census figure of 213,137,000 and a rate of 1.55 per 1,000, we arrive at a figure of 330,362 amputees for the United States. There are about six lower-limb amputees for every upper-limb amputee. Some interesting ratios concerning the relative incidences of amputations are shown in Figures I-1 through I-5.[1] By far the greatest cause of amputation in the United States is vascular disease resulting in surgical removal of part of the lower limb.

A recent examination of the waiver files of the Bureau of Motor Carrier Safety revealed that there are over 150 drivers participating in the waiver program. Almost all of the drivers were unilateral (occurring on only one side) amputees (Table I-1). Only one driver was a bilateral (symmetrical, occurring on both sides) amputee. The remaining drivers had disabilities resulting from related structural defects such as arthritis.

LOSSES INCURRED

Many of the limitations resulting from amputation are obvious, others less so. An amputation through the lower limb makes standing and walking 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 results in loss of the ability to sense position of the parts of the limb in space. The sense of touch of the absent portion is also lost, but in the case of the lower-limb amputee, this is not quite as important as it might seem, because the varying pressure occurring between the stump and the socket replaces the sense of touch. In the upper-limb amputee, sense of touch is more important.

A special feature found in Sections II-IV of this booklet is the Amputee Driver Functional Matrix Chart. Listed in the chart are the capabilities expected at various limb amputation levels when the amputee is performing designated functional activities necessary in operating a commercial vehicle. These charts will be helpful in responding appropriately to the waiver applicant's limitations resulting from his amputation.

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[1] Kay, H.W., and Newman, J.D. Relative incidence of new amputations. Orthotics and Prosthetics, 1975, 29(2), 3-16.

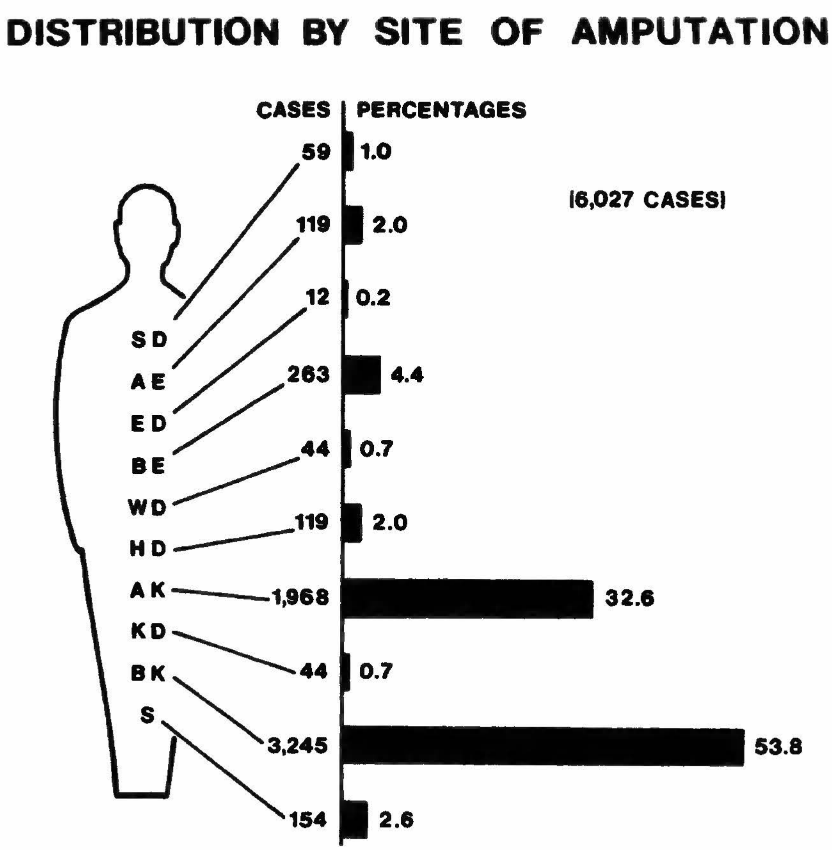

Figure I-1. Distribution by Site of Amputation.

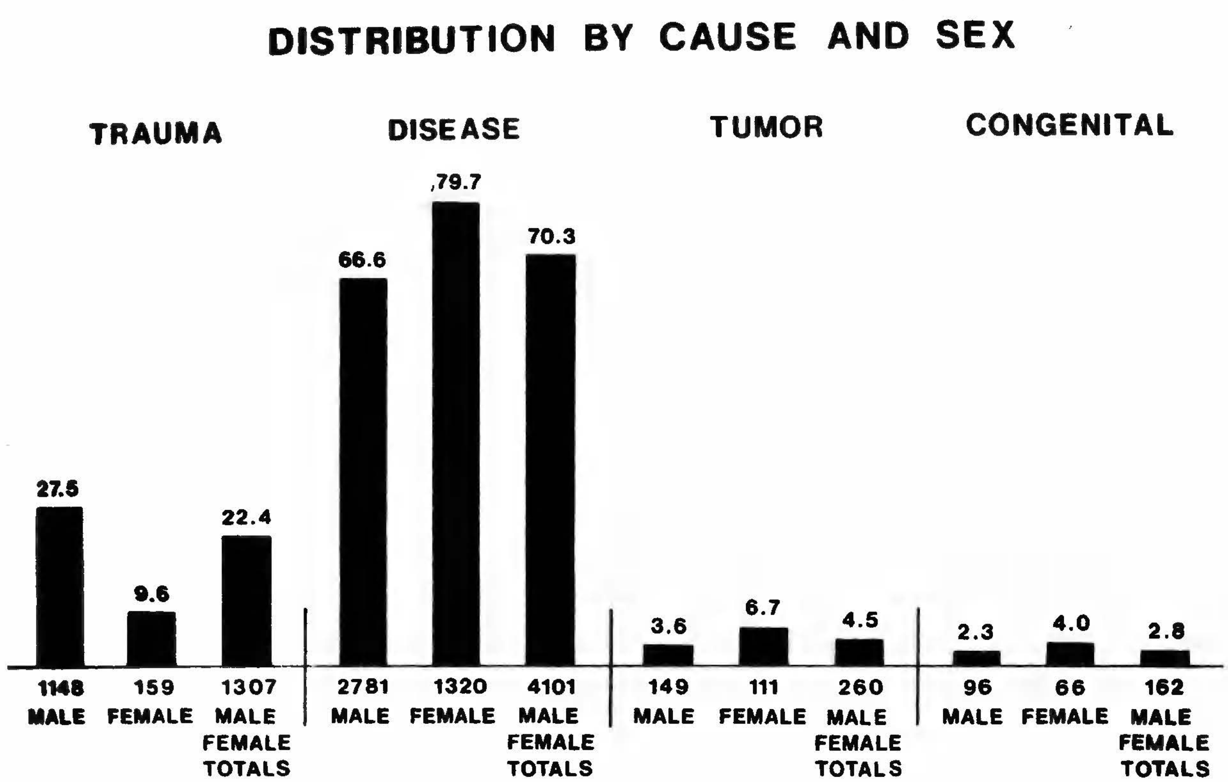

Figure I-2. Distribution by Cause and Sex.

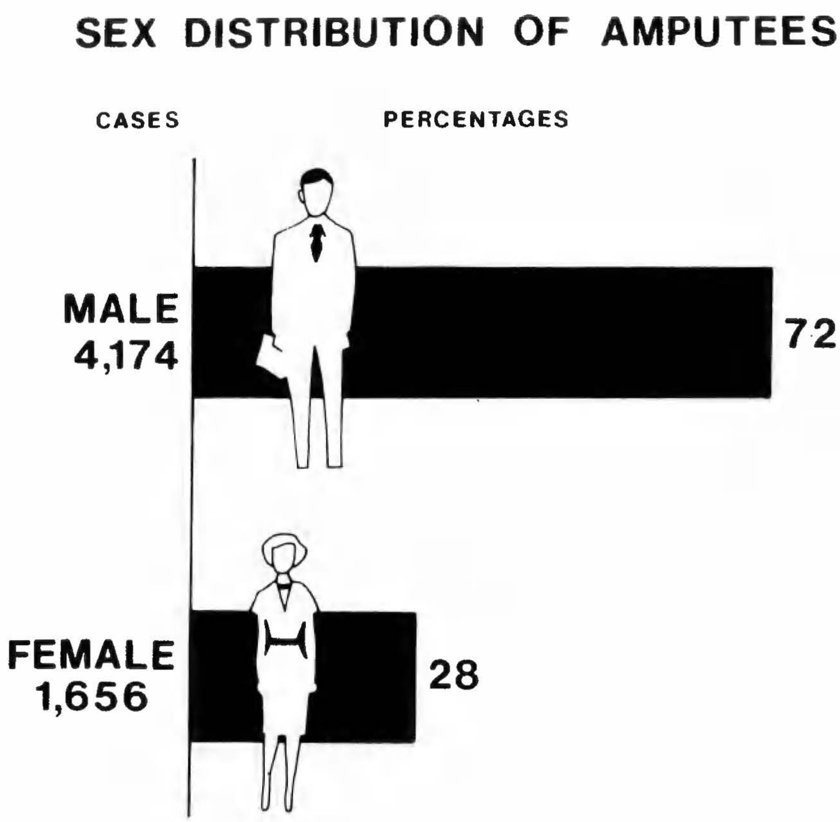

Figure I-3. Sex Distribution of Amputees.

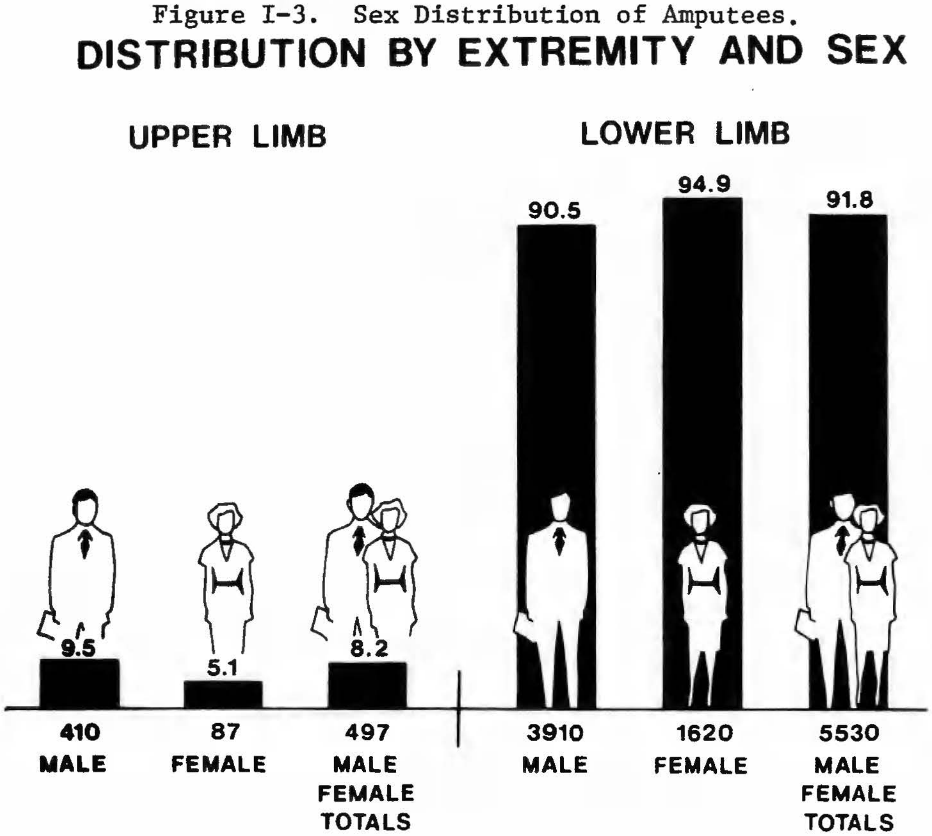

Figure I-4. Distribution by Extremity and Sex.

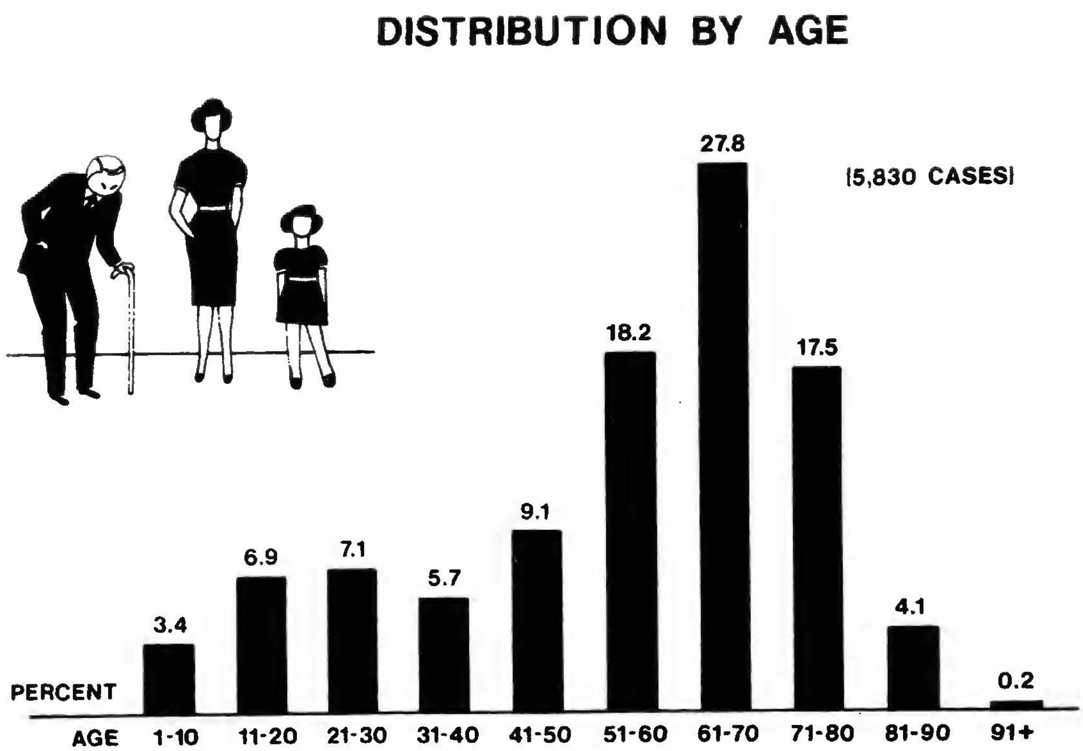

Figure I-5. Distribution by Age.

Table I-1: Unilateral Amputees Operating Commercial Vehicles Under Waivers from the Bureau of Motor Carrier Safety (August, 1976)

Type of Amputee	Number of Amputee Waiver Operators	
	Zone I (Upper left limb)	Zone II (Upper right limb)
Partial Hand	10	1
Wrist Disarticulation	7	8
Below Elbow	4	6
Elbow Disarticulation	0	0
Above Elbow	6	2
Shoulder Disarticulation	0	0
Total:	27	17
	Zone III (Lower left limb)	Zone IV (Lower right limb)
Partial Foot	0	0
Ankle Disarticulation	6	1
Below Knee	46	26
Knee Disarticulation	0	0
Above Knee	13	10
Hip Disarticulation	0	0
Total:	65	37

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 relatively recently, 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.

About 1960, Duke University 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, well-fitted prosthesis as soon as the sutures were removed, some two to three weeks after surgery. In 1963 in an address in Copenhagen, Dr. Marian Weiss of Poland reported success with fitting amputees immediately after surgery while the patient was still anesthetized, and beginning ambulation training the day afterward. Dr. Weiss's work stimulated similar work in this country. Records on several thousand patients of all types have shown immediate post-surgical fitting of prostheses to be the method of choice. Healing seems to be accelerated; postsurgical pain is greatly alleviated; contractures are prevented from developing; phantom pain seems to be virtually nonexistent; few 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.

TYPES OF AMPUTATION

Amputations are generally classified according to the level at which they are performed (Figures I-6 and I-7). Some amputation levels are referred to by the name of the surgeon credited with developing the amputation technique used. Appendix B contains the prosthetic nomenclature used in this booklet. Appendix C lists the degree of limb impairment caused by the amputation levels. Each limb has been designated as a zone. The upper left limb is Zone I; the upper right limb is Zone II; the lower left limb is Zone III; and the lower right limb is Zone IV.

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.

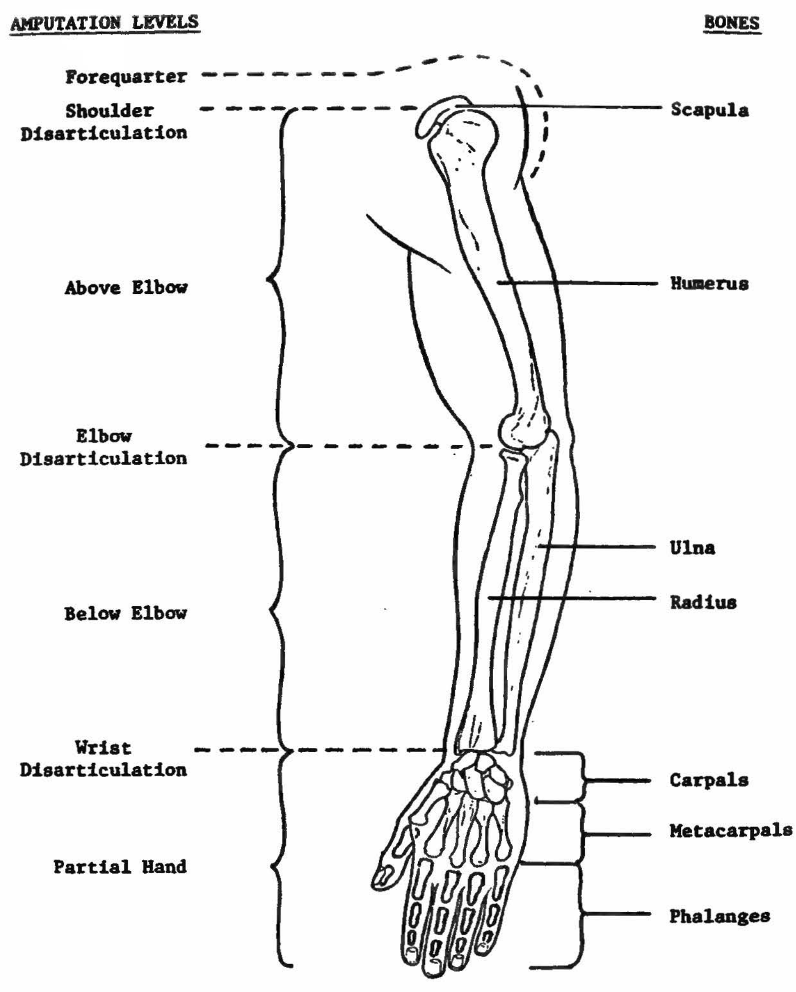

Figure I-6. Upper Limb Amputation Levels.

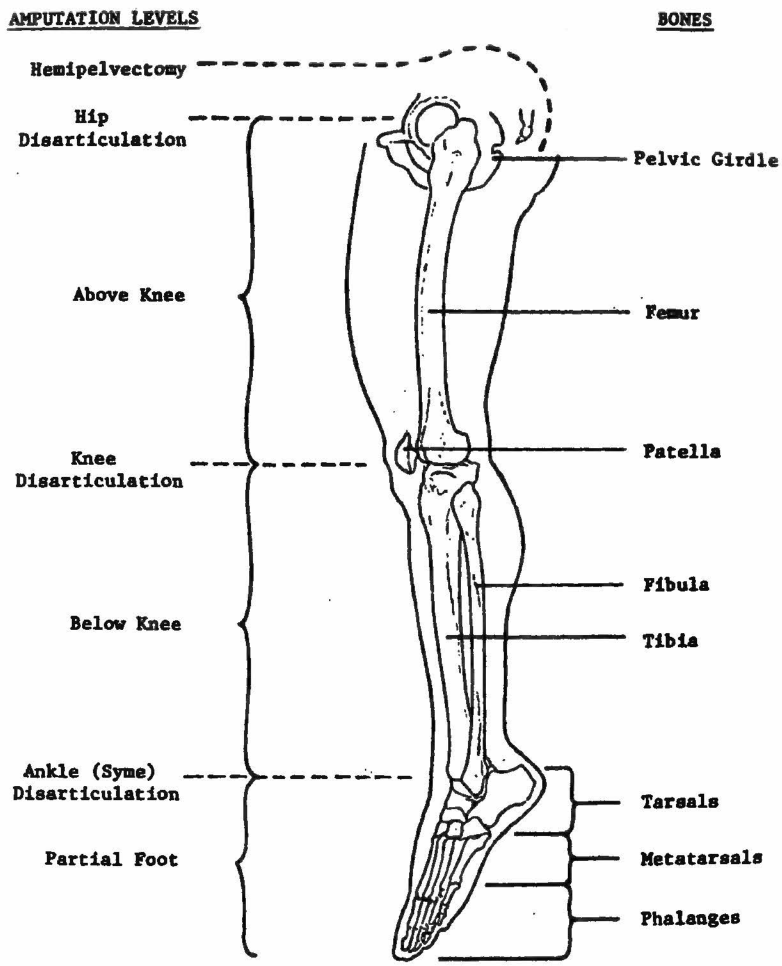

Figure I-7. Lower Limb Amputation Levels.

The Weiss 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 (Figure I-8). 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 re-aligned. 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.

When immediate postsurgical fitting of the stump is not practical because of a lack of trained personnel, a rigid dressing of plaster-of-paris should be used to reduce the formation of excessive edema, or accumulation of fluid. This practice promotes healing and makes it possible to provide the patient with a temporary, or preparatory prosthesis in the early fitting procedure.

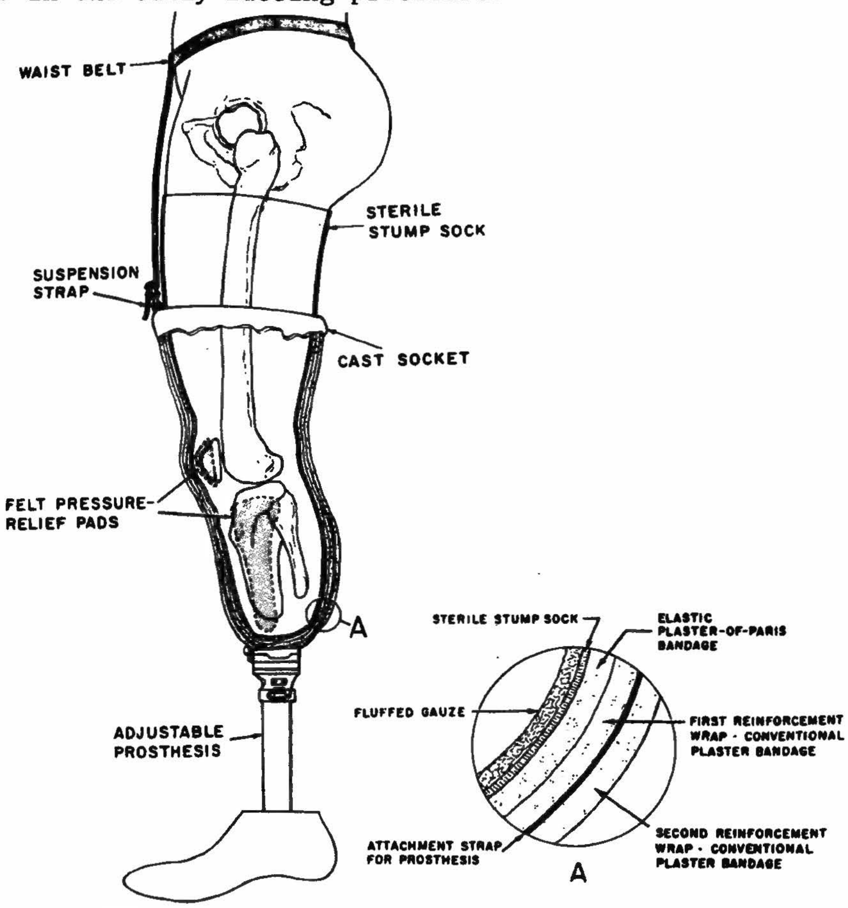

Figure I-8. Schematic cross section showing the major elements of a prosthesis as applied immediately following surgery to a below knee amputee. The suture line, silk dressing, and drain are not shown. The fluffed gauze does not extend beyond the area indicated in "A."

CONTRACTURES

A contracture is a deformity at a joint where there is limitation or absence of movement even against resistance. Situations that undoubtedly can lead to this type of deformity are muscle imbalance, tissue scarring, and pain-induced interference of muscular action. 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 prevent the development of muscle contractures. They can be easily avoided, but it is most difficult, and sometimes impossible, to correct them.

At first, preventive exercises are administered by a therapist or nurse; later, the patient is instructed concerning the type and amount of exercise that should be undertaken. To further reduce the possibility of contractures, the lower limb stump must not be propped upon pillows. Wheelchairs should be used as little as possible; crutch walking is preferred, but the above knee amputee must not be allowed to rest his stump on the crutch handle.

THE PHANTOM SENSATION

After amputation, the patient almost always has the sensation that the missing part is still present. This sensation is referred to as the phantom sensation. 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.

PROSTHESES FOR VARIOUS LEVELS 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.

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 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 the manufacture of small boats, form the basis for construction of most artificial limbs. Some artificial legs are made of wood, but the trend is toward the plastic laminates. They are light in weight, easy to keep clean, and do not absorb perspiration. They can 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.

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 (Figure I-9). 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. The model stump is to ensure that weight will be taken in the proper places in order to provide relief for any tender spots, and to take full advantage of the remaining musculature. Often a "check" socket of cloth impregnated with beeswax is made over the model and tried on the stump to determine the correctness of the modifications. The modified model stump is then used for molding a plastic-laminate socket.

For upper-limb cases, the socket is attached to the other parts of the prosthesis, and a harness is fabricated and installed for operation of the various parts of the artificial arm. For lower-limb cases, the socket is fastened temporarily to an adjustable, or temporary, leg for walking trials (Figure I-10). 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.

An alternate temporary procedure is use of the so-called modular prostheses which consist of one of the adjustable pylon types of prosthesis covered with foam rubber. A light, removable, cosmetic cover is used over the pylon (Figures I-11 and I-12). This arrangement permits the prosthetist to change alignment relatively easily at any time.

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.

More specific information concerning prostheses for the various levels of amputation will be found in Sections II-IV.

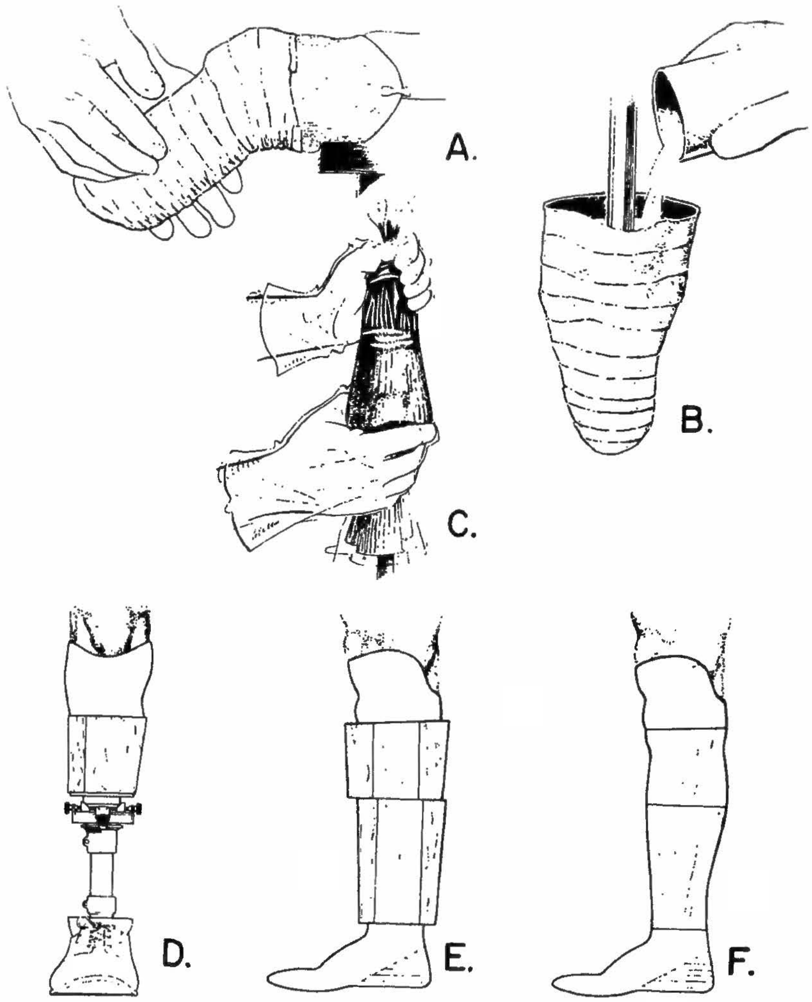

Figure I-9. Steps in the fabrication of a plastic prosthesis for a below knee amputation: A, taking the plaster cast of the stump; B, pouring plaster in the cast to obtain model of the stump; C, introducing plastic resin into fabric pulled over the model to form the plastic-laminate socket; D, the plastic-laminate 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.

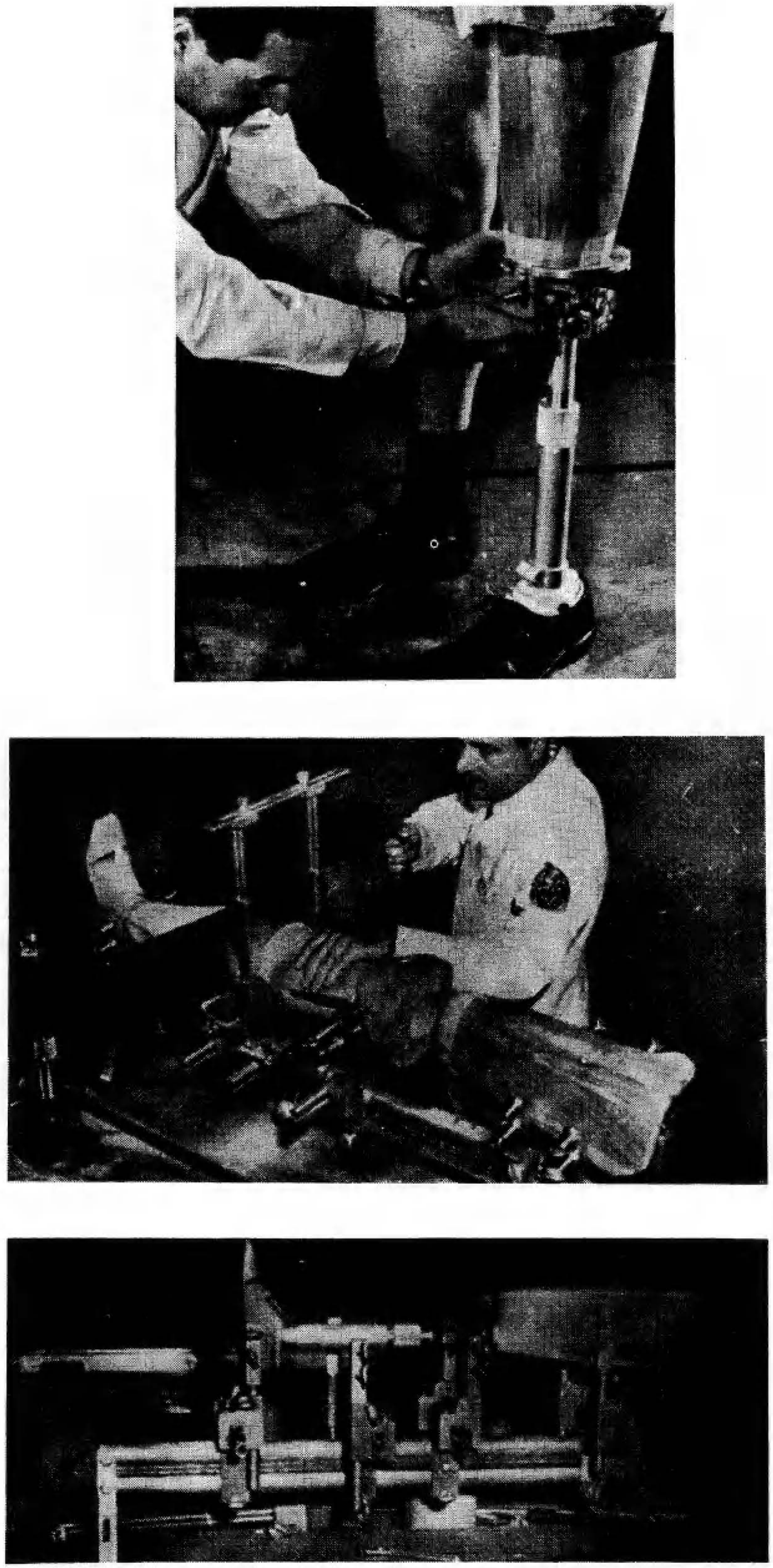

Figure I-10. Using the above knee adjustable leg and alignment duplication jig. A, adjusting the adjustable leg during walking trials; B, the socket and adjustable leg in the alignment duplication jig; C, replacement of the adjustable leg with a permanent knee and shank.

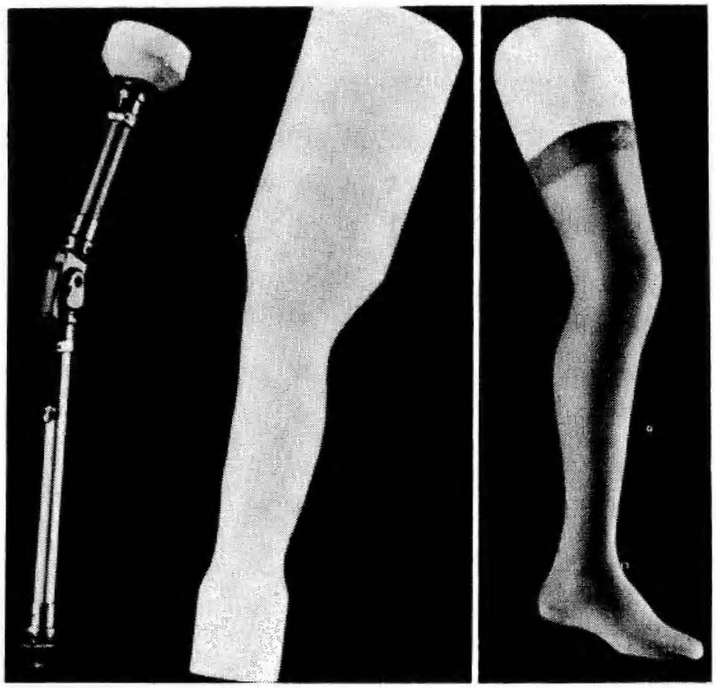

Figure I-11. An adjustable below knee pylon with cosmetic cover.

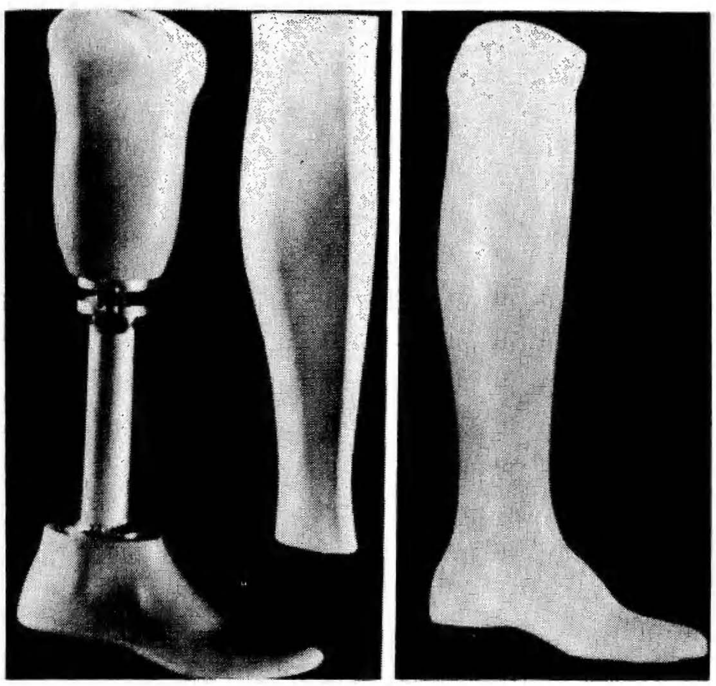

Figure I-12. An adjustable above knee pylon-type prosthesis available from the Otto Bock Company. The components shown on the left are used to provide the finished prosthesis shown on the right.

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Section II. UPPER LIMBS - ZONES I AND II

AMPUTATIONS THROUGH THE HAND

The hand has a multitude of functions comprising both grasp and release as well as coordinated actions utilizing varying degrees of skill and sensation. When the hand has been injured and has lost the capacity for performing many of its more skilled actions, the hand may still retain some basic grasp functions. Grasp, or prehension, activities are of two types: power grip and precision grip. The power grip is especially important in the driver's ability to grasp the steering wheel. In the power grip, a clamping force is produced by wrapping the fingers around the wheel against the counterpressure offered by the palm and thumb. In a precision grip, an object like a pencil is held just between the tips of the fingers and the opposing thumb. The surgeon's objective in reconstruction of a mutilated hand, where parts are destroyed or missing, is to try to salvage a useful hand with functional grasp.

In recent years surgeons have come to appraise the loss of parts of the hand in relation to the resultant loss of function in daily work activities.[1] Amputation of all the digits removes the most essential parts and is considered 100 percent impairment of the hand (Figure II-1). Loss of each of the digits has been assigned the following values: thumb or first digit (40%), second (20%), third (20%), fourth (10%) and fifth digit (10%).

Amputation of Individual Digits

Thumb or first digit

An amputation of the thumb is considered 40 percent loss of the hand primarily because of the loss of opposition, the ability of placing the thumb against the other digits, so important in precision grasp. Any sacrifice of thumb length has a tendency to diminish its functional ability. A short thumb stump can be a very functional digit provided that the other digits can reach it and the space between the stump and the second digit is deep enough.

A variety of surgical methods has been utilized in primarily maintaining thumb length (Figure II-2). 100 percent loss of the digit would probably require some form of replacement reconstruction. One form of reconstruction is digit pollicization. Digit pollicization is transferring another finger, preferably the second digit, with a bridge of skin containing its nerves, blood supply, and tendons, onto the stub of the metacarpal bone of the amputation thumb (Figure II-3). If a surgical procedure is not possible for reconstruction of the thumb or thumb sensation is lacking, a prosthetic aid is the only solution.

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[1]Swanson, A.B. Evaluation of impairment of function in the hand. Surgical Clinics of North America, 1964, 44(4), 925-940.

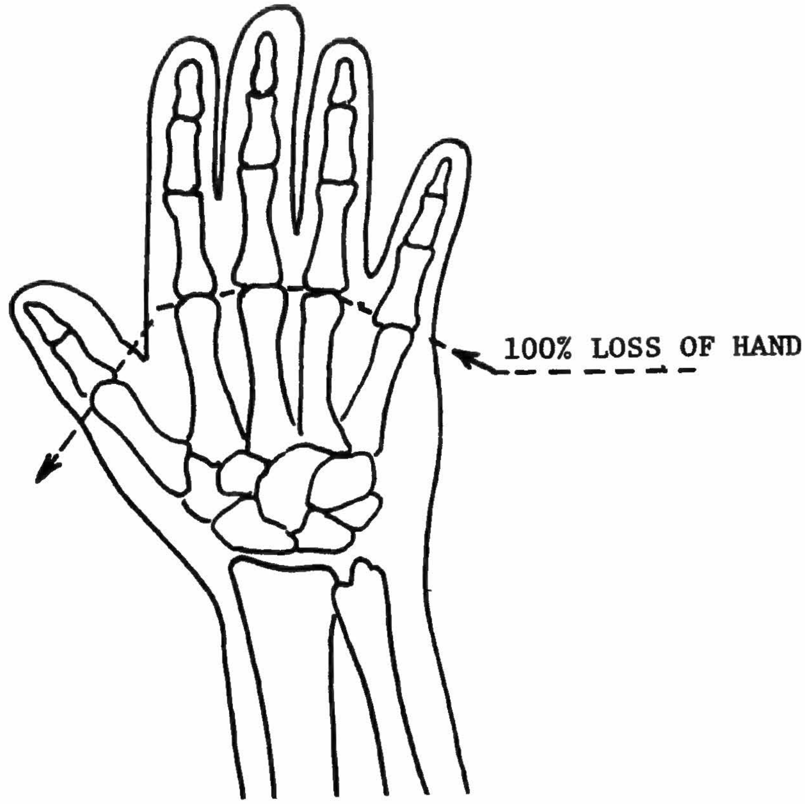


Figure II-1. 100% loss of the hand at the metacarpophalangeal joints of the fingers (dotted line).

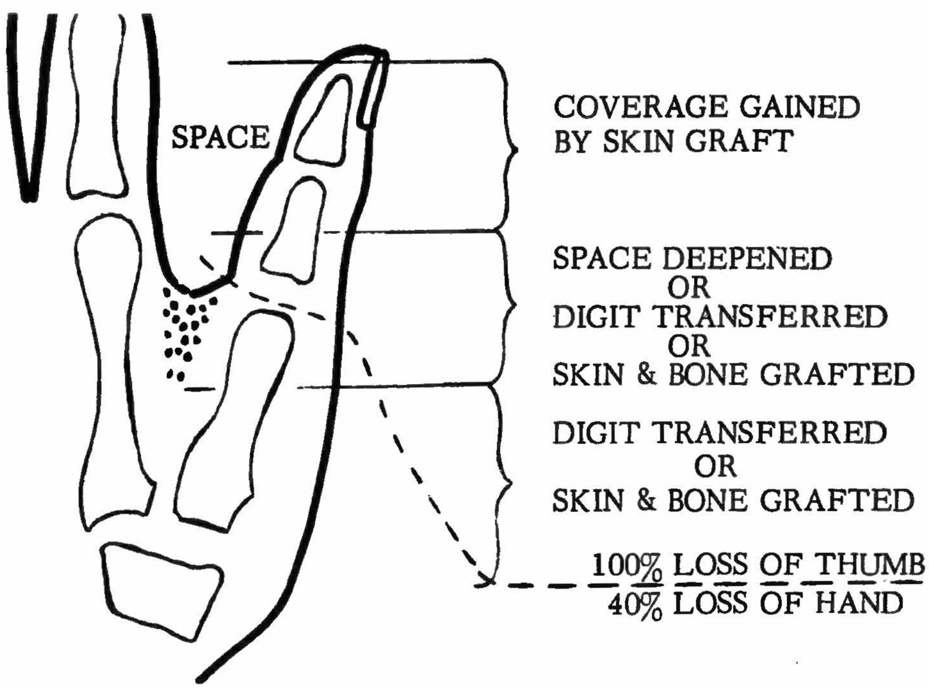


Figure II-2. Methods of Surgical Treatment to Primarily Maintain Thumb Length in Relation to Amputation Level.

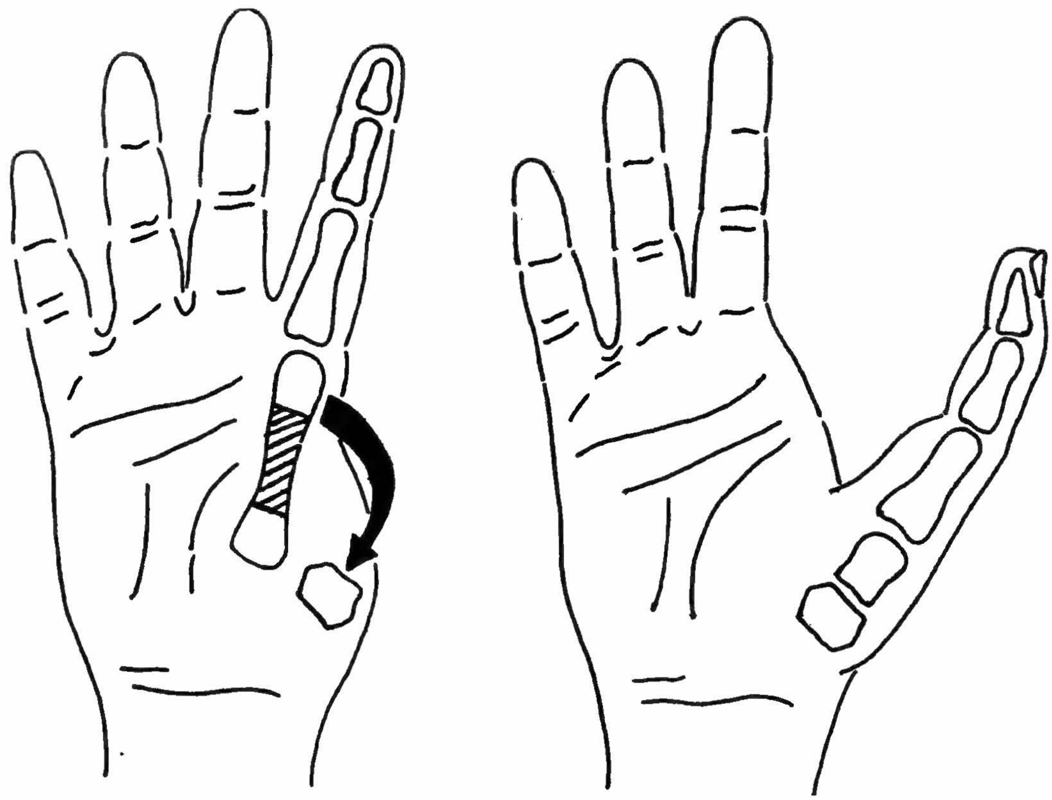


Figure II-3. Pollicization of the Second Digit.

Second, third, fourth, or fifth digit

The second and third digits are each considered to represent 20 percent of the hand and are most important in providing posts for precision prehension with the thumb as well as significant contribution to power grasp. In the absence of the second digit, the third digit may substitute for it completely. When the second digit has been amputated both types of grasp can be improved by surgically removing most of the second metacarpal and transferring the attached muscle to the base of the third digit (Figure II-4). Amputation of the other digits occurring as isolated injuries are less critical than the loss of the first and second digits. However, any narrowing of the palm as a result of cosmetic surgery could make the hand less effective for power grasping.

Multiple Digit Amputation

When several digits of a hand are completely amputated the relative usefulness of each remaining digit assumes new importance. If the first two or three digits are lost, surgical procedures are used to reconstruct a thumb post in order to re-establish some form of grasp with the remaining digits. A hand with only the fourth and fifth digit and a thumb post results in a more functional hand than if a prosthesis were applied.

Partial or Complete Amputation of All Metacarpals

A prosthesis is necessary for gross prehension when a partial (transmetacarpal) or complete amputation of all the metacarpals has occurred. Figure II-5 illustrates these levels of amputations.

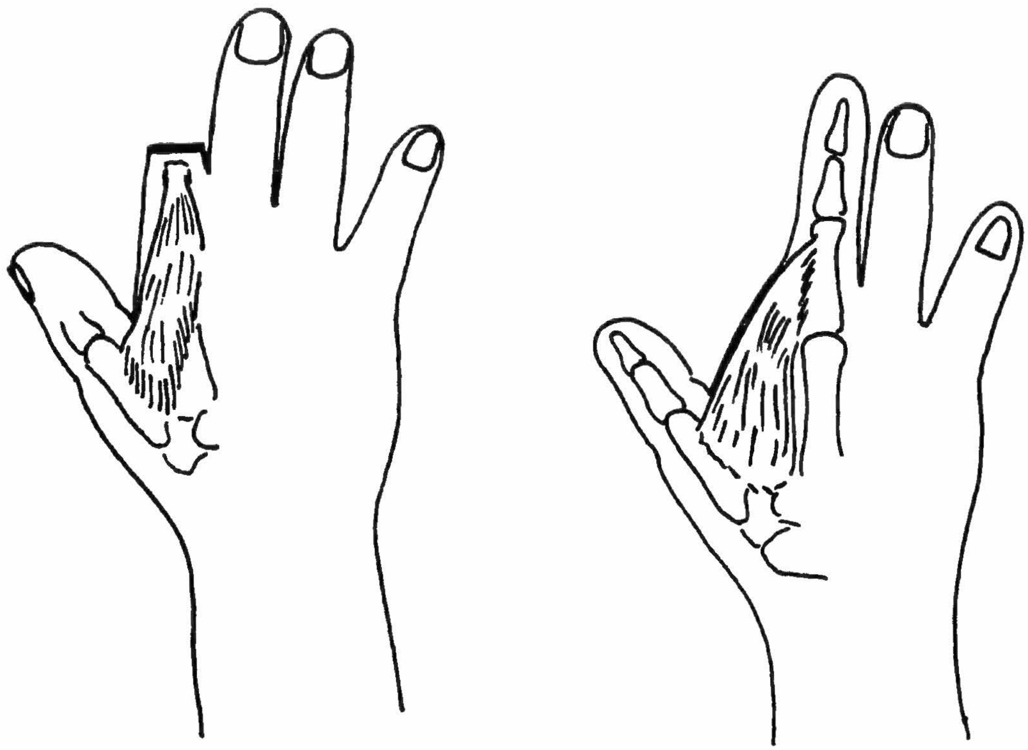


Figure II-4. Amputation of the second metacarpal and transfer of muscle tendon (first dorsal interosseous) to the third digit resulting in a smooth web space and improved function in the third digit.

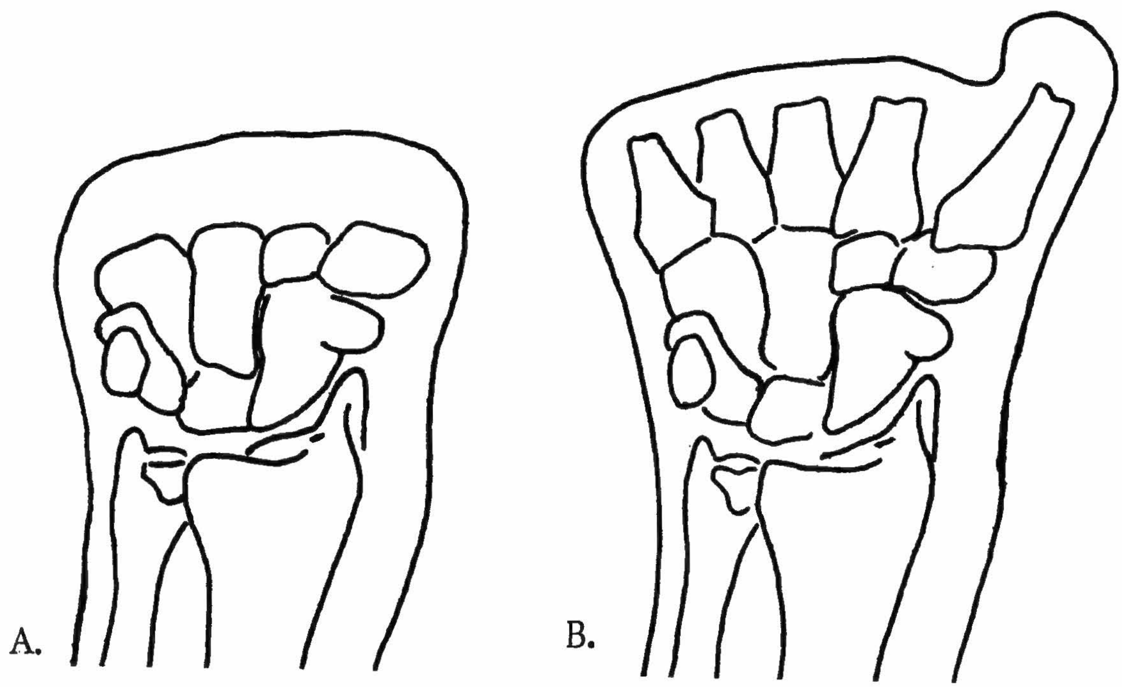


Figure II-5. Levels of hand amputation requiring a prosthesis. A, Complete metacarpal amputation; B, partial (transmetacarpal) amputation.

WRIST DISARTICULATION AMPUTATION

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 amputation (Figure II-6) can be fitted so that most of the pronation-supination of the forearm - an important function of the upper limb - can be used.

BELOW ELBOW AMPUTATIONS

Amputations through the forearm are commonly referred to as below elbow amputations, and are classified as lower 1/3, middle 1/3, and upper 1/3, depending upon the length of stump.

Lower 1/3 stumps (Figure II-7) retain the rotation function in proportion to length. Range of pronation-supination decreases rapidly as the length of the forearm stump decreases; when 60 percent of the forearm is lost, no residual pronation-supination is present. Lower and middle 1/3 stumps without complications possess full range of elbow motion and full power about the elbow, but often upper 1/3 stumps are limited in both power and motion about the elbow. Prostheses have been developed to make full use of all functions remaining in the stump.

ELBOW DISARTICULATION AMPUTATION

An elbow disarticulation amputation consists of removal of the forearm at the elbow, resulting in a slightly bulbous stump (Figure II-8), 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 AMPUTATIONS

Amputations through the arm are generally referred to as lower 1/3, middle 1/3, and upper 1/3 above elbow amputations (Figure II-9). In practice, stumps with more than 90 percent of the humerus (arm) remaining are fitted as elbow disarticulation cases; those with less than 30 percent of the humerus are fitted as shoulder disarticulation cases.

SHOULDER DISARTICULATION AND FOREQUARTER AMPUTATIONS

Removal of the entire arm is known as a shoulder disarticulation amputation (Figure II-10), but whenever feasible, the surgeon will leave intact as much of the humerus as possible to provide stability between the stump and the socket. When it becomes necessary to remove the clavicle and scapula, the operation is known as a forequarter amputation. The upper 1/3 above elbow, the shoulder disarticulation, and the forequarter cases are all provided with essentially the same type of prosthesis.

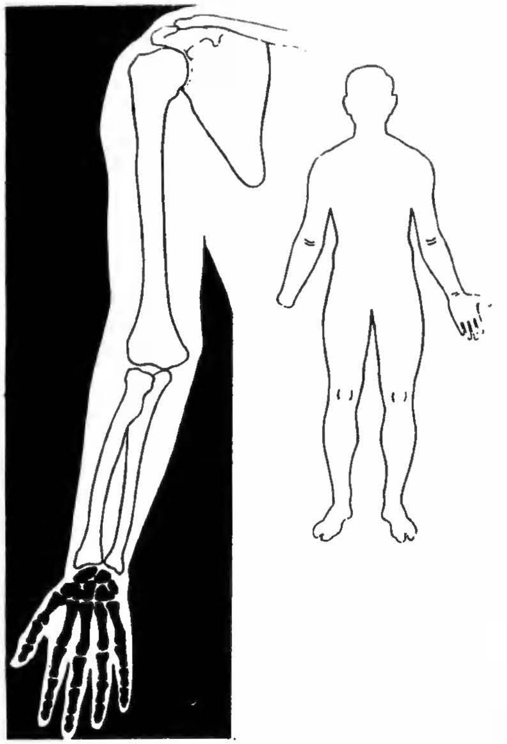


Figure II-6. Wrist Disarticulation.

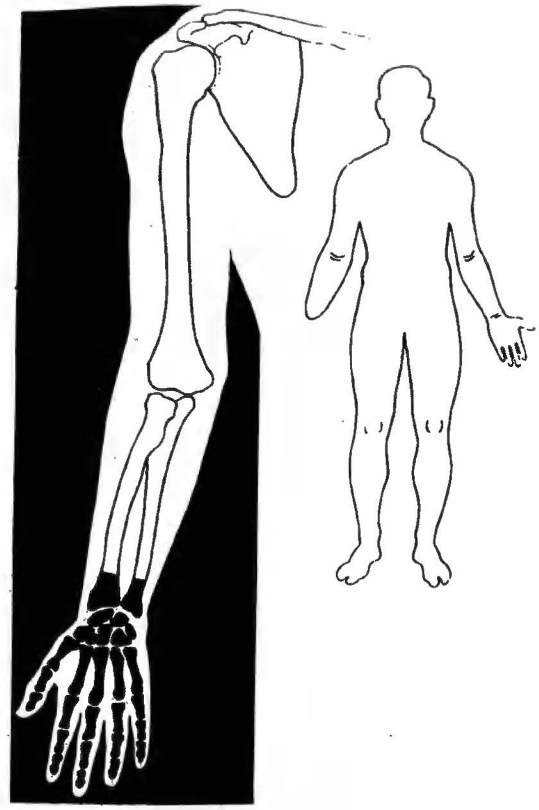


Figure II-7. Lower 1/3 Below Elbow.

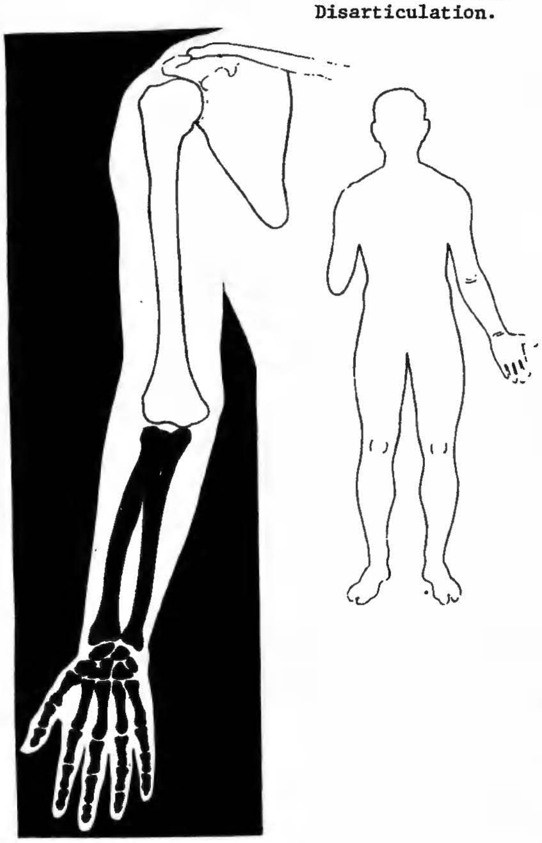


Figure II-8. Elbow Disarticulation.

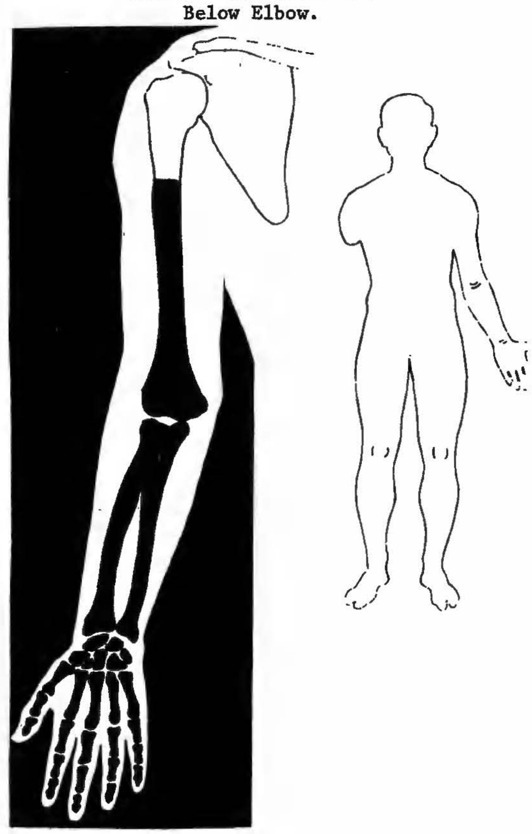


Figure II-9. Upper 1/3 Above Elbow.

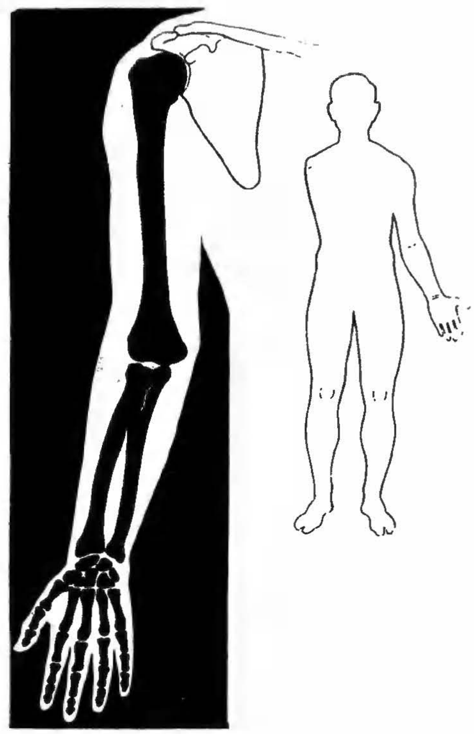


Figure II-10. Shoulder Disarticulation.

UPPER-LIMB PROSTHESES

The major roles of the arm in the human are 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 conventional upper-limb prostheses is derived from relative motion between two parts of the body (Figure II-11). Energy for operation of the elbow joint, when necessary, can also 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 complete arm and shoulder 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 (Figure II-12).

All upper limb 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 limb amputees can perform the activities of daily living with a single device, or at most with two devices.

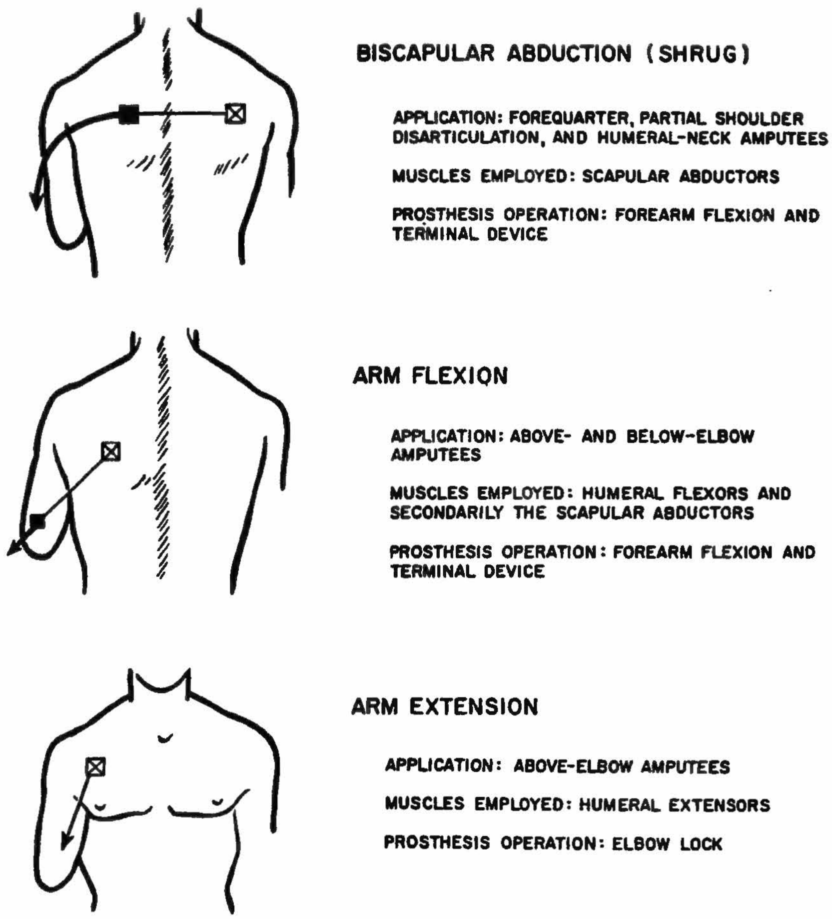


Figure II-11. Major harness controls. The points stabilized by harness (⊠) are beginning points for the control cable, which passes into a Bowden-type housing at movable points (■). The relative motion is transmitted via the Bowden cable to distal points on the prosthesis.

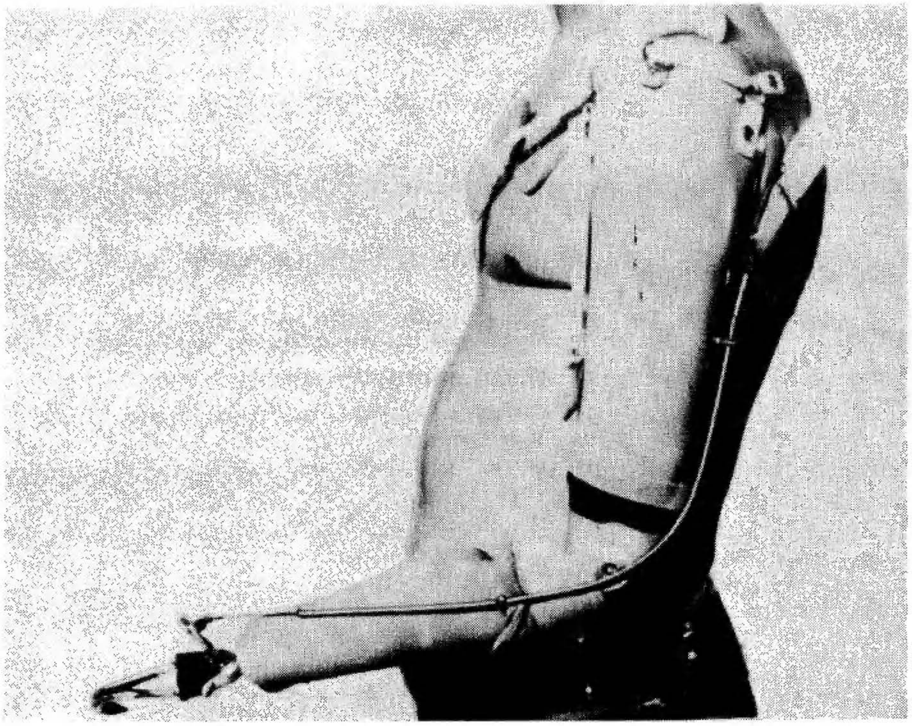


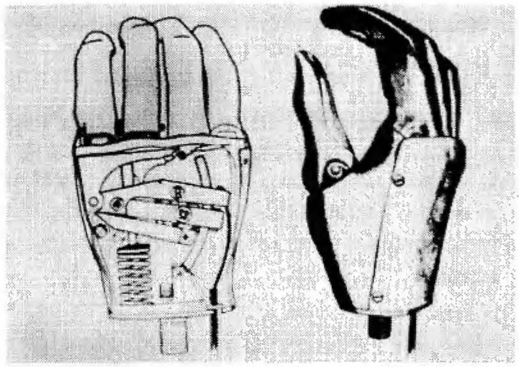
Figure II-12. Above-elbow prosthesis that uses the Veterans Administration Prosthetics Center's electric elbow. Note that the control cable for the terminal device is used for that purpose only.

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 permits more visibility. It also offers more in 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, and interchange them as the occasion warrants.

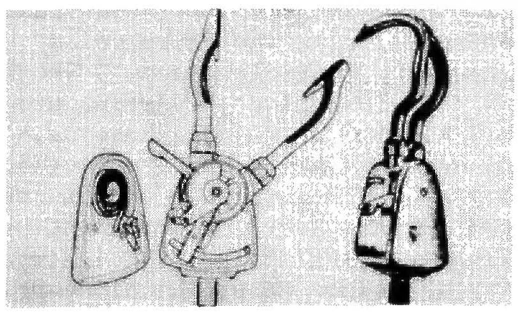
Two basic types of mechanisms have been developed for terminal-device operation - voluntary-opening and voluntary-closing. In the former, tension on the control cable opens the fingers against an elastic force; in the latter, tension in the control cable closes the fingers against an elastic force.

Each type of mechanism has its advantages and its 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 II-13 and II-14.

Wrist units are used to attach terminal devices to prostheses. These units permit manual rotation (supination and pronation) of the terminal device, interchange of terminal devices, and addition of a wrist



A



B

Figure II-13. Voluntary-closing terminal devices. A, APRL - Sierra Hand; left, cutaway view showing mechanism; right, assembled hand without cosmetic glove; B, APRL - Sierra Hook.

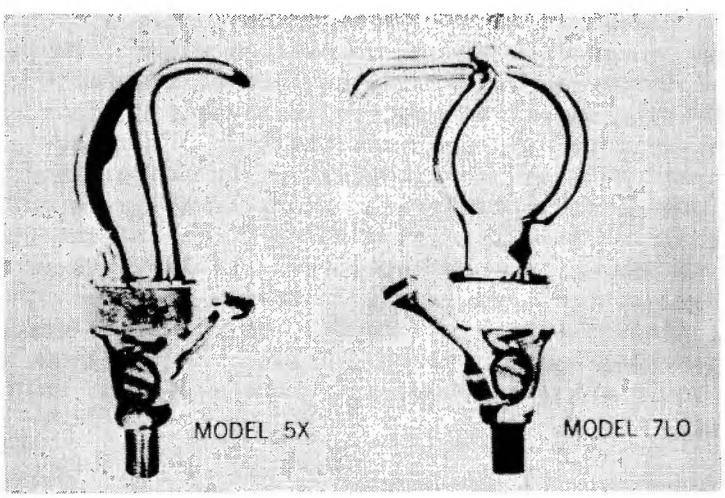


Figure II-14. Some common voluntary-opening terminal devices.

flexion component for close body activity (Figure II-15). Wrist units are constructed as either friction or locking units. The friction type holds the terminal device in the desired rotational position by friction obtained from compression washers. The locking type locks the terminal device in a fixed position.

In the construction of prostheses for any amputations below the elbow, hinges are used to connect the socket to a cuff or pad on the arm (Figure II-16). These hinges provide both suspension and stability. The hinges are of three basic types: flexible, rigid, and, "step-up." Their selection depends primarily upon the level of amputation and the remaining functional ability of the stump.

When an amputation occurs at or above the elbow, elbow function is supplied to the appropriate prostheses by use of an elbow unit. The elbow unit provides flexion of the forearm section as well as a method of locking the elbow in any degree of flexion with the least possible amount of effort. The two types, internal locking and external or outside locking, are both actuated by the amputee's control harness. The internal locking unit is used with the above elbow, shoulder disarticulation, and forequarter prostheses (Figure II-17A). These prostheses also incorporate a turntable between the elbow unit and arm socket to provide manual humeral or arm rotation (Figure II-17C). The turntable permits the amputee to adjust the prosthesis so the forearm socket and terminal device can be made to operate in any desired vertical plane. The external locking elbow unit is used only with the elbow disarticulation prosthesis (Figure II-17B).

In the complete forequarter amputation case, several components are available to provide manual shoulder motion. One example is a universal joint which permits passive motion of the arm section of the prosthesis to occur in all planes.

Considerable effort in recent years in the United States, Canada, and Europe has been devoted to the development of upper-limb prostheses powered by electricity or compressed gases. Prostheses for below elbow amputees using electric hands, and controlled by electrical signals from stump muscles, are available in the United States. They have been used widely in Europe, but have not been popular in the United States because of high costs for the functional regain. No externally powered hooks are available. An electric elbow is available for those special cases that can benefit from its use in its present form. Trials to date have shown that unilateral above elbow cases rarely find any advantage in external power unless other disabilities are present. Effective control of externally powered prostheses, except for the simplest below elbow devices, still presents a major problem. However, research groups come closer to solutions each year.

PROSTHESES FOR AMPUTATION THROUGH THE HAND

When sensation is present, the surgeon will save any functional part of the hand in lieu of a wrist disarticulation amputation. Any method of

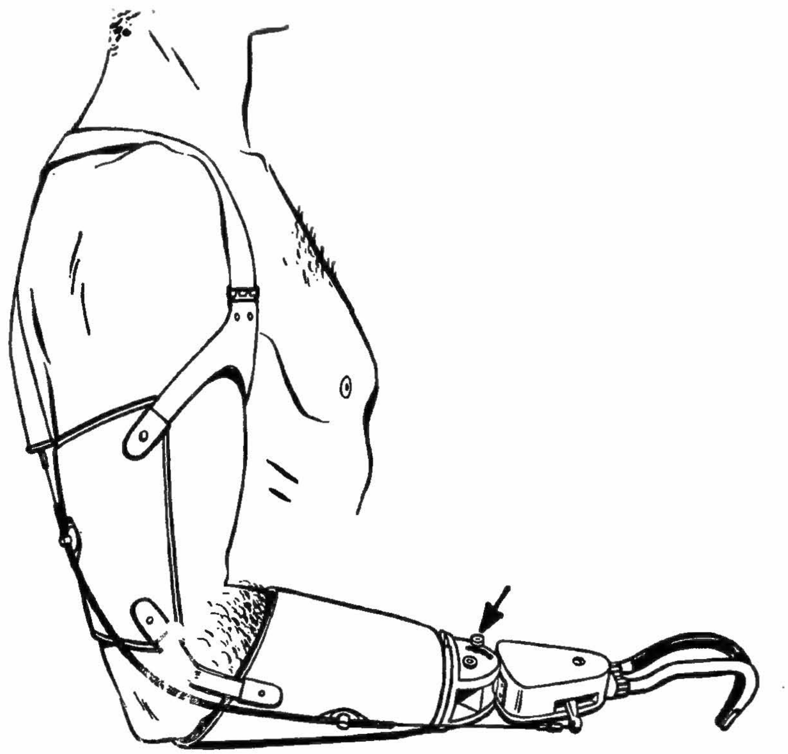


Figure II-15. Complete prosthesis incorporating a wrist-flexion unit (arrow) and a APRL Hook.

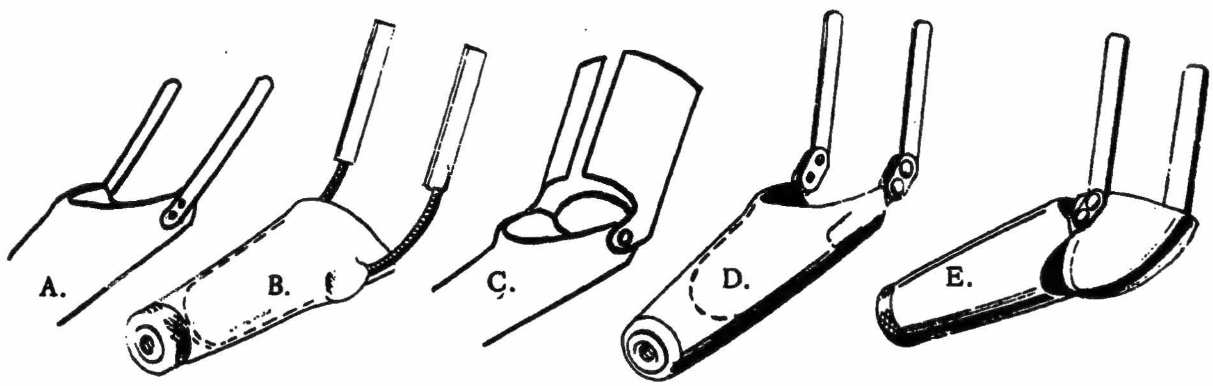


Figure II-16. Elbow hinges: A and B, flexible; C and D, rigid; E, "step-up."

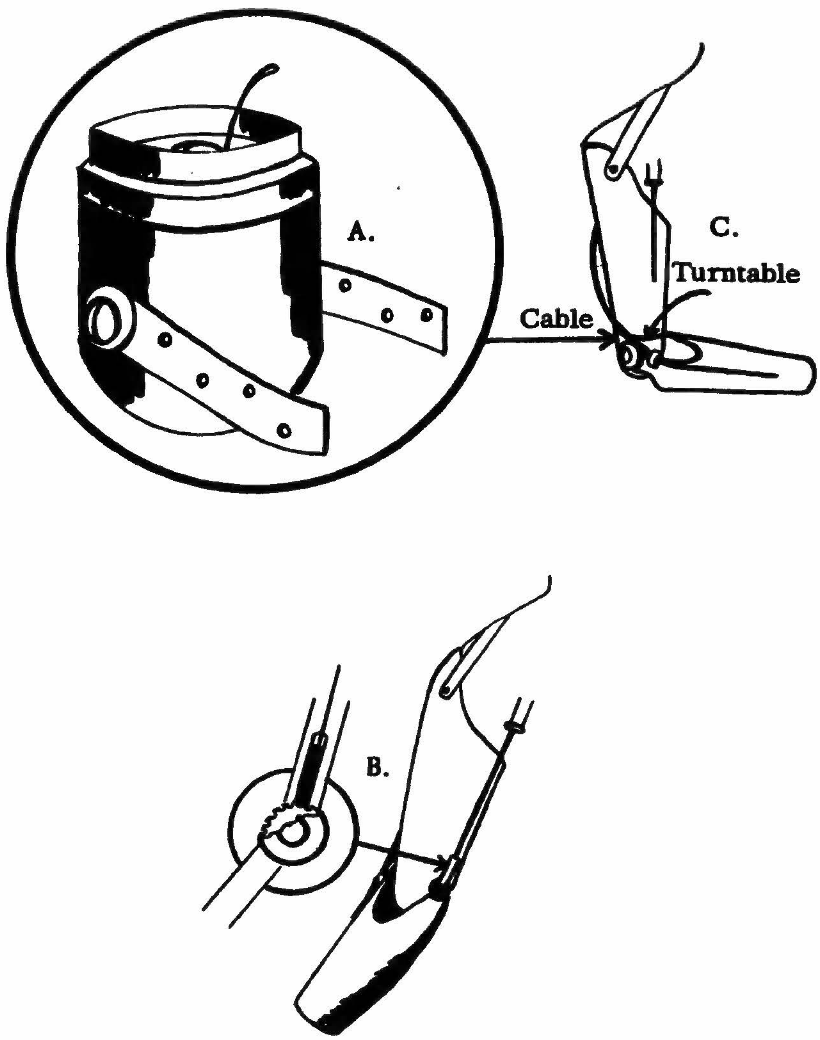


Figure II-17. Elbow units: A, internal lock with a turntable (C); B, external or outside lock.

obtaining some form of grasp, or prehension, is preferable to the best prosthesis. If the result is unsightly, the stump can be covered with a plastic glove, life-like in appearance, for those occasions when the wearer would prefer to sacrifice for his appearance's sake. One solution to one man's problem is shown in Figure II-18.

PROSTHESES FOR THE WRIST DISARTICULATION AMPUTATION

Removal of the hand at the wrist joint was once condemned because it was thought to be too difficult to fit in such a manner as to yield more function than a shorter forearm stump. One of the problems in fitting the wrist disarticulation amputation in the past has been to keep the overall length of the prosthesis commensurate with the opposite arm. The development of very short wrist units, especially for this type of prosthesis, has materially reduced this problem. However, these units are available in only the screw or thread type and cannot be obtained in the type which lends itself to quick interchange of terminal devices.

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 can be used - an important function of the upper limb. In the case of the wrist disarticulation amputation, nearly all of the normal forearm pronation-supination is present if proper surgical techniques are employed. The socket for the wrist disarticulation

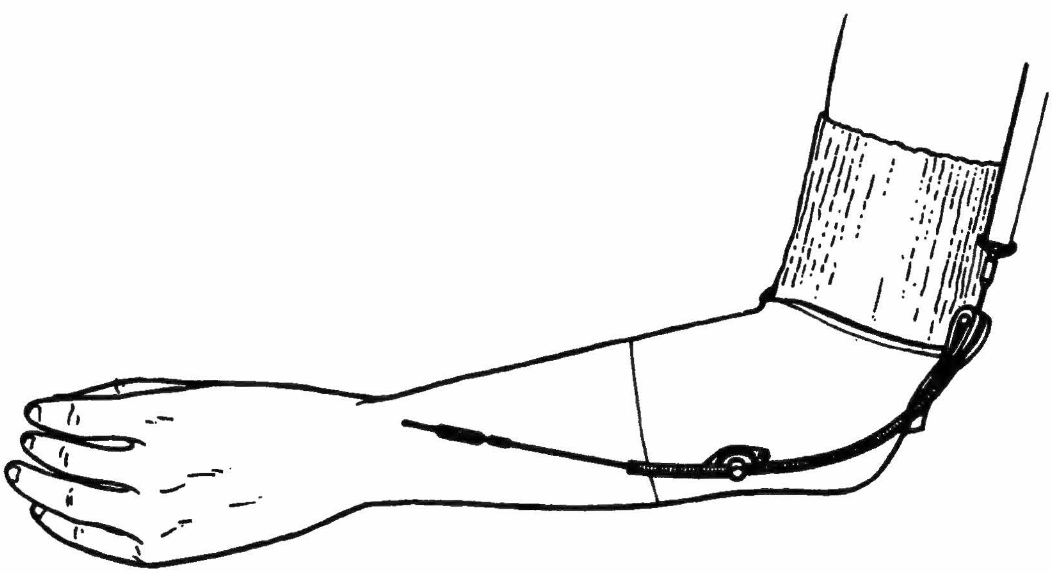


Figure II-18. Short below-elbow prosthesis with preflexed socket (Munster type) and cosmetic glove.

case need not extend the full length of the forearm and is fitted somewhat loosely at the upper, or proximal, end to permit the arm to rotate. A simple figure-eight harness and Bowden cable are used to operate the terminal device (Figure II-19).

PROSTHESES FOR BELOW ELBOW AMPUTATIONS

The prosthesis for the lower 1/3 below elbow case is essentially the same as that for the wrist disarticulation amputee except that the quick-disconnect wrist unit can be used.

The socket for the middle 1/3 below elbow stump, where there is little or no residual rotation of the forearm, is usually fitted snugly to the entire stump. If necessary, rigid hinges connecting the socket to a cuff about the upper arm are used to provide additional stability.

The upper 1/3 below elbow case cannot effectively control the prosthesis generally used for the middle 1/3 case because the stump is too short to provide the necessary leverage. For many years, a "split socket" and "step-up" hinge was used, but a better understanding of the biomechanics of the elbow joint has led to the development and use of the so-called Munster technique in which an intimately fitted socket is extended over the olecranon to provide suspension and stability (Figure II-20). Some range of motion is sacrificed but the harnessing is simpler and the patient is more comfortable. To permit control of the prosthesis in the area about the face, the arm is built so that the prosthetic forearm is flexed up to 25 degrees with respect to the socket and stump.

When the forearm stump is so short as to make it impossible to control the prosthesis or has a severely limited range of motion, an "outside" elbow lock operated by a small amount of stump motion is used.

Either the figure-eight harness, preferably incorporating a metal ring at the point of crossover, or the chest-strap harness may be used, the latter being indicated when heavy-duty work is required since its larger area tends to spread the loads involved in lifting, and thus improve comfort by lowering the unit pressure.

PROSTHESES FOR THE ELBOW DISARTICULATION AMPUTATION

The elbow disarticulation amputation consists of removal of the forearm, resulting in a slightly bulbous stump but usually one with good end-bearing characteristics. The long bulbous end, while presenting some fitting problems, permits good stability between the socket and stump and therefore allows use of nearly all of the rotation normally present in the upper arm - a function much appreciated by the amputee. Because of the length of the elbow disarticulation stump, the elbow locking mechanism is installed on the outside of the socket (Figure II-21). Otherwise the prosthesis and harnessing procedures are identical to those of the above elbow case.

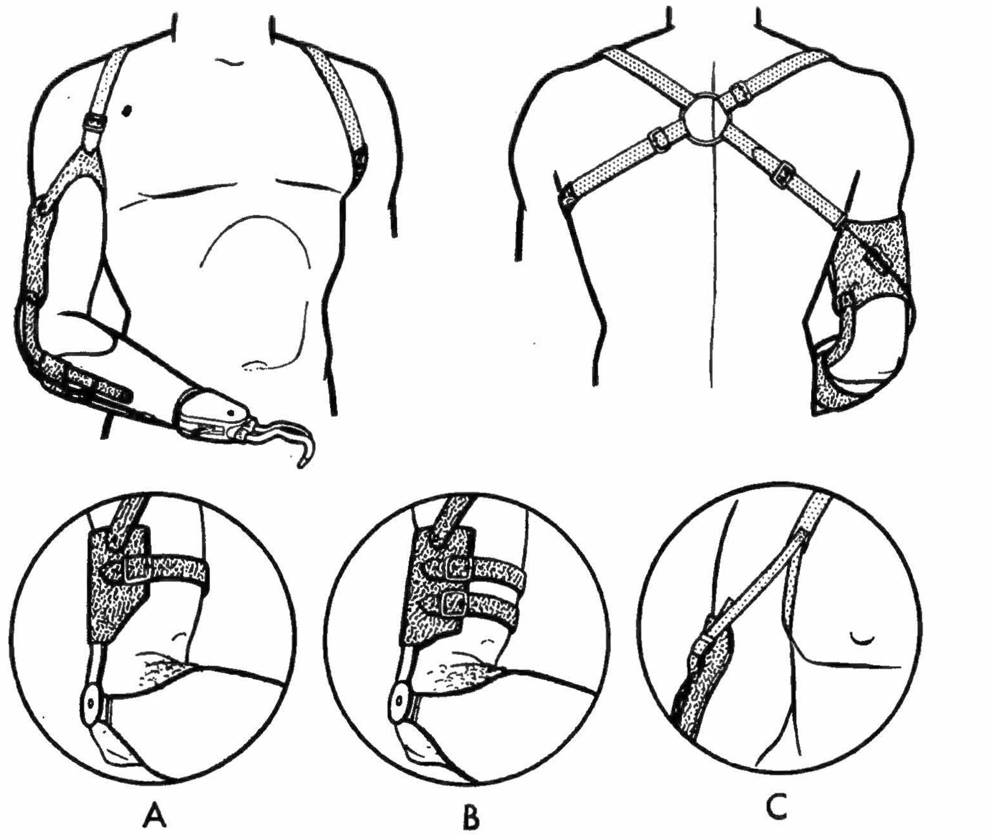


Figure II-19. Typical methods of fitting partial forearm amputees with medium or long stumps. Top, the figure-eight, ring-type harness is most generally used. Where possible, flexible leather hinges and open biceps cuff or pad are used (i.e.: complete carpal case). When more stability between socket 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.

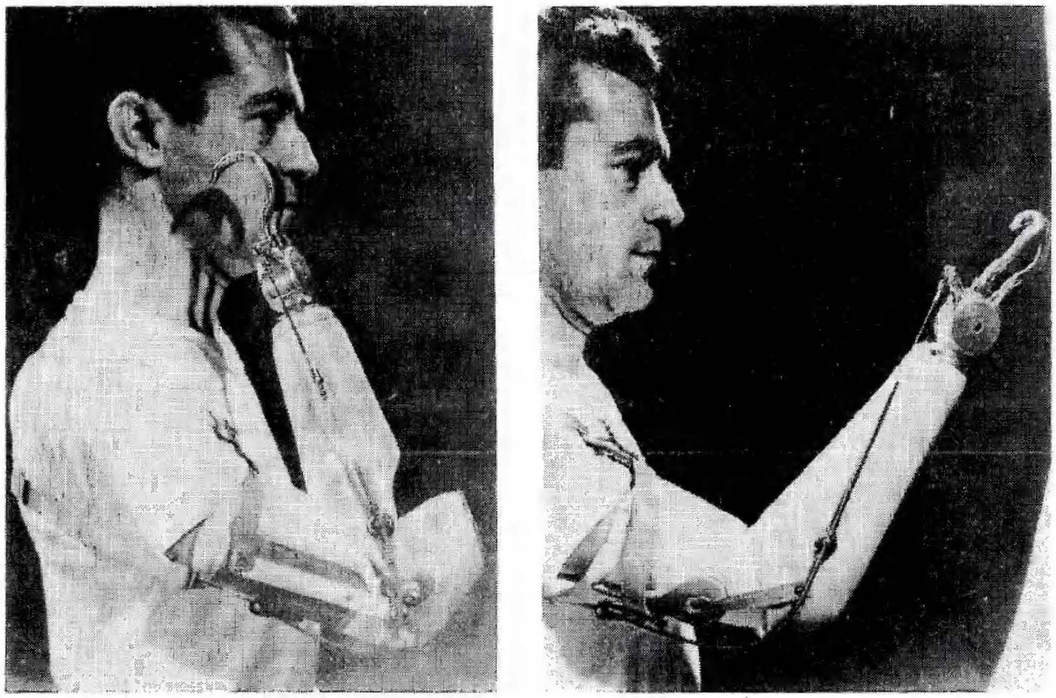


Figure II-20. Comparison of split socket and Munster-type fitting of short upper 1/3 below elbow case. A, split socket and step-up hinge provides 140 degrees of forearm flexion; B, Munster-type fitting permits less forearm flexion but enables the amputee to carry considerably greater weight with flexed prosthesis unsupported by harness (courtesy New York University College of Engineering Prosthetic and Orthotic Research).

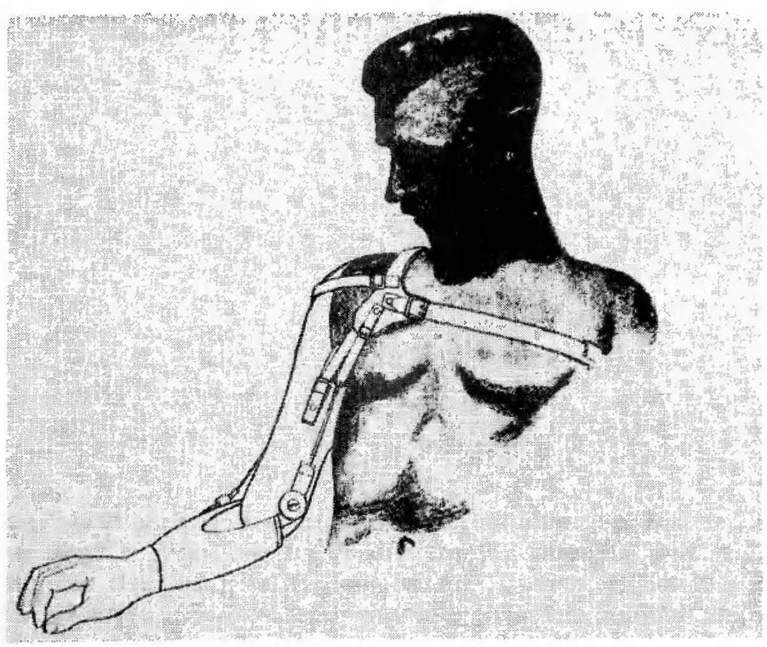


Figure II-21. Typical prosthesis for the elbow disarticulation case. The chest-strap harness with shoulder saddle is shown here, but the figure-eight is also used. See Figure II-19.

PROSTHESES FOR ABOVE ELBOW AMPUTATIONS

Any amputation through the arm is generally referred to as an above elbow amputation. In practice those stumps in which less than 30% of the humerus remains are treated as elbow disarticulation cases. Those with more than 90% of the humerus remaining are treated as complete forearm cases.

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 can be 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. 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.

The most popular harness used is the figure-eight, ring-type, dual-control design 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 (Figure II-22). When the elbow is locked, the control force is then diverted to the terminal device. The chest strap harness may also be used in the dual-control configuration.

PROSTHESES FOR SHOULDER DISARTICULATION AND FOREQUARTER AMPUTATIONS

Removal of the entire arm is known as a shoulder disarticulation amputation, but whenever feasible the surgeon will leave intact as much of the humerus as is possible to provide stability between the stump and the socket. When it becomes necessary to remove the clavicle and scapula, the operation is known as a forequarter amputation. The short upper 1/3 above elbow, the shoulder disarticulation, and forequarter cases are all provided with essentially the same type of prosthesis (Figure II-23).

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 and 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, and which have proven useful.

To date it has not been possible to devise a shoulder joint that can be activated usefully 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.

Figure II-22. Typical prosthesis for the above elbow case. The figure-eight harness is shown but the chest-strap harness with shoulder saddle may also be used. See Figure II-21.

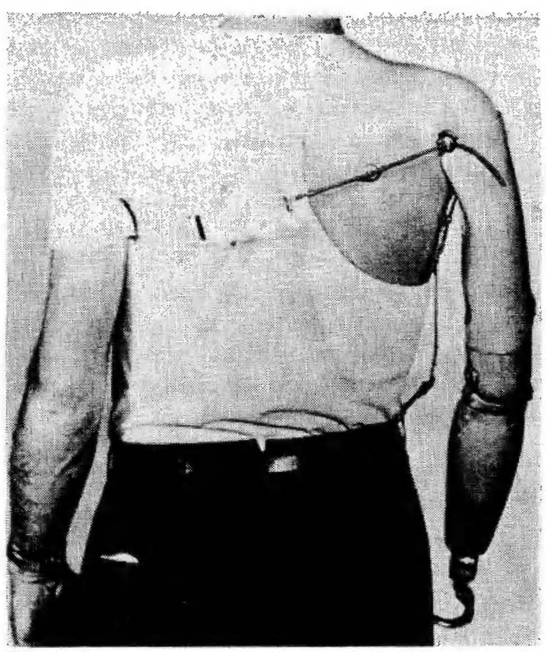


Figure II-23. Typical prosthesis for the shoulder disarticulation case.

The shoulder disarticulation case can often benefit from an electric elbow.

FUNCTIONAL CAPACITIES OF UPPER-LIMB AMPUTEES

As a general rule the higher the amputation level, the less the functional capacity of the amputee. There is a wide spectrum of loss of function between the possible amputation levels of an upper limb. Often the unilateral (occurring on only one side) upper-limb amputee can compensate to a degree for his loss by making more use of the usually untapped potential of the other hand, elbow, and shoulder. Furthermore, practically all activities of daily living can be mastered by the properly trained unilateral upper-limb amputee, especially when provided with an appropriate prosthesis. For some amputees psychological problems are apt to present greater hurdles to maintaining or obtaining an occupation than the lack of function.

Functional capacities of operating tractor-trailers by the various classes of unilateral upper-limb amputees are given in Tables II-1 and II-2 (functional matrix charts). Table II-1 relates those designated functional activities performed at various amputation levels of the upper left limb (Zone I) while Table II-2 relates those designated functional activities performed at the various amputation levels of the upper right limb (Zone II). Several of the functional activities are found on both tables because these activities require equally both limbs or permit one limb to be substituted for the other to safely perform the activity.

Each of the functional activities and their subdivisions are ranked within three categories on the tables. The categories are defined as follows:

Without Difficulty:	The driver at this amputation level can safely perform this activity.
Difficult:	The driver at this amputation level can perform this activity but has difficulty.
Extremely Difficult:	The driver at this amputation level has extreme difficulty performing this activity safely.

These categories have been designed on each table by the following symbols to provide contrast for easy reading. The symbols for each category are:

Without Difficulty. . . . . .


Difficult . . . .


Extremely Difficult. . . . . .

The user must remember that both tables were formulated with the assumption that a prosthetic device was being worn by each type of amputee while performing a specific functional activity. The exception was the partial hand amputee.

The Safety Investigator should acquaint himself with the functional capacities of the amputee-waiver applicant found within the respective zone table before administrating an on-the-road test to the applicant. The appropriate zone table should serve as a focus of potential areas of difficulty to be reviewed by the investigator during the applicant's evaluation.

Table II-1. Amputee driver functional matrix chart - Zone I, upper left limb

Function / Type of Amputee	Partial Hand (1st and 2nd digits present)	Wrist Disarticulation	Below Elbow	Elbow Disarticulation	Above Elbow	Shoulder Disarticulation
9. Pumps off air brake pressure until goes into "emergency condition"; depresses "third" tank air supply control button and tractor parking brake control button and holds down simultaneously						
8. Controls steering						
7. Shifts gears: two gear boxes, two shift levers						
6. Sounds horn: B. Air (with lanyard)						
6. Sounds horn: A. Electric (center of wheel)						
5. Operates switches (i.e.: headlights)						
4. Turns engine on/off (key with push button starter)						
3. Fastens/unfastens seat belt						
2. Gets up/down to hook/unhook						
1. Enters/leaves cab; adjusts outside mirrors						

Table II-1. Amputee driver functional matrix chart - Zone I, upper left limb
(continued)

Function / Type of Amputee	10. Hooks/unhooks electrical cables and air hoses	11. Operates signals: A. "Stalk" turn signal	B. Push button type	C. Emergency flashers	12. Raises/lowers landing gear assembly	13. Releases fifth wheel locking device	14. Operates emergency equipment (i.e.: fire extinguisher)	15. Inspects engine compartment: A. Conventional	B. Short nose cab	C. Cab over (hydraulic hand pump)
Partial Hand (1st and 2nd digits present)										
Wrist Disarticulation										
Below Elbow										
Elbow Disarticulation										
Above Elbow										
Shoulder Disarticulation										

Table II-2. Amputee driver functional matrix chart - Zone II, upper right limb

Function / Type of Amputee	1. Enters/leaves cab; adjusts outside mirror	2. Gets up/down to hook/unhook	3. Fastens/unfastens seat belt	4. Turns engine on/off (key with push button starter)	5. Operates switches (i.e.: headlights)	6. Sounds horn: electric (center of wheel)	7. Shifts gears: A. One gear box, single speed rear axle	7. Shifts gears: B. One gear box, two or more speed rear axle, axle control on shift lever or dashboard	7. Shifts gears: C. Two gear boxes, one shift lever, range control on shift lever	7. Shifts gears: D. Two gear boxes, two shift levers	8. Performs emergency downshifting	9. Controls steering	10. Operates trailer brake
Partial Hand (1st and 2nd digits present)													
Wrist Disarticulation													
Below Elbow													
Elbow Disarticulation													
Above Elbow													
Shoulder Disarticulation													

Table II-2. Amputee driver functional matrix chart - Zone II, upper right limb (continued)

Function / Type of Amputee	11. Applies/releases (hand) parking brake	12. Pumps off air brake pressure until goes into "emergency condition"; depresses "third" tank air supply control button and tractor parking brake control button and holds down simultaneously	13. Hooks/unhooks electrical cables and air hoses	14. Operates signals: emergency flashers	15. Raises/lowers landing gear assembly	16. Releases fifth wheel locking device	17. Operates emergency equipment (i.e.: fire extinguisher)	18. Inspects engine compartment: A. Conventional	18. Inspects engine compartment: B. Short nose cab	18. Inspects engine compartment: C. Cab over (hydraulic hand pump)
Partial Hand (1st and 2nd digits present)										
Wrist Disarticulation										
Below Elbow										
Elbow Disarticulation										
Above Elbow										
Shoulder Disarticulation										

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Section III. LOWER LIMBS - ZONES III AND IV

LOWER-LIMB AMPUTATIONS

AMPUTATIONS THROUGH THE FOOT

Removal of one or more toes (phalanges) is the most common foot amputation, frequently necessitated by insufficient circulation or by frostbite (Figure III-1). Although the cosmetic and functional loss is minor in comparison with an above or below knee amputation, the phalangeal amputee may experience some difficulty in standing, because of the reduced dynamic base of support, and in the push-off phase of gait, particularly if he has lost the great toe (phalanges) completely, with all of its tissue.

Partial metatarsal and tarsal amputations have an effect on the two arches of the foot. The two arches, longitudinal and transverse, form the hollow associated with the sole of the foot (Figure III-2). The longitudinal arch is the principal of the two arches. Both are formed by the metatarsals and several tarsal bones. An amputation at this level will decrease the two functions of the arches which consist of supporting the body weight while standing and of absorbing the shocks of locomotion.

ANKLE DISARTICULATION AMPUTATION

Loss of the ankle joint by amputation can be a severe disability to some drivers. The ankle joint is a hinge joint formed by the distal ends of the tibia and fibula as well as a tarsal bone. Because it is a hinge joint, the movements of the ankle joint are flexion, also called dorsiflexion, and extension, also called plantarflexion. Flexion is a movement of the dorsal surface of the foot toward the anterior surface of the leg, and extension is the reverse action. A driver who has experienced an ankle disarticulation amputation eliminating dorsi- and plantarflexion will have lost the natural ability to actuate the accelerator and clutch or brake.

Developed about 1842 by James Syme, a leading Scottish surgeon, the ankle disarticulation amputation leaves the long bones of the shank (the tibia and fibula) of the leg virtually intact, only a small portion at the very end being removed (Figure III-3). 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 amputee 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 ankle disarticulation amputation can usually get about the house without a prosthesis, even though normal foot and ankle action has been lost. Atrophy of the severed muscles that were formerly attached to bone in the foot to provide ankle action results in a stump with a bulbous end which, although not of the most pleasing appearance, is quite an advantage in holding the prosthesis in place.

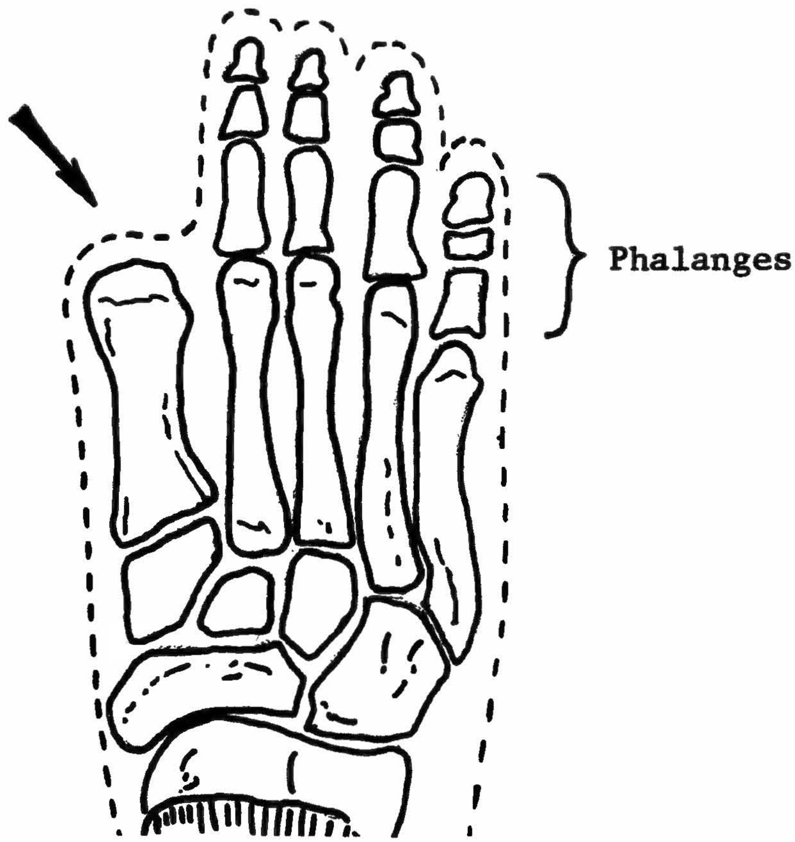

Figure III-1. Amputation of the great toe (arrow).

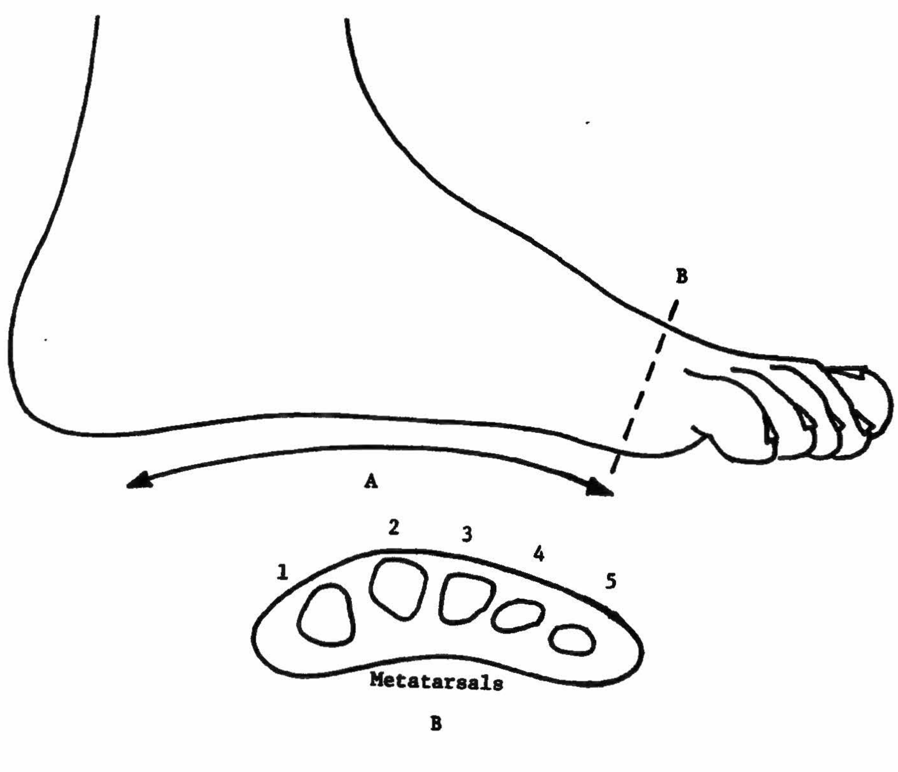

Figure III-2. The Two Arches of the Foot: A, The Longitudinal Arch; B, The Transverse Arch.

BELOW KNEE AMPUTATIONS

Any amputation above the ankle disarticulation level and below the knee joint is known as a below knee amputation. Because circulatory troubles have often developed in long leg 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 (Figure III-4). 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 parts of the anatomy. 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 DISARTICULATION AMPUTATION

Complete removal of the leg, or shank, is known as a knee disarticulation amputation. When the operation is performed properly, the result is an efficient, though bulbous stump (Figure III-5), capable of end weight-bearing. The length of the stump has, in the past, caused some problems in providing an efficient prosthesis. The space that would be used to house an internal knee mechanism is occupied by the end of the

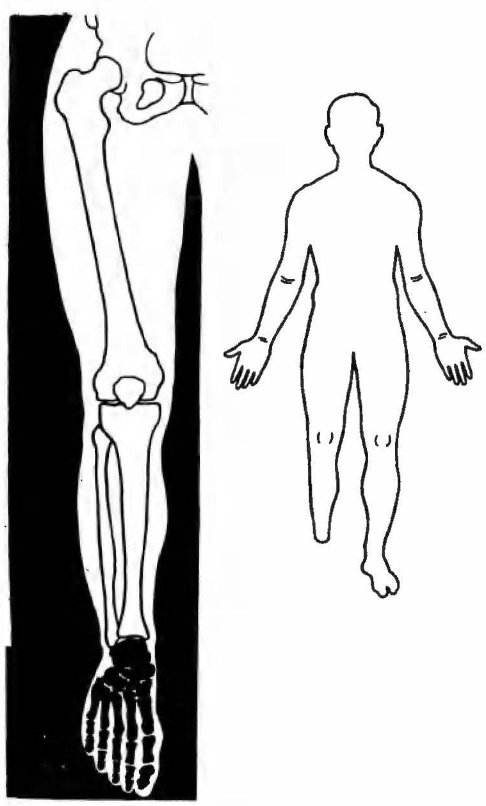

Figure III-3. Ankle Disarticulation.

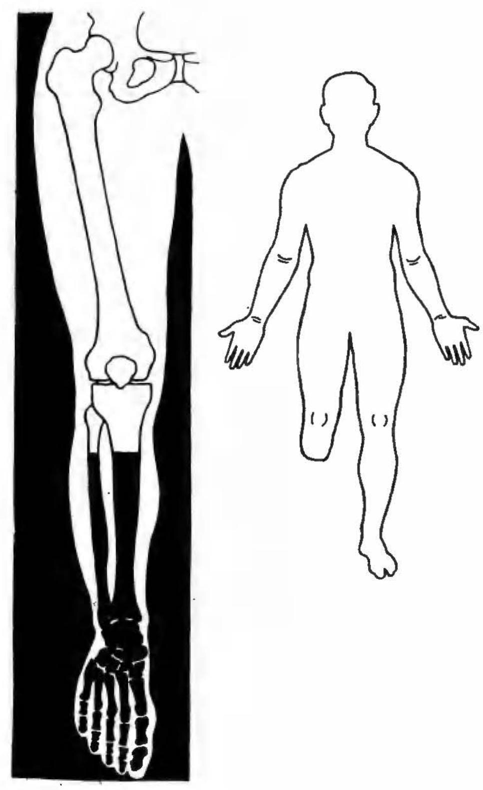

Figure III-4. Upper 1/3 Below Knee.

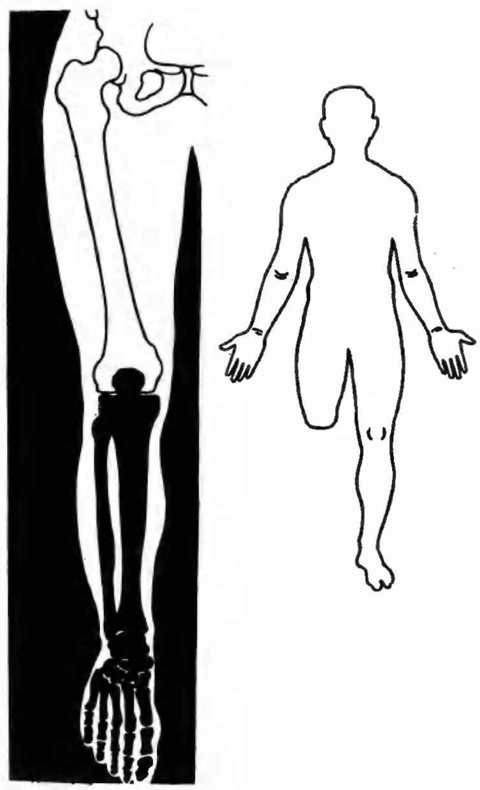

Figure III-5. Knee Disarticulation.

stump. 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 knee cap, or patella, directly over the end of the femur after it has been cut 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.

Recent clever mechanical designs using polycentric linkages are replacing the need for the Gritti-Stokes or other similar techniques (Figure III-6). The polycentric linkages permit the center of rotation of the prosthetic knee to approach the natural motion of the anatomical knee thus providing greater knee stability and control for weight-bearing activities by the knee disarticulation amputee.

ABOVE KNEE AMPUTATIONS

Amputations through the thigh are among the most common (Figure III-7). 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 accommodated through the ischium, that part of the pelvis upon which a person normally sits.

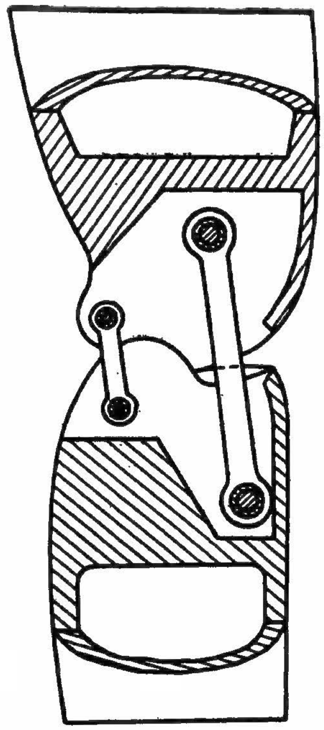

Figure III-6. Polycentric knee with two parallel links.

HIP DISARTICULATION AND HEMIPELVECTOMY AMPUTATIONS

A hip disarticulation amputation (Figure III-8) involves removal of the entire femur of the thigh. Whenever possible, the surgeon leaves some upper portion of the femur in order to provide additional stabilization between the prosthesis and the wearer even though no additional function can be expected over the hip disarticulation amputation. 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 amputation patient, that is, when half of the pelvis has been removed. It is surprising how well hip disarticulation and hemipelvectomy amputees have been able to function when fitted with the proper type of prosthesis.

LOWER-LIMB PROSTHESES

The energy and power required for actuation of lower-limb prostheses comes from remaining parts of the body. The artificial leg is connected to the amputee by a socket that fits over the stump (Figure III-9). The prosthesis may be held in place, or suspended, by straps and belts, or by suction created by an intimate fit (for above knee amputees), or simply by intimate fits that take advantage of the anatomy (for ankle disarticulation and knee disarticulation amputees). The fit, or the relationship between the socket and the stump, is obviously quite critical in the success of a prosthesis. If the socket is too tight it

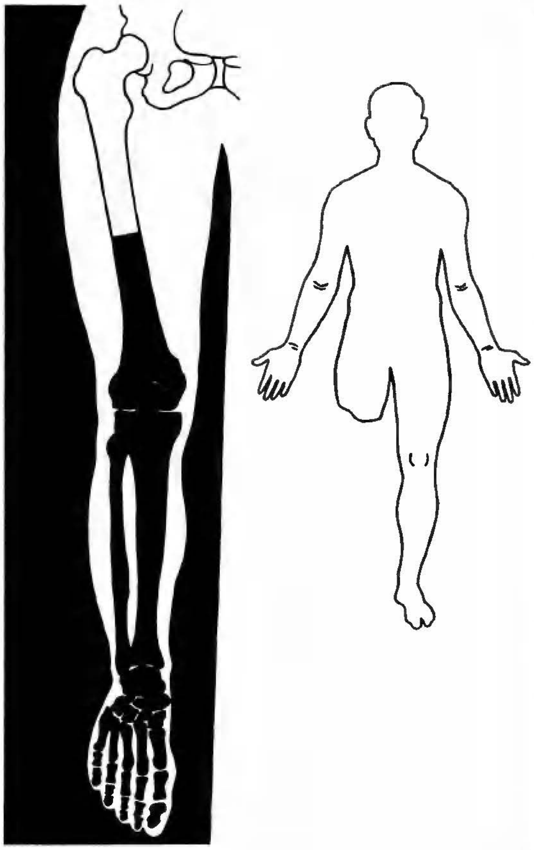

Figure III-7. Middle 1/3
Above Knee.

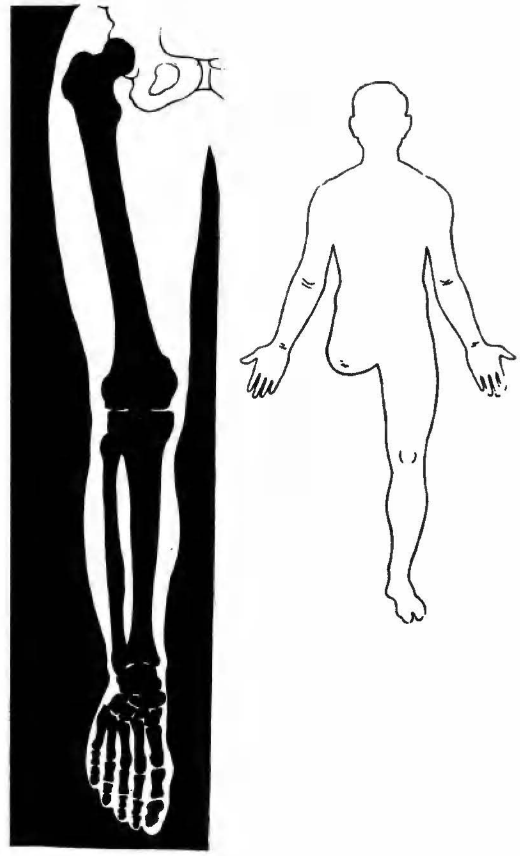

Figure III-8. Hip
Disarticulation.

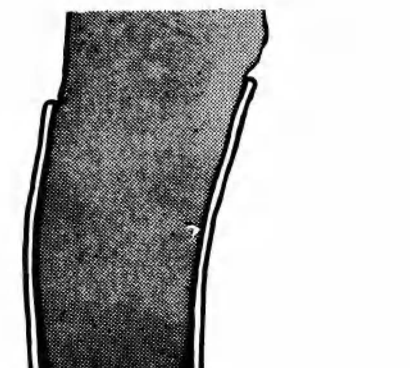

Figure III-9. Lateral view of a prosthesis for an ankle disarticulation. Note the plastic socket which surrounds the stump.

may constrict the flow of blood; if it is too loose the user has inadequate control of the prosthesis.

Alignment, the positioning of the various components of an artificial leg with respect to the wearer, is also most critical to the successful use of a lower-limb prosthesis. In fact fit and alignment are much more important to successful use than mechanical components.

In general an artificial leg should be as light as possible and still withstand the loads imposed on it. As a result modern plastic materials are used widely. Aluminum and stainless steel alloys are used judiciously to supplement the plastics to provide high ratios between strength and weight.

PROSTHESES FOR AMPUTATIONS THROUGH THE FOOT

Functional losses from amputations through the foot, often referred to as partial foot amputations, present few problems. Usually, ordinary shoes with the void in the forepart filled with a plastic foamed in place is usually all that is required.

PROSTHESES FOR THE ANKLE DISARTICULATION AMPUTATION

The prosthesis most often used for the ankle disarticulation case consists of a snug-fitting plastic socket extending to a point below the knee and a solid-ankle cushion-heel (SACH) foot (Figure III-10). A cutout or window is often provided in the socket wall to permit entry of the bulbous stump. An alternative method that seems to be gaining favor uses an expandable liner to retain the socket in place, thus eliminating the need for a window in the socket wall and providing a stronger prosthesis. The equivalent of ankle motion is afforded by the resilience of the heel portion of the SACH foot.

When the weight of the body cannot be tolerated on the end of the stump some of the weight can be transferred through the proximal (upper) portion of the socket.

PROSTHESES FOR BELOW KNEE AMPUTATIONS

Since the motion which occurs at the knee is controlled by muscles above the knee joint, a below knee amputation retains virtually full strength and range of motion at the knee. The artificial limb of choice for the below knee amputee is the PTB (patellar-tendon-bearing) prosthesis (Figure III-11). The PTB, in contrast to the original or "conventional" below knee prosthesis (Figure III-12) which used metal "side-joints" and "thigh corset" to support the body weight, does not extend above the knee. The conventional below knee prosthesis often caused constriction, limited knee flexion, and piston or stump sliding motion in and out of the socket resulting in stump edema. Obviously a driver, wearing a conventional below knee prosthesis would traumatize his stump from repeated motions like braking and accelerating.

Figure III-10. The ankle disarticulation prosthesis adopted by the Canadian Department of Veterans Affairs. The posterior opening extends the length of the shank.

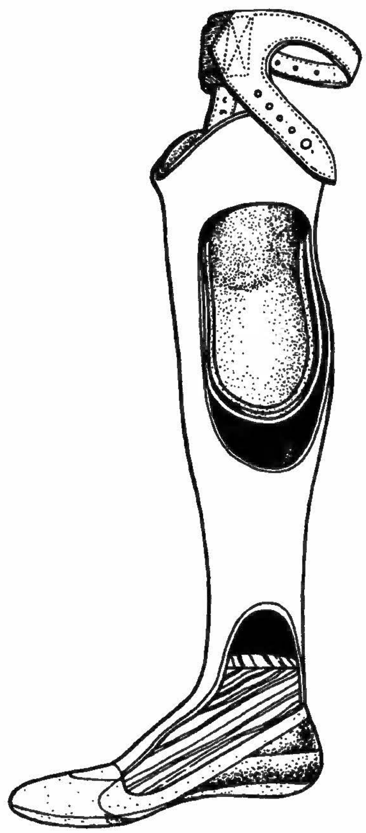

Figure III-11. Cutaway view of the patellar-tendon-bearing leg for a below knee amputation.

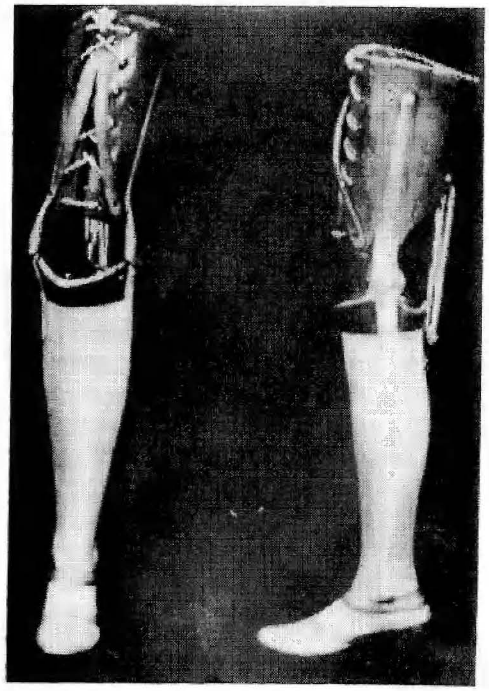

Figure III-12. Below knee prosthesis with wood socket-shank, thigh corset, and steel side bars (courtesy Veterans Administration Prosthetics Center).

In the early model of the PTB prosthesis, the socket was provided with a lining consisting of a thin layer of sponge rubber and leather; and, the limb was suspended by means of a simple cuff, or strap, around the thigh just above the kneecap (Figure III-11). Pressure was reduced on the stump by distributing body weight along the sides of the socket. Recently new variations of the PTB obtain uniform pressure over the entire distal end of the stump from foaming Silicone rubber with the stump in place.

Several new methods of suspension have been introduced since the early PTB model. One method called the PTS consists of molding the socket brim to a point just above the patella (Figure III-13). In another method, the area over the patella or kneecap is left open, lateral and medial "ears" are molded over the condyles of the femur, and a rubber wedge is inserted between the medial ear and the thigh to provide suspension (Figure III-13). Both methods provide more stability at the knee than the original design.

The foot prescribed is usually the SACH design, but other types can be used.

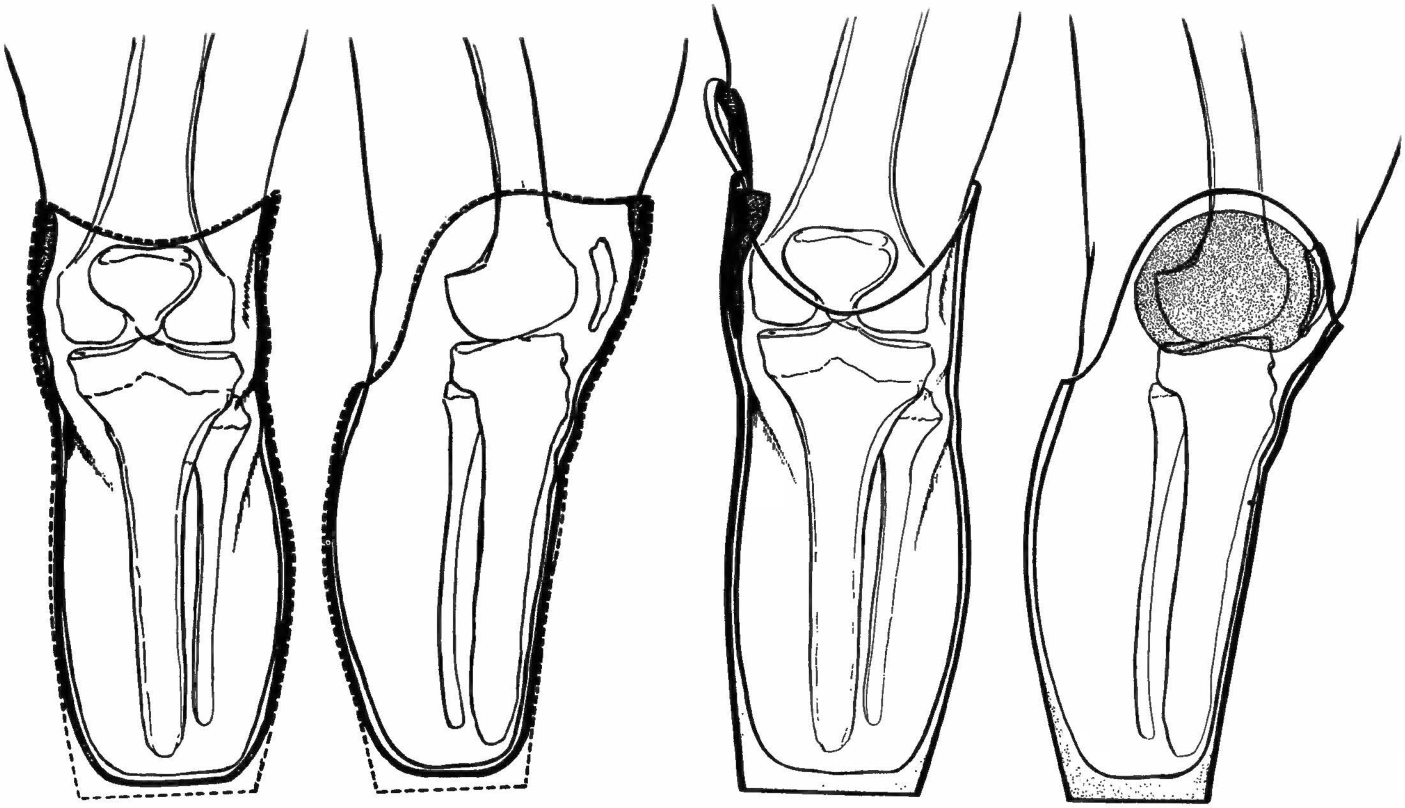

Figure III-13. Variations of the patellar-tendon-bearing prosthesis socket brim. Left, the PTS suspension method; right, the supracondylar wedge suspension method.

It is now general practice in many areas to prescribe the PTB prosthesis, or one of its variants, in most new cases and in many old ones. If sidebars and a corset are indicated later, these can be added. Stumps as short as 4 inches can generally be fitted successfully with the PTB prosthesis without the use of sidebars and corset.

In special cases, such as an 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 complete leg case.

PROSTHESES FOR THE KNEE DISARTICULATION AMPUTATION

Amputation at the knee yields a highly functional stump capable of full end-bearing. A molded plastic-laminate socket with a lengthwise anterior slit that can be laced to adjust the socket to the stump is used to allow entry of the bulbous distal end of the stump and at the same time to provide suspension. Newer designs using an expandable inner liner eliminate the need for a cutout and lacing. Because of the length of the stump, it has not been possible until recently to install a knee unit. The resulting limbs were bulky and usually without adequate swing control.

With the introduction of the OHC* complete leg prosthesis, which employs a four-bar linkage for knee motion that can be placed in the shank area, the knee disarticulation and lower 1/3 above knee stumps can now be fitted quite satisfactorily (Figure III-14). Built into the OHC unit is a hydraulic swing control unit.

PROSTHESES FOR ABOVE KNEE AMPUTATIONS

Amputations through the shaft of the femur are referred to as above knee amputations. As much length as possible is saved. Some abduction contracture is usually inevitable in the case of the upper 1/3 above knee stumps.

The articulation of the above knee prosthesis is in effect a compound pendulum actuated by the thigh stump (Figure III-15). 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 backward too far and slam into extension as it rotates forward, except when walking at a very slow rate. 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.

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 of gait 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 who are in good health, such an arrangement has been quite satisfactory. An automatic knee brake, however, is indicated for the weaker or infirmed individuals.

A variety of knee units providing automatic braking or locking action are available (Figure III-16). Legs in which the shank is controlled during the swing phase by either a pneumatic or a hydraulic cylinder are available. Also available is a hydraulic unit that provides automatic control in both swing and stance phases of walking.

A number of methods for suspending the above knee leg are available. For younger, healthy patients, the suction socket is generally the method of choice. In this design the socket is simply fitted tightly enough to create sufficient negative pressure, or suction, between the stump and

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*Orthopaedic Hospital, Copenhagen

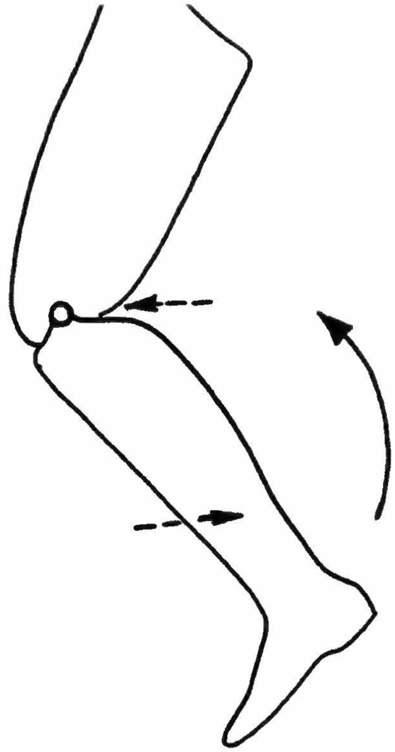


Figure III-14. The OHC (Orthopaedic Hospital, Copenhagen) prosthesis for the knee disarticulation case.

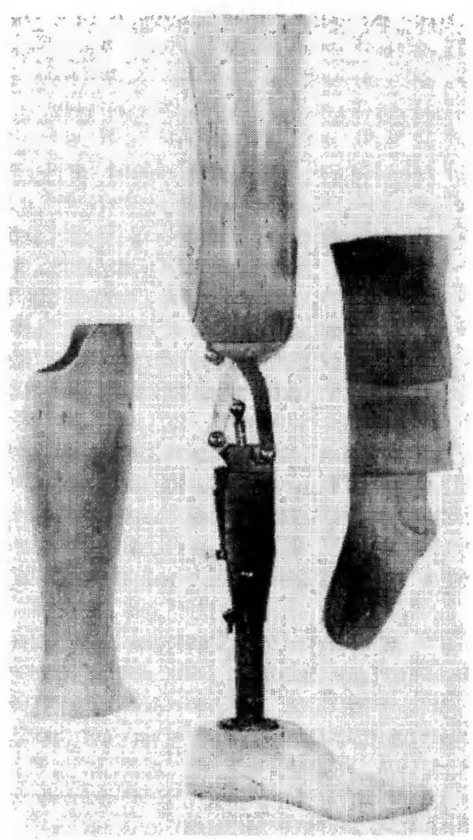


Figure III-15. Pendulum effect of the above knee prosthesis.

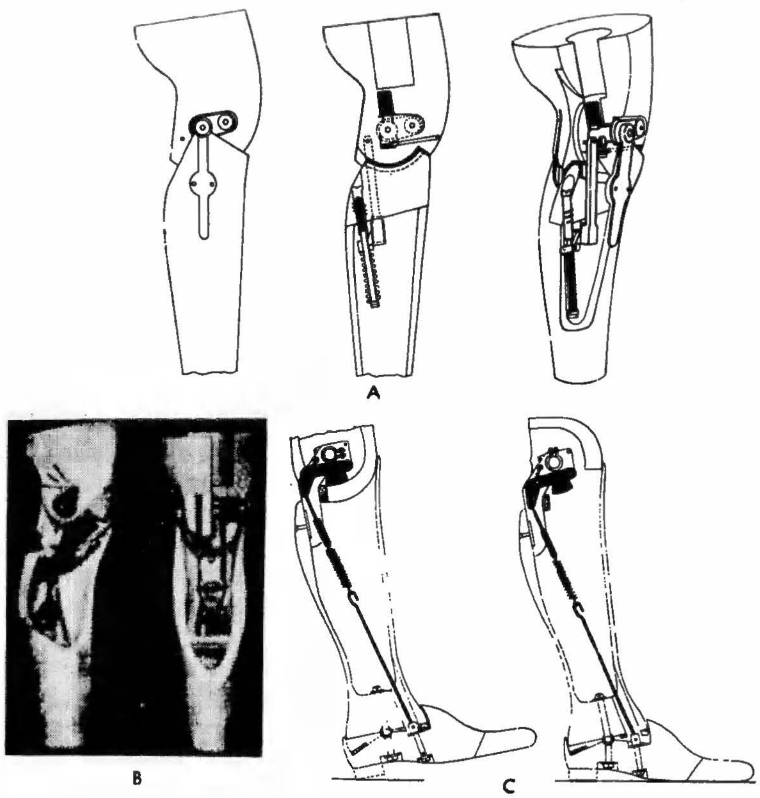


Figure III-16. Some examples of knee units with automatic braking or locking action. A, Block "Safety-knee"; B, Vari-Gait knee; C, Mortensen leg.

the bottom of the socket (Figure III-17A). Special values are used to control the amount of negative pressures 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 virtue of the elimination of all straps and belts, and wearers tend to feel that the suction-socket prosthesis is lighter than others.

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 (Figure III-17A) evolved, and now is virtually the standard for above knee sockets regardless of the type of suspension used. 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. The original 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. Subsequent studies show that sockets that contact the entire area of the stump reduce the tendency for edema, increase comfort, and improve proprioception. The total-contact socket is now the method of choice in treatment of most new above knee cases.

Successful fitting of the suction socket is apt to require a series of adjustments, and therefore careful consideration should be given to the ability and willingness of the amputee to visit the limb facility for modifications.

In some cases additional suspension is provided by adding a "Silesian Bandage" (Figure III-17B) 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.

When a pelvic belt or suspender straps are used, the socket is fitted somewhat looser than in the case of the suction socket, and a stump sock is generally worn. Most of the body weight is taken on the ischium of the pelvis. Amputees with weak stumps and most of those with very short stumps will require a pelvic belt connected to the socket by means of a "hip" joint. 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 amputee because of the problems encountered in donning the suction socket, especially that of bending over to remove the suction socket (Figure III-17C).

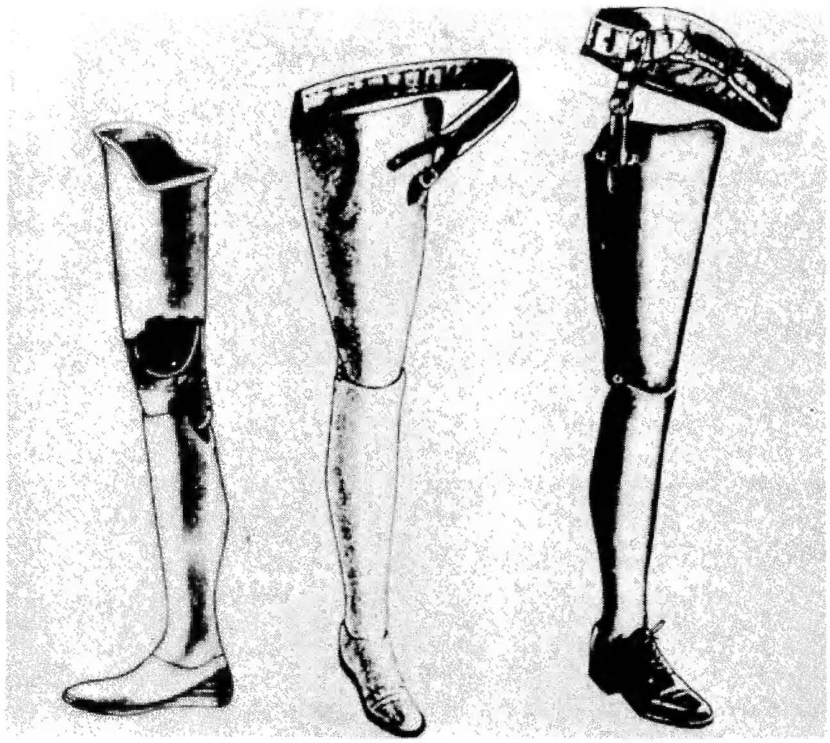


Figure III-17. Above knee sockets and methods of suspension: A, total-contact suction socket; B, above knee leg with Silesian bandage for suspension; C, above knee leg with pelvic belt for suspension. Most above knee sockets have a quadrilateral-shaped upper section as shown.

There is no average prescription for above knee cases today. The type of suspension, the type of socket, the kind of knee, shank, and foot are each selected to meet the individual needs of the patient.

PROSTHESES FOR HIP DISARTICULATION AND HEMIPELVECTOMY AMPUTATIONS

Whenever possible, the head and the neck of the femur, the trochanter, and any part of the shaft of the femur is left when amputation about the hip is necessary. Even though movement about the hip joint produces no useful function, the presence of these and surrounding tissues permits the application of a more stable socket than is the case for the true hip disarticulation and hemipelvectomy amputation.

A prosthesis (Figure III-18) developed by the Canadian Department of Veterans Affairs in 1954 and modified slightly through the years has become accepted as standard practice. 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

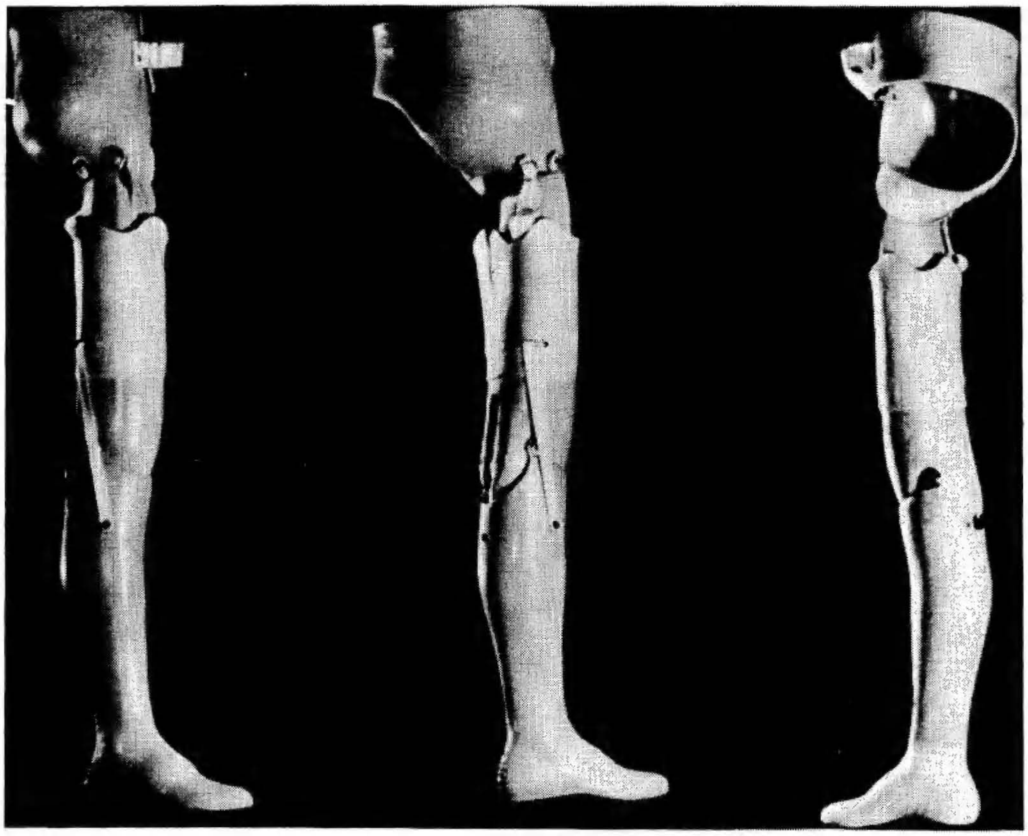


Figure III-18. Hip disarticulation prosthesis, known as the Canadian type because its principle was originally conceived by workers at the Department of Veterans Affairs of Canada.

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 a hip disarticulation prosthesis, but some prosthetists have reported successful use of hydraulic knee units with the Canadian-type arrangement.

A new modular design (Figure III-19) that also allows the patient to assume the sitting position easily has been introduced recently. Features of this new device include alignment adjustability and a soft one-piece foam cover that provides excellent cosmesis.

The hemipelvectomy amputee is provided with essentially the same type of prosthesis (Figure III-19). Because of the loss of the pelvic structure, the socket must be designed so that support can be carried through the semi-fluid viscera of the abdomen. In some cases the socket must be extended to encase a portion of the thorax for additional stability.

Recently it has been demonstrated that the entire pelvis can be removed (transcorporectomy) and these amputees can be fitted so that ambulation is possible.

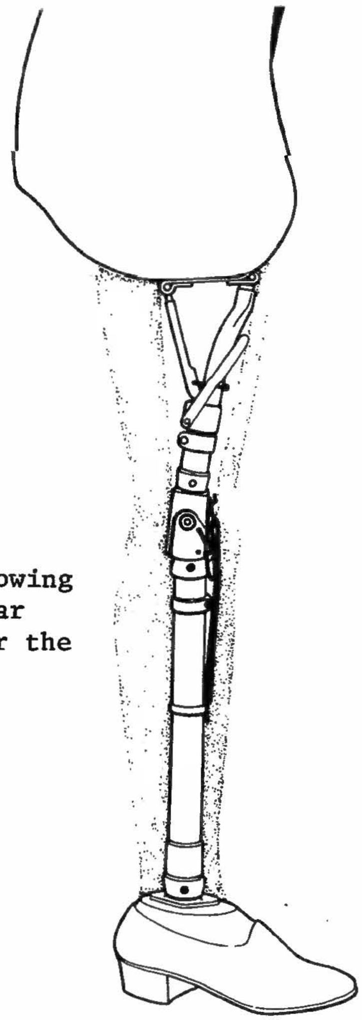


Figure III-19. Line drawing showing lateral view of a typical modular construction of a prosthesis for the hip disarticulation case.

FUNCTIONAL CAPACITIES OF LOWER-LIMB AMPUTEES

As a general rule the higher the amputation level, the less the functional capacity of the amputee. There is a wide spectrum of loss of function between the possible amputation levels of a lower limb. Most unilateral (occurring on only one side) ankle disarticulation and below knee amputees wearing the appropriate prosthesis have very few limitations with respect to daily living activities and many occupations, while for individuals at the other end of the spectrum, the above knee and hip disarticulation amputees, the limitations are more severe. For some amputees psychological problems are apt to present greater hurdles to maintaining or obtaining an occupation than the lack of function.

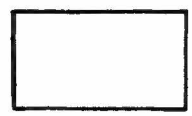
Functional capacities of operating tractor-trailers by various classes of unilateral lower-limb amputees are given in Tables III-1 and III-2 (functional matrix charts). Table III-1 relates those designated functional activities performed at various amputation levels of the lower left limb (Zone III) while Table III-2 relates those designated functional activities performed at the various amputation levels of the lower right limb (Zone IV). Several of the functional activities are found on both tables because these activities require equally both limbs or permit one limb to be substituted for the other to safely perform the activity.

Each of the functional activities and their subdivisions are ranked within three categories on the tables. The categories are defined as follows:

Without Difficulty:	The driver at this amputation level can safely perform this activity.
Difficult:	The driver at this amputation level can perform this activity but has difficulty.
Extremely Difficult:	The driver at this amputation level has extreme difficulty performing this activity safely.

These categories have been designated on each table by the following symbols to provide contrast for easy reading. The symbols for each category are:

Without Difficulty. . . . . . .



Difficult . . . .

Extremely Difficult . . . . . .

The user must remember that both tables were formulated with the assumption that a prosthetic device was being worn by each type of amputee while performing a specific functional activity.

The safety investigator should acquaint himself with the functional capacities of the amputee-waiver applicant found within the respective zone table before administrating an on-the-road test to the applicant. The appropriate zone table should serve as a focus of potential areas of difficulty to be reviewed by the investigator during the applicant's evaluation.

Table III-1. Amputee driver functional matrix chart - Zone III, lower left limb

Function / Type of Amputee	Partial Foot	Ankle Disarticulation	Below Knee	Knee Disarticulation	Above Knee	Hip Disarticulation
1. Checks wheels, tires, brakes and suspension system						
2. Inspects fifth wheel						
3. Maintains balance while hooking/unhooking cables and hoses						
4. Enters/leaves cab						
5. Applies (foot) parking brake						
6. Depresses brakes and clutch simultaneously when stopping						
7. Drags brakes while accelerating to dry wet brakes						
8. Operates floor dimmer switch						
9. Operates windshield washer pump						

Table III-2. Amputee driver functional matrix chart - Zone IV, lower right limb

Function / Type of Amputee	1. Checks wheels, tires, brakes and suspension system	2. Inspects fifth wheel	3. Maintains balance while hooking/ unhooking cables and hoses	4. Enters/leaves cab	5. Applies brakes: A. Applies deep initial pressure on foot brake; as vehicle decelerates, gradually reduces pressure to initiate stop (air)	5. Applies brakes: B. Applies deep initial pressure on foot brake; as vehicle decelerates, gradually increases pressure to initiate stop (hydraulic)	6. Depresses brakes and clutch simultaneously when stopping	7. Drags brake while accelerating to dry wet brakes	8. Operates windshield washer pump
Partial Foot									
Ankle Disarticulation									
Below Knee									
Knee Disarticulation									
Above Knee									
Hip Disarticulation									

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Section IV. COMBINATIONS OF LIMB AMPUTATIONS

AMPUTATION COMBINATIONS OF ZONES I-IV

The typical amputee with a combination of amputations is a 55 year old man with vascular disease who sustained an amputation in one leg and, after a variable period of time, required an amputation of the opposite extremity. Double leg amputees are usually not symmetrical; they present amputations at all levels above and below the knee, sometimes with an amputation above or below the knee on one side and a hip disarticulation on the other. When the amputation sites are symmetrical (occurring on both identical extremities at the same level), the amputations are referred to as being bilateral. On occasion an amputee may have multiple amputation sites. When this situation occurs it is usually the result of a traumatic injury such as an injury from an automobile accident or a congenital amputation.

For specific information concerning combinations of amputations other than those that are bilateral refer to the appropriate zones for each amputation site which can be found elsewhere in this booklet.

BILATERAL-LIMB PROSTHESES

PROSTHESES FOR BILATERAL UPPER-LIMB AMPUTATIONS

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 (Figure IV-1). In addition to being neater, this arrangement makes the harness easier for the amputee 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.

PROSTHESES FOR BILATERAL LOWER-LIMB AMPUTEES

Bilateral lower-limb prostheses are essentially the same as unilateral ones. Since heavy limbs are fatiguing, lightweight components are used in their fabrication. Also, particular care must be taken to prevent one prosthesis from striking the other, which would produce excessive wear of clothing and prostheses.

The principal prosthetic problem for the bilateral lower-limb amputee is his stability. These bilateral amputees very often develop hip flexion and abduction and knee flexion contractures, aggravated by prolonged sitting. These contractures interfere with the prosthetic alignment stability during weight-bearing and may necessitate the use of knee locks. Prostheses are fabricated shorter in length than the bilateral amputee's preoperative leg length in order to lower his center of gravity, making it easier for him to maintain balance. Usually the below-knee prostheses are 1 inch shorter and the above-knee prostheses 2 to 4 inches shorter than the former leg length.

Bilateral amputees 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.

Figure IV-1. Harness for the bilateral below-elbow/above elbow case.

FUNCTIONAL CAPACITIES OF BILATERAL AMPUTEES

The general rule "the higher the amputation level the less the functional capacity of the amputee" applies also to the bilateral (symmetrical, occurring on both sides) amputee but to a greater degree. The bilateral upper-limb amputee, at the wrist disarticulation level or higher, has a special problem. He has lost his sense of touch and must rely on his vision to aid his terminal devices to safely perform many upper-limb daily activities. Also, his limb mobility, stability, and strength decrease with each increase in the amputation levels. The bilateral lower-limb amputee has his own specific problems. Both the bilateral above-knee and the bilateral hip disarticulation amputees even while wearing the appropriate prostheses have extreme disability. They cannot be expected to stand for long periods or do much walking although they can stand for short periods and ambulate for short distances usually with the aid of two canes. They require employment where they can sit down for most of the work day. The bilateral below-knee amputee can walk and stand well but he should also be employed where he can be seated at times during the work day. The bilateral ankle disarticulation and the bilateral partial foot amputee's functional capacity is approaching that of the able-bodied individual. For some bilateral amputees psychological problems are apt to present greater hurdles to maintaining or obtaining an occupation than the lack of function.

Functional capacities of operating tractor-trailers by the various classes of bilateral amputees are given in Tables IV-1 and IV-2 (functional matrix charts). Table IV-1 relates those designated functional activities performed at various bilateral amputation levels of the upper-limbs while Table IV-2 relates those designated functional activities performed at the various bilateral amputation levels of the lower-limbs.

Since many amputees do not have amputations that are symmetrical, these tables will not be useful. For the amputee who has amputations in more than one zone but not bilateral, it is recommended that the user refer to the appropriate zone tables where those amputations occur.

Each of the functional activities and their subdivisions are ranked within three categories on the tables. The categories are defined as follows:

Without Difficulty:	The driver at this amputation level can safely perform this activity.
Difficult:	The driver at this amputation level can perform this activity but has difficulty.
Extremely Difficult:	The driver at this amputation level has extreme difficulty performing this activity safely.

These categories have been designated on each table by the following symbols to provide contrast for easy reading. The symbols for each category are:

Without Difficulty . . . . . .

Difficult. . . . .

Extremely Difficult. . . . . .

The user must remember that both tables were formulated with the assumption that prosthetic devices were being worn by each type of bilateral amputee while performing a specific functional activity. The exception was the bilateral partial hand amputee.

The safety investigator should acquaint himself with the functional capacities of the bilateral amputee-waiver applicant found within the respective table before administrating an on-the-road test to the applicant. The appropriate table should serve as a focus of potential areas of difficulty to be reviewed by the investigator during the applicant's evaluation.

Table IV-1. Amputee driver functional matrix chart - Bilateral upper limbs

Function / Type of Amputee	1. Enters/leaves cab; adjusts outside cab mirrors	2. Gets up/down to hook/unhook	3. Fastens/unfastens seat belt	4. Turns engine on/off (key with push button starter)	5. Operates switches (i.e.: headlights)	6. Sounds horn: A. Electric (center of wheel)	6. Sounds horn: B. Air (with lanyard)	7. Shifts gears: A. One gear box, single speed rear axle	7. Shifts gears: B. One gear box, two or more speed rear axle, axle control on shift lever or dashboard	7. Shifts gears: C. Two gear boxes, one shift lever, range control on shift lever	7. Shifts gears: D. Two gear boxes, two shift levers	8. Performs emergency downshifting	9. Controls steering
Bilateral Partial Hand (1st and 2nd digits present)													
Bilateral Wrist Disarticulation													
Bilateral Below Elbow													
Bilateral Elbow Disarticulation													
Bilateral Above Elbow													
Bilateral Shoulder Disarticulation													

Table IV-1. Amputee driver functional matrix chart - Bilateral upper limbs (continued)

Function / Type of Amputee	10. Operates trailer brake	11. Applies releases (hand) parking brake	12. Pumps off air brake pressure until goes into "emergency condition"; depresses "third" tank air supply control button and tractor parking brake control button and holds down simultaneously	13. Hooks/unhooks electrical cables and air hoses	14. Operates signals: A. "Stalk" turn signal	14. Operates signals: B. Push button type	14. Operates signals: C. Emergency flashers	15. Raises/lowers landing gear assembly	16. Releases fifth wheel locking device	17. Operates emergency equipment (i.e.: fire extinguisher)	18. Inspects engine compartment: A. Conventional	18. Inspects engine compartment: B. Short nose cab	18. Inspects engine compartment: C. Cab over (hydraulic hand pump)
Bilateral Partial Hand (1st and 2nd ddigits present)													
Bilateral Wrist Disarticulation													
Bilateral Below Elbow													
Bilateral Elbow Disarticulation													
Bilateral Above Elbow													
Bilateral Shoulder Disarticulation													

Table IV-2. Amputee driver functional matrix chart - Bilateral lower limbs

Function / Type of Amputee	Bilateral Partial Foot	Bilateral Ankle Disarticulation	Bilateral Below Knee	Bilateral Knee Disarticulation	Bilateral Above Knee	Bilateral Hip Disarticulation
1. Checks wheels, tires, brakes and suspension system						
2. Inspects fifth wheel						
3. Maintains balance while hooking/unhooking cables and hoses						
4. Enters/leaves cab						
5. Applies (foot) parking brake						
6. Applies brakes — A. Applies deep initial pressure on foot brake; as vehicle decelerates, gradually reduces pressure to initiate stop (air)						
6. Applies brakes — B. Applies light initial pressure on foot brake; as vehicle decelerates, gradually increases pressure to initiate stop (hydraulic)						
7. Depresses brakes and clutch simultaneously						
8. Drags brakes while accelerating to dry wet brakes						
9. Operates floor dimmer switch						
10. Operates windshield washer pump						

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Section V: APPENDICES

APPENDIX A: ANATOMY OF THE HUMAN MOTOR SYSTEM

Our survival depends in large part upon our ability to adjust to the changing environmental conditions we experience. Movements constitute the major part of this adjustment. Whereas most of the systems of the body play some role in accomplishing movement, it is the skeletal, articular, muscular and nervous systems acting together which actually produce movements.

THE SKELETAL SYSTEM

The skeleton provides the supporting framework for the body, protection for underlying tissues, and levers for body movements. The skeleton can be divided into two systems: axial skeleton and appendicular skeleton. The axial skeleton includes the bones of the head, the neck and trunk of the body. The bones of the upper and lower limbs comprise the appendicular skeleton (Figure VA-1).

The upper limbs can be further described as consisting of the bones of the shoulder girdle and those of the arms, forearms, wrists, and hands. The specific bones are:

Shoulder girdle: scapula (shoulder blade) and clavicle (collar bone)

Arm: humerus

Forearm: radius and ulna

Wrist and Hand: 8 carpal bones, 5 metacarpals, and 14 phalanges

The lower limbs include the bones of the hip, the thighs, the knees, the legs, the ankles, and the feet. The specific bones of the lower limb are:

Pelvic girdle: innominate bone

Thigh: femur

Leg: tibia and fibula

Ankle and Foot: 7 tarsal bones, 5 metatarsals, and 14 phalanges

THE ARTICULAR SYSTEM

The location where two bones come together is called a joint or articulation. Many joints are freely movable and permit movement to occur. One type is a ball and socket joint which provides freedom of movement by means of a spherical head (ball) emplaced in a cuplike cavity (socket). The shoulder and hip joints are examples of a ball and socket joint.

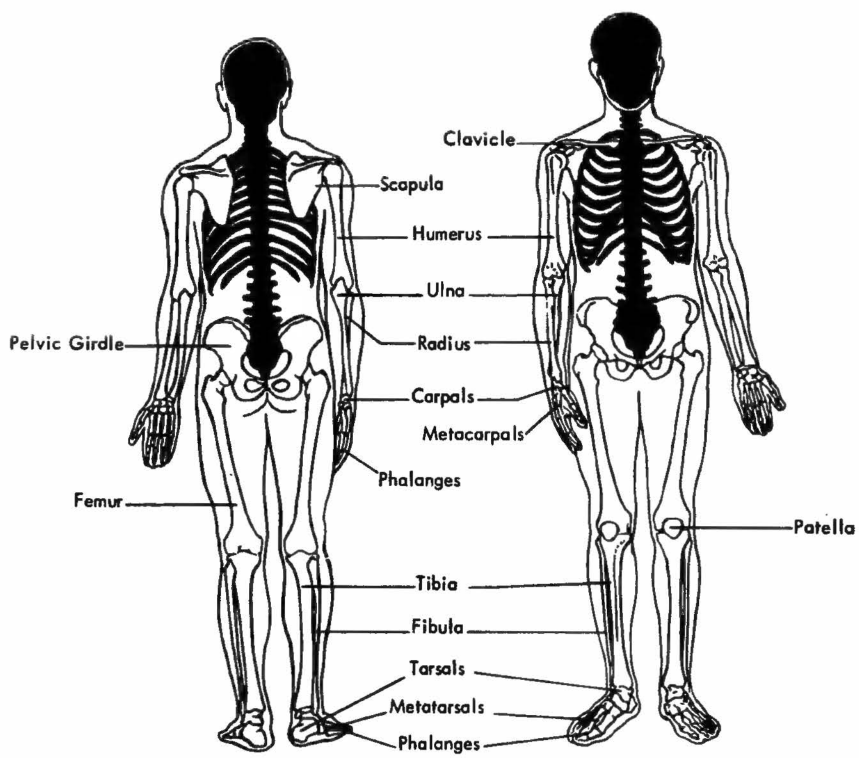

Figure VA-1. The Appendicular Skeleton (Unshaded Areas).

THE MUSCULAR SYSTEM

While the skeletal system is associated with body movement, none of that movement would be possible without the muscular system to provide the power. The following are some basic principles about skeletal muscle actions:

Contraction is the unique function of skeletal muscles.

Skeletal muscles can do only two things: contract and relax. Contraction is the unique function of muscles, and contraction produces the force that moves or prevents the movement of the body and its parts.

Skeletal muscles contract only if stimulated.

A skeletal muscle deprived of nerve impulses by whatever cause is a functionless mass. One should think of a skeletal muscle and its motor nerve as a single unit, always functioning together, either useless without the other.

Skeletal muscles produce movements by pulling on bones.

Bones serve as levers and joints serve as fulcrums of these levers (by definition a lever is any rigid bar free to turn about a fixed point called its fulcrum). When a skeletal muscle contracts, it applies a pulling force on a bony lever and causes the lever to rotate about its point fulcrum. Therefore, a skeletal muscle, its motor nerve, the bony levers to which it is attached, and the joint(s) that its tendon crosses work together as a neuromusculoskeletal unit. This unit's parts always function together, each being practically useless without the normal functioning of the others.

Skeletal muscles that move a part usually do not lie over that part.

In most cases the body of a skeletal muscle lie proximal to the part moved. Thus muscles that move the forearm lie proximal to it, that is, in the arm.

Skeletal muscles and gravitational forces work together to produce many body movements.

The lifting of an object (weight) against the force of gravity is produced by muscle forces, whereas the gradual lowering of the weight is produced by the force of gravity. The same muscles are involved in both lifting and lowering of the weight. The muscles control the lowering of the weight through the gradual relaxation of their contractions.

Skeletal muscles almost always act in groups rather than singly.

Most movements are produced by the coordinated action of several skeletal muscles. Some of the group muscles contract while others relax.

To identify each muscle's special function in the group, the following classification is used:

prime movers - muscle or muscles whose contraction actually produces the movement.

antagonists - muscles which relax while the prime mover is contracting. An exception is when the antagonist contracts at the same time as the prime mover when some part of the body needs to be held rigid, such as the knee joint when standing.

synergists - muscles which contract at the same time as the prime mover. Synergists may help the prime mover produce its movement, or they may stabilize a part so that the prime mover produces a more effective movement.

In order to describe the specific body movements occurring at the freely moving joints one must start from a zero starting position or "anatomical position." The anatomical position is the position of the body standing erectly with arms and legs straight, the palms facing forward, and the feet parallel and flat on the ground (Figure VA-2). With the body in its standardized position, three principal reference planes are used to define the different motions of the body (Figure VA-3). They are:

Midline plane: divides the body into left and right.

Frontal plane: divides the body into front and back.

Horizontal plane: divides body into upper and lower parts.

The motions of the body that occur in a plane parallel to the midline plane are <u>flexion</u> and <u>extension</u>. Flexion is bending a part while extension is returning the part to its original position (Figure VA-4). <u>Abduction</u> and <u>adduction</u> are motions which occur in the frontal plane. Abduction is moving a body part away from the body midline while adduction returns the part toward the midline (Figure VA-5). <u>Circumduction</u> is a combination of the motions of flexion, abduction, extension, and adduction in succession whereby a body part describes a surface of a cone as it moves (Figure VA-6). Finally, <u>rotation</u> of a body part occurs in a horizontal plane (Figure VA-7).

Rotation of the forearm, elbow bent at 90 degrees, can be further described as the positions of supination and pronation. The position of supination is achieved with the palm of the hand facing upward with the thumb pointing away from the body (Figure VA-8A). Supination is the movement involved in unlocking a door with a key. The position of pronation is achieved with the palm facing downward with the thumb pointing toward the body (Figure VA-8B). Grasping often takes place with the forearm pronated.

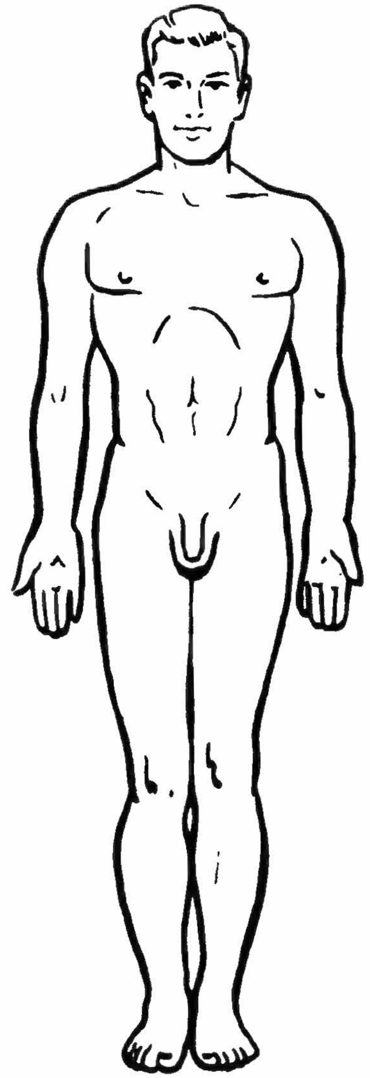

Figure VA-2. Anatomical position of the body.

A B C

Figure VA-3. Three principal body reference planes: A, midline plane; B, frontal plane; and C, horizontal plane.

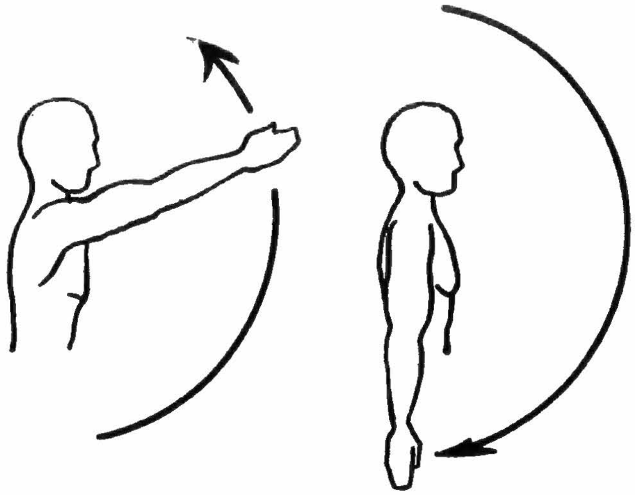

Figure VA-4. Flexion and Extension.

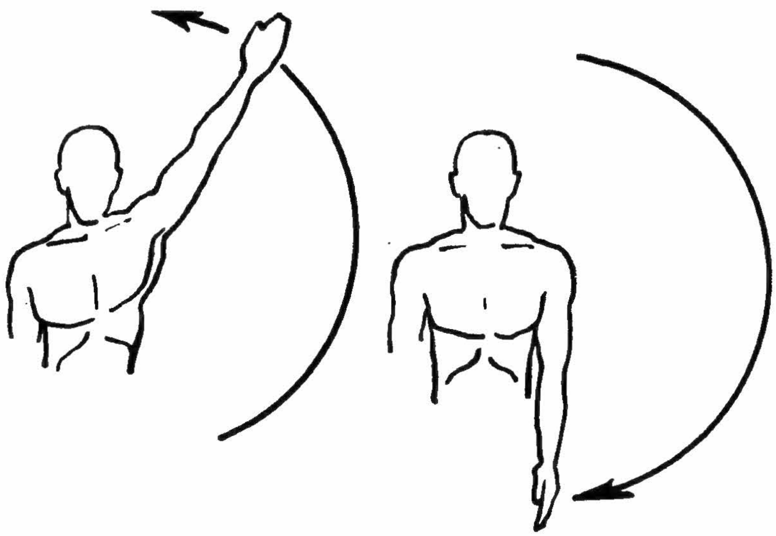

Figure VA-5. Abduction and Adduction.

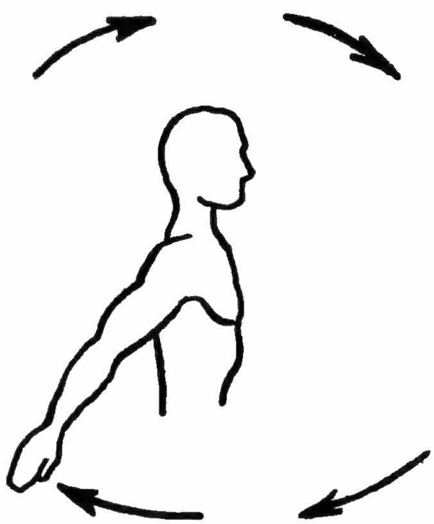

Figure VA-6. Circumduction.

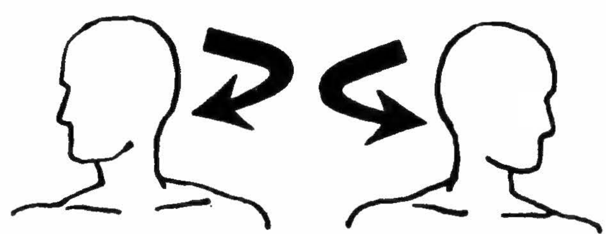

Figure VA-7. Rotation.

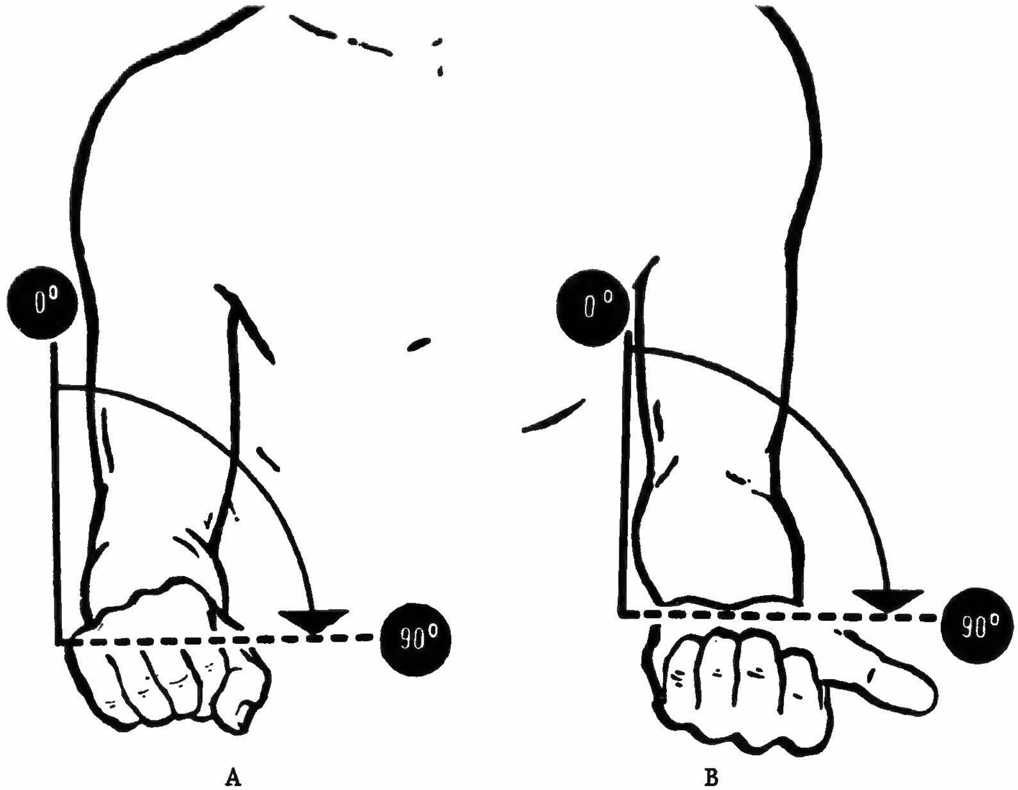

Figure VA-8. Supination and pronation of the forearm. A, Supination; B, Pronation.

In summary, each muscle of the body has its own specific action or actions and in most instances will work with other muscles to carry out a described motion.

THE NERVOUS SYSTEM

The nervous system has two major divisions: the central nervous system and the peripheral nervous system. The peripheral nervous system is especially important because it contains the nerves which activate the muscles and transmit impulses relating to muscular tension as well as changes in the environment outside the body.

CONCLUSION

Any limitation occurring in one or more of these systems will result in a disability which may interfere with the movements essential for performing specific tasks like those found in operating a tractor-trailer.

APPENDIX B: PRESENT AND PROPOSED NOMENCLATURE FOR LIMB PROSTHETICS[1]

AMPUTATION LEVELS - LOWER LIMB

Present Terms:	Proposed Terms:
Hemicorporectomy	Pelvic, Complete
Hemipelvectomy	Hip, Complete
Hip disarticulation.	Thigh, Complete
Short Above Knee (upper 1/3)	Thigh, Partial (upper 1/3)
Medium Above Knee (middle 1/3) . . .	Thigh, Partial (middle 1/3)
Long Above Knee (lower 1/3).	Thigh, Partial (lower 1/3)
Knee disarticulation	Leg, Complete
Short Below Knee (upper 1/3)	Leg, Partial (upper 1/3)
Medium Below Knee (middle 1/3) . . .	Leg, Partial (middle 1/3)
Long Below Knee (lower 1/3).	Leg, Partial (lower 1/3)
Ankle disarticulation or . . . . . . Syme's amputation	Tarsal, Complete
Known collectively as partial foot amputations	Tarsal, Partial Metatarsal, Complete* Metatarsal, Partial * Phalangeal, Complete* Phalangeal, Partial *

*(For amputations involving the metatarsals and the phalanges, detail can be provided as desired by use of the standard numbering system, e.g., an amputation of the fourth and fifth toes would be designated as "Phalangeal 4, 5, complete.")

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[1]Kay, H.W. A proposed nomenclature for limb prosthetics. Orthotics and Prosthetics, 1974, 28(4), 37-47.

AMPUTATION LEVELS - UPPER LIMB

Present Terms:	Proposed Terms:
Forequarter	Shoulder, Complete
Shoulder disarticulation.	Arm, Complete
Short Above Elbow (upper 1/3)	Arm, Partial (upper 1/3)
Medium Above Elbow (middle 1/3) . . .	Arm, Partial (middle 1/3)
Long Above Elbow (lower 1/3).	Arm, Partial (lower 1/3)
Elbow disarticulation	Forearm, Complete
Short Below Elbow (upper 1/3)	Forearm, Partial (upper 1/3)
Medium Below Elbow (middle 1/3) . . .	Forearm, Partial (middle 1/3)
Long Below Elbow (lower 1/3).	Forearm, Partial (lower 1/3)
Wrist disarticulation	Carpal, Complete
Known collectively as partial hand amputations	Carpal, Partial Metacarpal, Complete* Metacarpal, Partial * Phalangeal, Complete* Phalangeal, Partial *

*(For amputations involving the metacarpals and the phalanges, detail can be provided as desired by use of the standard numbering system, e.g., an amputation of the first and second digits would be designated as "Phalangeal 1, 2, complete.")

APPENDIX C: DEGREE OF AMPUTATION IMPAIRMENT OF THE UPPER LIMBS AND THE LOWER LIMBS[1]

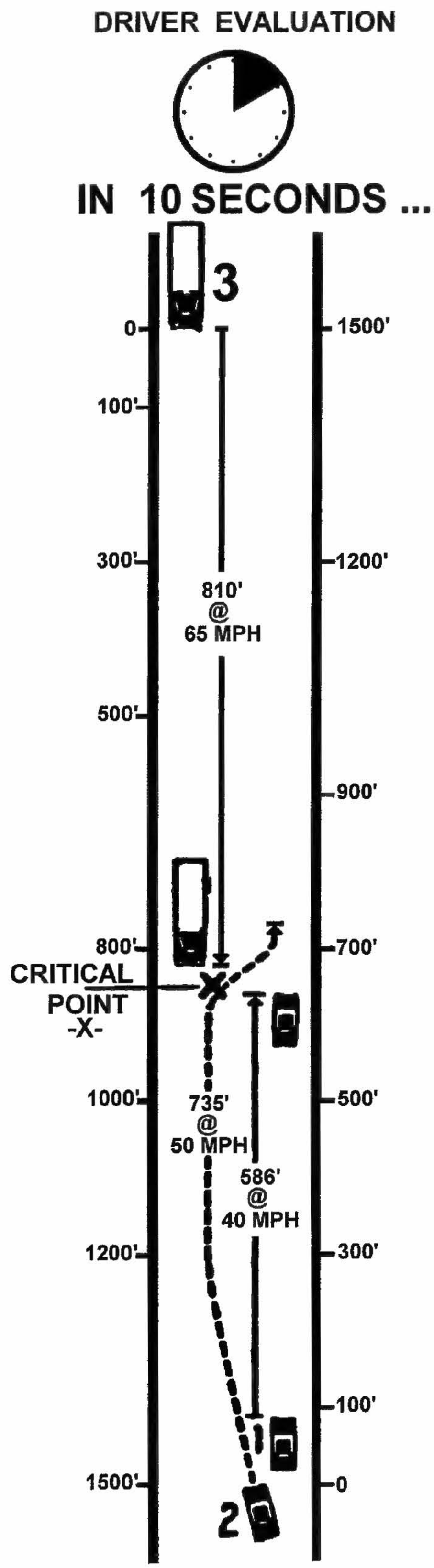
DEGREE OF AMPUTATION IMPAIRMENT OF THE LOWER LIMBS

Amputation Levels	% Impairment of:		
	Foot	Lower Limb	Whole Man
Hemipelvectomy	-	-	50%
Hip disarticulation	-	100%	40%
Above Knee	-	90%-100%	36%-40%
Knee disarticulation	-	90%	36%
Below Knee	-	70%-90%	28%-36%
Ankle disarticulation (Syme)	100%	70%	28%
Partial foot (amputation of all digits at metatarsophalangeal joints)	30%	21%	8%

[1]Committee on Rating of Mental and Physical Impairment. Guides to the evaluation of permanent impairment - the extremities and back (Special Edition) Journal of the American Medical Association, 1958.

DEGREE OF AMPUTATION IMPAIRMENT OF THE UPPER LIMBS

Amputation Levels	% Impairment of:		
	Hand	Upper Limb	Whole Man
Forequarter	-	-	70%
Shoulder disarticulation	-	100%	60%
Above Elbow	-	95%-100%	57%-60%
Elbow disarticulation	-	95%	57%
Below Elbow	-	90%-95%	54%-57%
Wrist disarticulation	-	90%	54%
Partial hand (amputation of all digits at metacarpophalangeal joints)	100%	90%	54%



DRIVER EVALUATION
IN 10 SECONDS ...
3
0
100'
300'
500'
800'
1000'
1200'
1500'
1500'
1200'
900'
700'
500'
300'
100'
0
810'
@
65 MPH
CRITICAL
POINT
-X-
735'
@
50 MPH
586'
@
40 MPH
2

Fig. 3

CORRECTING DRIVER ERRORS

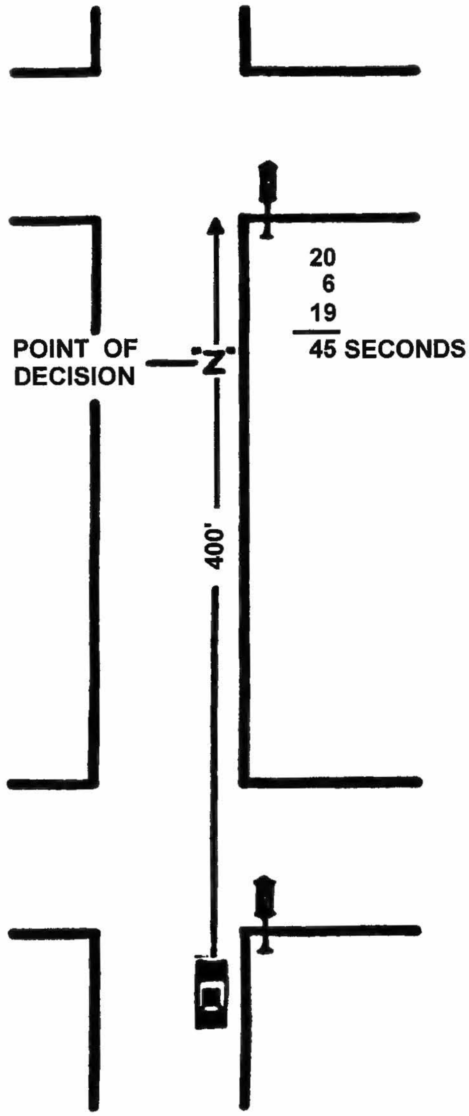


Fig. 4

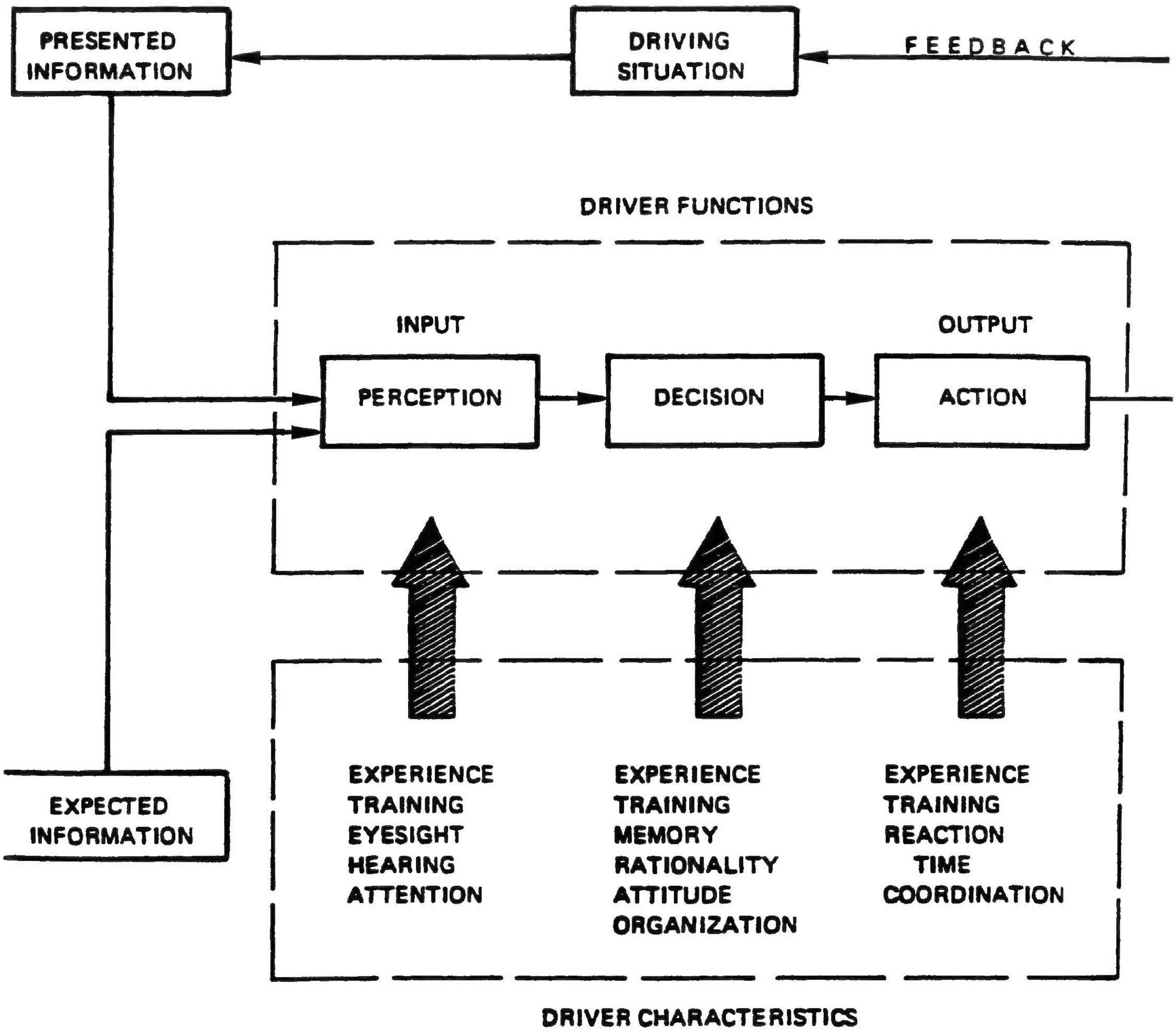


Figure 2-1. Functional Model of Commercial Vehicle Driver. (Horizontal Arrows Indicate Information Flow and Vertical Arrows Indicate Some Driver Characteristics Affecting Basic Driver Functions.)