THE PATELLAR-TENDON-BEARING BELOW-KNEE PROSTHEIS

By C. W. RADCLIFFE and J. FOORT

BIOMECHANICS LABROATORY

School of Medicine
University of California
San Francisco

Department of Engineering
University of California
Berkeley

THE PATELLAR-TENDON-BEARING BELOW-KNEE PROSTHESIS

By C. W. RADCLIFFE and J. FOORT

This Publication Was Supported in Part
by Veterans Administration Research Contract V1005M-2075
and in Part by a Research Grant from the Office of Vocational Rehabilitation
Department of Health, Education, and Welfare

V. T. Inman, M.D. and H. D. Eberhart, Principal Investigators

1961

BIOMECHANICS LABORATORY

DEPARTMENT OF ENGINEERING
UNIVERSITY OF CALIFORNIA
BERKELEY

SCHOOL OF MEDICINE
UNIVERSITY OF CALIFORNIA
SAN FRANCISCO

Copyright 1959, 1961

By The Regents of the University of California

Revised edition 1961

Printed in the United States of America

TABLE OF CONTENTS

Preface	i
Introduction	vii
Prescription Criteria	1
Anatomy of the Below-Knee Stump	8
Biomechanics of Below-Knee Prostheses	26
Information for the Prosthetist	52
Information for the Amputee	62
The Plaster-Bandage Wrap Cast	67
Preparing the Plaster Model of the Stump	77
Fabrication of the Soft Insert	85
Fabrication of the Plastic Shell	92
The Below-Knee Adjustable Shank	98
The Solid Ankle - Cushion Heel (SACH) Foot	104
Assembly and Static Alignment of the Below-Knee Adjustable Shank	114
Cuff Suspension	119
Belt Suspension	125
Preliminary Dynamic Alignment	131
Preliminary Training	136
Dynamic Alignment	144

Alignment Duplication 151

Finishing the Prosthesis 163

Use of Side Joints and Thigh Corset 168

Prosthetic Problems 191

PREFACE

Publication of this manual represents one end product of an activity that has extended over a period of years and has involved many people in addition to the personnel of the Biomechanics Laboratory. The primary goal of this activity is, of course, improvement in the prosthetic rehabilitation of below-knee amputees that should result from correct application of the principles presented here.

Many false starts were made, initially, in attempts to define problem areas that would permit a rational research approach to the improvement of the below-knee prosthesis. Then, in April 1957, a selected group of professional prosthetists was asked to meet at the Biomechanics Laboratory for the Symposium on Below-Knee Prosthetics. The symposium had as its objective the organization of the material constituting the "state of the art" at that time and the formulation of possible research objectives. Participants included Mr. Carlton Fillauer, Mr. James Foort, Mr. John Galdik, Mr. Henry Gardner, Mr. Charles Hennessy, Mr. William Hitchcock, Mr. William Hoskinson, Mr. Frank Moos, Dr. Eugene Murphy, Mr. Chester Nelson, Professor Charles W. Radcliffe, and Mr. Howard Thranhardt.

There followed several years of detailed work in testing and

evaluating principles and procedures leading to the development of the patellar-tendon-bearing concept. A draft of the manual was prepared in June 1959; it was reviewed by the members of the symposium and used as a text for a pilot school for instructors in August 1959. At this school the draft was reviewed page by page as each prosthetist, under supervision, carried out a complete fitting on an amputee. Many revisions and modifications were recommended. After this thorough check, a revised version was published under the title "Manual of Below-Knee Prosthetics" in November 1959.

The manual was used as a textbook for courses in the prosthetics schools at the University of California, Los Angeles; New York University; and Northwestern University, Chicago, during the fall of 1959 and the spring of 1960. In June 1960, a meeting of all school instructors was held to review the manual again and to recommend revisions that would reflect improvements in technique and increase the manual's usefulness as a textbook. A period of extensive rewriting and illustrating followed. The present publication has been given the revised title, "The Patellar-Tendon-Bearing Below-Knee Prosthesis."

The study was supervised and the material written by C. W. Radcliffe and James Foort, with all illustrations and the chapter on anatomy contributed by Frank N. Todd. Typing and layout of the manuscript was by Geraldine Stephen. Other members of the prosthetics research group of the Biomechanics Laboratory of the University

of California who made major contributions to the research are Jim C. McKennon, Principal Research Prosthetist, William H. Hoskinson, Research Prosthetist, and Jose M. Cross, Orthopaedic Technician.

INTRODUCTION

The following chapters describe in detail the principles and procedures required to fit the stump of the below-knee amputee with an improved device known as the "patellar-tendon-bearing below-knee prosthesis." In fitting, a careful consideration of the complete biomechanical problem is required in order to take full advantage of the weight-bearing capabilities of the patellar tendon. Therefore, in addition to detailed instructions on the techniques of fitting and alignment, a considerable amount of reference information is presented concerning the associated areas of anatomy, biomechanics, human locomotion, and prosthetic-medical problems. This information is vital to a clear understanding of the functional advantages and limitations of this prosthesis.

In past years, there have been many differences in the techniques used for fitting the below-knee stump with a weight-bearing socket, particularly in the manner in which the body weight was supported. Some of the common methods evaluated in the studies which led to the development of the technique include weight-bearing on the wedge-like shape of the medial and lateral tibial flares (usually with the socket open distally), partial support through a snugly fitted leather thigh corset, and, in exceptional cases,

weight-bearing on an ischial-gluteal ring. There have been major differences in the types of material used: Sockets have been formed of hard, soft, rigid, and flexible materials either singly or in combination. In many cases the material used is the major factor in determining the type of fitting.

For the present project, the conventional fabrications of carved wood, molded leather, and laminated plastic sockets were studied. The methods used at the Navy Prosthetic Research Laboratory and the Veterans Administration Prosthetic Center and those used by Schindler, Blevins, Fillauer, and others have been evaluated carefully. No attempt will be made to describe all the techniques in use today or to discuss their relative merits. Every effort has been made, however, to become familiar with the present state of the art and to evaluate impartially each idea.

Though the principles established here should prove helpful in fitting any type of socket to a below-knee amputee, it is apparent that if the socket is to provide an efficient means of connecting the stump to a truly functional prosthesis it must satisfy certain definite requirements.

Several distinguishing features of the patellar-tendon-bearing below-knee prosthesis can be observed while the prosthesis is being worn by an amputee. Viewed from the side, the alignment of the socket over the foot is somewhat different than has been customary in the past. In order to take full advantage of the patellar tendon as a weight-bearing area and to make full use of the remaining

knee function, the socket is aligned with the knee in a flexed position and is located over the middle third of the foot. The amputee, if properly trained, is thus able to walk with his knee constantly flexed during the stance phase of each step. The customary metal side joints and leather thigh corset have been replaced by a simple cuff-type suspension strap, requiring the knee to provide lateral stability. The necessarily more intimate fit of the stump also allows the foot to be aligned more medially under the socket and permits the amputee to walk with a more nearly normal narrow-based gait during stance phase. (As a general rule side joints and thigh corset should be added to the socket only when necessary for supplementary stabilization or for occupational needs.)

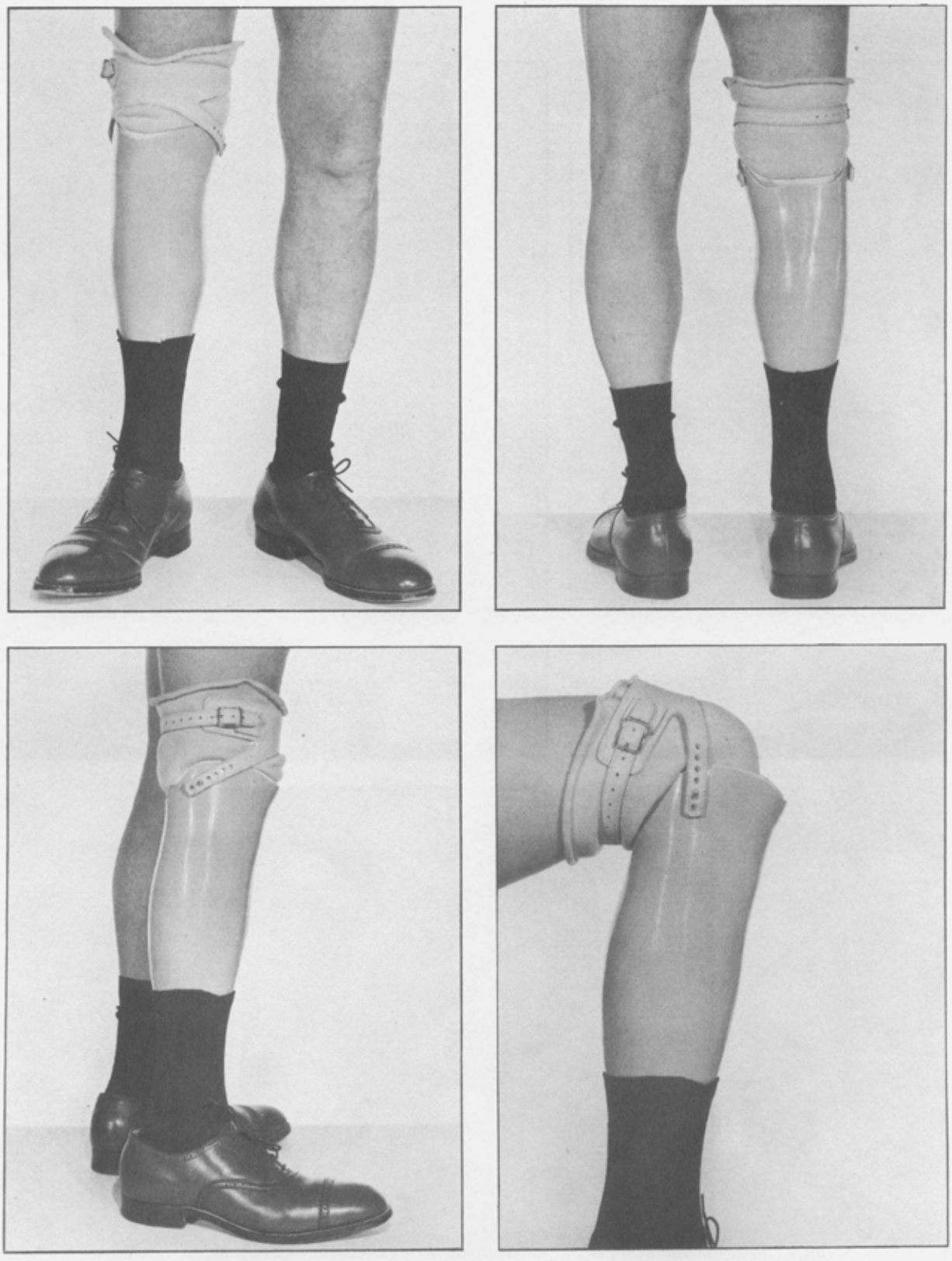
The socket of the prosthesis contains a soft insert which, when removed, discloses the protuberance in the anteroproximal socket wall that fits against the patellar tendon. The closed end of the socket provides just enough contact pressure against the distal end of the stump to prevent edema. The socket is not "end-bearing" except for stumps that have been surgically prepared for such fitting.

Experience has shown that very short below-knee stumps are well adapted to the patellar-tendon-bearing technique. The cuff-suspension system can also be used with many very short below-knee stumps if the alignment compensates for the lack of external mediolateral support.

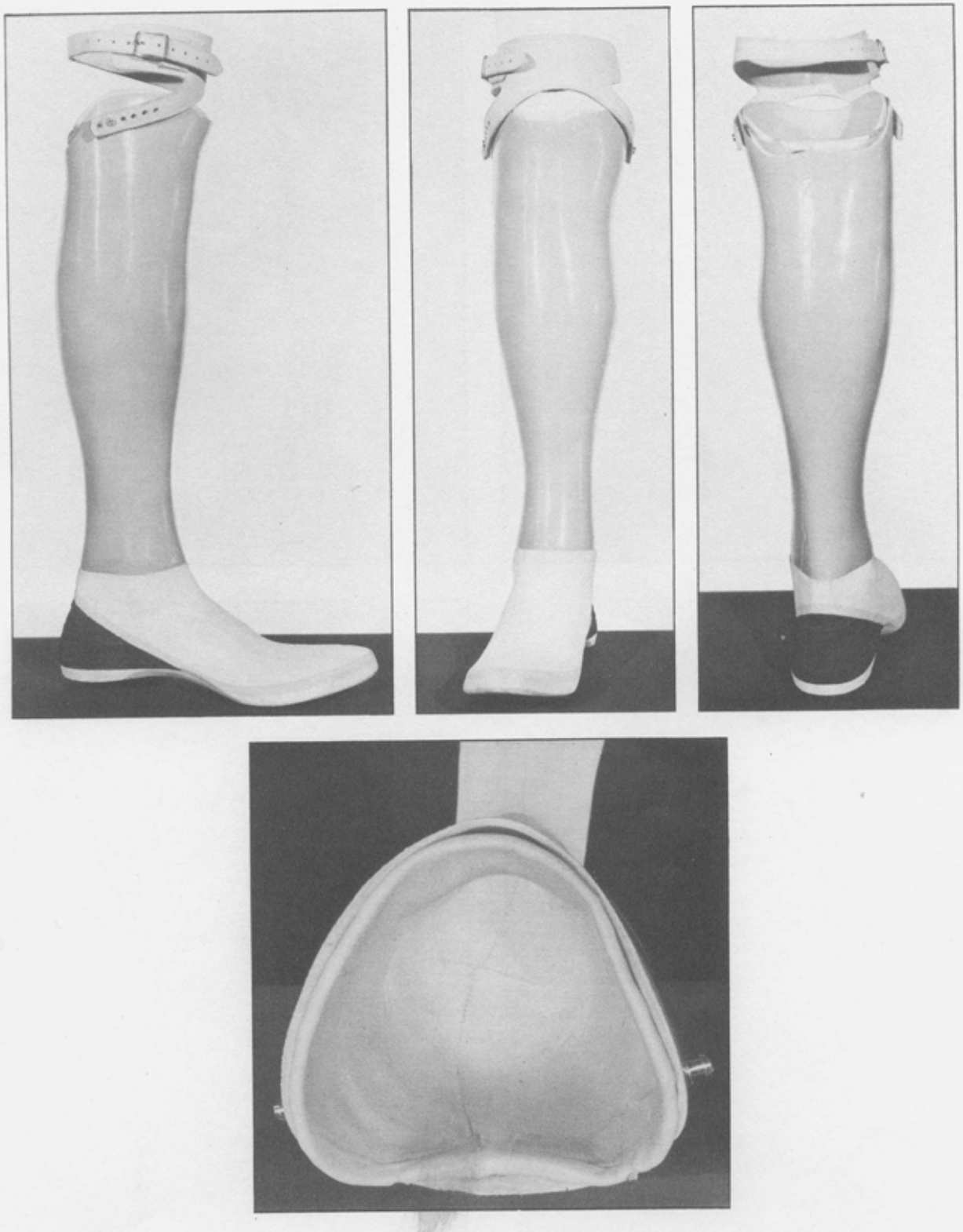
The Solid Ankle - Cushion Heel (SACH) foot is particularly recommended for use with the prosthesis.

In the years since the principles of the patellar-tendon-bearing below-knee prosthesis were first introduced in 1959, thousands of amputees in the United States and in foreign countries have been fitted with this type of prosthesis. Comfort and function have been improved, particularly with regard to a more efficient distribution of stump-socket contact pressures and control of edema through distal stump pressure. Also, this prosthesis, free of the conventional side bars with mechanical hinges, does not restrict motion of the knee.

Though the principles of this prosthesis are basically simple, it must be emphasized that a thorough understanding of the interrelationship between fitting, alignment, and suspension factors is necessary if consistent results are to be achieved in fitting a wide variety of stump conditions. Properly used, the patellar-tendon-bearing prosthesis offers a major improvement in the comfort and function that a below-knee amputee can expect from his prosthesis.



Patellar-Tendon-Bearing Cuff-Suspension Below-Knee Prosthesis



Patellar-Tendon-Bearing Cuff-Suspension Below-Knee Prosthesis

PRESCRIPTION CRITERIA

A wide variety of amputees can wear the patellar-tendon-bearing cuff-suspension prosthesis. In centers where this prosthesis is preferred, few amputees have been found to require other types. This fact suggests that criteria for its use may be easier to define through examination of the conditions with which it is definitely contraindicated. Discussion of these conditions and of "borderline" conditions will be presented in this chapter under the general headings of control, weight-bearing, and acceptance. It will be seen that successful application of the patellar-tendon-bearing cuff-suspension prosthesis depends on how well the amputee can control the prosthesis, whether he can bear weight on his stump, and how he accepts the functional differences from a prosthesis he has previously worn. Ability to control the prosthesis is related to the amount of stump available for leverage, the condition of the stump musculature, and neuromuscular function. Weight-bearing ability is related to such factors as strength of bone, joint function, presence or absence of pain, condition of skin in weight-bearing areas, and vascular state. Acceptance depends on the amputee's motivation and his activity level.

Control

To use the patellar-tendon-bearing cuff-suspension prosthesis

with best results, the below-knee amputee should have at least 2" of tibia below the most prominent point of the tibial tubercle. For amputees with shorter stumps, this prosthesis can be tried for a reasonable period of time and then converted to another type if necessary. Often, considerable pressure can be tolerated on the end of a shorter stump, especially if the amputation has been done through cancellous bone.

In some cases, muscular control may not be great enough to make use of this prosthesis advisable. Lack of control may be due to general weakness, such as is seen after a long convalescence, or to weakness of a particular muscle or muscle group. General weakness is not, in itself, sufficient contraindication, since the amputee's strength can be built up over a period of time. Weakness of musculature controlling the knee is not a serious problem if the muscles can be strengthened by use; in fact, this prosthesis can be an effective part of treatment, even when some mediolateral knee instability is involved. However, when mediolateral instability is extreme, use of this prosthesis without side joints is contraindicated. Physical therapy may correct the condition enough to allow use of the cuff-suspension system, or cuff suspension can be used for a time with the aid of crutches or a cane, but a prosthesis that provides bracing against the thigh will usually be more serviceable and will allow enough movement of the joint mediolaterally to exercise muscles which stabilize the knee.

Flexion-extension instability does not contraindicate use of

this prosthesis, provided hip control is good. Aided by the alignment, the amputee can maintain balance over the prosthesis to control knee action. That control can be achieved in this way has been borne out by experience with amputees who, because of extremely short stumps or other conditions which reduce effective stump length, had little potential for flexion-extension control. Again, the therapeutic value of the prosthesis should not be overlooked.

The condition of the nerve supply to the stump must also be considered in questions of muscular control. When the distal portion of the stump is anesthetic because of nerve damage, a corset and side joints will help mediolateral stabilization and transfer proprioception to the thigh. However, this may not be necessary if the stump is long enough to insure mediolateral stability of the prosthesis on the stump and if there is sufficient sensation to give the amputee an awareness of the action of his prosthesis. The problem of the anesthetic stump is especially severe if the skin condition is also poor.

Sometimes the amputee may find it difficult to coordinate his motions and thus not obtain the maximum benefit from his prosthesis. Poor coordination does not, however, contraindicate its use, since, even when the amputee's motions are likely to throw high mediolateral loads on the stump, stabilization may be increased by addition of side joints and a corset to serve as a brace against the thigh.

Weight-Bearing

The patellar-tendon-bearing cuff-suspension prosthesis is

contraindicated if the stump cannot be loaded in weight-bearing because of osteoporosis of the femur or fracture of the femur. When osteoporosis is associated with disuse, conditioning the residual bony structures by application of safe loads, which are then gradually increased, will improve the chances of eventually using this prosthesis. If a fracture is present, the time which must elapse before the femur can be loaded and the degree to which loading is possible must be taken into account when planning a course of prosthetic treatment. The possibility of using the prosthesis with crutches or a cane should not be overlooked when conditioning is being considered, and thigh bracing or ischial support may also be helpful in some cases.

Certain knee-joint impairments may also make weight-bearing impossible. If the problem is joint instability, which is sometimes caused by a congenital anomaly, bracing must be used, as with side joints and corset for mediolateral stability. Once stabilized, the joint may be able to carry weight. Joint involvement which reduces range of knee motion does not contraindicate use of this prosthesis; with the recommended alignment and gait pattern, it can be good therapy, providing other prohibitive factors are not present. In cases of arthritis, there may be little hope that the joint, whether knee or hip, can be successfully loaded, either because of pain or because of the possibility of increasing joint damage. Such a condition would contraindicate use of this prosthesis.

When the problem is pain, the first consideration is whether the

condition is temporary (perhaps associated with preoperative factors). If the pain is expected to subside, prosthetic treatment should be directed toward eventual use of this prosthesis. In the case of a painful joint, even immediate use of this prosthesis is possible if crutches are also used. Pain from other sources can make weight-bearing difficult or impossible. If the pain is related to the injury which led to amputation and a change in the situation cannot be hoped for, use of this prosthesis is contraindicated. Sometimes bracing against the thigh is required to alleviate the pain. Otherwise, the stump could be fitted in anticipation of diminishing discomfort and crutches used as an aid in the meantime.

Delicate skin in weight-bearing areas is always a serious problem. Prosthetic treatment is difficult when amputation has been done because of burns and when there are delicate skin grafts in strategic areas. Sometimes disease is responsible for the delicate skin condition; for instance, the skin may be poorly nourished because of vascular insufficiency. In this case, use of a prosthesis will often stimulate circulation and restore the skin to a healthier condition, provided forces are within tolerable limits. Use of the prosthesis must be closely supervised until a more rugged status is established for the skin. Bracing against the thigh may help reduce motion during weight-bearing on the prosthesis, but its advantages are lost if relative motion is introduced during swing phase or there is constriction during sitting.

The whole problem of vascular involvement and prosthetic treat-

ment still needs much consideration. It is apparent, however, that prosthetic treatment should help stimulate circulation distally and not cause constriction proximally; this requirement is provided by the patellar-tendon-bearing cuff-suspension prosthesis. Therefore, it has a place in the treatment of amputees with vascular insufficiency. If the blood supply to the stump is known to be partially obstructed, however, use of this prosthesis is contraindicated. When circulation is, for any reason, obstructed after the amputee begins wearing his prosthesis, he will experience pain and numbness and, when the prosthesis is removed, his stump will feel cold. It is not easy to decide what to do in such a situation; support at the ischial level may be the only solution.

Acceptance

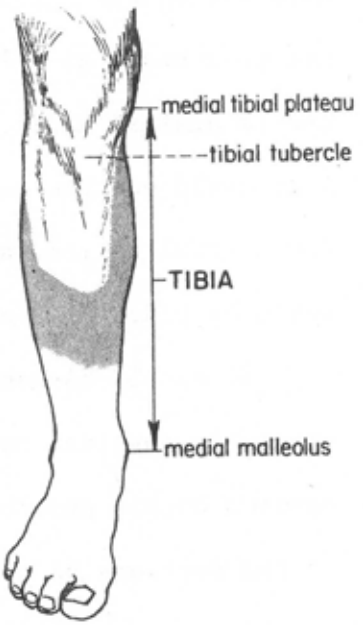
If an amputee makes it clear that he prefers a specific type of prosthesis, it is sometimes better not to go against his wishes. He may have worn a corset type of prosthesis successfully for years and wish to avoid the problems of changing, i.e., new habits to form, socket adjustments and replacements to take care of stump changes, and time of adaptation. He should be shown the advantages for him of the patellar-tendon-bearing cuff-suspension prosthesis, and he should see other amputees wearing this prosthesis. He can be assured that, if the prosthesis is unsatisfactory with cuff suspension, it is a small matter to add a corset and side joints. A recent amputee will usually have a more favorable attitude than one who has worn other prostheses over a period of time.

For the very active amputee, freedom from the corset gives a sense of relief comparable to a change from heavy boots to light shoes. However, the amputee who does heavy manual labor may prefer to have a prosthesis with corset and side joints, at least for the work situation. It is not uncommon for a below-knee amputee to use his prosthesis as a lever. Also, the side joints stabilize the prosthesis against axial rotation when the amputee kneels. Such a subject could use the patellar-tendon-bearing cuff-suspension prosthesis for a trial period, and then, if necessary, the corset and side joints could be added or a second prosthesis could be provided for work.

It should be kept in mind that conditions which decrease an amputee's physical capabilities also result in his making fewer demands on his prosthesis. Therefore, some of the factors described in the sections on control and weight-bearing may be found, through experience, not to contraindicate use of the patellar-tendon-bearing cuff-suspension prosthesis.

ANATOMY OF THE BELOW-KNEE STUMP

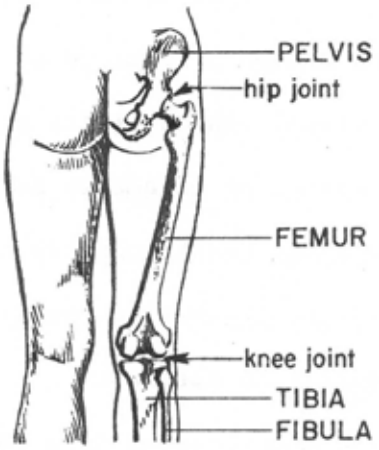
A below-knee amputation leaves a functioning knee joint and as much tibia as medical considerations permit. Amputation at the level of the lower border of the tibial tubercle leaves intact nearly all the structures which directly involve the knee joint. Amputation which leaves more than half of the tibia is avoided by many surgeons in the belief that circulatory disturbances may result.

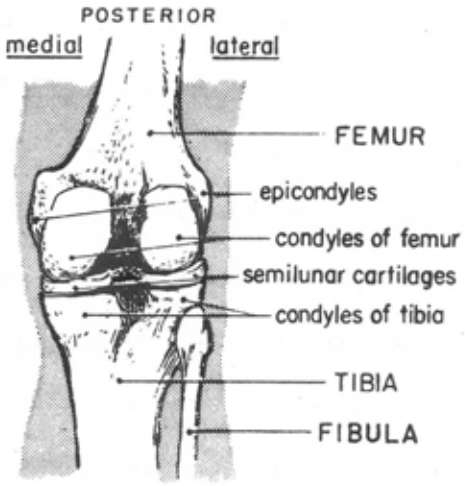


The knee joint functions primarily in a parasagittal plane in which extension (straightening) and flexion (bending) of the knee occur. The joint surfaces, ligaments, and muscular attachments provide considerable mediolateral stability while allowing a flexion-extension range of about 160°.

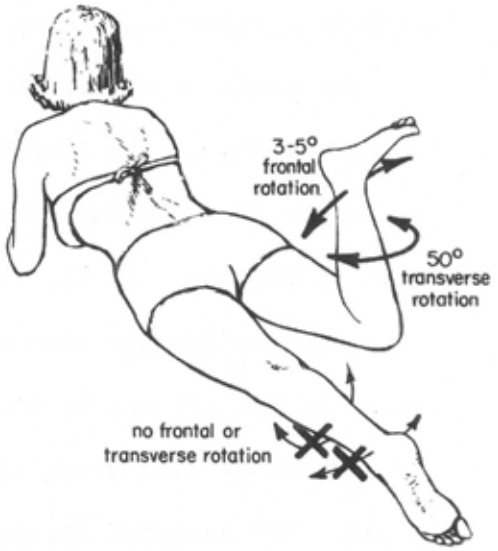


The thigh bone, or femur, flares distally to form two bearing surfaces: an outer one, the lateral femoral condyle, and an inner one, the medial femoral condyle. At the side of each femoral condyle is a rounded prominence, the epicondyle. The diameter of the knee is greatest at the level of the epicondyles. Each of the femoral condyles rides on a concave pad of cartilage which rests on the surface of a corresponding medial and lateral condyle of the tibia. The articulating surfaces of the femur and tibia are encapsulated by a synovial membrane which secretes the lubricant for the joint.

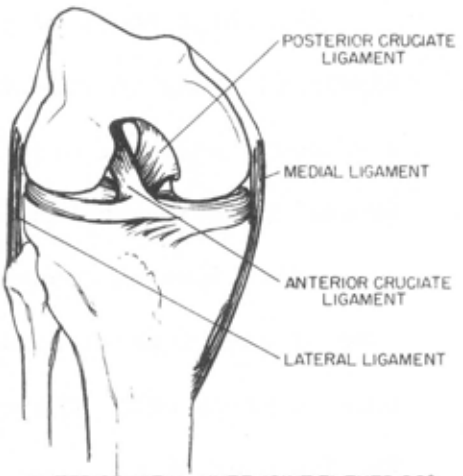




When the knee is sharply flexed, about 50° of transverse rotation between the tibia and femur are possible; as the knee is extended this range is reduced, and when the knee is locked in full extension no rotation can occur. Rotation in the



frontal plane is similar, although the motion is limited to a few degrees. These limits are set by a system of ligaments arranged to hold the joint together as the knee assumes its varied positions and engages in actions.

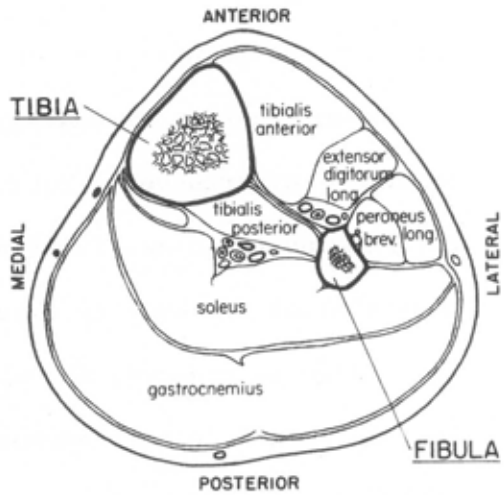


ANTERIOR VIEW - KNEE JOINT FLEXED 90°

Knee-bearing is a commonly assumed human posture. Like other weight-bearing areas, such as the heel and the region around the ischial tuberosity, the front of the knee consists of relatively insensitive bony prominences, tough ligamentous and tendinous structures, and a strategically located fat pad which contains a dense supporting structure.



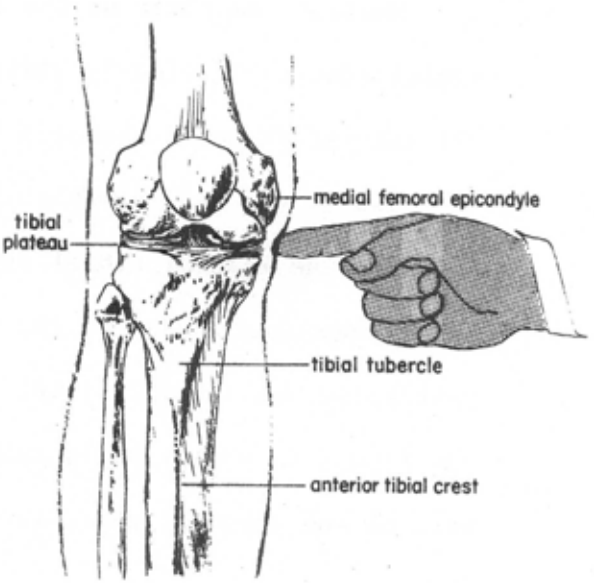
The shaft of the tibia is roughly triangular in section, with one corner of the triangle at the front of the leg. In the intact leg this edge, called the shin or tibial crest, is not covered by muscle or fat and can be felt along its entire length. The muscular atrophy which

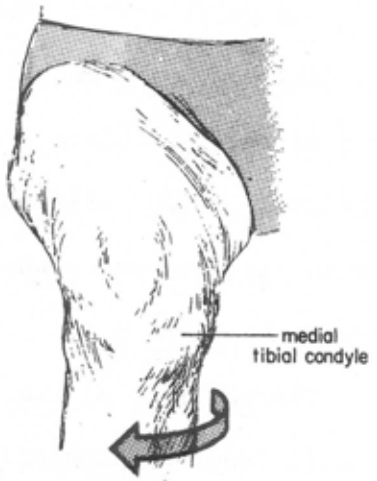


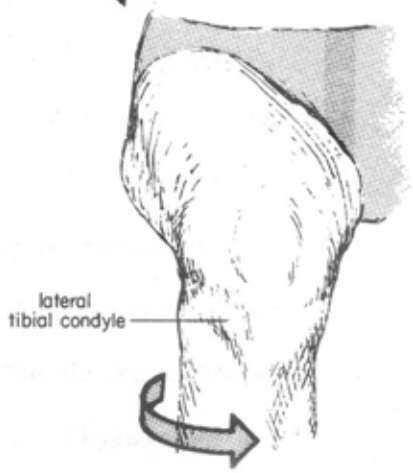
CROSS SECTION ABOUT 4" DISTAL TO TIBIAL PLATEAU

follows amputation accentuates the prominence of the sensitive ridge. The tibial crest terminates near the knee in the rounded prominence called the tibial tubercle. At the same level, the tibial shaft flares medially and laterally to buttress the condyles which support the femur. The relatively flat bearing surfaces of the condyles are referred to as "plateaus." The location of the medial plateau can be felt as a depression about 3/4" below the femoral epicondyle. The lateral tibial plateau can be palpated less distinctly, because of denser surrounding structures, at about the same level on the lateral side.

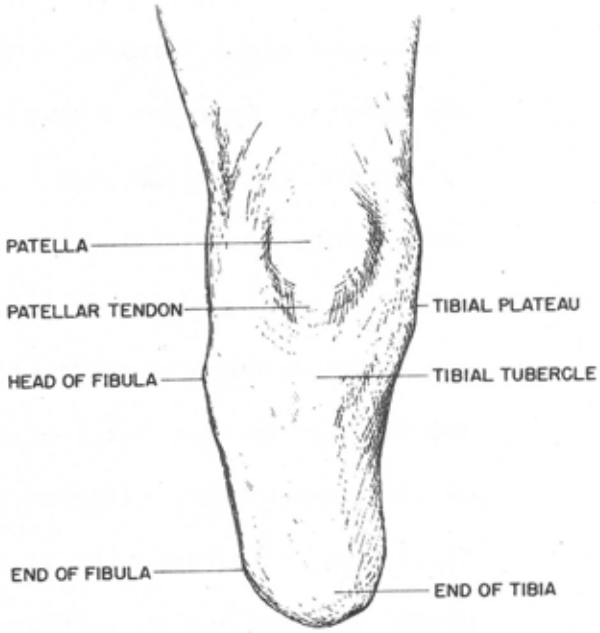
Palpation of the tibial plateau is facilitated by flexing the knee 90^{o}. If the tibia is then rotated outward, the medial condyle becomes prominent; conversely, internal tibial rotation results in a prominent lateral condyle.





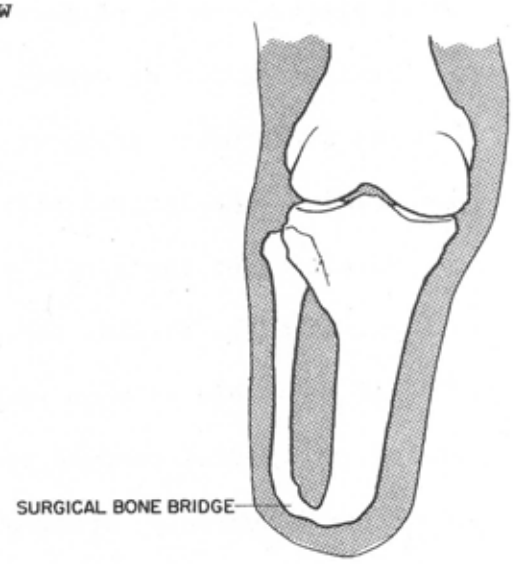


Whereas the flare of the medial tibial condyle is clearly visible, the lateral flare is obscured by the fibula, the head of which is bound to the lateral tibial condyle, and by muscular tissue in the space just below the lateral tibial condyle. The fibula is occasionally removed as part of the surgical amputation procedure.



The shaft of the fibula parallels the tibia downward but is usually cut shorter than the tibia at the time of amputation. (In child amputees, a faster growth rate may cause the fibula to grow beyond the tibia.)

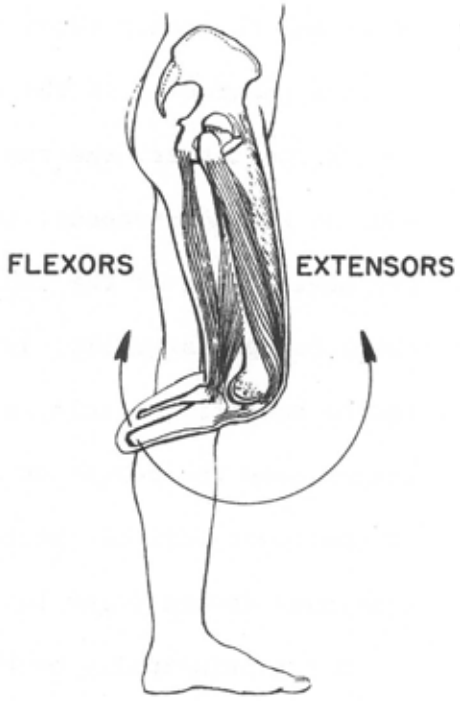
The mobility of the fibula which results from the amputation of its distal attachment to the tibia is sometimes prevented by a natural or surgical bone bridge.

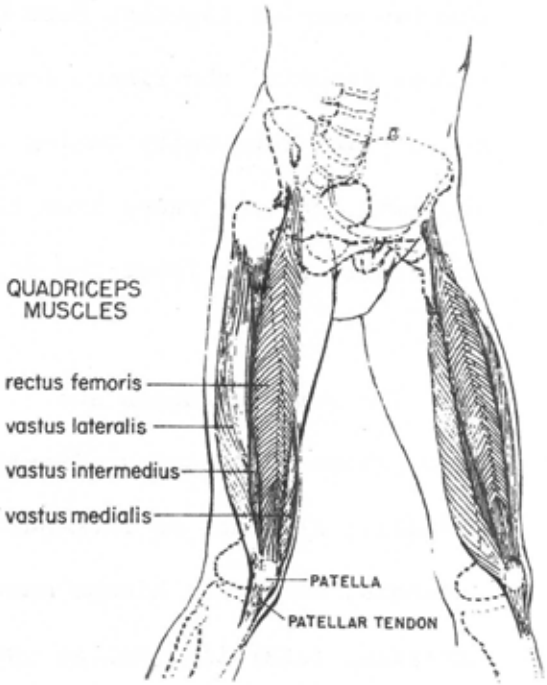


Since flexion-extension is the principal action of the knee, most of the muscles which act on the knee joint can be classified as either

flexors or extensors.

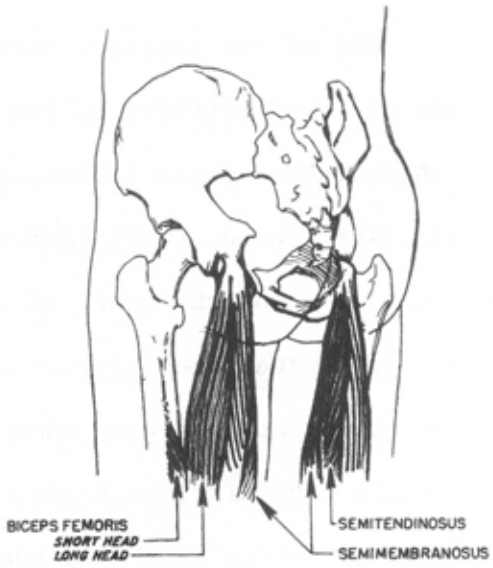
All of the extensor muscles are attached distally to the tibial tubercle by a thick tendon, the patellar tendon, to the underside of which is bound the flat, circular patella. The extensors are called the quadriceps, because there are usually four distinct heads or origins. Three of these, the vasti, arise from the femur and are named, according to their locations, the vastus lateralis, on the outside, the vastus medialis, on the inside, and, between these, the vastus intermedius. The fourth head, the rectus femoris, originates on and around the anterior inferior iliac spine of the pelvis and passes down the thigh over the vastus intermedius, to which it becomes fused near or at the tendinous insertion on the patella.

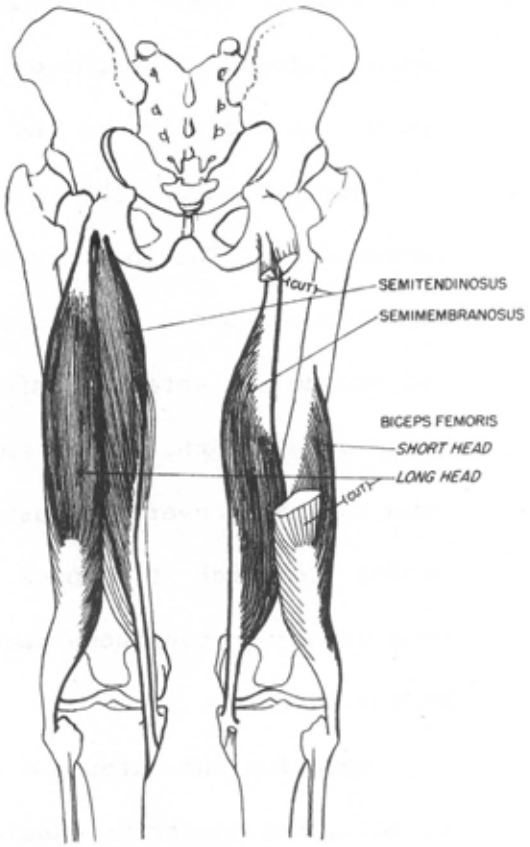




Opposing the extensors are the flexors, the hamstring muscles, which

also have four origins--one on the femur and the other three on the ischial tuberosity of the pelvis. Two of the latter, the semitendinosus and the semimembranosus, insert on the medial side of the tibia. The third swings laterally, joins the fourth hamstring muscle, which arises from the posterior aspect of the lower part of the femur, and continues downward and laterally to insert principally on the head of the fibula. Fusion usually occurs at or before the insertion; the two muscles together form the biceps femoris, the fibers from the ischial tuberosity making up the long head and those from the lower part of the femur the short head.

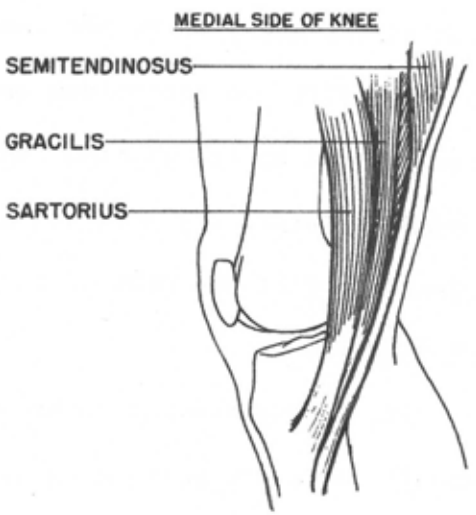




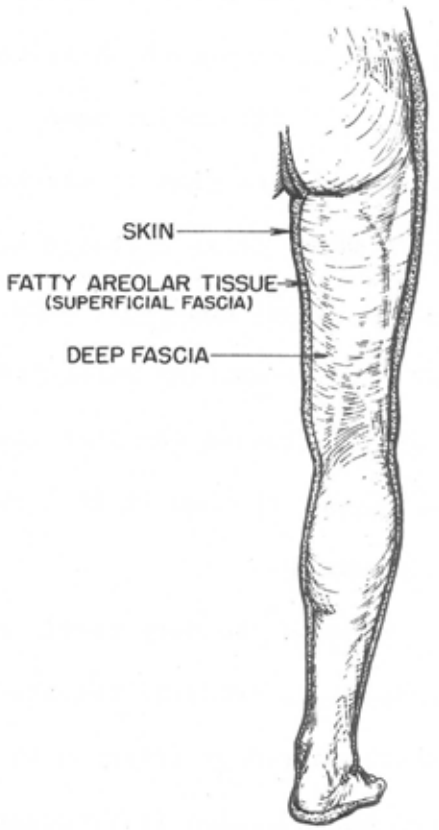
The semitendinosus and semimembranosus muscles, inserting medially, also act as internal rotators, while the biceps muscles, inserting laterally, act as external

rotators of the knee.

Additional internal rotators from the pelvis are the sartorius from the anterior superior iliac spine and the gracilis from the pubic ramus. The tendons of these two muscles join the tendon of the semitendinosus at the knee joint and wrap around and insert on the medial tibial flare. The semimembranosus, which lies under the semitendinosus, inserts at the posteromedial corner of the tibial condyle.



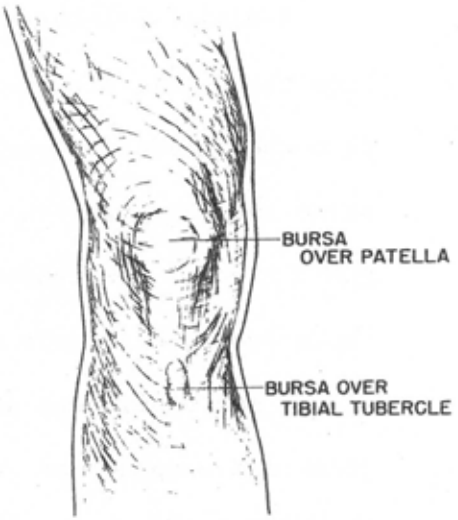
Sheathing the musculoskeletal system like a stocking is the deep fascia, a thin, tough membrane through which are numerous small openings for the nerves, blood vessels, and lymphatics which serve the overlying tissues, including the skin. The fascia is a continuous system, with connections with periosteum and with ligaments. This is particu-



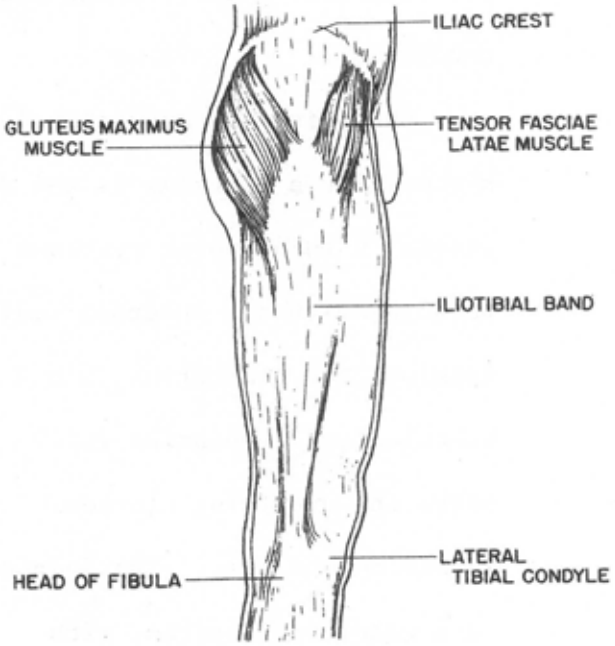
larly evident at certain joints, such as the knee, where the fascia is fused with the periosteum and strengthened by fibers from tendons. A band of fascia may even act as a ligament, or it may provide tunnels for long tendons.

The tensor fasciae latae muscle, from the anterior portion of the pelvis, and most of the gluteus maximus muscle, from the posterior portion of the pelvis, insert into the lateral fascia which is thickened to form the iliotibial band. This broad tendon extends to the knee joint, where it is attached to the lateral tibial condyle. Thus, this band and the muscles connected with it aid in flexing the knee and in stabilizing it when it is locked in extension.

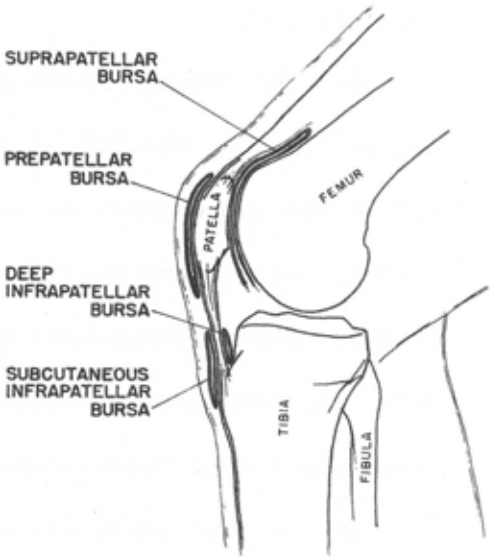
Outside the deep fascia are subcutaneous synovial bursae, closed sacs which reduce friction in those areas where motion is frequently



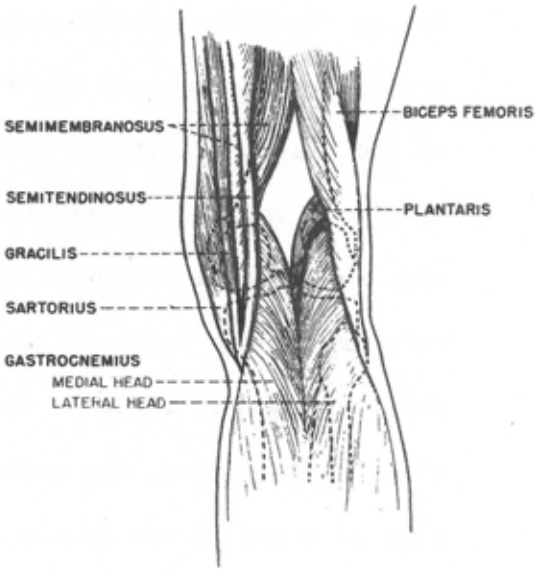
FASCIA AT KNEE — ANTERIOR VIEW



accompanied by pressure, as where a tendon moves directly over a bone. If they are injured, they are unable to tolerate even light pressure. The bursa over the tibial tubercle is a frequent source of difficulty.



Another flexor of the knee joint is the intact gastrocnemius muscle, which originates by a head from each of the femoral condyles and normally inserts by way of the Achilles tendon in the heel bone or calcaneus. When this insertion is removed by amputation, the cut end of the muscle or tendon fuses to the fascia at the site of amputation and the remaining muscular tissue continues to act as a knee flexor.

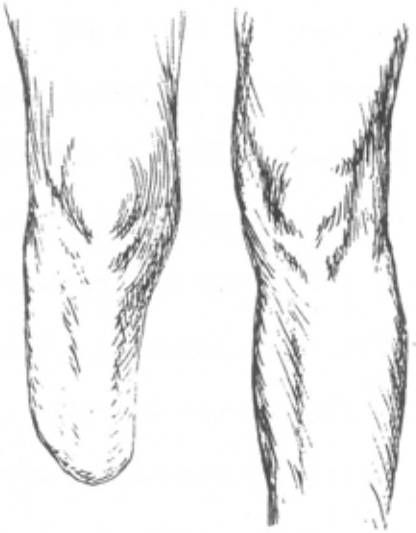


The plantaris muscle, if present, is embedded on the medial head of the gastrocnemius and presumably functions in a similar way.

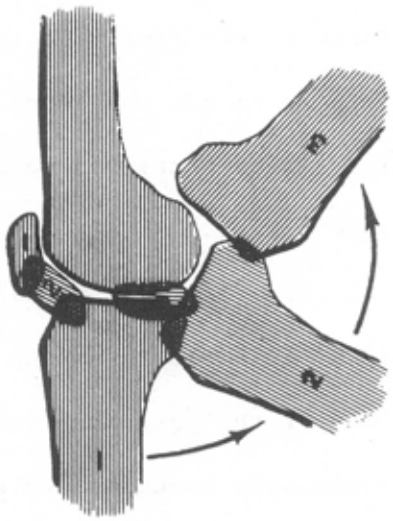
Another minor muscle, the popliteus, a medial rotator, is

not affected by the usual below-knee amputation.

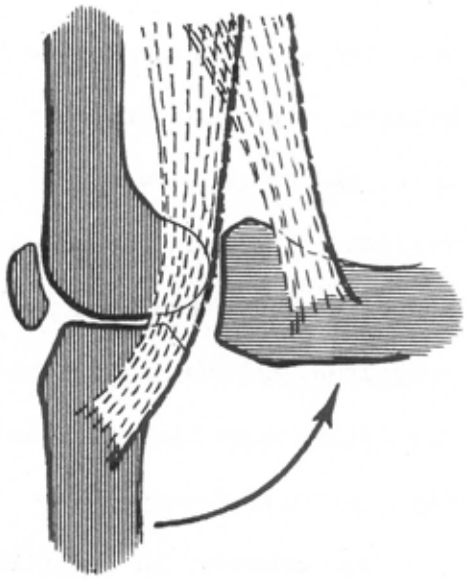
All the muscles which originate on the tibia or the fibula normally act on the ankle joint or other foot joints, and, consequently, they atrophy after a below-knee amputation. Thus, the nonedematous below-knee stump has a bony appearance.



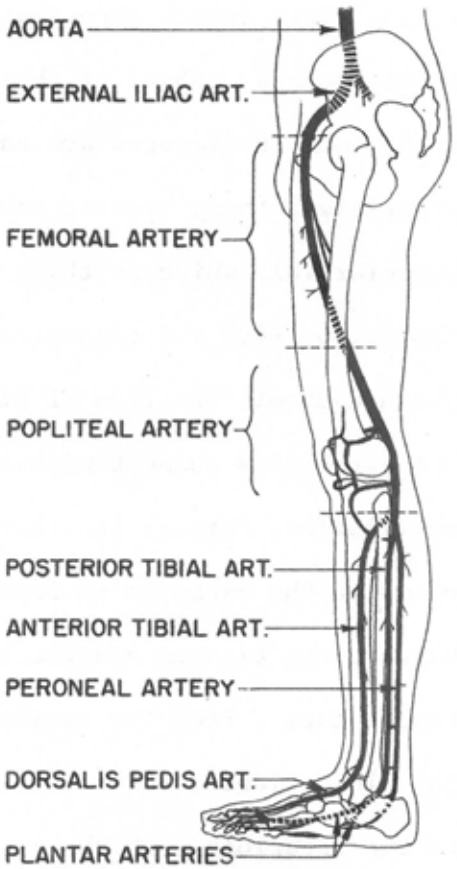
As the knee angle varies during flexion and extension, there are four major influences on the change in contours. Grossly, there is a change in the angle of thigh and leg as the tibia rotates around the femur. Because of the clubshape of the distal end of the femur, the effect of femoral rotation is to move the femoral condyles posteriorly relative to the front of the tibia. When the knee is extended with the quadriceps relaxed, the patella lies on a pad of fat at the front of the knee joint; with flexion, the quadriceps is stretched and



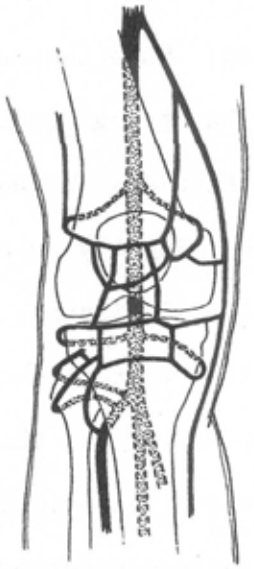
the patella is pulled into the groove between the femoral condyles. When the knee is extended, the hamstring tendons inserting at the sides of the tibia appear to be slightly anterior to the soft popliteal tissues, but, as the knee is flexed, the insertions are moved posteriorly and the tendons appear to swing posteriorly, increasing the anteroposterior diameter of the knee joint. The increase is more marked on the medial side, because the insertion of the semitendinosus is more distal than that of the biceps.



The blood supply for the greater part of the lower limb passes through a large artery which traverses the femoral (Scarpa's) triangle just under the skin, courses between the muscles on the medial side of the femur, and then passes behind the bone to cross the popliteal region, at the lower border of which the

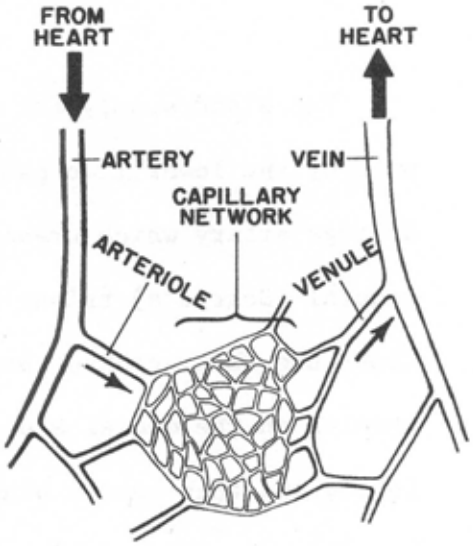


artery divides to form one anterior and then two posterior branches. Smaller branches carry the blood to various regions. The branches immediately above and below the knee are interconnected, so that circulation is maintained when knee flexion pinches the popliteal artery.



GENICULAR BRANCHES OF POPLITEAL ARTERY
ANTERIOR VIEW — SCHEMATIC

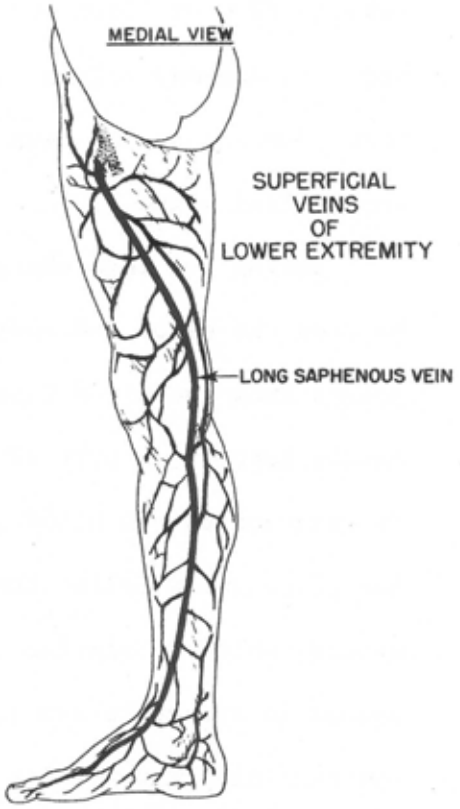
The arteries in the limbs have a thick muscular layer in their walls. They branch into smaller and smaller tubes. Those of about 0.3 to 0.1 mm. in diameter are called arterioles; these vessels have a muscular wall which is thick in comparison with the channel and which controls the flow of blood. The arterioles connect with the capillaries, through the thin walls of which the exchange of materials between the tissues and the blood takes place. From the capillaries the blood flows into venules, similar to the arterioles, which, in turn,

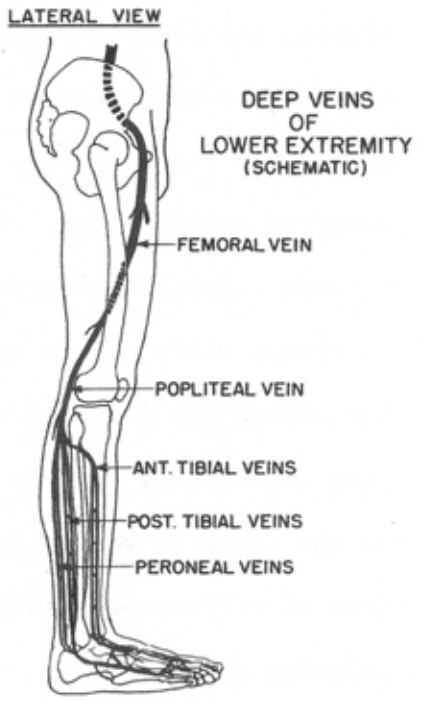


combine,to form larger veins which carry the blood toward the heart.

There are two systems of veins that return the venous blood to the heart. One, called the deep system, accompanies the arterial system. The other, called the superficial system, returns the blood from outside the deep fascia. Most of the blood supply to the skin and subcutaneous tissues is provided by small arteries branching from the arteries which supply the muscles, and the greater part of the venous return from these tissues is carried out by the superficial system of veins. In the leg, the regional branches drain into the great and small saphenous veins, which are located along the medial and posterior surfaces of the lower limb.

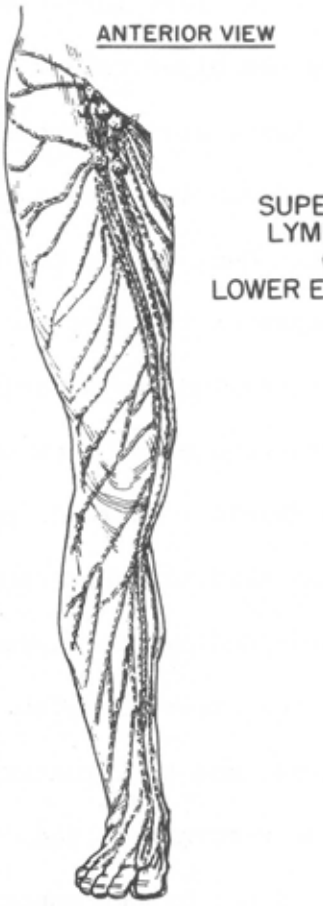
Maintenance of flow through the veins of the lower limb depends in great part on the squeezing action of the adjacent muscles. An important factor in preventing





reverse flow of blood is the presence of numerous one-way valves, which are more abundant in the deep than in the superficial veins.

During the interchange of materials between the blood and body cells, water passes from the blood faster than it passes into it; a part of this water is returned to the blood through a set of channels called the lymphatic system, which is similar to the venous system in structure and location. When the remaining water fails to return to the blood at the same rate at which it crosses the capillary walls from the blood, it accumulates in the spaces around the tissue cells, producing a swelling called edema. Causes of edema include increased permeability of the capillary walls and an impairment in the mechanisms for removing water from the tissue, such as obstruction in the lymph or venous system, breakdown of valves, or insufficient muscular action.



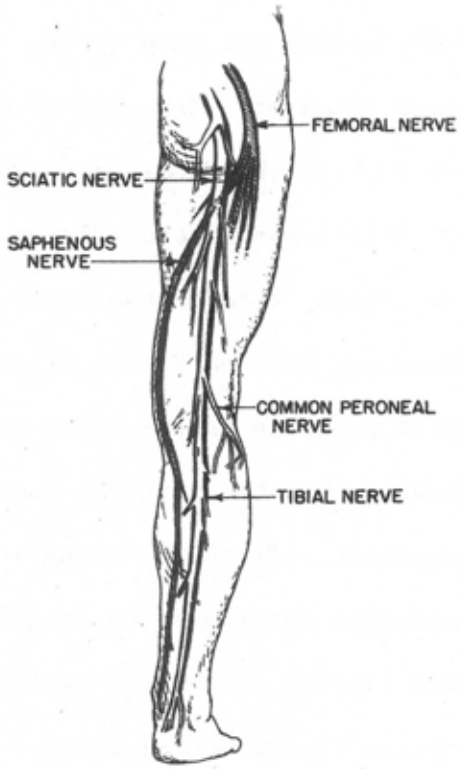
SUPERFICIAL LYMPHATICS OF LOWER EXTREMITY

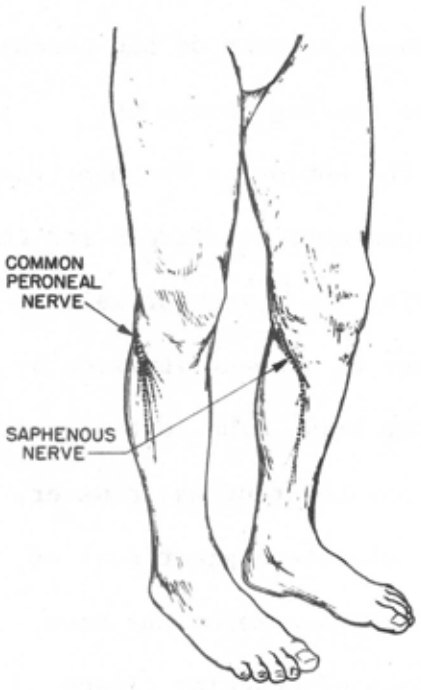


Two principal nerve trunks enter the thigh, the femoral nerve anterior to the femur and the sciatic nerve posterior to the femur. The femoral nerve splits into a number of branches, most of which serve the anterior muscle and overlying skin of the thigh. One branch, the saphenous, extends past the knee joint, where it is subcutaneous on the medial condyles of the femur and tibia.

The sciatic nerve is deeply embedded in the posterior muscles of the thigh and leg, but one major branch, the common peroneal nerve, passes anteriorly over the distal part of the head of the fibula, where, like the saphenous on the medial side, it is subject to injury and irritation.

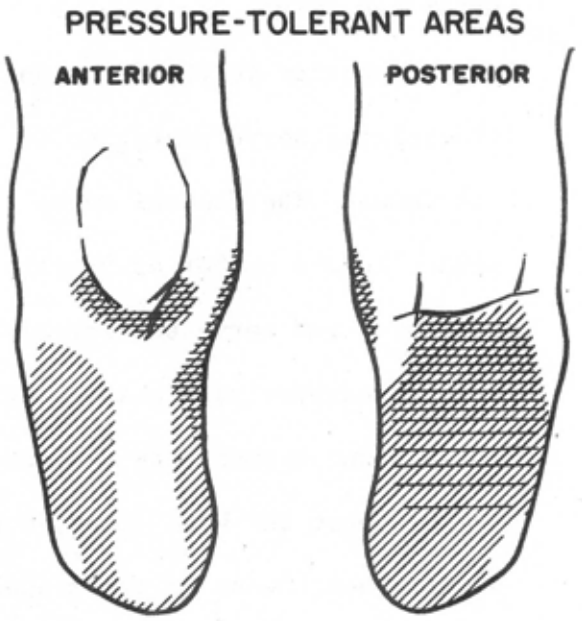
If the weight-bearing capacity of the stump end is somewhat limited, the prosthesis must be designed to place a major portion

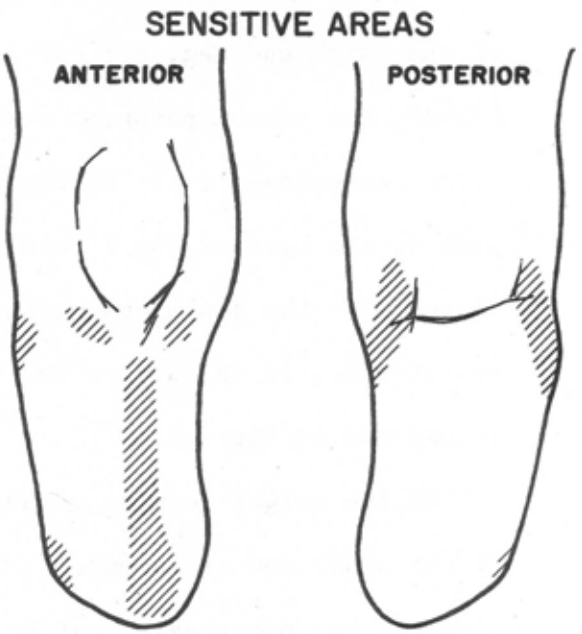




of the supporting loads on structures around the knee joint. The areas which are adaptable to weight-bearing are the patellar tendon and the medial and lateral flares of the tibia. Because the flare surfaces are oblique to the floor, the total pressure on them must be greater than the vertical support component. Pressure on the saphenous nerve must be avoided when fitting around the posterior portion of the medial flare. The head of the fibula cannot take pressure because of the peroneal nerve passing around it.

The motion of the hamstring tendons must be allowed for in fitting the posterior wall of the socket to prevent abrasion by the socket brim. The soft tissues between the tendons, however, can tolerate a great deal of distortion. Below the knee, atrophy of muscular tissue





permits a stable fit of the prosthesis to the stump with a minimum distortion of the soft tissues.

BIOMECHANICS OF BELOW-KNEE PROSTHESES

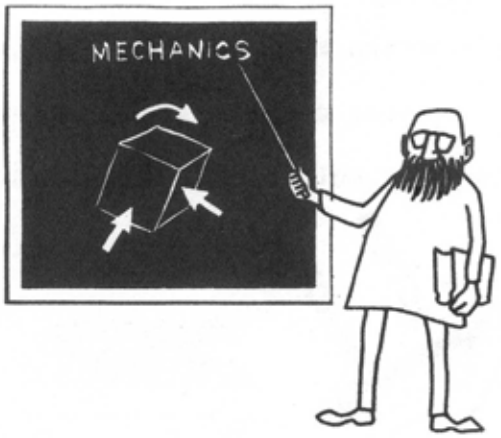
Introduction

The fitting of a prosthesis to an amputation stump involves the fabrication of a receptacle for the stump. This receptacle, or socket, to which the remainder of the prosthesis is attached, is perhaps the most important single component of the prosthesis. The socket is not a simple female duplication of the stump shape into which the stump "fits"; rather, its contours must be designed to provide a comfortable and functional connection between the stump and the prosthesis under the conditions of dynamic loading that exist when the prosthesis is in use. The socket will not provide an optimum connection unless the contact forces and pressures between stump and socket have been anticipated prior to fitting and unless proper shaping of the socket has been planned and carried out.

The purpose of this chapter is to show how techniques of biomechanical analysis can be used to gain a better understanding of typical problems of fitting the socket and aligning below-knee prostheses. After a discussion of certain principles of mechanics, analyses will be presented of normal level walking, knee action in amputee gait, and stump-socket pressures.

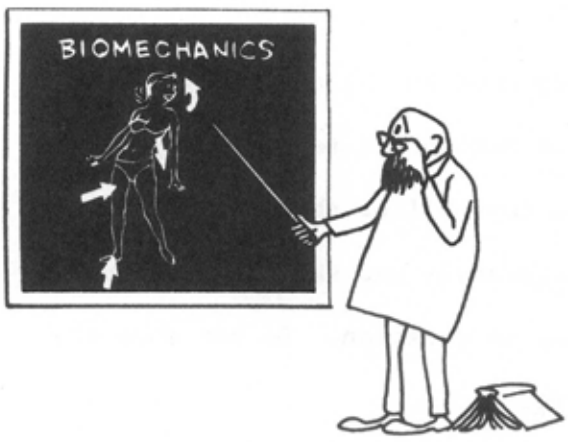
Principles of Mechanics

Much of this discussion deals with the analysis of contact forces between stump and socket under various conditions. At this point, therefore, definitions of certain principles and terms used in the branch of physical science known as mechanics will be useful:



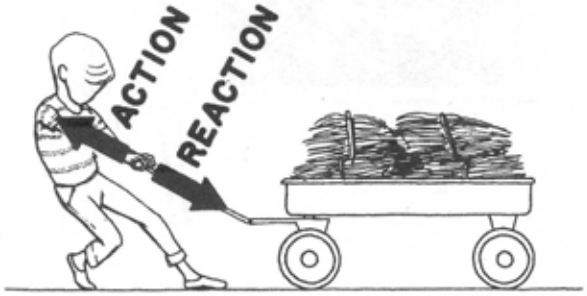
Mechanics itself deals with the action of forces on material bodies.

Biomechanics deals with the action of physical forces on the human body and of those exerted by it. This definition could be broadened to include studies of many other factors which influence the behavior of the musculoskeletal system, such as electrical activity within muscle, external pressures that result in skin changes, energy cost of locomotion, and motion patterns of the extremities as studied by kinematic analysis.



Force is an action of one body on another that tends to change the state of motion of the second body. More than one body is always involved when a force is discussed. Forces between bodies always exist in pairs. This is Newton's third law of motion: "To every action force there is an equal and opposite reaction force."

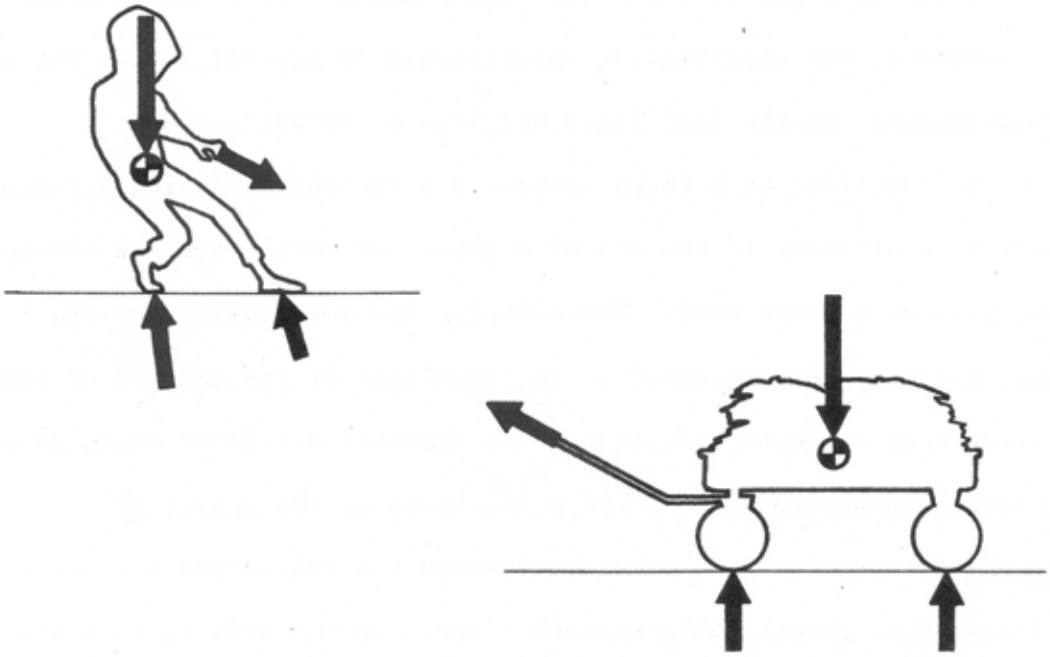
In some cases we are more consciously aware of the action, as when a boy pulls a wagon. In other cases, the reaction is more





evident, as in the propulsion reaction of a jet engine. It is often convenient in analyzing forces to look at the action and reaction separately.

The free body diagram is widely used in engineering analysis as a means of showing the effects of action and reaction separately. Consider again the situation of the boy pulling the wagon. Now draw each of the physical bodies separately and show on each body only the forces that act on the body in question. Do not show the force applied by the body in question.



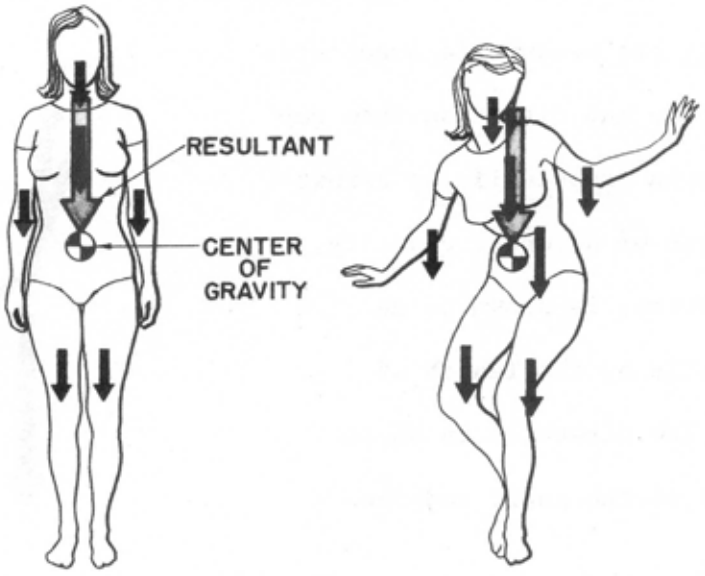
This technique of isolating a body from its surroundings and showing the forces exerted by the surrounding bodies leads to the so-called free body diagram. This technique will be used in this manual for the analysis of stump-socket contact forces.

Vectors are measurable quantities with magnitude and direction that may be represented graphically by arrows. The magnitude of a vector quantity, such as a force, is shown to an arbitrary scle by the length of an arrow. The direction is shown by the line of the shaft and the arrowhead.



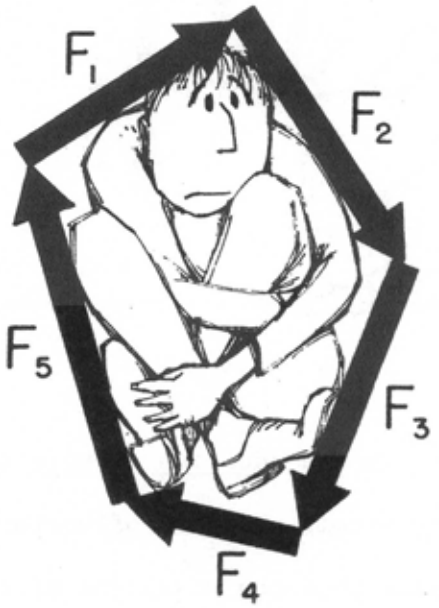
If the concepts of the force vector and the free body diagram are combined, the quantitative relationship of several forces acting simultaneously on the same rigid body can be investigated.

The resultant of a force system is a hypothetical single force which is equivalent to the sum of a number of forces applied simultaneously to a given body. For example, the total weight of the human body may be considered as the resultant of the weights of the various body segments and, thus, as a hypothetical force which acts vertically downward through the point known as the center of gravity (that point in a body about which the forces and moments of all its parts exactly balance each other when the body is in a state of equilibrium). Note that the position of the center of gravity varies slightly as the relative position of the extremities are changed.

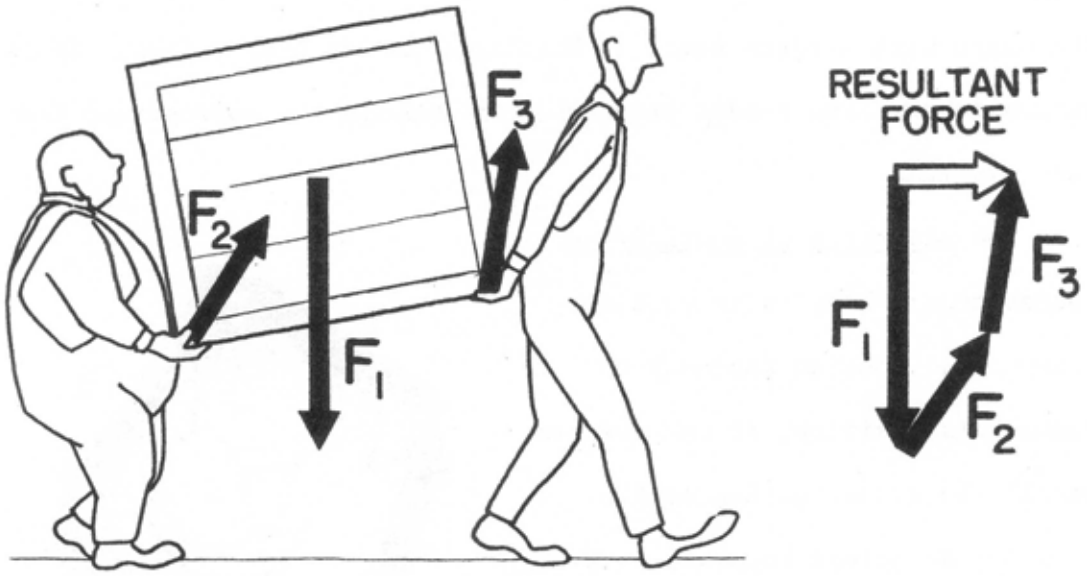


The weight of any material body is one of the pair of forces of attraction between that body and the earth. A human being attracts the earth with a force equal in magnitude to his body weight. It is suggested that the reader prove this by drawing the appropriate free body diagrams.

The principle of equilibrium states that a body is in equilibrium, i.e., has no tendency to change its position, if the vectors of all the forces acting on the body may be joined together to form a closed polygon. This shows that the forces are in balance; the resultant of the forces is zero. In analysis of certain prosthetics problems the inverse of this principle is often used. That is, if a body is known to be in equilibrium, the requirement that the force polygon be closed is helpful in solving for an unknown force.



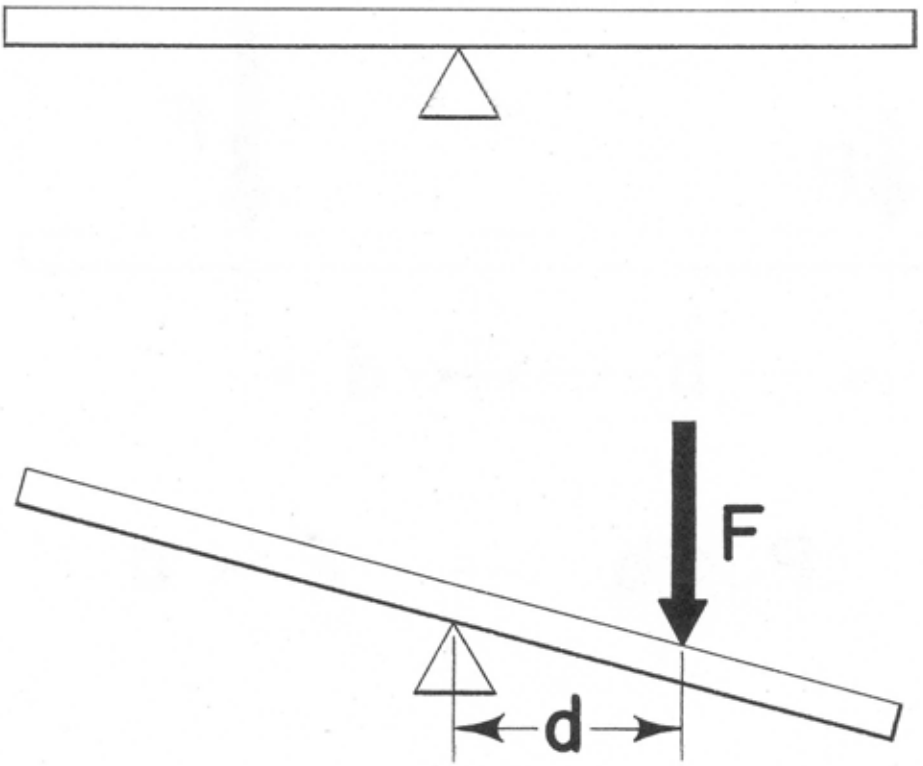
In the addition of two forces to find their resultant, the parallelogram method is often used. Draw two force vectors to scale from a common origin. Consider the vectors as adjacent sides of a parallelogram and complete the parallelogram. The diagonal of the parallelogram is the resultant of the two given forces.



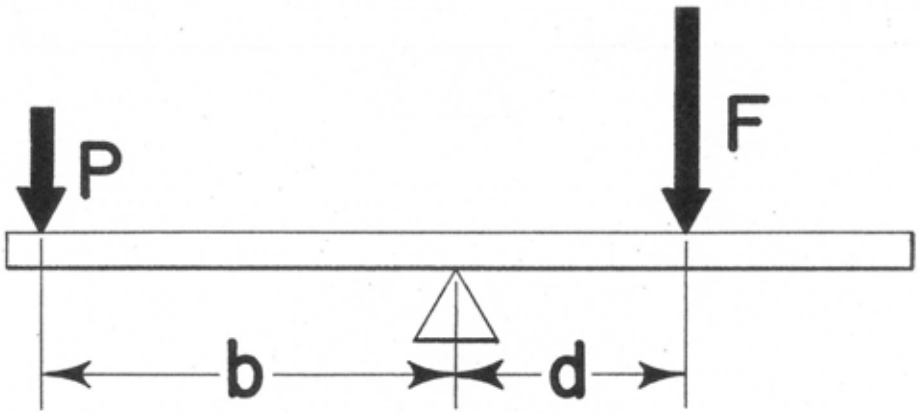
In the addition of more than two forces the polygon method, or tip-to-tail addition of vectors, is more convenient. For example, assume that the resultant of three forces acting on a box, as shown in the figure, is to be calculated. By tip-to-tail addition it is possible to find the single resultant force, the force that has the same effect on the box as a whole as the combination of the three forces acting simultaneously.

The moment of a force is the tendency to produce rotation of a body about a reference point. Its magnitude is the product of the force times the perpendicular distance from the line of direction of the force to the reference point.

Consider a bar originally balanced on a fulcrum. If a certain



force F is applied at distance d, the bar rotates clockwise. If either the force F or the distance d is increased, the tendency to rotate is increased proportionately. If the force is measured in pounds and the distance in feet, the moment is expressed in lb.-ft., clockwise.



$$P \times b = F \times d$$

To prevent rotation due to the action of the force F, a counteraction must be applied. Add a second force P with a lever arm b. Force P now provides a counterclockwise action whose moment is the product of P times b (lb.-ft.). To establish moment equilibrium, i.e., to prevent rotation, the product of F times d must equal that of P times b.

Normal Level Walking

Human locomotion is an extremely complicated process which is largely taken for granted. It involves the transformation of a series of controlled and coordinated angular motions, occurring simultaneously at the various joints of the lower extremity, into a smooth path of motion for the center of gravity of the body. The complexity of the locomotion process becomes evident when one considers that six major factors influence the path of motion: (1) knee-ankle interaction, (2) knee flexion, (3) hip flexion, (4) pelvic rotation about a vertical axis, (5) lateral tilting of the pelvis, and (6) lateral displacement of the pelvis.

A thorough study of human locomotion would include the influence on the total displacement pattern of each of the above factors, as well as a complete analysis of the action of major muscle groups of the lower extremity. The present discussion will be limited to a consideration of the hip, knee, and ankle joints and their interaction during level walking.

Phases of the Walking Cycle. A typical walking cycle can be divided into two phases: "stance" or weight-bearing phase and "swing" phase. Stance phase begins at the instant the heel contacts the ground and ends at toe-off, when contact is lost by the foot on the same leg. Swing phase begins at toe-off and ends at heel contact. Both feet are in simultaneous contact with the walking surface for approximately 25% of a complete two-step cycle; this part of the cycle is designated as the "double-support" phase. To identify

cyclic events on the graphs the following abbreviations are used:

HC - heel contact

FF - foot flat (forefoot makes contact)

HO - heel-off (heel loses contact)

TO - toe-off

MF - maximum knee flexion

Figure 1 gives a graphic account of the interaction between the

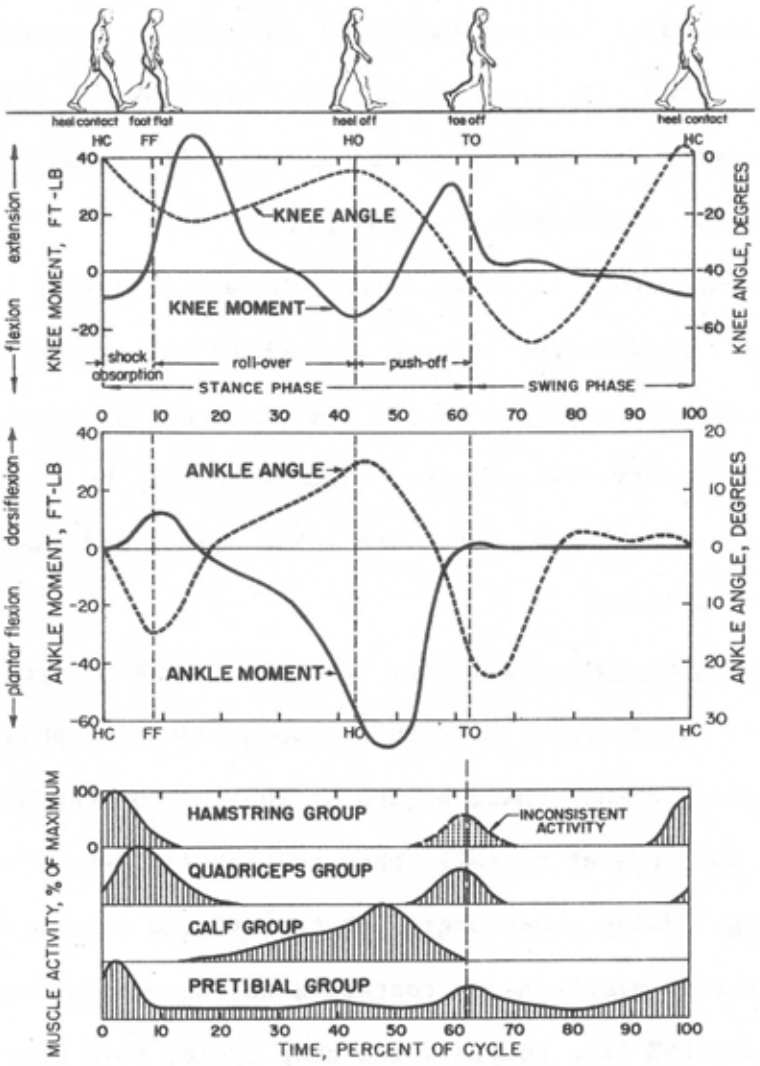


FIG.1 CORRELATION BETWEEN JOINT ACTION AND MUSCULAR ACTIVITY

knee and ankle joints and the phasic action of major muscle groups during a typical walking cycle. The curves shown refer to the average of actual measurements recorded during studies of four male college students considered to be representative of a larger population sample. The sequence of events is arbitrarily started at heel contact and followed until the next heel contact of the same foot. The term "knee moment" refers to the action of the muscle groups about the knee which tends to change the knee angle, either in flexion or extension. Similarly, "ankle moment" refers to the muscular action about the ankle joint which may cause either plantar flexion or dorsiflexion. The mechanics of major muscle groups of the lower-extremity are indicated in figure 2.

(a) Events Just Prior to Heel Contact. In reference to figure 1, and particularly to the curves in the region corresponding to the end of swing phase (about 95% of a complete cycle), it may be noted that the knee joint reaches its maximum extension just prior to heel contact and that a period of knee flexion has then begun which continues on into stance phase. This decrease in the rate of knee extension at the end of swing phase, preparatory to the foot making contact with the floor, is primarily due to the action of the hamstring muscle group, as seen in the curves of muscle activity. The hamstring group is attached to the pelvis posterior to the hip joint and to the tibia and fibula below the knee joint. Tension in the hamstring group may cause hip extension, knee flexion, or both simultaneously.

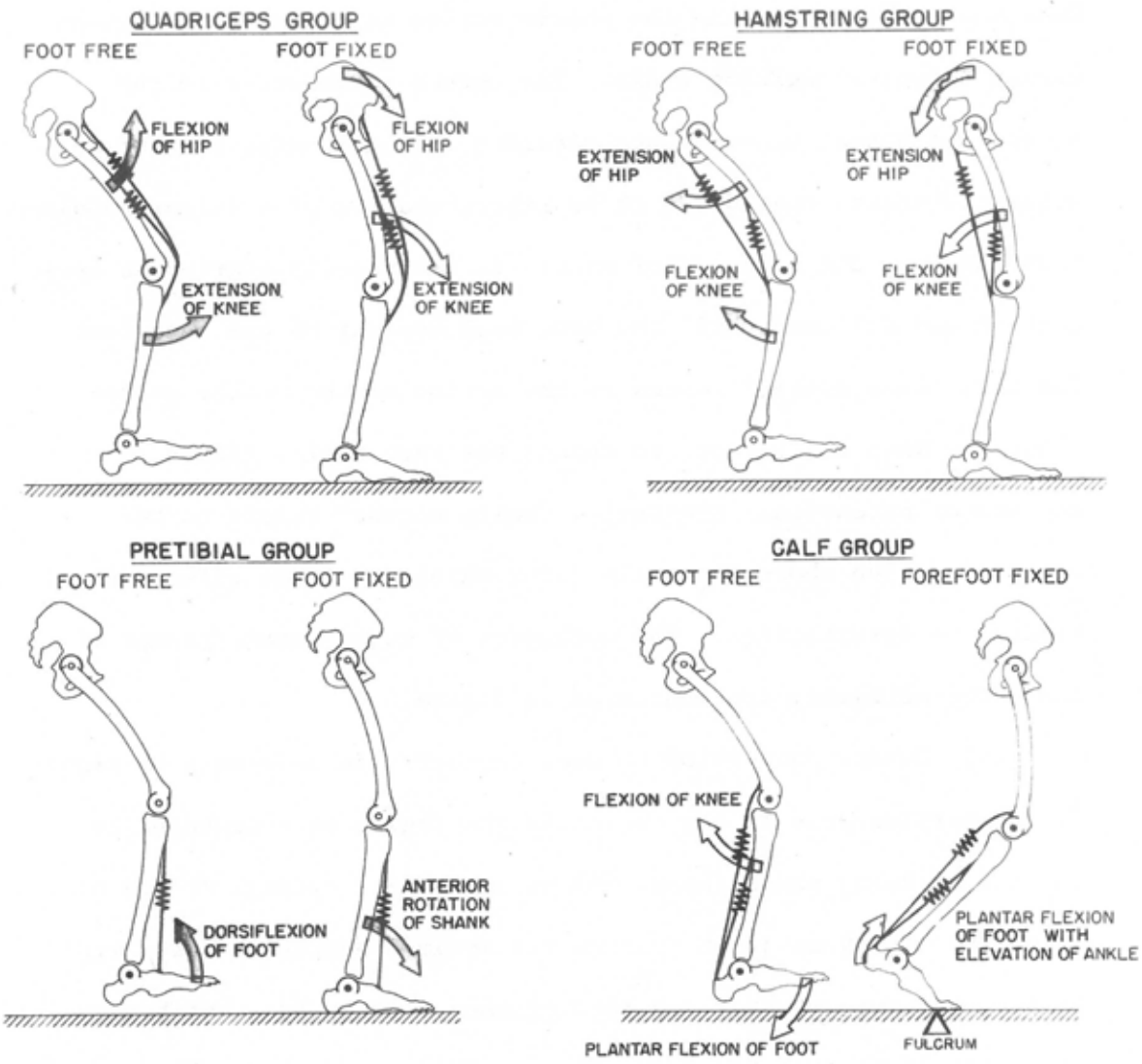


FIG.2 MAJOR MUSCLE GROUPS OF THE LOWER EXTREMITY
Demonstrating the major mechanics of the lower extremity in the lateral plane

(b) Heel-Contact Phase. As the heel makes contact, the hamstring action tends to bring it forcibly backward into contact with the floor. The knee continues to flex rapidly during this phase. The activity in the hamstring group continues, but with decreasing magnitude, while the quadriceps action begins to build up rapidly. The quadriceps group, acting anteriorly about the knee joint, and

the pretibial group, acting about the ankle joint, serve to control knee-ankle interaction and thus effect a smooth motion of the forefoot toward the floor. The major function of both knee and ankle during this phase is smooth absorption of the shock of heel contact and maintenance of a smooth path of the center of gravity of the whole body. Energy studies have shown that the knee and ankle contribute equally in this function. The function of the knee as a shock absorber is often overlooked.

(c) Midstance Phase. The controlled knee flexion of heel-contact phase continues into midstance phase (between foot flat and heel-off). The maximum angle of knee flexion is approximately 20° and occurs in this first part of midstance phase. As the body rides over the stabilized knee, the upward thrust of the floor reaction moves forward on the sole of the foot, gradually increasing the dorsiflexion of the ankle and causing the knee to begin a period of extension. In this period the control of the leg is through ankle-knee interaction, with minimum muscular activity in the groups acting about the hip and knee. The knee reaches a position of maximum extension about the time the heel leaves the ground, with the calf group providing the resistance to knee extension and ankle dorsiflexion. As the heel leaves the ground, the knee again begins a period of flexion, resulting primarily from muscular action about the hip joint. This sequence of controlled flexion at heel contact, release to allow gradual extension in midstance, and controlled flexion preparatory to swing is important in accomplishing a smooth and energy-saving gait in normal persons.

(d) Push-off Phase. Push-off phase is complex and often misunderstood. During this phase, the knee is brought forward by action of the hip joint and a sensitive balance must be maintained between the interaction of hip, knee, and ankle joints. This combined action has two purposes: (1) to maintain the smooth forward progression of the body as a whole and (2) to initiate the angular movements in the swing phase which follows. As the knee begins to flex (about the time the heel leaves the ground), the knee musculature must first resist the external effect of the force on the ball of the foot which passes through space on a line ahead of the knee joint. Then, as the knee is brought forward by hip-joint action, so as to pass through and then anterior to the line of the force acting upward on the foot, the knee must reverse its action to provide controlled resistance to flexion by increasing quadriceps activity. Some inconsistent hamstring activity is noted as antagonistic. The calf group continues to provide active plantar flexion during the entire push-off phase. At the time the toe leaves the floor the knee has flexed 40° to 45° of the maximum of 65° it will reach during swing phase. Note that knee flexion in swing phase is not primarily due to hamstring action in normal persons, as might be supposed. Complete prosthetic restoration of normal function in push-off phase is difficult, if not impossible. A proprioceptive sense of knee position is necessary, as well as an active source of energy in the ankle. Because of lack of an active source of ankle energy, initiation of knee flexion in amputees wearing a prosthesis

must come from active hip flexion.

(e) Swing Phase--Quadriceps Action. The over-all objective in swing phase is to get the foot from one position to the next in a smooth manner while clearing the usual obstacles of terrain. At the start of swing phase the leg has just completed a period of rapid increase in kinetic energy caused by the active extension of the ankle and flexion of the hip during push-off phase. The knee is flexing and continues to flex after toe-off. During rapid walking this would result in excessive knee flexion and heel rise were it not for the action of the quadriceps group in limiting the angle of knee flexion to approximately 65^{o} and then continuing to act to start knee extension. Knee extension continues as a result of a combination of pendulum effects, which are due to the weight of the inclined shank and the foot, and muscle action. Little quadriceps action is required, since other factors are of equal importance. For example, the iliopsoas muscle contributes by developing active hip flexion which accelerates the knee forward and upward.

(f) Midswing. During midswing, there is a period of minimum muscular activity and the leg accelerates downward and forward like a pendulum with forced motion of its pivot point.

(g) Terminal Deceleration--Hamstring Action. Near the end of swing the rate of knee extension must be reduced in order to decelerate the foot prior to heel contact. This "terminal deceleration" of the normal leg is primarily due to the resistance

to extension of the hamstring group.

Knee Action in Amputee Gait

A common cause of difficulty in the use of the so-called "Muley" prosthesis (a below-knee prosthesis without side joints) in the past was the "breakdown" of the stump, particularly the knee joint. The cause of the difficulty has been due, in part, to the overstraining of the ligamentous structures of the knee by excessive hyperextension of the knee under load. In order to protect these ligamentous structures on the amputated side, it is necessary to maintain within safe limits the forces and moments about the knee which tend to force the knee into hyperextension. In normal persons, a precise sense of knee position limits the hyperextension moment by maintaining the knee center close to the line of the force transmitted through the lower extremity. In this way the tendency of the knee to hyperextend is controlled. Since in many below-knee amputees the knee action is unaffected by amputation, it is reasonable to expect the amputee to walk with a normal knee action. Therefore, when this ability is anticipated and accounted for in the fitting and alignment procedure, a below-knee amputee whose stump is at least of average length can make use of the controlled flexion-extension-flexion sequence of knee action which is necessary to absorb shock and smooth the path of motion of the center of gravity. The socket must be fitted to accommodate the dynamic forces which result, and the amputee must contribute voluntary control of the knee by action of the musculature.

Stump-Socket Pressures

The contact pressures between the stump and socket of a below-knee amputee are influenced by a combination of many factors. Some of the most important are (1) fit of the socket, (2) alignment of the socket, (3) relationship of socket to foot, (4) modifying effects of the thigh corset, and (5) relationship of socket to side joint and thigh corset.

In discussing the relationship between fit and alignment, it is often helpful to discuss alignment factors first, since the method of fitting a socket to an amputee's stump is largely dictated by the manner in which he can be expected to perform while wearing his prosthesis. His performance, in turn, is influenced considerably by the structural relationship between the elements of his prosthesis, i.e., the alignment.

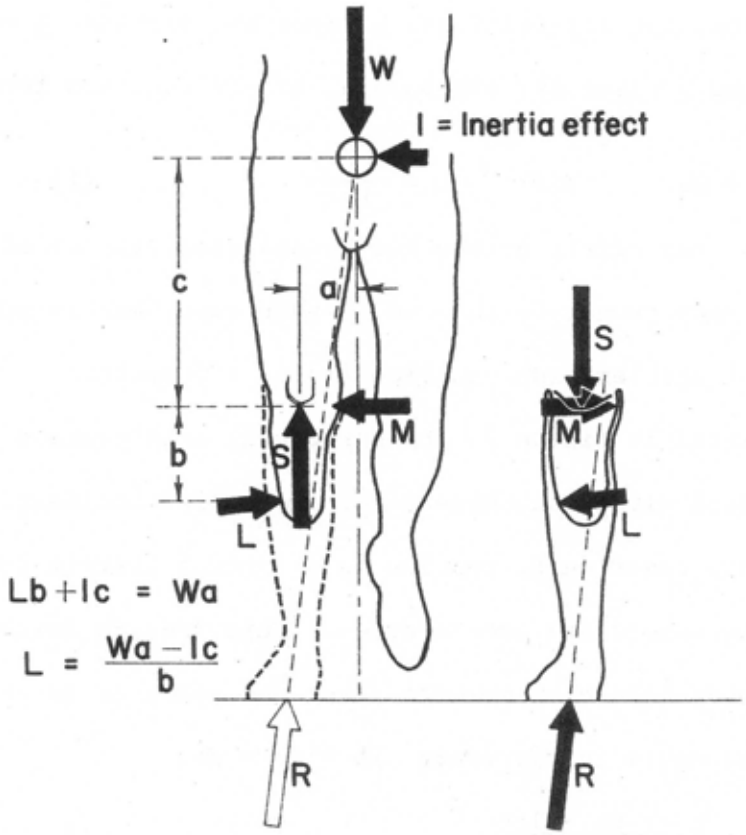
The patellar-tendon-bearing cuff-suspension below-knee prosthesis, without side joints and corset, will be discussed first, and then the modifying influences resulting from the addition of side joints and corset will be considered.

Stump-Socket Force Analysis. The following analysis is based on the assumption that a below-knee amputee, with a stump of at least average length, can be expected to walk in a manner similar to that of a normal person. That is, if the prosthetic foot is properly designed to minimize the effects of the loss of normal ankle function, the amputee can compensate by hip and knee action so as to achieve a gait which closely approximates the normal.

Therefore, he should be expected to go through the following sequence of knee motions:

1. He should use controlled knee flexion at the time of heel contact until the foot reaches a stable position flat on the floor.
2. He should then walk over the flexed knee with the knee gradually extending. The foot-shank serves as a firm base during this portion of stance phase. The position of the knee relative to the force acting on the foot can be gauged accurately by properly trained amputees. The muscular moment about the knee required to maintain a particular knee position serves as an excellent source of proprioceptive sensation if the socket fit is intimate enough to reduce lost motion to a minimum.
3. The amputee should use controlled knee flexion during push-off phase as an aid in accelerating the prosthesis forward in swing phase.

Mediolateral Forces. Figure 3 shows a front view of a below-knee amputee in a position corresponding to midstance phase. Two separate free body diagrams are shown. Figure 3a shows the forces exerted on the amputee. These forces are of two types: the body weight resulting from the effect of the earth's gravitational pull and the forces applied through contact with the socket. Figure 3b shows the forces acting on the prosthesis.



(a) Forces on the Amputee (b) Forces on the Prosthesis

FIG.3 MEDIOLATERAL FORCE DIAGRAM, PATELLAR-TENDON-BEARING BELOW-KNEE PROSTHESIS

If, as seen from the front, the prosthesis is considered as a means of supporting the body, it must be capable of providing both vertical support and mediolateral balance. It is apparent that vertical components of pressure are applied against the surfaces of many areas of the stump, but for purposes of simplified analysis the combined effect of all these forces is shown as the single support force S.

Considering the point of application of the support force S as a balance point, the lateral force L times the distance b equals the body weight W times the distance a, or, in equation form:

$$Lb = Wa \qquad \text{and} \qquad L = \frac{Wa}{b} \qquad (1)$$

Unfortunately, the effect of the horizontal acceleration of the center of gravity cannot be ignored in this case, and in neglecting the horizontal acceleration equation (1) is incorrect.

As indicated in figure 3, the horizontal acceleration of the body in a medial direction, because of the medial inclination of the total floor reaction R, results in a lateral inertia force which tends to oppose the acceleration. This inertia force must be included when balancing moments about the point of support. The correct relationship is therefore $Lb + Ic = Wa$:

$$L = \frac{Wa - Ic}{b} \qquad (2)$$

Equation (2) shows that the magnitude of the required lateral stabilizing (balancing) force L can be reduced in one of two ways: (1) by increasing the horizontal inertia force or (2) by increasing the effective lever arm b. Increasing the horizontal inertia force requires that the horizontal acceleration be increased or, in other words, that the foot be moved laterally so as to increase the medial inclination of the total floor reaction.

The complete elimination of the lateral stabilizing force L by outsetting the foot is generally undesirable. The resulting wide-based gait is abnormal and unnecessary. Actually, the use of a

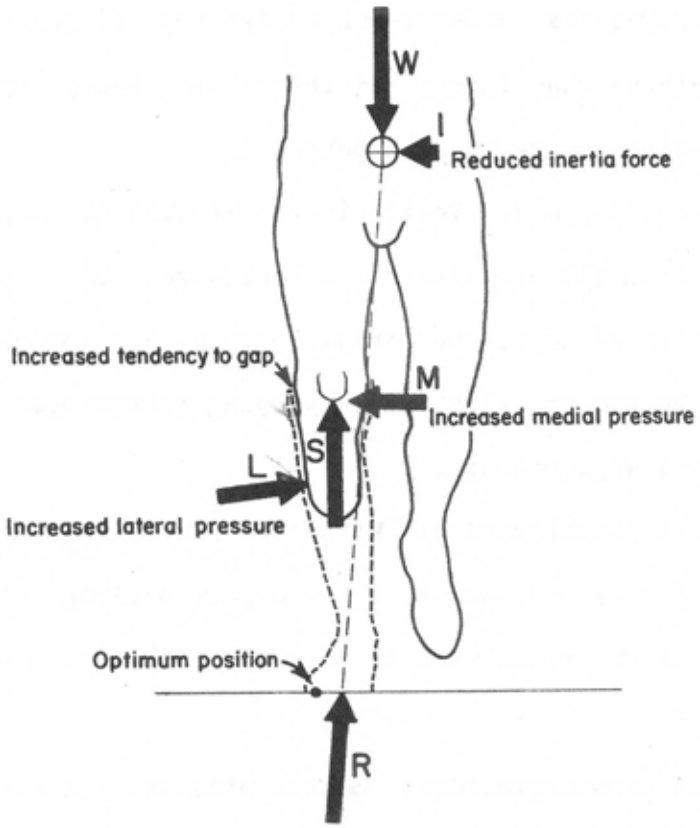


FIG.4 CHANGES IN MEDIOLATERAL FORCE DIAGRAM DUE TO INSET OF FOOT FROM OPTIMUM POSITION, PATELLAR-TENDON-BEARING BELOW-KNEE PROSTHESIS

narrow-based gait as shown in figure 4, with a need for the lateral force L (and corresponding lack of pressure on the head of the fibula), is definitely indicated for stumps 4" or more in length; the wide-based alignment should be reserved for very short below-knee stumps. It must be remembered, however, that planning the fit and alignment of a below-knee prosthesis to accommodate a narrow-based gait requires that the need for a definite lateral stabilizing force be recognized and accounted for in the fitting of the socket.

In summary, the analysis of mediolateral forces acting between the stump and socket for the cuff-suspension type of below-knee prosthesis indicates that functional forces and, hence, an increase in pressure magnitudes are to be expected.

(a) Vertical Support. Vertical support will be composed of forces derived from (1) patellar-tendon pressure, (2) pressure against the medial flare of the tibial condyle, and (3) partial end-bearing. The sum of all three in varying percentages will be a single equivalent support force S.

(b) Lateral Stabilization. With good functional alignment, a lateral stabilizing pressure is to be expected along the entire lateral aspect of the stump with its net effect L acting on the distal one third.

(c) Medial Counterpressure. Medial pressure against the tibial condyle is to be expected as a direct result of the wedge-like shape of the condyle and the need to counter the effect of lateral pressure.

Anteroposterior Forces. Figure 5 shows a side view of a below-knee amputee and the cuff-suspension prosthesis under three conditions: at heel contact (a), during the shock-absorption portion of the midstance phase (b), and during the push-off phase (c).

At the instant of heel contact, for a short time corresponding to about 5% of the walking cycle, knee stability is maintained primarily by active extension of the hip joint. The tendency of the external load on the prosthesis to extend the knee is resisted

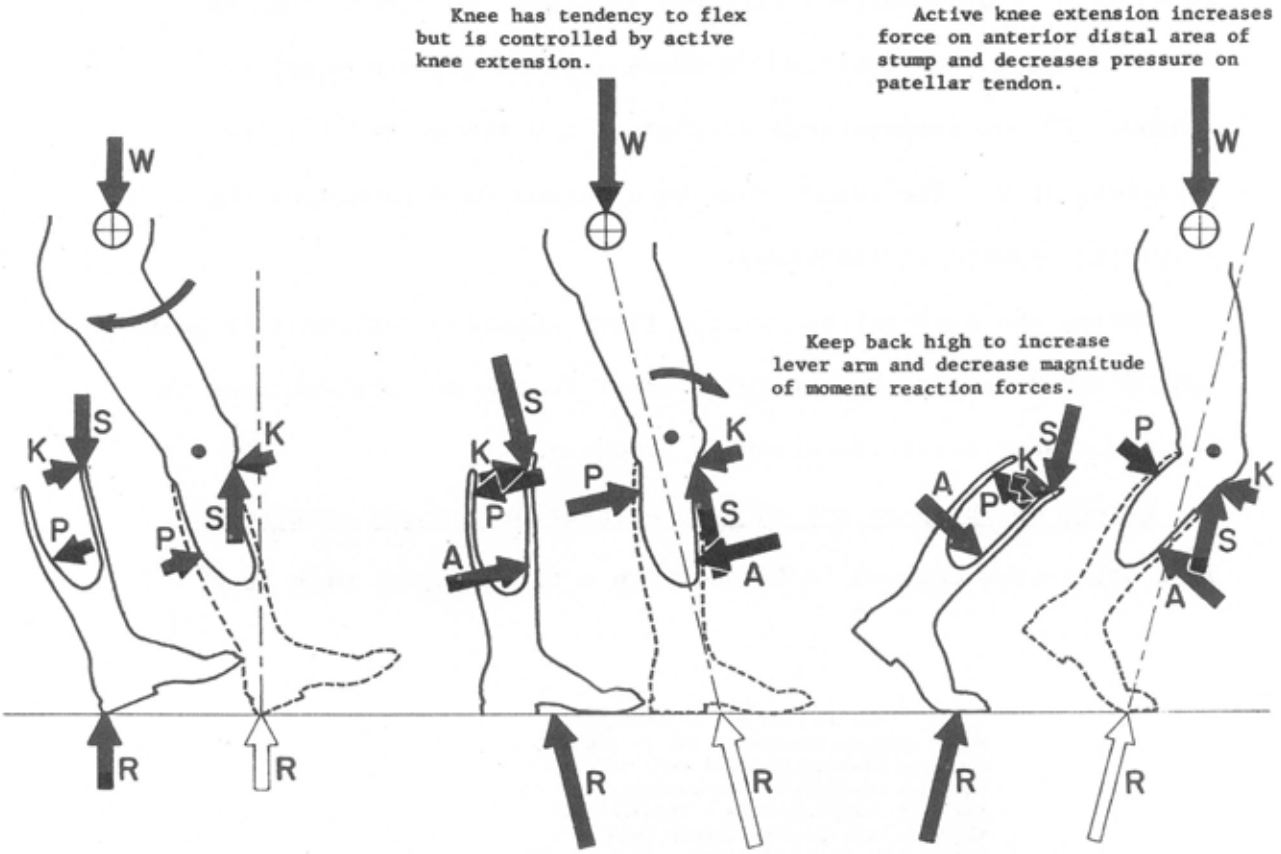


FIG.5 ANTEROPOSTERIOR FORCE DIAGRAMS, PATELLAR-TENDON-BEARING BELOW-KNEE PROSTHESIS

by hamstring action. During this phase forces would be acting as shown in figure 5a.

Analysis of the forces acting during the shock-absorption portion of the midstance phase shows that it is typical for the floor reaction force R to be acting along a line which passes posterior to the knee center. The would cause a completely relaxed knee to buckle, but the amputee is able to resist this tendency by active knee extension. The resulting force pattern on the stump

(disregarding end-bearing) is shown in figure 5b. Note that the forces would be concentrated in three areas: (1) the patellar tendon, (2) the anterodistal portion of the tibia, and (3) the popliteal area. The socket must be designed to accommodate the resulting functional pressures.

During the push-off phase, the floor reaction continues to pass behind the knee and the anteroposterior forces are concentrated in the same three areas, as shown in figure 5c.

Effect of Thigh Corset on Anteroposterior Stump-Socket Forces. If a below-knee amputee is fitted with a thigh corset with back

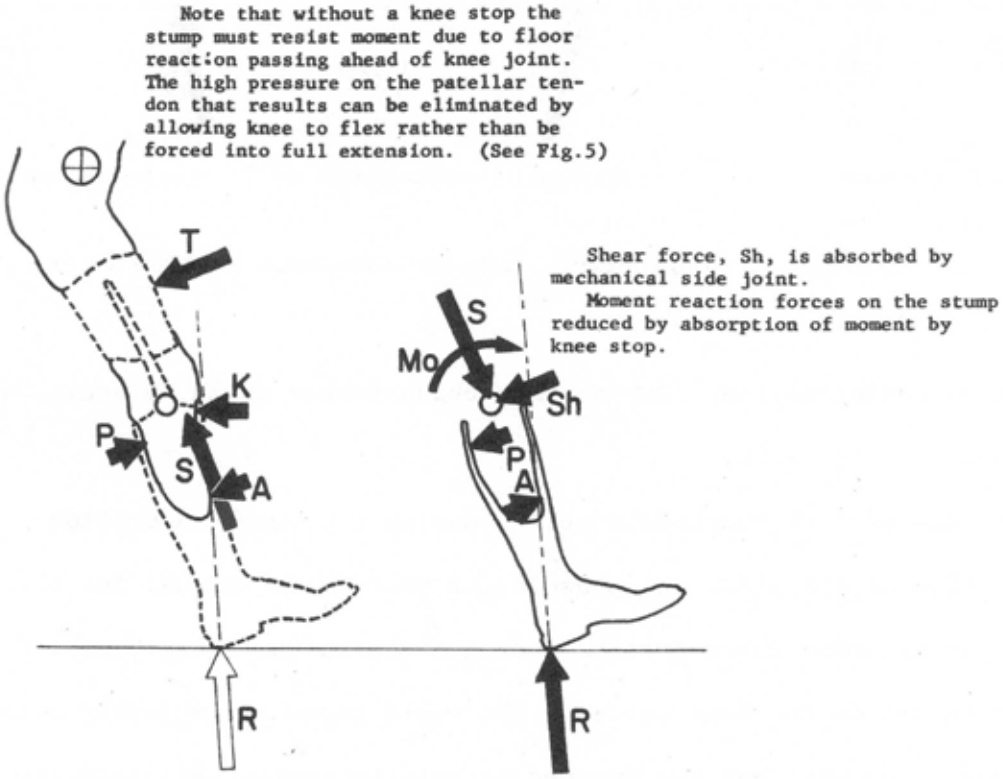


FIG.6 EFFECT OF THIGH CORSET – KNEE STOP (OR BACK CHECK) COMBINATION ON ANTEROPOSTERIOR STUMP-SOCKET FORCE DIAGRAM

check so that he relies on the mechanical action of the back check to resist knee extension, the force pattern is altered considerably. Figure 6 shows this effect. In this case, looking at the forces acting on the prosthesis helps in understanding the problem. Consider the effect of the floor reaction R, which now must be assumed to pass anterior to the knee, since, otherwise, the knee would not be extended against the back check. If the knee joint is considered as a moment center, the effect of the force R is resisted by the back check moment M and the two forces A and P exerted by the stump within the socket. It is possible, under the proper conditions, for the mechanical back check to provide the total resistance to the floor reaction with the stump suspended freely in the socket.

This would indicate that, by proper adjustment of thigh corset, side bars, and back check, it is possible to modify the pattern of anteroposterior stump-socket contact pressures. However, as pointed out in the chapter, "Use of Side Joints and Thigh Corset," such adjustments are extremely critical and attempts to relieve pressure in one area may result in difficulty in other places.

INFORMATION FOR THE PROSTHETIST

The examination of the amputee by the prosthetist is an important part of the treatment procedure. It provides a better understanding of whether the amputee is ready for treatment, what further preparations (such as stump shrinkage) may be needed, what the probable course of events for a given method of treatment will be, and what special provisions (such as relief for sensitive areas) are required.

Careful records should be kept throughout the treatment, not just in the initial phase. They will not only help the prosthetist make a successful prosthesis but also provide a continuous history which may later be useful in pinpointing causes of difficulties. In addition, they will serve as a basis for discussion of the amputee's case with the doctor or therapist, who may not be as familiar with it as the prosthetist. The records will make it possible to arrive at decisions as to what type of prosthetic treatment is desirable and whether help from other members of the rehabilitation team is needed.

The Prosthetic Information Form is designed to simplify collection of data and to provide a useful permanent record. For the most part, the form is self-explanatory. The first page is a guide for prescribing, fitting, and aligning the limb. It also records the status of the amputee at the time of examination for comparison

PROSTHETIC INFORMATION — BELOW-KNEE PROSTHESIS

Name _____ Date _____

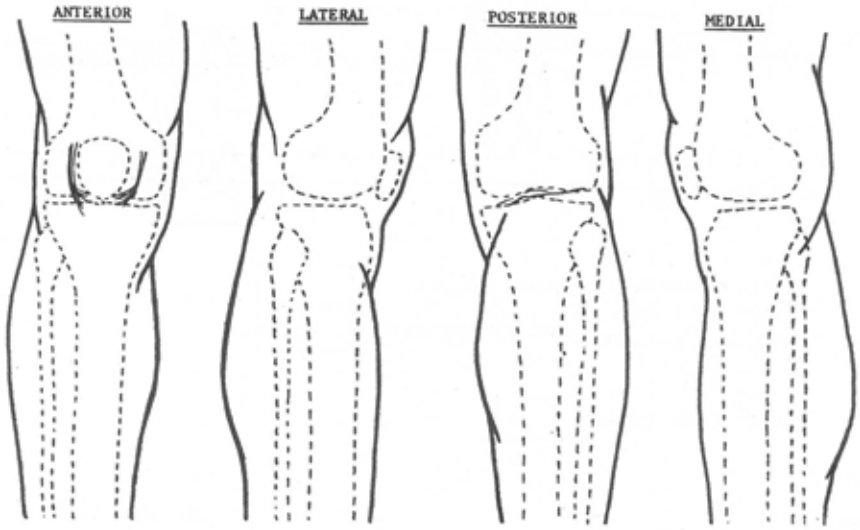
Height _____ Weight _____ Age _____ Sex _____ Prosthetist _____

Date of Amputation _____ Cause _____ Right or Left _____

Present Type of Prosthesis _____ Date Fitted _____

STUMP DESCRIPTION

Draw stump, indicating levels of tibia and fibula. Show location of stump details. Identify with letter code.



A abrasion
B boil or other skin infection
BS bone spur
Bu bursa
D discoloration
E edema
P pressure point
S scar
T trigger point

Stump shape _____ Distal padding _____

Condition of subcutaneous tissue _____

Type of skin _____

Condition of thigh musculature _____

Condition of stump musculature _____

Condition of knee joint (a) stability _____ (b) range _____

(c) patella _____ (d) contracture _____

Condition of the cut bones (a) tibia _____

(b) fibula _____

Condition of the femur _____

Pain _____

Type of prosthesis recommended _____

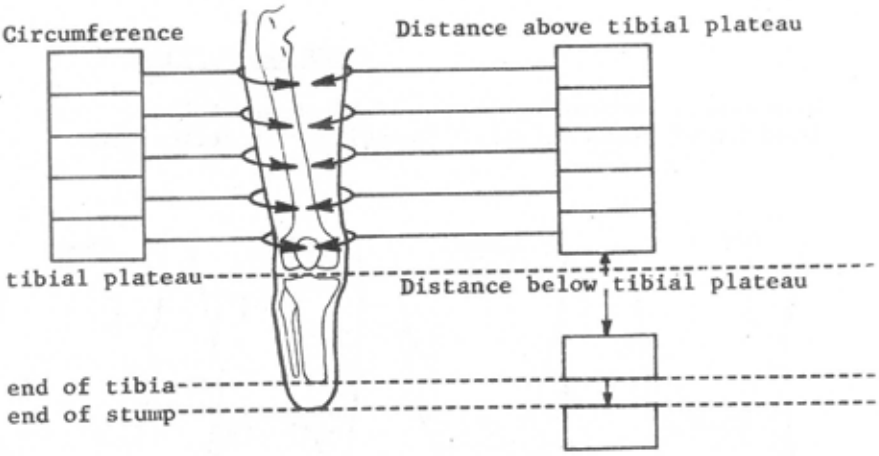
_____

PROSTHETIC MEASUREMENTS

Fitting Aids: Plaster cast of stump ☐

Tracings of normal shank ☐ anterior and lateral views with circumferences at 2" intervals

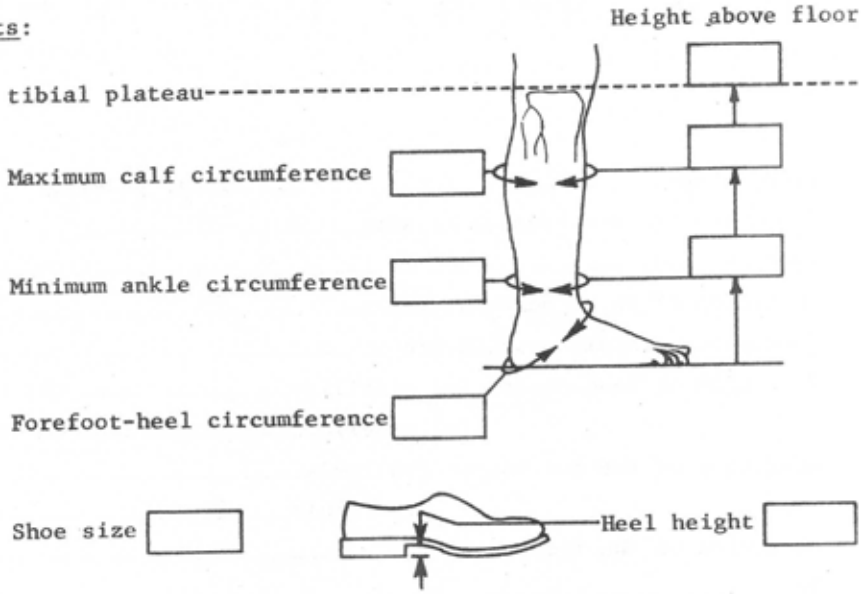
Stump Measurements:



Stump diameters at level of patellar tendon { mediolateral ☐ anteroposterior ☐

Stump sock size ☐

Normal Leg Measurements:



Shoe size ☐

Heel height ☐

with his status at any future date. The second page is a convenient aid for bench work and selection of components.

It is sometimes useful to supplement the information which can be recorded on the Prosthetic Information Form with photographs, special sketches, tracings, x-rays (these may be especially valuable), and written descriptions. Anything done in the course of the prosthetic treatment should be added to the amputee's information form.

Equipment for Data Collection

(1) Measuring tape

(2) Calipers (for knee measurement)

(3) Combination square (for measurements of stump length)

(4) Wrapping paper (for tracing)

(5) Goniometer or large protractor (for measuring angles of contractures or ranges of joint motion)

Stump Description

The important characteristics of the stump at the time of examination can be recorded on the sketches of the stump provided in the form. These characteristics are drawn on the sketches and labeled with the code letters given in the box at the right. Other descriptive details are entered in the spaces provided. Additional information may be added as required.

Abrasions. Abrasions are caused by rubbing between the prosthesis and the skin, usually over bony prominences. They should not be a factor in a new fitting, but with continued wearing of a prosthesis any source of friction must be minimized. Abrasions may take the form of blisters or raw (denuded) skin surfaces.

Boils and Other Skin Infections. Boils are pus-filled infections, with a core of dead tissue, that occur, usually, around a hair root. Other follicular lesions or pimple-like formations may also be seen around hairs. Small openings and sinuses give evidence of old cyst formations, which may or may not have been infected, that have drained to the outside. Medical care may be required before provision of a new prosthesis, and fitting may have to be postponed until the infections have cleared up.

Bone Spurs. Bone spurs are bony outgrowths; they may often be found by palpation, but x-rays, usually an anteroposterior and a lateral view, are required to identify them positively. Both methods of identification should be used, since x-rays provide only a two-dimensional view. The commonest region of spur formation in the below-knee stump is the end of the fibula. The typical spur is thin, tapered, and pointed downward toward the end of the tibia. Much smaller spurs also form from the cut edges of the tibia. Prominent spurs must be avoided in fitting.

Bursae. A bursa is a sac filled with a viscous fluid; it lies beneath the skin and over a bony prominence, i.e., in a place at which friction would otherwise develop. Naturally occurring bursae are located over the patella and around the tendons of the knee. When there is too much pressure and movement over them, they enlarge, although sometimes only temporarily. New, abnormal bursae may also form; these are called adventitious bursae. Both normal and adventitious bursae may become infected, in which case medical care or changes in the prosthesis may be indicated.

Discoloration. Skin which has adapted to pressure or which has been damaged by bruising or edema is often discolored. Pressure first reddens and then, after several weeks, toughens and darkens the skin to brown. When skin is bruised, discolorations may be blue, yellow, green, or brown. These colors reflect the presence of free blood, extravasated from broken blood vessels, in the deeper layers of the skin (dermis) and subcutaneous tissues. Edema damage reddens the skin; if prolonged, it results in blue discoloration; and, finally, after chronic edema has subsided, brown stains are left. They fade slowly and may eventually disappear if there is no recurrence of stress.

For the prosthetist, discoloration is primarily a useful guide to areas of pressure. If the pressure has occurred at an undesirable point or has caused tissue damage, redistribution of pressure is indicated.

Edema. Edema is the collection of fluid in soft tissues of the stump. The condition may be a postoperative edema, or it may be caused by a poorly fitting prosthesis. When the prosthesis is at fault, contributing causes may be constriction by the prosthesis proximally.

Edema should be reduced to the barest minimum before fitting is done; otherwise, the socket fit soon becomes too loose. Shrinkage is accomplished by wrapping the stump. The period of wrapping required varies from a few hours to several days, depending on the individual case.

Pressure Points. The areas of the stump which respond painfully to pressure are identified as pressure points. An example of a pressure point is the area where the peroneal nerve passes over the lower surface of the head of the fibula. Such points usually require clearance in the socket.

Scars. There are two kinds of scar tissue: atrophic (thin, fragile, easily torn) and hypertrophic (thickened, adherent, painful). All scar tissue tends to be inelastic, and care must be taken to insure that it is not stretched or rubbed. Excessive stretching will tear it. When it adheres to bone or muscle, movement may loosen the fibrous attachment. Direct pressure over broad scarred areas has been tolerated when piston action has been reduced to a minimum.

Trigger Points. A trigger point is a sensitive spot on the stump which causes pain when touched even lightly. Although intermittent pressure may be painful, steady pressure can often be tolerated.

Stump Shape. The stump may be described as bulbous, cylindrical, or conical. The conical stump shrinks the least; the bulbous stump shrinks the most, in the distal portions.

Distal Padding. The tissue covering the cut bones may vary in thickness from a thin cover of skin to a considerable amount of redundant tissue. When the cover is sparse, care is needed in fitting, especially if the cut bones are prominent or sharp. Redundant tissue can usually be contained by the bottom of the socket without discomfort. Because this tissue often tends to become

edematous, containment by the socket is important for improved circulation. Redundant tissue should be pulled upward when the cast is taken so that the constricting turns of plaster bandage do not elongate the stump; otherwise, it will be difficult to push the stump into the finished socket.

Condition of Subcutaneous Tissue. The problem of concern in regard to the condition of tissue beneath the skin is shrinkage. The tissue may be pinched lightly between thumb and forefinger to gauge its condition. It is described as heavy or light. The heavier the tissue, the more shrinkage can be expected.

Type of Skin. For our purposes, the skin may be described as delicate or tough. On most persons, tough skin is present at such pressure areas as the elbow and knee and delicate skin covers the inner surface of the arm, the back of the knee (popliteal space), and the groin. The amputee with particularly delicate skin needs more time to adapt to socket pressures.

Condition of Thigh Musculature. Is thigh musculature prominent or atrophied? Is musculature light? Patients with slender thighs are easy to fit with cuff suspension. More trouble can be expected in fitting the cuff to those whose thighs have prominent musculature in the region of the knee.

Condition of Stump Musculature. The stabilized below-knee stump has poor musculature, but the stump of the new amputee has a mass of muscle. This will atrophy, and the stump can be expected to start shrinking soon after the prosthesis is fitted. Atrophy will take longer if the musculature is firm.

Condition of Knee Joint. In describing the condition of the knee joint, stability, range, patella condition, and contracture are included.

(a) Stability. Sometimes the knee joint dislocates easily or is unstable mediolaterally, as with certain injuries or congenital anomalies. Under these circumstances a cuff-suspension prosthesis would be contraindicated unless the socket could be extended high--for example, when range of knee flexion is limited.

(b) Range. When range of knee motion is restricted, the prosthetist can exploit the range that is present by making the socket brims higher. But he must fit and align to increase the range if this is medically sanctioned, and he must anticipate the changes that will occur.

(c) Patella. Absence of the patella or a split patella may be encountered. These conditions are problems only if they affect the position and availability of the weight-bearing patellar tendon. If they do, other support areas need to be used more carefully.

(d) Contracture. A contracture will not be a problem unless it is severe. Since the aim of prosthetic treatment is also to improve physiologic function, fit and alignment may have to be modified in anticipation of a reduced contracture.

Condition of the Cut Bones. If the fibula is absent, the stump still be conical and the region where the head of the fibula was attached to the tibia may be sensitive to pressure. Also, the position of the biceps tendon may be altered. If the fibula is

present, it is usually shorter than the tibia. Problems may arise because the end of the fibula sometimes moves with knee flexion and the cut ends may be sharp rather than beveled. However, when properly fitted, the fibula helps keep the stump in the socket.

Though the tip of the tibia will eventually round off with use, it will need protection initially if it is sharp.

Condition of the Femur. It is important to know whether the shaft of the femur will support the body weight before fitting an amputee with a patellar-tendon-bearing cuff-suspension prosthesis. Also, knowledge of whether the hip joint can be controlled and will support body weight is important in determining the treatment.

Pain. Pain is described by location, degree, and sensations experienced. The pain may be referred to an area other than that stimulated. Because the amputee must furnish the information, a variety of terms are encountered. He may describe his pain as mild, moderate, or severe, as continuous or intermittent. He may describe the sensation as pressing, stabbing, cramping, tingling, or burning. Most important to the prosthetist is whether the pain is caused by the prosthesis or whether it is due to an inherent stump condition.

Type of Prosthesis Recommended. The prosthetist records the type of prosthesis he considers suitable in view of his analysis of the foregoing information.

Prosthetic Measurements

The measurements recorded on this page will facilitate bench work on all types of below-knee prostheses.

Fitting Aids. Fitting aids include a plaster cast of the stump and tracings.

(a) Plaster Cast of the Stump. Plaster impressions are superior to measurements as a record of size and shape of the below-knee stump. A cast, taken as outlined in this manual, gives clues to problems of fit. Casts taken at intervals show the course of stump shrinkage so that socket changes or replacements can be planned.

(b) Tracings of Normal Shank. Tracings are used to shape the prosthesis. The measurements, associated with the tracings, make shaping more accurate.

Stump Measurements. Measurements of the mediolateral and anteroposterior diameters of the stump at the patellar-tendon level, of stump length, and of thigh circumference are recorded.

The mediolateral and anteroposterior diameters are used to check the model of the stump when it is modified. When the cast is distorted, it may spread mediolaterally. In that case it must be modified so that the socket will fit more closely. The anteroposterior measurement is used to insure that the stump is properly supported by the patellar-tendon protuberance and the back wall of the socket.

Stump length classifies the stump for purposes of alignment and for fitting and suspension of the prosthesis. Thigh measurements serve two purposes: (1) They are used in corset design, and (2) they are a good check on thigh atrophy or hypertrophy when taken at time intervals.

Normal Leg Measurements. Measurements of the normal shank and foot are helpful in shaping the prosthesis. Shank length measurement allows nearly correct leg length to be established when the adjustable leg is assembled.

The record of shoe size and heel height are used to select the foot. Heel stiffness is determined by the patient's weight (recorded on the reverse side of the form).

INFORMATION FOR THE AMPUTEE

The first steps with the prosthesis will be a significant experience for the new amputee. How well he does and how confidently he proceeds from the initial trials depends very much on the condition of his stump, his age, and his general condition, but also important is how well he has been prepared physically and mentally for this new experience.

For purposes of orientation before treatment begins, the amputee should be shown a prosthesis of the type it is felt he should wear, as well as other types. The differences and reasons why there are other types should be explained. This will forestall uncertainties as to whether he is getting the kind of treatment that is best for him. Doubts may arise when he talks to other amputees or sees them on types of prostheses which differ from his own. He should be told that the kind of prosthesis an amputee receives depends on his individual needs.

Next, the procedure that will be used in fitting the prosthesis should be explained. If he rehearses, at least mentally, what is required of him, he will feel that he is participating in his treatment. Explain how the plaster cast is taken and removed. For example, a cast cutter or knife is sometimes required for removal of a cast. This can be a disturbing experience unless the amputee knows that the prosthetist has placed a lead strip under the area where the

cut will be made, or that he will gauge the depth carefully by the way he holds the knife, and that the cast cutter is not a buzz saw but a vibrating tool which does not easily cut soft tissue.

The use of the cast should be explained without technical details. Questions should be answered honestly as they arise. When no answer can be given, it is better to say so and offer to find the answer if this is reasonable. Sometimes the amputee's questions betray a fear that he will not be able to walk. His potential should be appraised conservatively. It is a good idea to have other amputees around during the early stages of his treatment.

When the completed socket is first tried, a simple explanation of its function is in order. The amputee should know where forces should be felt, why the liner is not trimmed, why the brims are high, and other information. If the adjustable leg is attached to the socket, its function should be explained, along with the function of the foot, how the final leg will have a wooden segment to replace the adjustable shank, and how the leg will look after trials are completed. Often the amputee is aurprised at the weight of the adjustable leg. Explain that the weight will be reduced when the leg is duplicated and finished.

By the time he gets his prosthesis for training, he should know that the stump may undergo change. He should be prepared for shrinkage, minor skin problems, and some discomfort. He needs to know that frequent checks and socket changes, especially in the initial stages, are required until the stump is stable. He should be advised that

if he allows problems to go unchecked for too long he may prolong his period of adjustment to the leg.

Special exercises may have been prescribed by his physician. If not, and if they seem to be needed, the prosthetist should refer him to the physician for prescription and should encourage the amputee to do the exercises.

Sometimes the new amputee will not wear his limb for periods if there is pain. The value of using the prosthesis to keep the stump in condition should be explained. However, if wearing it is not practical for some reason he should be encouraged to wrap the stump as he did before receiving the prosthesis. If he thinks the pain is caused by the prosthesis, he should return to the prosthetist; otherwise, he should check with his physician.

Hygiene of both the stump and the prosthesis is important. Some amputees, told by their physician not to wash the stump, do not do so even after prosthetic treatment starts. The amputee should know that the previous instruction was to protect him from infection and to aid healing. He can then be told to wash his stump daily as he would any other part of his body. He should know that socket liners and inserts can be replaced easily when worn or excessively soiled and that periodically the insert should be wiped clean with a slightly damp, soaped cloth or sponge.

He should be equipped with enough stump socks to allow a daily change. The importance of following the laundering directions on the package and of using the correct size should be stressed. Too

large a stump sock can be uncomfortable if it wrinkles or bags so that there is poor contact or no contact at the end.

The prosthesis is a machine. Like any machine it needs certain regular care and periodic maintenance checks. Tell the amputee that when a part is worn it should be repaired or replaced to maintain comfort and proper function.

Sometimes the amputee changes shoes and the heel heights vary. He should have the prosthetist make insoles to fit under the foot so that shoe changes will not affect alignment. The amputee should know the signs of malfunction:

1. If the foot creaks, either (a) the foot attachment bolt is loosening or (b) the belting under the keel of the SACH foot has broken its bond.
2. If the leg drops in swing phase, the suspension aids need adjustment. Poor suspension will increase energy expenditure and make the leg feel heavy.
3. If the stump feels loose in the socket or two or more socks are needed, the socket needs to be adjusted or replaced.
4. Stump abrasions or other skin changes indicate unfavorable concentrations of pressure and friction. Adjustments in fit or alignment or changes in components are required.

Any of these problems should bring the amputee to the prosthetist. But he should not wait for malfunctions to develop. If he makes a habit of periodic visits to the prosthetist, he can usually forestall the inconvenience and discomforts of these problems.

The experienced amputee who is changing from a conventional prosthesis to the patellar-tendon-bearing cuff-suspension prosthesis may have trouble initially with the flexed-knee gait. He should be told that he must expect difficulty at first, especially fatigue in the knee and thigh, but that if his case is typical this should not continue for more than a few weeks. He should be made aware of the importance of follow-up visits, since the changed force pattern on the stump may change stump shape and even cause some shrinkage. Explain to him that shrinkage can be accommodated by the addition of liners between the insert and socket shell but that if it is extensive a new socket may be needed.

THE PLASTER-BANDAGE WRAP CAST

A stump model which can be modified to serve as a basis for the fabrication of a socket is an important part of the procedure of fitting and constructing a prosthesis for a below-knee amputee. In forming the model (a duplication of the stump contours), use is made of a plaster cast. Many different procedures have been used in the past for obtaining a cast of the below-knee stump. These procedures may be grouped into three classes: (1) wrapping with a plaster-impregnated bandage, (2) use of stockinette sleeves saturated with plaster, and (3) taking an impression of the stump by dipping it into a container filled with fluid plaster of Paris or other impression material. There are certain advantages to each method; for example, use of a stockinette sleeve tends to give a smoother inside finish than wrapping with a plaster bandage, and the container-impression method may give a more accurate model of the lower third of the stump. The plaster-bandage wrap cast is the most convenient and versatile; it is commonly used in all types of plaster-cast work; it makes it simple to build up a wrap of variable thickness; and the tightness of the cast may be controlled.

In making the wrap cast, (1) the stump is placed in a flexed position and marked to emphasize certain anatomic characteristics; (2) the plaster bandage is applied with moderate tension to achieve a relatively undistorted wrap; and (3) finger pressure is applied

as the plaster hardens so that the resulting indentations may serve as a guide for modification of the model.

Supplies Needed

The following supplies are needed for wrapping the stump:

(1) two rolls of orthopedic plaster bandage, 4" width

(2) a basin of clean water

(3) a thin cast sock that fits snugly over the stump and covers the thigh well above the subject's knee

(4) one 4' length of 1" webbing

(5) two harness clamps

(6) an indelible pencil

Procedure

1. Have the amputee sit on an examining table with the thigh supported and the back of the knee approximately 4" from the edge. Pull a thin, moistened cast sock over the stump. Maintain a snug fit by applying tension on the top of the cast sock from a strap around the waist clamped on each side of the cast sock. Tension can be increased by having the amputee flex the hip while the clamping is being done; then, when the hip returns to sitting position, the cast sock is pulled tight.

   As shown in the figure, the stump should be held at approximately 30^{o} flexion during the entire marking and wrapping sequence. This is necessary to emphasize certain bony prominences, to aid in the definition of the patellar



tendon, and to locate the insertions of the hamstring tendons. In addition, this amount of flexion anticipates and compensates for the change in position of certain bony prominences during the dynamic sequences of locomotion.

2. Mark on the moistened cast sock with indelible pencil, indicating prominences with a cross and other sensitive areas with a circle. Before doing this, the prosthetist should have become familiar with the individual stump in

its entirety. The Prosthetic Information Form must be completed before the cast is taken. After the various questions have been answered, the information recorded, and a prescription written, the prosthetist will be ready to proceed to the cast-taking with a better idea of the eventual objective in fitting the stump and will be prepared to pay attention to the particular problems of the individual amputee.

The following markings are always made:

(a) outline of the patella

(b) midpatellar tendon--a horizontal mark midway between the lower edge of the patella and the tubercle of the tibia which indicates an important weight-bearing area in the finished socket

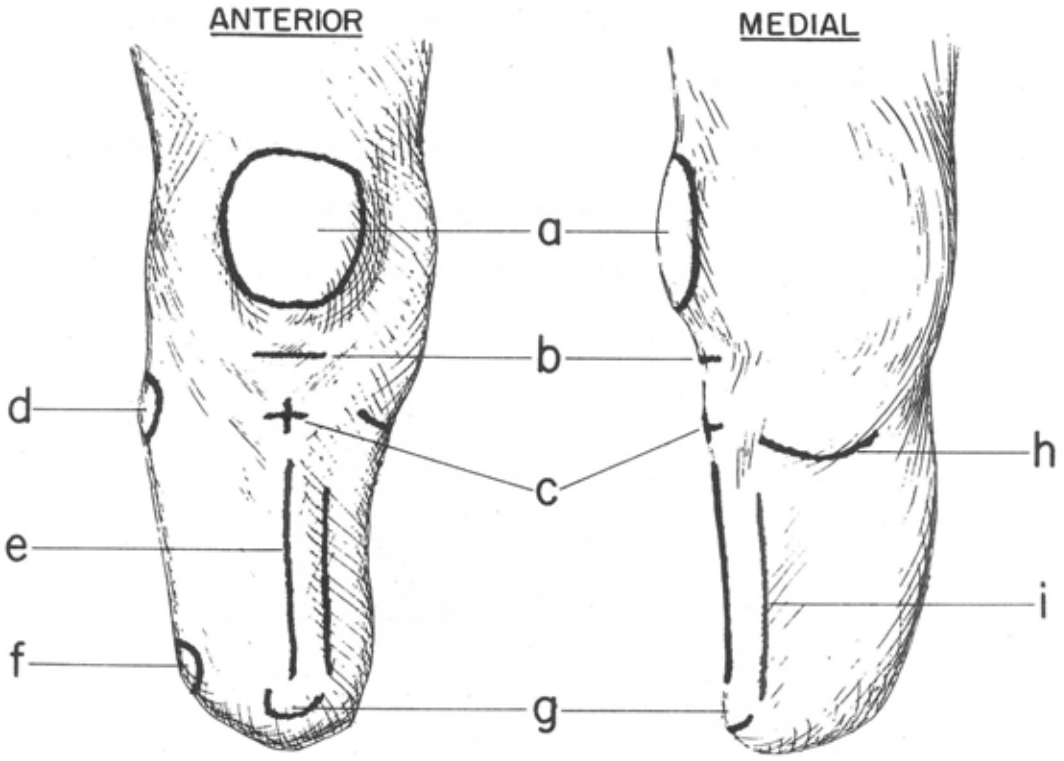
(c) tubercle of the tibia

(d) head of the fibula, which requires a relief area in the socket to prevent skin abrasion and pinching of the peroneal nerve between the head of the fibula and the socket (the peroneal nerve wraps around the lateral side of the fibula, coming from above and behind the head and passing anteriorly just below the head of the fibula)

(e) anterior crest of the tibia

(f) distal end of the fibula

(g) anterior distal end of the tibia



(h) the medial flare of the tibia

(i) medial border of the tibia

The following areas are outlined on the stump only if they require special treatment because of prominence, sensitivity to pressure, or other reasons:

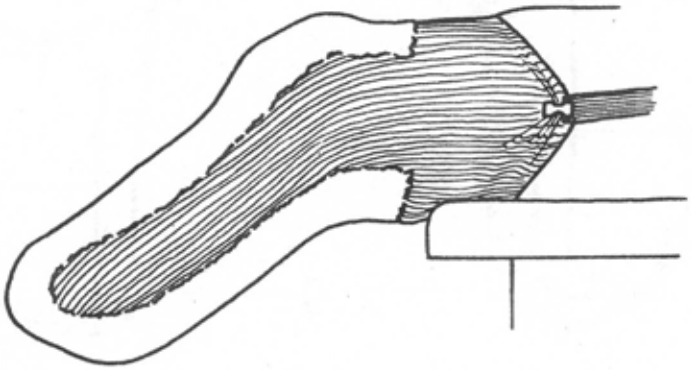
(j) anterior prominences of the lateral and medial tibial condyles

(k) the lateral border of the tibia

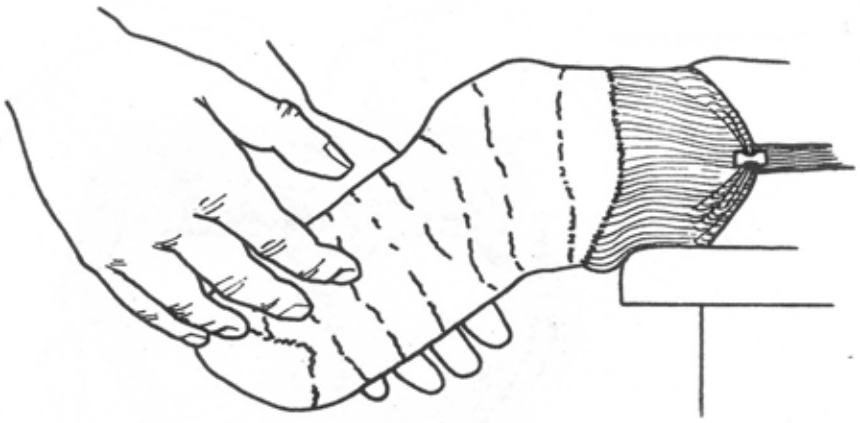
(1) any other sensitive areas which may indicate the presence

of bone spurs, adherent scar tissue, neuromas, or similar conditions.

3. Unwrap as many rolls of 4" plaster bandage as will be needed and place them on the floor beside the water basin. Submerge each roll of plaster individually for approximately four seconds (or according to the manufacturer's recommendation); then squeeze out excess water prior to use.

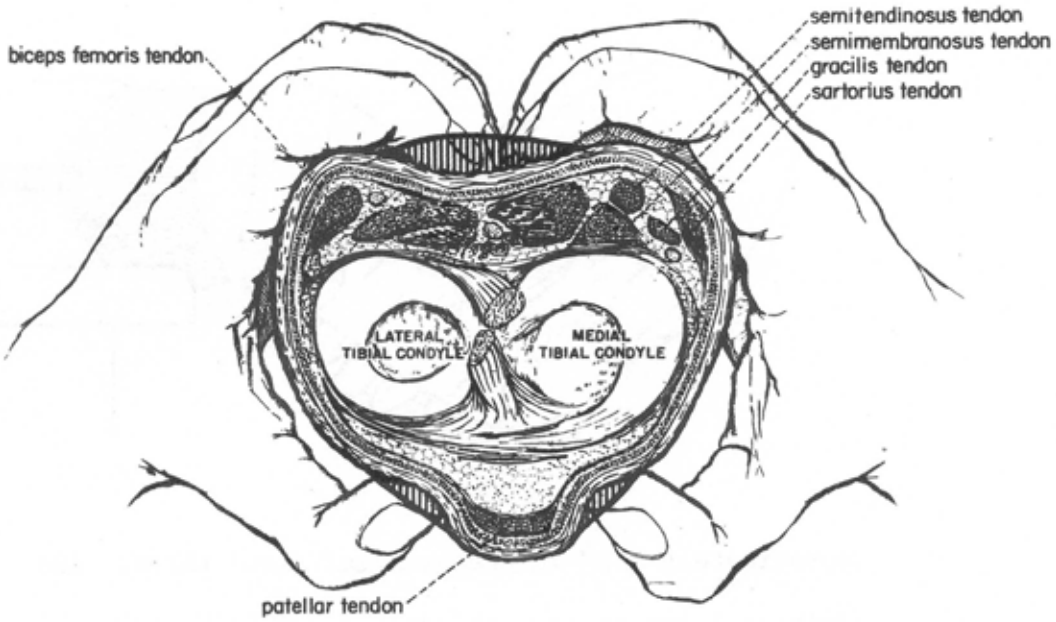


4. Begin the wrap by laying on one or two layers of bandage lengthwise, starting in front slightly above the patella and passing down and around the end and up the back of the stump to the posterior crease of the knee.
5. Begin a series of circumferential wraps, starting at the upper border of the patella and spiraling down and up the stump, overlapping one half the width of the plaster bandage with each layer. Smooth each layer as it is applied. Apply bandage until the shell has a maximum thickness of



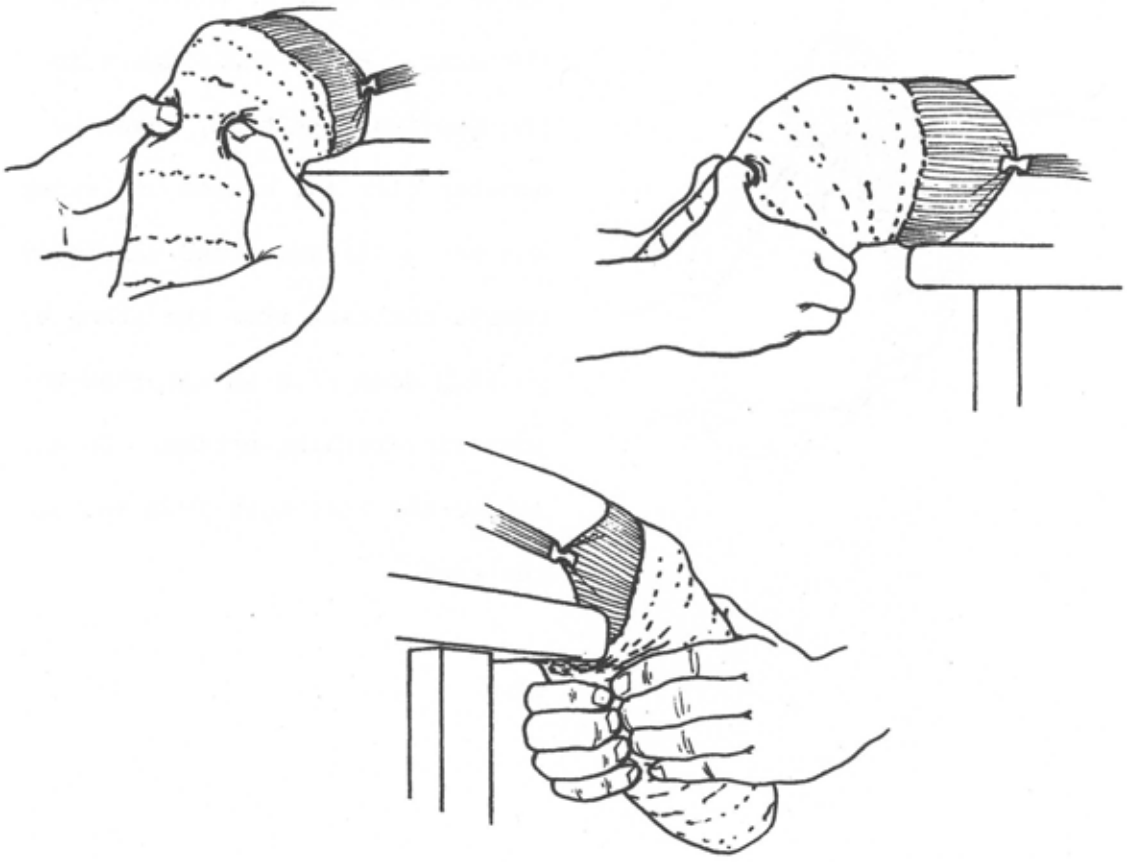
approximately 1/8" in the proximal (top) third. Add additional layers over the distal end to build up a thickness of approximately six layers of bandage. Be sure to cover the femoral condyles; this requires that the wrap extend approximately 3" above the mid-patellar-tendon level. Caution: Do not enclose the entire patella; otherwise, it will be difficult to remove the cast.

6. Instruct the amputee to keep his stump muscles relaxed and to hold a fixed angle of knee flexion. Smooth the plaster over the surface of the stump by moving the hands around the stump and working toward the knee. Work the plaster around bony prominences so that they are clearly defined in the cast, and continue to work the cast until it begins to harden.
7. As the plaster begins to harden, use the ends of the thumbs



and fingers to outline the patellar tendon and compress the popliteal tissues. Place the thumbs at a 30° to 45° angle to the long axis of the tibia and on either side of the patellar tendon. Press inward, as shown in the accompanying sketch, midway between the lower edge of the patella and the tubercle of the tibia. Be careful not to push up on the inferior edge of the patella or on the anterior prominences of the tibial condyles.

8. Wrap the fingers around the knee and press the pads of the fingers into the popliteal area. The upper fingers should be at the level of the posterior crease of the knee. Maintain contact at the sides of the knee to prevent bulging, but do not apply pressure on the hamstring tendons.



9. Use firm finger pressure. Hold the stump until the plaster has hardened sufficiently to hold its shape. Finger fatigue indicates that too much pressure is being exerted. The depth of the finger-pad impressions in the popliteal area will serve as a measure of tissue firmness and an indication of how much modification of the model is required.

10. When the plaster has hardened, release finger pressure but



allow the wrap to remain on the stump an additional minute or two. Reflect the cast sock down over the cast. Place the fingers in the previous position, have the amputee flex and extend his stump against resistance, and carefully remove the cast from the stump by pulling down with an anterior-to-posterior-rocking action. Do not remove the cast sock from inside the cast.

PREPARING THE PLASTER MODEL OF THE STUMP

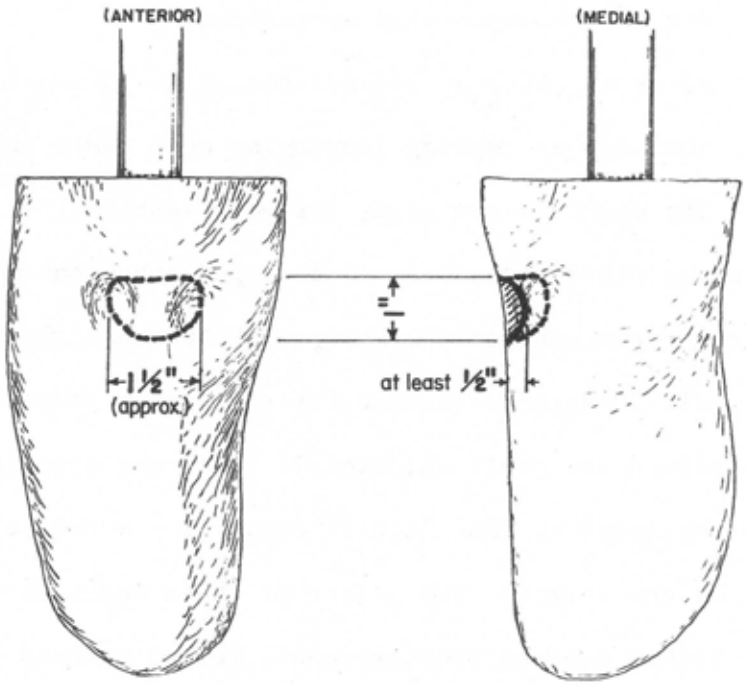
The plaster-bandage wrap cast of the stump is used as a mold in making the plaster model of the stump.

1. Fill the wrap cast with plaster of Paris. Insert an 18" length of 1/2" iron pipe (approximately 1" O.D.) to a depth of not more than 6"; this will serve as a mandrel for future bench-vise operations.
2. After the plaster has set for 20 to 30 minutes, strip off the wrap by cutting lengthwise down the posterior surface. The model is now ready for modification.

When the plaster wrapping is stripped away, the model will duplicate the contours of the stump with the knee flexed at approximately 30 degrees (except for the finger indentations in the patellar-tendon and popliteal areas). The next step is modification of the stump model so that it will serve as a model for the inside contours of the socket. The object of these modifications is to increase socket-contact pressure where forces between stump and socket must be developed (as indicated by prosthetic experience or biomechanical analysis) and to decrease contact pressure in sensitive areas. Wherever greater pressures are required, more plaster is removed from the corresponding areas on the model. To provide relief of pressure in the final socket, the model is built up with patches of leather shaped to fit the sensitive area. The model should be

examined and the prominences and sensitive areas noted that will require building up as well as the areas which will support weight, such as the medial tibial flare and the patellar tendon.

1. Modify the patellar-tendon area by cutting away the model midway between the lower edge of the patella and the tubercle of the tibia to a minimum depth of 1/2". The channel thus formed (which will become a protuberance in the socket) should have a height of approximately 1" as

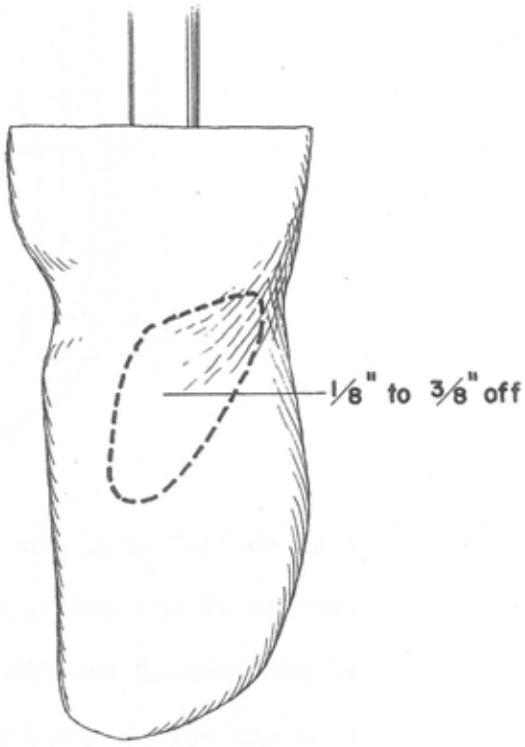


seen from the side. It should start just below the patella and extend downward to the upper border of the tubercle of the tibia. The modified area should extend on either side to the center of the thumb prints and, as seen from the front, should have a width of approximately 1 1/2".

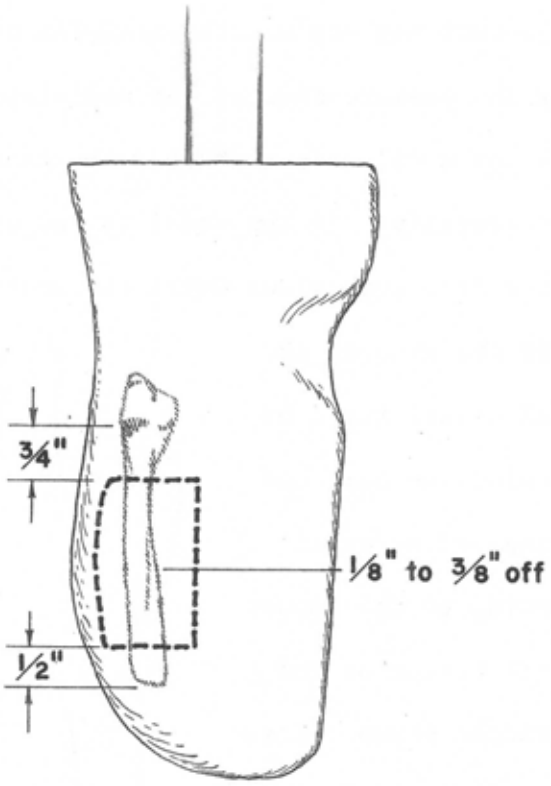
Caution: Do not remove material in the area of the thumb prints; otherwise, the socket may contact the condyles of the tibia.

2. Using the measurements of the mediolateral stump diameter, check the model to see whether the cast has been distorted mediolaterally. If the model is too wide, shave away plaster from both sides until the measurements are correct.

3. Modify the area of the medial tibial flare by smoothing the cast and shaving off material according to the amount of soft tissue on the individual stump. Shave off at least 1/8" to 3/8" of plaster at the deepest point, tapering out to the edges.



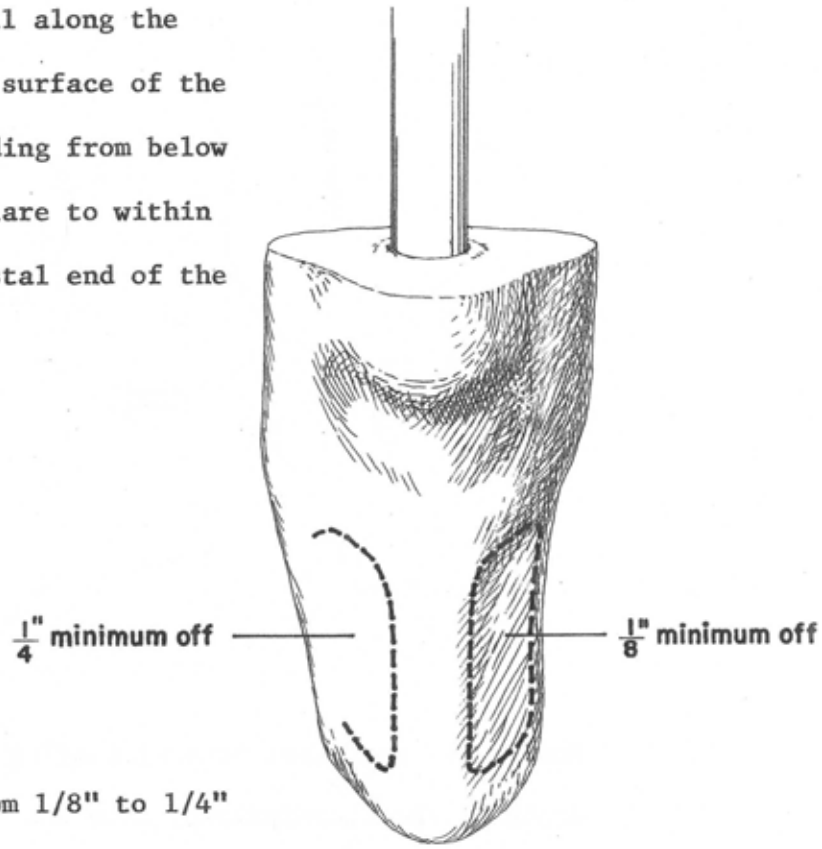
4. To assure lateral stability, definite contact pressure is provided for against the lateral surface of the stump. Depending on the characteristics of individual stumps, the model should be modified along the lateral aspect by removing plaster to flatten the model and to emphasize contact pressure in this region. A minimum of approximately



1/8" to 3/8" of plaster should be removed from the lateral surface of the model, starting 3/4" below the distal border of the head of the fibula and continuing to within 1" from the end of the fibula.

The below-knee amputee must extend his knee actively in many situations. Stabilization of the stump against the anterodistal portion of the socket is a definite requirement for fixation of the joint below the knee so that knee action can be used in the control of body motions. The anterior surface of the stump model, extending downward along both sides of the anterior tibial crest, should be modified as follows.

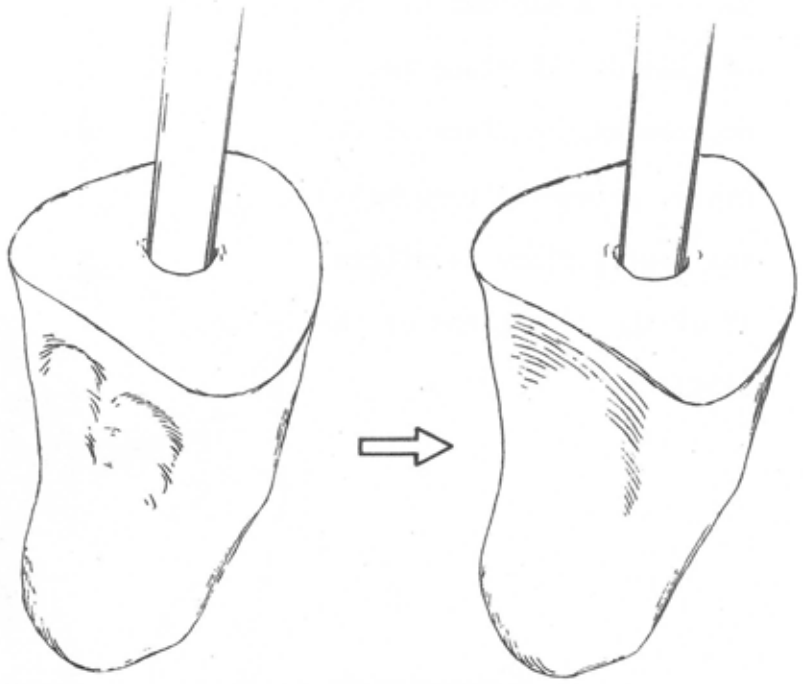
5. Shave off a minimum of 1/8" of plaster all along the anteromedial surface of the tibia, extending from below the medial flare to within 1" of the distal end of the tibia.



6. Shave off from 1/8" to 1/4" of plaster from the antero-lateral surface of the stump model, blending in with any modification of the lateral surface, to within 1" of the distal end of the fibula.

The modifications of the anteromedial and anterolateral surfaces of the model will form a wedgelike support along both sides of the front of the tibia.

Preparing the Plaster Model of the Stump

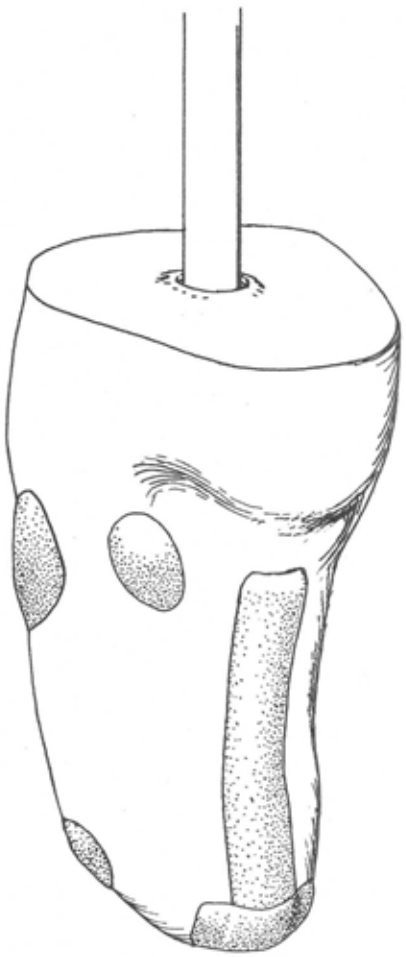


7. Modify the popliteal area by shaving away plaster, to the depth of the fingerprints, from the crease of the knee approximately 2" downward. Round out the upper popliteal area to form a flared posterior socket brim extending upward from the level of the center of the area of patellar-tendon modification. Caution: Never touch the hamstring area. A cast should not require much smoothing if it has been properly taken.
8. If smoothing is necessary, use wire screen and sandpaper, taking care not to remove much plaster in the process, especially from the end. The end of the socket will provide containment of the stump for improved circulation rather than provide end-bearing.

9. Trim excess plaster (a lip or sharp edge) at the top of the model to prevent bridging during lamination.

10. When lamination over a wet plaster model is necessary, the plaster should be coated with Hi-Glo parting lacquer or an equivalent moisture barrier, such as fast-setting air-cure polyester resin.

11. Bond patches of 6-oz. (approximately 3/32"-thick) soft leather over all spots marked for relief. Extend the patches for bony prominences at least 1/4" below their lower borders. Extend the patch on the head of the fibula 3/8" below its lower border. If the stump settles into the socket later, the extra clearance will continue to provide relief of pressure.



12. Use double-thickness patches over particularly sensitive areas, such as the head of the fibula and the anterior distal end of the tibia. The patch for the head of the fibula should be extended proximally

for bony stumps to facilitate entry into the socket. All patches should be skived for a smooth transition into the surface of the model.

13. The modification is now complete, and the model is ready for use in fabrication of the socket.

FABRICATION OF THE SOFT INSERT

Materials required for fabrication of the soft insert for the below-knee socket are as follows:

(1) medium-weight horsehide (4 to 6 oz.) or its equivalent

(2) Kemblo 2113, 1/8" thick (a firm, closed-cell, synthetic sponge rubber)

(3) type 181-114 Fiberglas cloth

(4) polyester resin (semirigid)

(5) polyester resin, non-air-inhibited (Laminac 4110 or its equivalent)

(6) 1/8" Dacron felt (1/2 oz.), Troytuf

(7) cotton cast sock

(8) PVA sleeve for below-knee socket

(9) cement (Stabond T-161 or its equivalent)

(10) blue chalk (carpenter's chalk line)

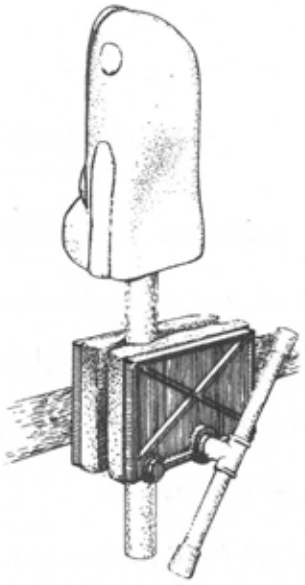
(11) phenolic microballoons

(12) below-knee shank block

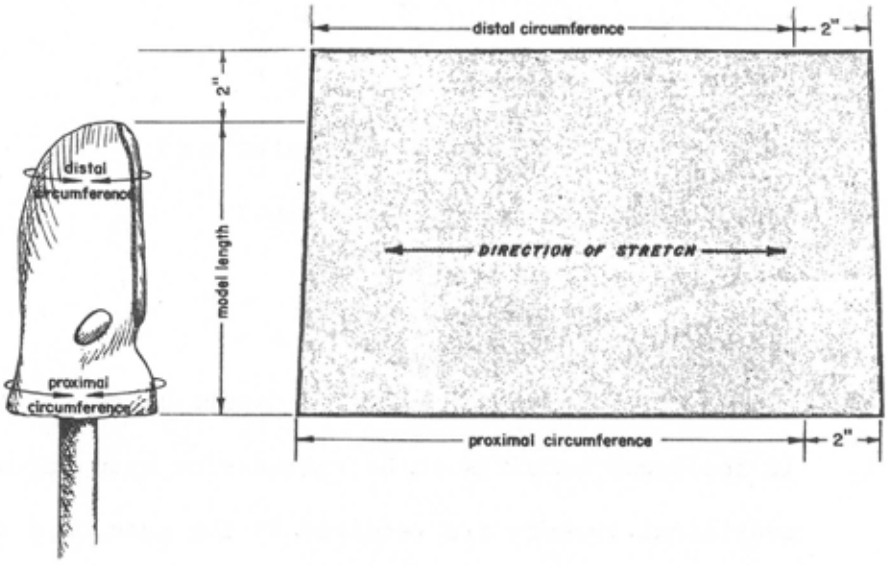
The procedure for lay-up of the soft insert is as follows:

1. If the stump model is to be reused--for example, when additional inserts are required in the case of a stabilized stump--make a two-piece split-plaster mold over the model so that duplicate stump models can be cast.

2. Place the mandrel of the stump model in the bench vise with the model held in a vertical position.



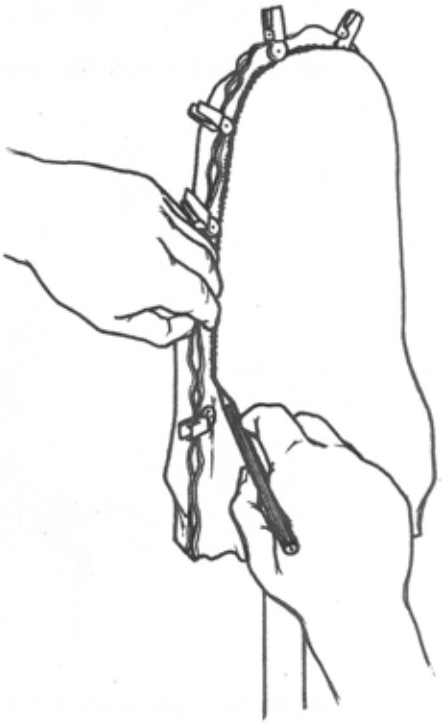
3. Cut a piece of medium-weight horsehide 2" longer than the length of the model and 2" wider at the top and bottom



than the distal and proximal circumferences. The direction of stretch of the horsehide should be parallel to the top

and bottom margins.

4. Fit the horsehide to the model, smooth side in, and determine the seam line by clamping with harness clamps in a minimum of six locations. The seam line should extend down the posterior center line of the model. Pinch the leather to the model between the clamps, and mark the seam line with a pencil.

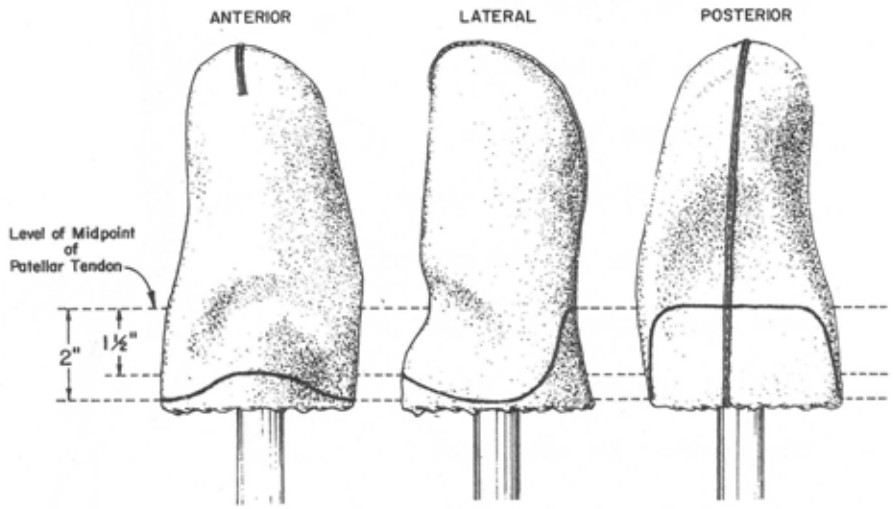


5. Sew the liner along this line, removing one clamp at a time. Trim the seam to within 1/8" of the stitching along its entire length.

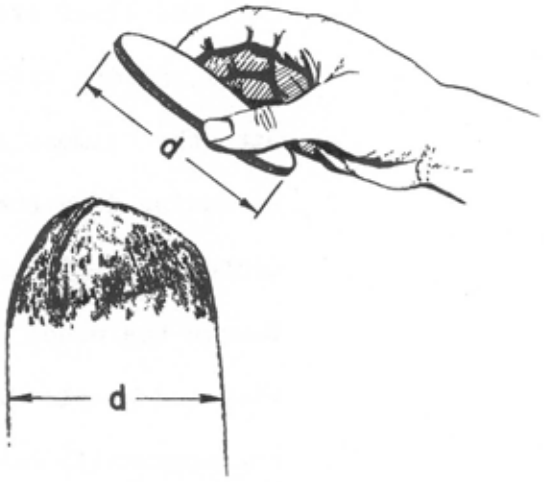
6. Pull the liner over the model, smooth side in, with the trimmed seam extending down the posterior center line of the model. Remove the model from the vise and staple or tack the proximally extending



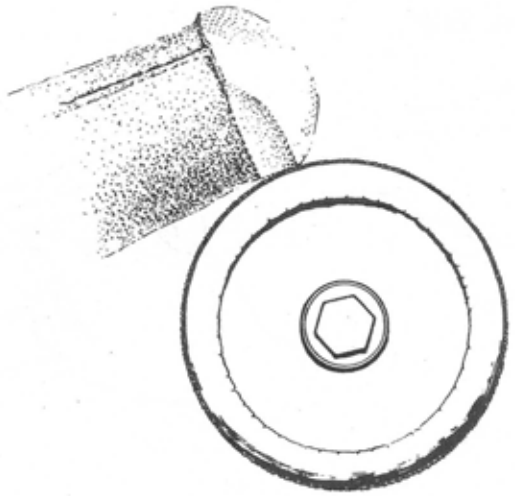
leather to the base of the model; then replace the model in the vise. Do not stretch the leather while stapling; or it will bridge the patellar-tendon indentation.



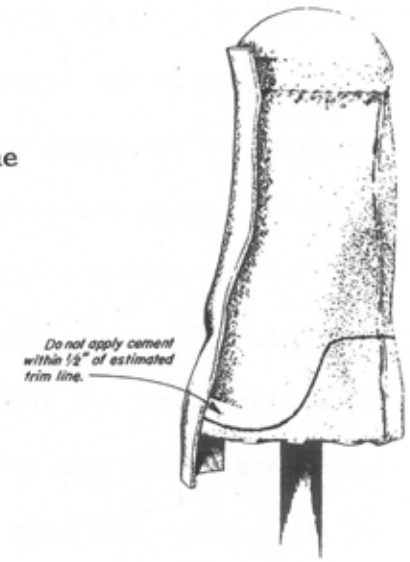
7. Draw an estimated trim line as shown; in subsequent steps, cement should not be applied within 1/2" of this line.
8. Form an end pad for the socket by cutting out a disk of 1/8" Kemblo to cover the distal end of the model. The diameter of the disk should be made to equal the average diameter of the stump.
9. Paint the distal end of the liner and Kemblo end pad with Stabond T-161 cement; allow to dry until tacky; then pound the end pad into place. Unless the curvature is extreme, the



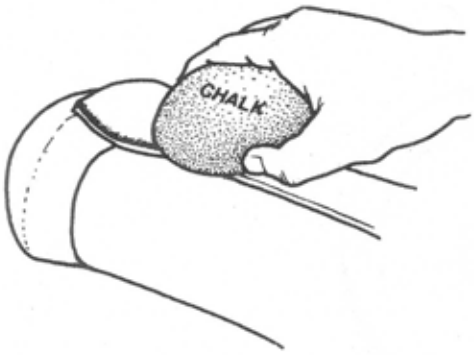
flat end pad will bend and conform to the spherical end. A dart or two may be required in some cases.

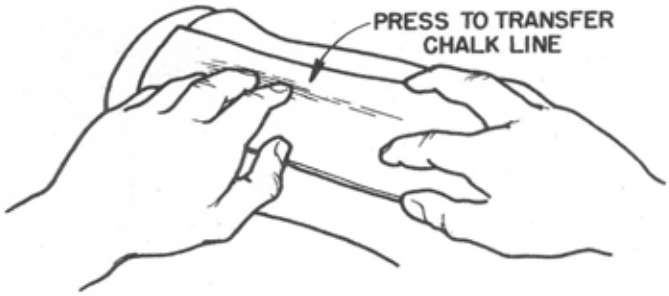


10. Using a sanding drum, skive the outer edge of the Kemblo and pad approximately 1/2" back from the edge, with the outer edge flush with the horsehide liner.
11. Cut a strip of Kemblo approximately 2" wide and long enough to overlap the distal end pad 1/2" and to extend beyond the model 1" proximally.
12. Coat the anterior surface of the liner, including the outer surface of the end cap, with Stabond T-161 cement. Coat the Kemblo strip with Stabond T-161 cement. Allow both surfaces to dry until tacky;



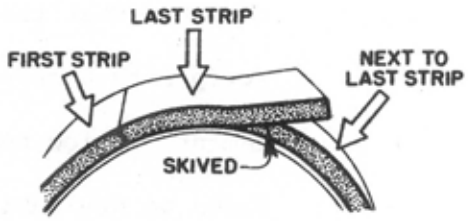
then press the first strip into place along the entire area for the anterior crest of the tibia and into the patellar-tendon indentation, placing it so that it overlaps the end cap 1/2".





13. Continue adding strips of Kenblo from 1" to 2" wide around the entire circumference of the model. Each strip should be tailored so that it will lie in place and conform to the irregular contours of the model without tension. Chalk the protruding edge of the previous strip and press the next strip into place with the free edge parallel to the axis of the model. The trim



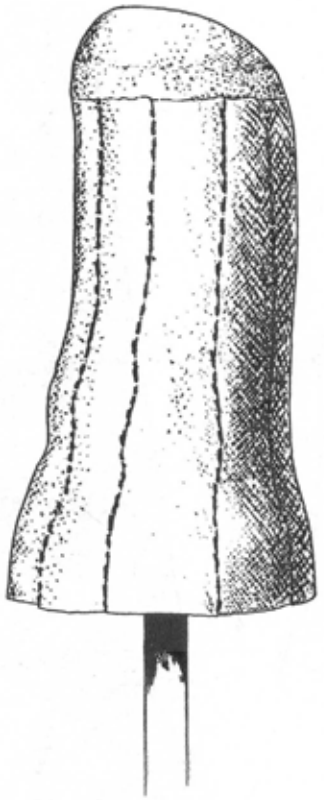


line will be imprinted on the new strip.

14. With a sanding drum, skive the strip ends where they overlap the distal end of the model.

15. Bond a second layer of the end pad over the distal end of the model.

16. Sand the outer edge of the second layer of the end pad flush with the surface of the vertical strips along the side of the model.

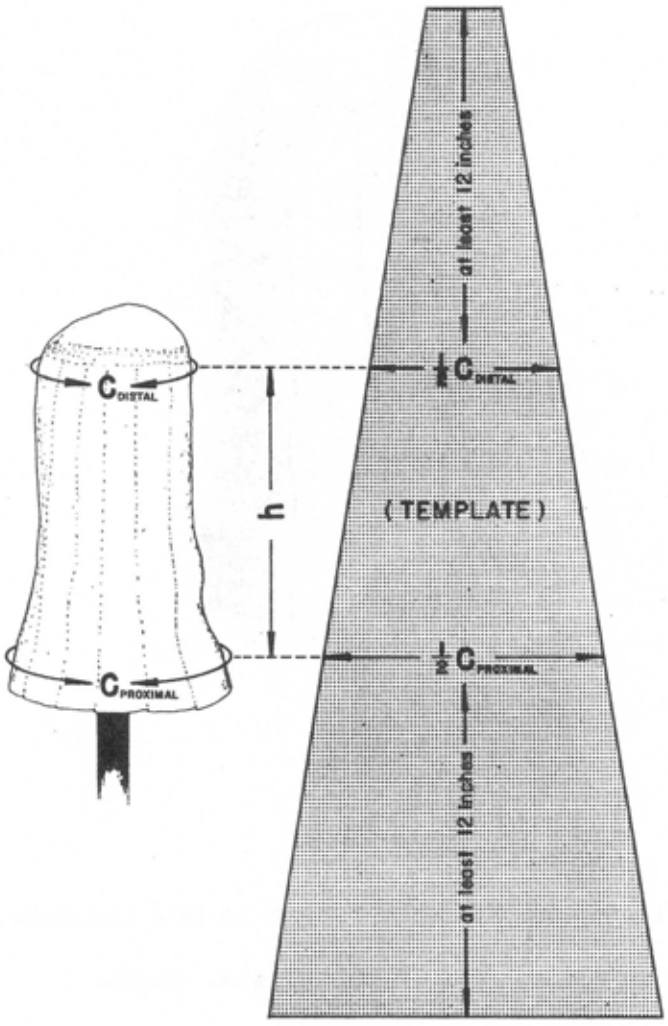


17. The lay-up of the soft insert is now complete. The next step is lamination of the plastic shell.

FABRICATION OF THE PLASTIC SHELL

The plastic shell of the below-knee socket is fabricated over the soft insert. To protect the insert from the plastic, the insert is covered by a PVA sleeve, capped at the end.

1. Fabricate two tapered PVA sleeves to the dimensions shown in the illustration.



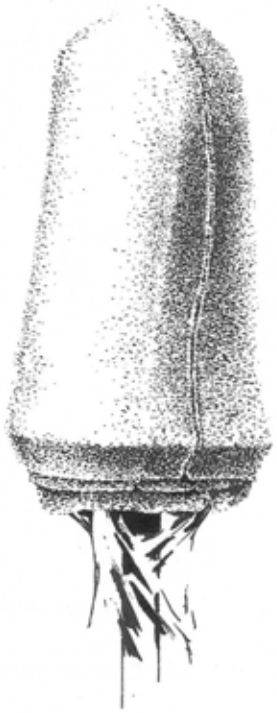




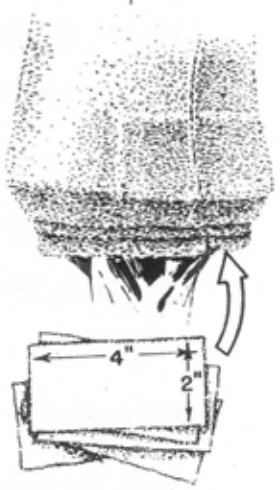
2. Coat the outer surface of the socket liner liberally with talc. Stretch the PVA sleeve over the model and insert; then trim around the distal end where the PVA sleeve no longer makes contact with the insert. Paint on a 1/2" strip of PVA adhesive around the cut edge; then pull a

sheet of PVA over the end to form an end cap bonded to the PVA sleeve. Tie off around the mandrel, and trim all loose material. The PVA covering over the insert prevents adhesion between the insert and the socket and allows removal of the insert from the final socket.

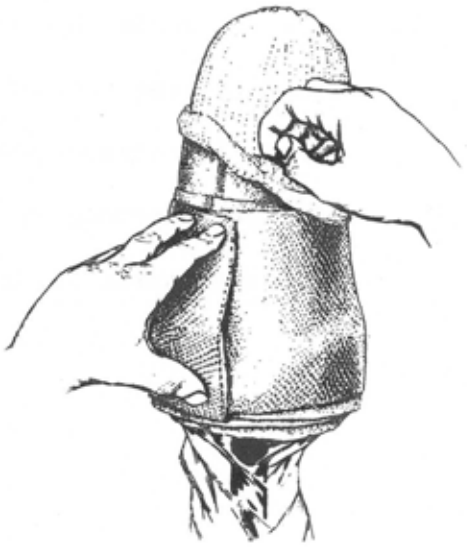
3. Cut out three pieces of 1/2-oz. Dacron felt to the same pattern as the socket liner (see p. 86). Sew them in a similar manner, and pull them over the model.



4. Under the last layer of felt, place five rectangular pieces of Dacron felt for thickening the posterior edge of the socket.



5. Cut a strip of Fiberglas cloth wide enough to cover the proximal half of the model. Wrap the glass cloth around the model with a minimum overlap of 1". Hold in place by rolling a light cotton cast sock over the lay-up.



6. Stretch the second PVA sleeve over the lay-up. Tie off the sleeve at the proximal end around the mandrel.

7. Prepare from 200 to 400 grams, depending on socket size, of plastic resin, using the following method for 100 grams:

   (a) Mix 2 grams of ATC catalyst per 100 grams of polyester resin.

   (b) Mix in color paste according to manufacturer's recommendation.

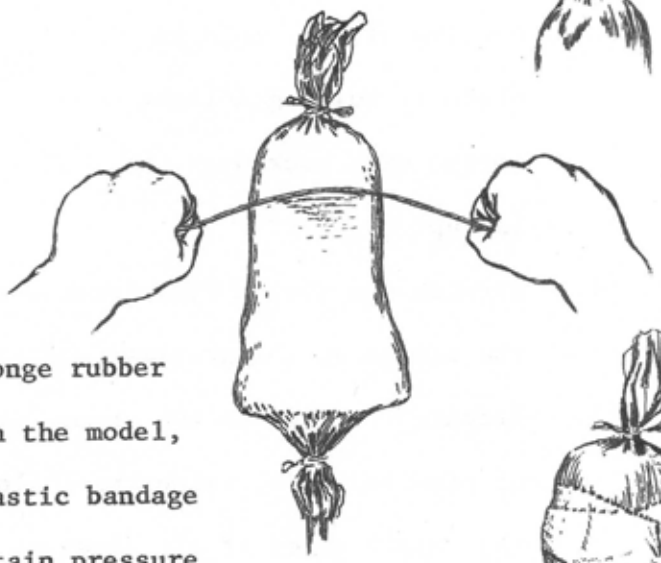
   (c) Add 10 drops of Naugatuck Promoter #3 per 100 grams.

   (d) Mix thoroughly.

   This mixture will gel in approximately 30 minutes.

8. Pour the resin into the small tapered extension of the PVA sleeve. Work the resin thoroughly down into the fabric layers.





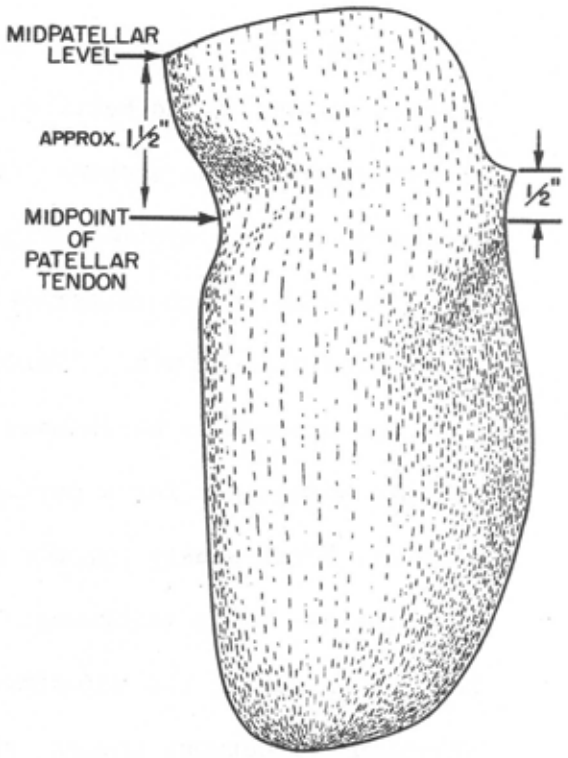
9. Place pads of sponge rubber over undercuts on the model, and wrap with elastic bandage in order to maintain pressure on the laminate in these areas. Pressure-sensitive tape can be used for the same purpose.



10. Allow the plastic to cure. Before the plastic cools, cut the trim line with a sharp knife and blow or knock the socket from the cast.

11. Should the plastic cool, trim the socket along the proximal edge. Sand the edge at a 45° angle until the underlying sponge rubber is barely exposed. Do not cut through the sponge rubber. Remove the shell from the model.

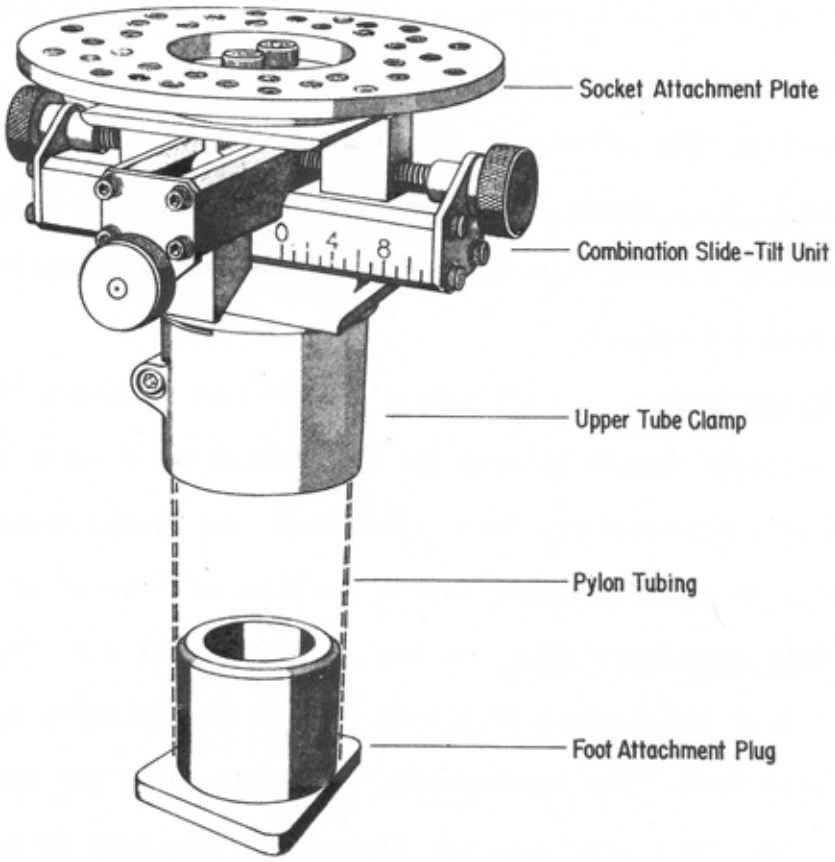
12. Trim the plastic shell as follows: Trim across the anterior brim of the socket at the midpatellar level. Trim across the posterior brim of the socket at a level corresponding to 1/2" above the midpoint of the patellar tendon. The sides of the socket should be held as high as possible and should dip down with a generous radius at the posterior corners in the region of hamstring-tendon attachment. Reinsert the soft liner but do not trim it yet.



THE BELOW-KNEE ADJUSTABLE SHANK

The fit of the socket to the below-knee stump and the alignment of the socket with respect to the prosthetic foot are related. Both procedures are influenced by such biomechanical factors as stump length, degree of end-bearing, pressure-sensitive areas, and physical coordination of the amputee. Before starting the procedure of achieving optimum dynamic alignment, the prosthetist must become familiar with the characteristics of the individual amputee and have a definite plan in mind. Various factors influencing dynamic alignment and procedures which have been found helpful in achieving optimum adjustment for a particular amputee will be discussed in the chapter, "Preliminary Dynamic Alignment."

The use of an instrument--the below-knee adjustable shank is helpful in making the adjustments necessary to achieve the proper relationship between socket, shank, and foot and the resulting comfortable, normal-appearing, and energy-saving gait, i.e., optimum dynamic alignment. The below-knee adjustable shank allows the prosthetist to adjust the socket in any desired position over the foot and to check the alignment as the amputee walks. When the alignment is considered satisfactory, the amputee can use the adjusted prosthesis for walking trials or gait training, after which its alignment can be duplicated in the permanent prosthesis.



Components

The below-knee adjustable shank consists of five elements:

Socket Attachment Plate. The socket attachment plate has a large number of drilled and countersunk holes to allow the choice of several locations for the use of no. 10 x 3/4" flat-head steel wood screws. The below-knee adjustable shank is screwed against the flat bottom of either a wooden below-knee socket or a laminated plastic socket with an added wood block bonded at the distal end.

Combination Slide-Tilt Unit. Two combination slide-tilt units with identical features are crossed back to back. Each slide can be

tilted about its slide axis through an angle of 15° each way and locked in place in a particular position. Adjustment and locking are done by a pair of adjustment knobs which control the motion of combination tilt-adjustment and locking wedges.

Upper Tube Clamp. The lower end of the unit is constructed in the form of a split tube clamp into which the pylon tubing is inserted and clamped in place.

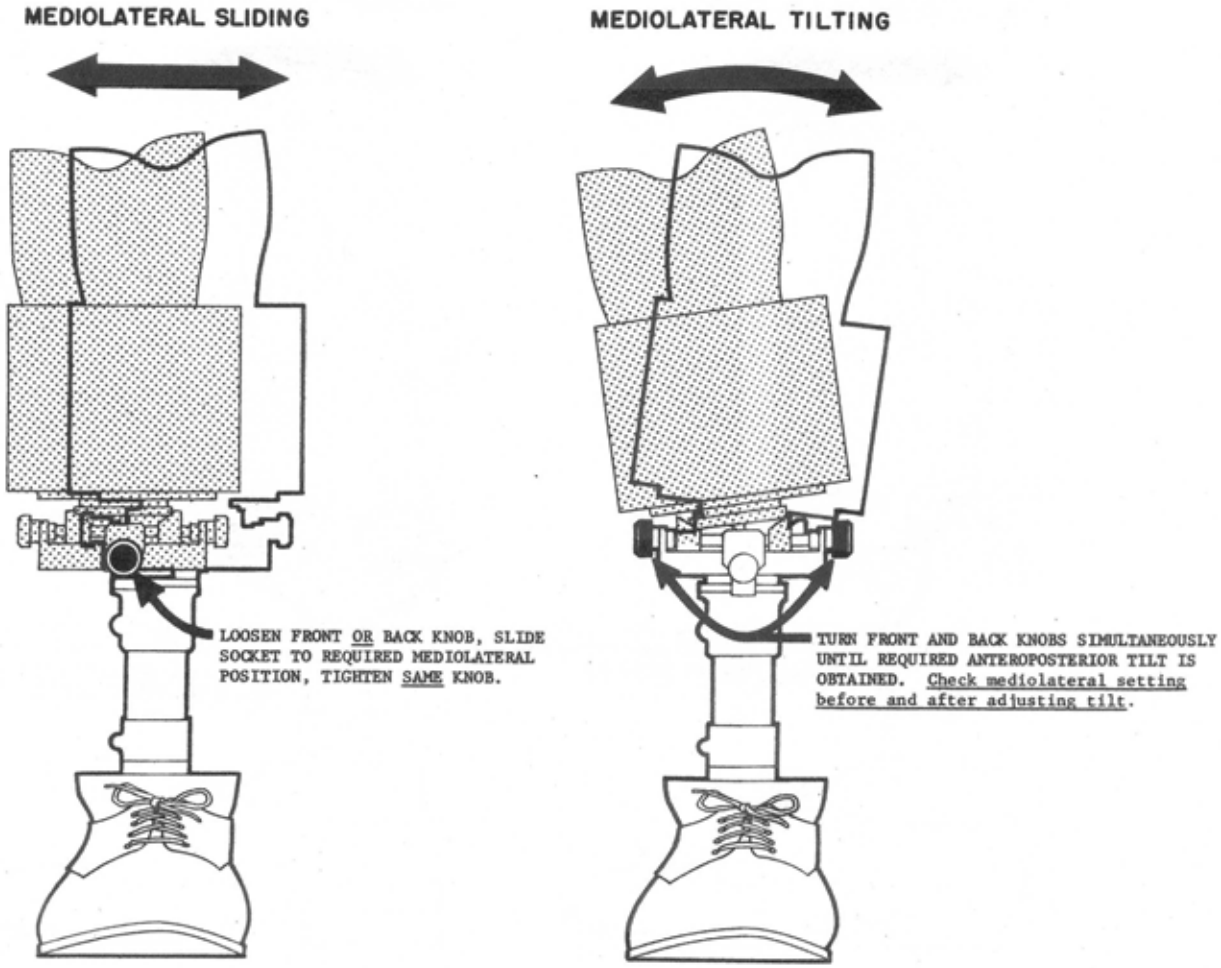
Pylon Tubing. 1.625" O.D. x 1.510" I.D. aluminum alloy tubing of a suitable length is used for the connection between the adjustable slide-tilt unit and the foot. The lower end of the aluminum tubing is split to allow clamping around the foot attachment plug.

Foot Attachment Plug. A foot attachment plug is first bolted to the flat top surface of a SACH foot or the hardwood ankle base of a wood foot. The pylon tubing then slips over the foot attachment plug, and a separate tube clamp holds the foot in place.

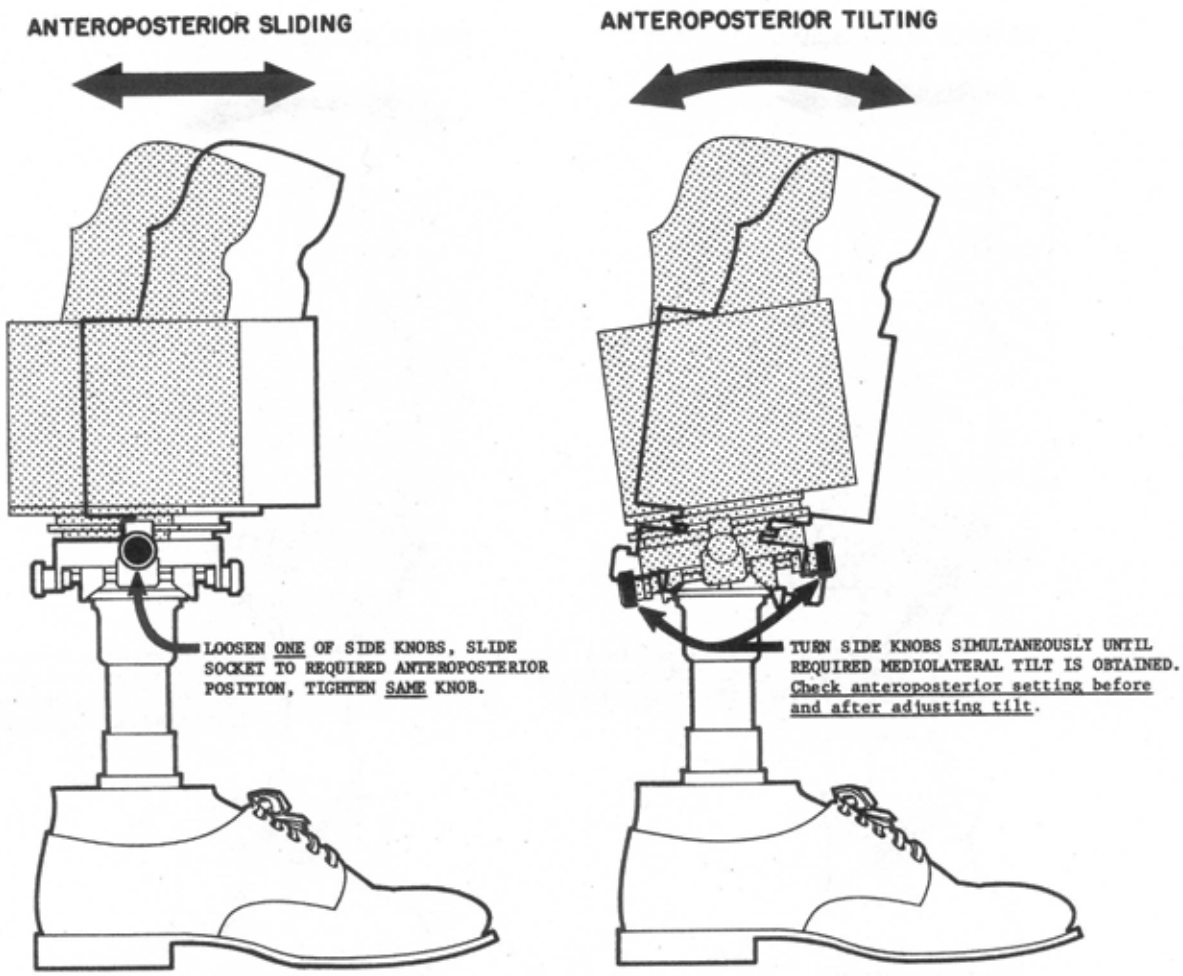
Adjustments

The below-knee adjustable shank allows six separate adjustments:

1. For mediolateral sliding, loosen either of the knobs at the front or back of the unit; make the adjustment as indicated on the front scale; and tighten the same knob to lock the mediolateral slide.
2. For mediolateral tilting, use both knobs at the side of the unit. Note the reading on the anteroposterior slide scale before loosening the knobs, since both the anteroposterior slide and the mediolateral tilt adjustments are



loosened with the same knobs and it is possible for the socket adjustment plate to slide anteroposteriorly while the mediolateral tilt adjustment is being made. The socket is tilted in the mediolateral direction by backing off with one knob while the other follows in the same direction, then tightening to clamp the tilt wedges in place. Recheck the anteroposterior position.



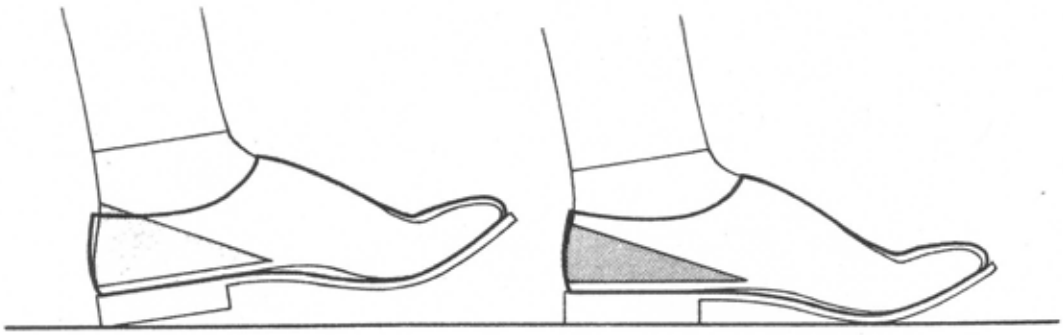
3. For anteroposterior sliding, adjust as for mediolateral sliding, but with use of the side knobs.
4. For anteroposterior tilting, adjust as for mediolateral tilting, but with use of front and back knobs; loosen the mediolateral slide and note the mediolateral scale before beginning the anteroposterior tilt adjustment.
5. For toe-out, loosen the ankle clamp; rotate the foot to the desired position; and tighten the ankle clamp.

6. To lengthen the unit, loosen the lower clamp, remove the foot, add spacers as required (not more than 1/2"), reattach the foot, readjust toe-out, and tighten the lower clamp. For amputees light in weight, on whom the clamp will not slip, the use of spacers may not be necessary. To shorten the unit, use a shorter length of aluminum tubing. The lower end should be slit to allow it to clamp against the foot attachment plug.

THE SOLID ANKLE - CUSHION HEEL (SACH) FOOT

Functional Characteristics

The Solid Ankle - Cushion Heel foot, or SACH foot, has been designed to provide, without the use of an articular ankle joint, shock absorption and other ankle actions which are like those of the normal ankle. These functions are accomplished by the use of two elements: (1) a properly shaped wedge of cushioning material built into the heel and (2) an internal structural core, or keel, shaped at the ball of the foot so as to provide a rocker action. The cushion heel not only cushions the heel impact efficiently but also simulates normal plantar flexion closely.



The action of the SACH foot is smooth; the amputee is not conscious of sudden changes in resistance such as are typically

experienced with a conventional foot that has an articulated ankle joint, a soft plantar-flexion bumper, and a firm dorsiflexion stop. At heel contact the heel cushion compresses approximately 3/8", allowing the forefoot to rotate toward the floor. This action, in combination with the additional forward inclination of the shank and foot as a whole, results in normal appearance during the first part of the stance phase. During the midstance, or roll-over, phase, the body weight is divided between the heel and ball of the foot and there is a gradual transfer of weight forward. The shape of the keel provides support and a smooth rocker action at push-off. The distance from the ankle center forward to the toe break is shorter than in many conventional feet, a feature that has been found desirable as one means of reducing the energy cost of walking, especially up inclines.

Sizing and Ordering Specifications

SACH feet may be purchased in a roughly shaped oversized blank in three shoe size ranges, 6-8, 8-10, and 10-12. Each size range has a common keel size, there being a 1/4" difference in the distance from toe break to ankle between size ranges. In addition, the heel cushions are fabricated in several stiffnesses, with medium and firm grades finding the greatest applicability.

A foot blank is specified as follows: (1) size range, (2) right or left, and (3) heel stiffness required; for instance, the order might specify 8-10 R medium.

Table 1 serves as a guide in making a choice of heel cushion

stiffness on the basis of type of amputation and body weight.

Table 1.--Heel Stiffness

Type of Amputation	Body Weight, Lb.	Recommended Stiffness
Above-Knee	Over 180	Firm
	Under 180	Medium
Below-Knee	Over 140	Firm
	Under 140	Medium

Table 2 indicates how the apparent overlap in shoe sizes can be used to advantage in prescribing for amputees of different heights. These recommendations provide a keel length proportionate to the length of the prosthesis.

Table 2.--Recommended Foot Blank Size for Borderline Sizes

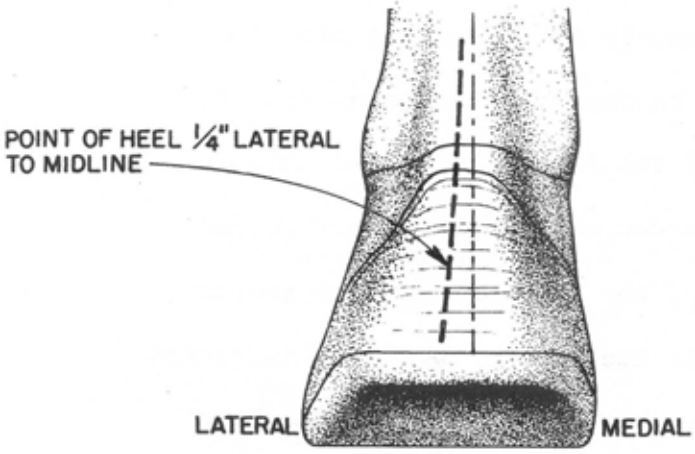
Shoe Size	Blank Size	
	Height Below 5'9"	Height Above 5'9"
8	6-8	8-10
10	6-10	10-12

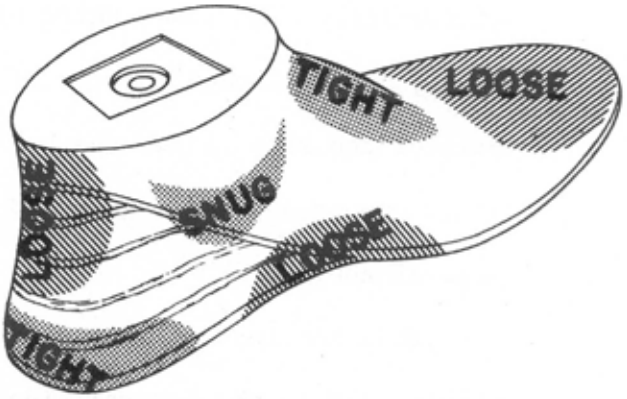
It should be emphasized that tables 1 and 2 are given only as guides. If, after trial or on the basis of experience, it appears that a change in heel-cushion stiffness is indicated, there is no objection ot making such a change. However, poor function can often be traced to improper installation, alignment, or adjustment rather than to the heel cushion.

Shaping

Do not shape the ankle portion of the foot above the shoe level until after final installation of the foot on the shank with proper toe-out. Leave the ankle area roughly shaped during walking trials.

The shaping of the SACH foot is important, since its function and the appearance of the gait are influenced by its shape. There are three areas where particular care is required: (1) the heel cushion, (2) the upper and lower surface of the arch of the foot, and (3) the toe section.





The general foot contours necessary for proper functional shaping are present in the oversize foot blank. Only minor changes are necessary, to reduce oversize dimensions. In particular, no change should be made in the lower third of the posterior heel contour,

since this contour has been preshaped to provide the proper distance from the heel to the toe break.

When inserting the foot into the shoe during fitting, always use a thin sock on the foot. Contouring the foot, as described below, can best be accomplished by sanding parallel to the laminations, using a cone or drum sander with a spindle speed of at least 1,750 rpm.

The heel of the SACH foot must fit the shoe in both the relaxed and compressed conditions. It is shaped to fit the shoe tightly near the sole of the heel, yet have considerable clearance near the brim of the heel counter. Approximately 1/8" clearance should be allowed at the brim of the counter between the posterior, medial, and lateral surfaces of the heel of the foot and the heel counter of the shoe. This clearance should decrease gradually and extend downward approximately two thirds of the depth of the heel counter of the shoe. The lower third of the heel of the SACH foot is fitted snugly into the heel counter of the shoe. The clearance near the brim of the shoe allows the heel cushion to expand horizontally as it is compressed under load and is extremely important in preventing wear of the shoe.

When the heel is shaped, its point should be displaced approximately 1/4" to the lateral side with the foot oriented straight ahead. Thus, as the toe of the foot is rotated laterally to give the proper toe-out, the point of the heel will rotate back toward the midline and the point of initial heel contact will again be at the geometric center of the foot. If this displacement is not done when the heel

is shaped, weight will be transferred through the lateral side of the heel cushion at the time of heel contact.

The bottom surface of the arch of the foot must be shaped to provide a minimum of 1/8" clearance between the foot and the inner sole of the shoe. If clearance is not provided, the arch of the foot will contact the sole of the shoe as the heel compresses, resulting in restriction of motion, shoe damage, and wear of hose in this area.

The upper surface of the arch of the foot is shaped so as to hold the heel cushion against the counter of the shoe and to match the shoe-lacing gap on the normal side. The toe-break area of the forefoot must be shaped to provide a looser fit than is usual with wooden feet. The flexible material of the forefoot expands with compression as the toe bends, and this expansion must be allowed for. Failure to provide sufficient clearance will resitrct the toe motion and cause shoe damage.

Adjustments

Two adjustments are possible with the SACH foot: changes in heel rise and changes in heel-cushion stiffness. The angle of wedge of the heel cushion should not be changed.

The heel rise of the foot sometimes requires adjustment because of differences in shoe lasts. The SACH foot is at present manufactured with an 11/16" heel rise, i.e., the bottom of the heel is 11/16" above the level of the ball of the foot with the attachment surface parallel to the floor. Before any adjustment of heel rise is attempted, a recheck of the clearance between the arch of the foot

and the shoe should be made.

An increase in heel rise is indicated if, with the top of the foot parallel to the floor, there is excessive heel-cushion compression. Such compression tends to limit plantar flexion in walking and to decrease knee stability both in walking and in the standing position. The heel rise may be increased up to 3/16" by sanding the lower surface of the foam crepe sole material in the heel area. If an increase in heel rise greater than 3/16" is indicated, improper sawing of the shank should be suspected. The alignment of the shank and foot should be rechecked and the junction of the shank and foot recut, sanded, or wedged as required.

A decrease in heel rise is indicated if there is insufficient compression of the heel cushion in the standing position. This will result in excessive knee stability and a feeling of "walking over a hill." Shims of crepe shoe sole material, leather, or any firm flexible material may be used to build up the bottom of the heel area until the desired heel-cushion compression is achieved in the standing position.

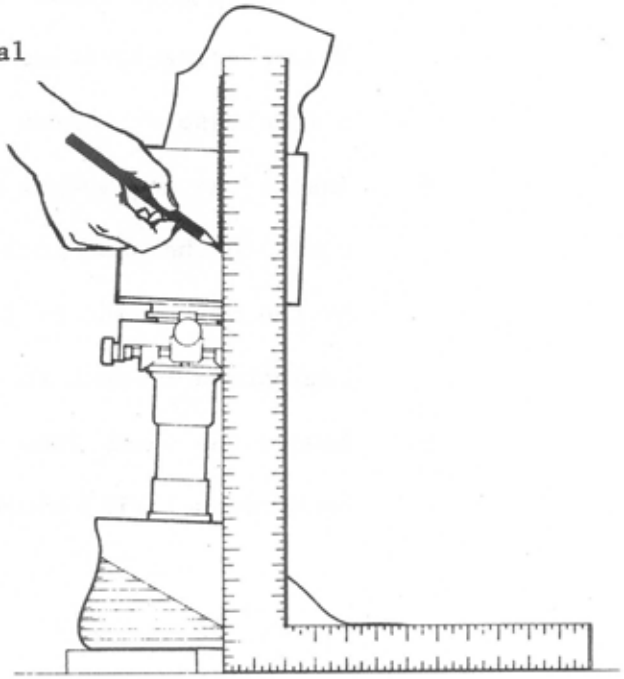
The optimum adjustment of heel rise will result in the heel cushion being slightly compressed in the standing position, balancing the amount of weight carried on the heel cushion and the ball of the foot. The amount of heel compression in the standing position will vary between 1/8" and 1/4", depending on the individual amputee. When heel rise is properly adjusted, the amputee should be able to stand comfortably and relaxed, with a tendency for the knee

to be forced into either extension or flexion.

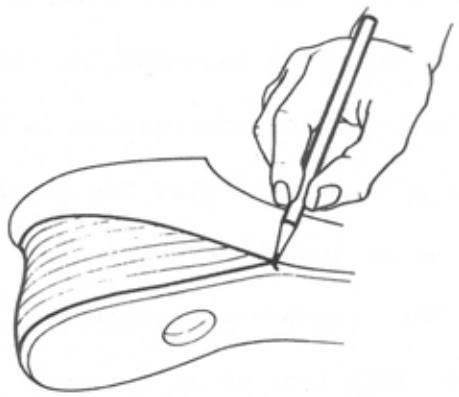
A change in heel-cushion stiffness is indicated if a check of the heel-cushion compression in the standing position shows proper adjustment of heel rise but observations indicate too soft or too hard an action while walking.

The step-by-step procedure for change of heel-cushion stiffness in the SACH foot is as follows:

1. Work on a smooth, level bench top.
2. Remove the shoe from the foot and stand the shank on the bench with an 11/16" block under the heel.
3. Using a carpenter's square, draw a vertical reference line on the medial or lateral aspect of the shank at approximately the midline.

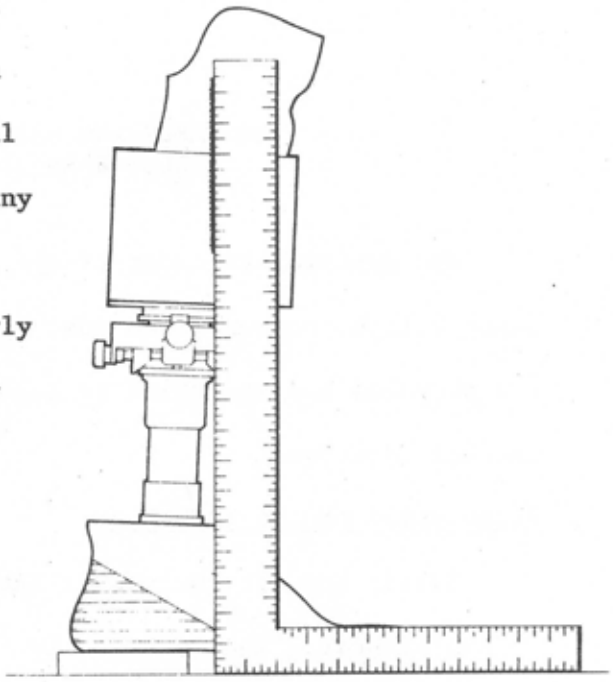


4. Mark the edge of the sole on medial and lateral sides to indicate the anterior point of the heel cushion.



5. Place the shank in a wood vise with <u>heel</u> up.
6. Use a sharp knife to cut out the heel cushion. First, cut along the sole glue line, bending the sole outward as the knife cuts; then, bending the wedge out, cut along the inner glue line.
7. Remove irregularities in the cut surfaces of the foot with a fine rasp or coarse file.
8. Insert the new wedge, without adhesive, so that the point comes to the same location as the one removed (indicated by the marks made on the sole). Be sure the longest lamination is next to the sole.
9. Remove the shank from the vise and replace it on the bench with 11/16" block under the heel.

10. Check the line drawn on the shank to see that it is in alignment with the vertical arm of the square. Make any necessary corrections by forcing the wedge anteriorly or slipping it posteriorly until proper alignment is obtained.



11. Install the new wedge at the point selected, using Stabond T-161 or its equivalent on the mating surfaces.
12. Shape the heel in accordance with instructions on page 107.

ASSEMBLY AND STATIC ALIGNMENT OF THE BELOW-KNEE ADJUSTABLE SHANK

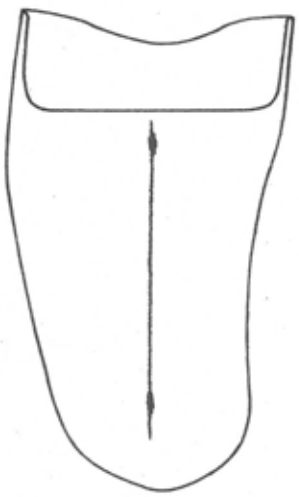
The dynamic alignment of the assembled below-knee adjustable shank will be accomplished most efficiently if the various components are prepared and assembled in such a way as to require a minimum of further adjustment.

Preparation of the SACH Foot

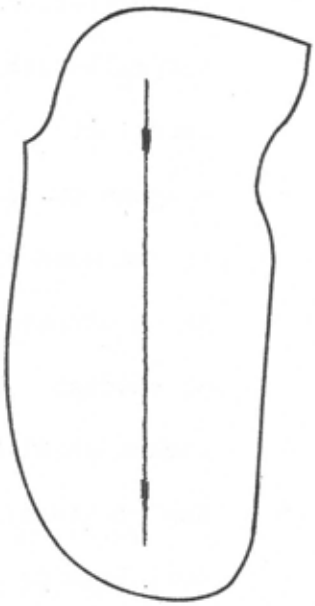
Select and fit the proper SACH foot into the shoe as described in the chapter, "The Solid Ankle - Cushion Heel (SACH) Foot." Pay particular attention to the shaping of the heel area and the amount of heel rise in the foot blank.

Mounting of Socket on Wooden Socket Block

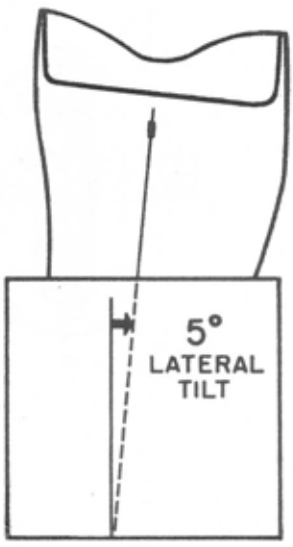
1. Select a block of willow (or similar) wood 6" in diameter and 6" long. Bore a hole 2" in diameter through the block parallel to the grain.
2. Draw a posterior reference line on the external surface of the socket shell, after the brim has been trimmed, by connecting center points at the posterior socket brim and near the posterior distal end of the shell.

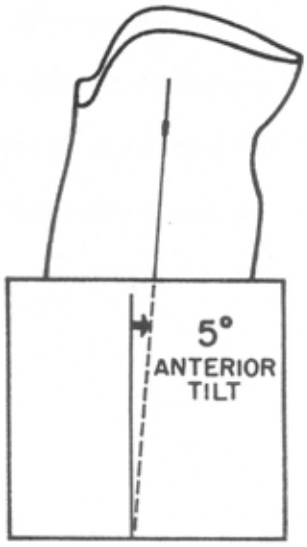


3. Draw a reference line on the lateral surface of the socket shell as follows: Find the midpoint of the distance from the center of the patellar-tendon protuberance to the posterior brim. Draw a line from this point down the lateral side of the socket shell to a center point near the distolateral edge.



4. Rout out the hole in the socket block and sink the lower end of the socket shell 3"-4" into the wood. Carve the





hole so that the shell rests loosely in the block with the posterior reference line tilted approximately 5° laterally and the lateral reference line tilted 5° anteriorly. The angles may be increased if required.

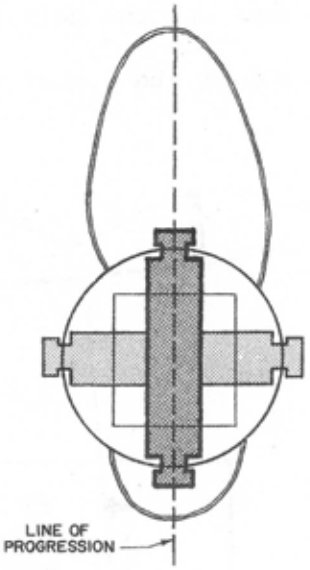
5. Roughen the distal end of the socket shell; then bond it to the wood block in the position established in step 4. Use a mixture of resin and either phenolic microballoons or sawdust. Mask any holes in the distal end of the socket shell before bonding.

6. Saw the lower end of the wood block parallel to the original cut, leaving approximately 1" of wood below the socket shell.

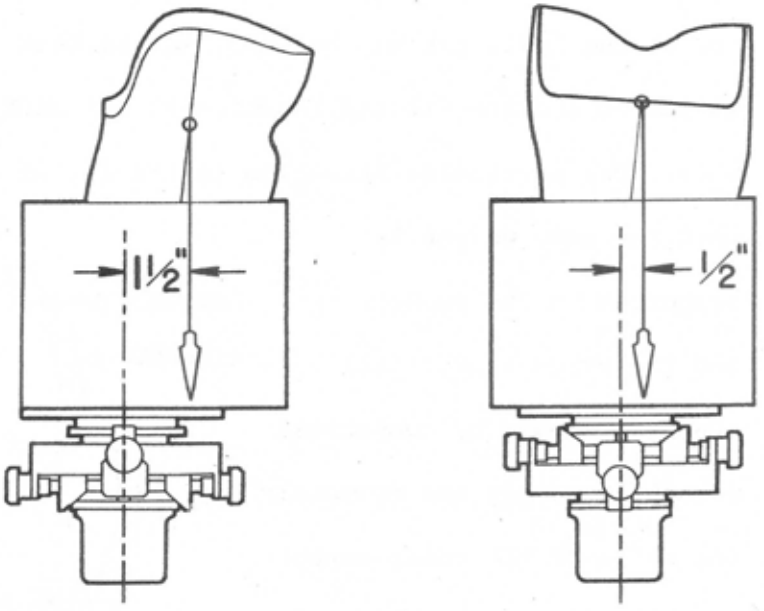
Mounting of the Socket on the Adjustable Shank

1. Adjust the leg unit so that all slide and tilt adjustments are at midrange.

2. Position the socket block on the unit so that the lower slide-tilt unit is parallel to the line of progression (perpendicular to the posterior wall of the socket).



3. Position the socket block so that a plumb line dropped from a point on the lateral reference line at the mid-patellar-tendon level passes 1 1/2" ahead of the center line of the pylon attachment clamp.



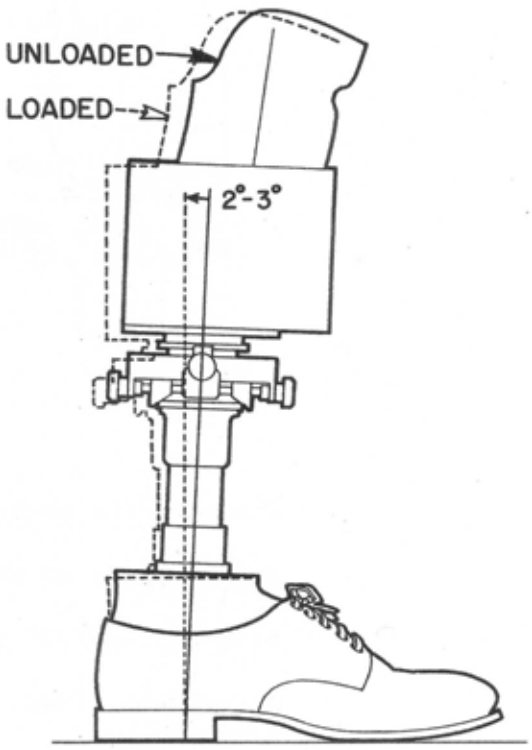
4. Position the socket block so that a plumb line dropped from a point on the posterior reference line at the socket brim passes 1/2" laterally to the center line of the pylon attachment clamp.

5. Attach the socket block to the socket attachment plate of the adjustable shank in the position established in steps 2, 3, and 4. Use a minimum of six no. 10 x 3/4" flat-head steel wood screws.

6. Secure the foot-attachment plug to the top surface of the foot.

7. Establish the distance from medial tibial plateau (MTP) to heel for the prosthesis from the Prosthetic Information Form and select a section of aluminum pylon tubing which will give the proper over-all length.

8. Attach the foot, put on the shoe, and recheck the static alignment and the fit and function of the SACH foot in the shoe. Pay particular attention to the fit of the heel. When the body weight is supported in the socket and the pylon is vertical, the heel should be compressed enough to supply approximately one third of the total support from the foot, with the other two thirds being supplied by the ball of the foot. The unloaded prosthesis will lean forward with the pylon inclined 2°-3°, depending on heel-cushion stiffness.



9. After attachment of the cuff-suspension system, the prosthesis is ready for walking trials.

CUFF SUSPENSION

The cuff-suspension system has two separate functions: It serves to suspend the prosthesis on the stump in swing phase, and during stance phase it acts as a check against hyperextension of the knee joint.

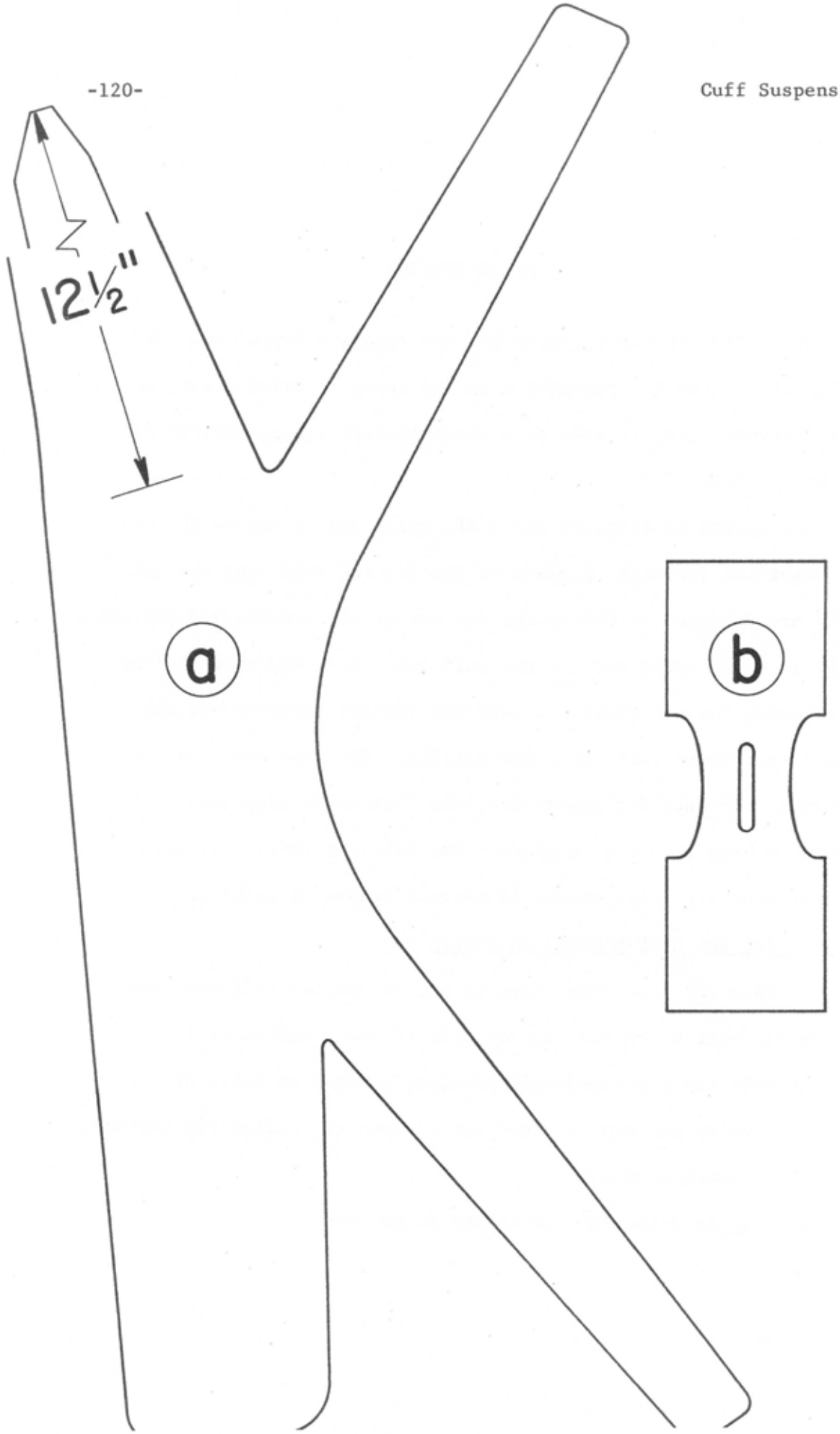
The system consists of the cuff, which passes around the knee and maintains the unit in place on the femoral condyles; the tabs, which are attached to the socket and act as suspenders; and the yoke, which is an integral part of the cuff anteriorly and which serves to transmit the tab tension around the femoral condyles and the quadriceps tendon just above the patella. The tabs and yoke are the important elements for suspension, the cuff being tightened just enough to hold the unit in place. The tab-yoke tension is much greater than the cuff tension in certain phases of walking.

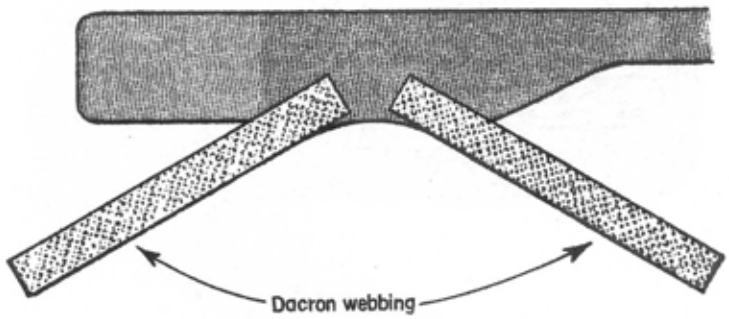
Fabricating the Cuff-Suspension System

Pattern (a) gives the shape of the suspension cuff with tabs. The buckle will be on the lateral side of the finished cuff.

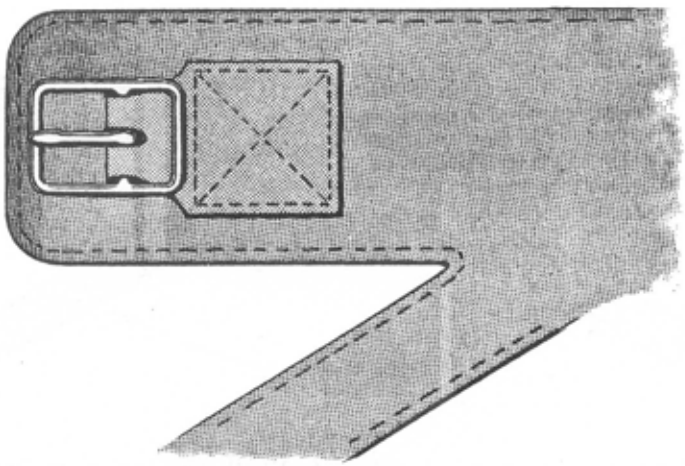
To make the cuff-suspension system, proceed as follows:

1. Using pattern (a), cut out a piece of pearled elk leather, smooth side out.
2. Apply rubber cement to the rough side.


12½"
a
b



3. Bond two pieces of 1/2" x 4 1/2" Dacron webbing to the rough side of the pearled elk, as shown. These strips will prevent the tabs from stretching too much.
4. Coat the exposed surfaces of the Dacron webbing with rubber cement.
5. Apply rubber cement to the rough side of a piece of horsehide large enough to line the cuff and tabs, and bond it in place.
6. Sew the pearled elk, Dacron webbing, and horsehide together at their edges.
7. Trim the horsehide flush with the pearled elk.
8. Cut out a buckle billet, using pattern (b).
9. Skive the ends of the billet on the rough side, and cut the buckle slot.
10. Insert a 5/8" buckle into the billet.
11. Apply rubber cement to the rough side and skived surfaces of the buckle billet and fold the billet over to bond evenly.



12. Bond and sew the billet to the pearled elk as shown.
13. Punch 6 or 7 3/16" holes in the tabs at 3/8" intervals, starting at the end.
14. Punch buckle holes 1/2" apart.

Installation of the Cuff-Suspension System

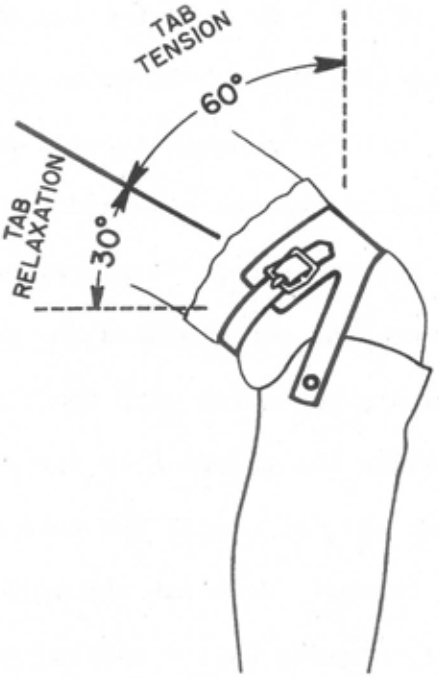
A cuff-suspension system constructed according to pattern (a) has been used successfully in a wide range of sizes and with a variety of types of amputation. For children and small adults, it may be necessary to scale the size downward. This is easily accomplished as long as the angular relationship between cuff and tabs in maintained.

1. Prepare the cuff-suspension system as described above. Leave all tabs extra long. (Prefabricated units are available commercially.)
2. Have the amputee stand in the socket with weight equally distributed on both legs. Be sure the stump is seated

properly in the socket.

3. Tighten the cuff snugly around the femoral condyles. With the edge of the yoke area resting on the proximal border of the patella, apply tension on both tabs to make sure that the cuff is securely located and that tab tensions are carried around the yoke and are borne by the femoral condyles and quadriceps tendon without discomfort.
4. Place a straight chair behind the amputee. Face the amputee and grasp a tab with the fingers and palm of each hand, leaving the thumbs free for positioning the tab attachment points. Press the tabs against the socket with the thumbs. Each tab should lie against the socket along a line given by its natural position relative to the cuff.
5. Locate the proper attachment point as follows: Pull firmly on each tab and press inward at a point slightly behind the center of the socket. Hold the tabs against the socket at the two points so located and ask the amputee to sit, flexing his knee slowly. Observe the change in tab tension with knee flexion. When the proper attachment points are located, the tabs will maintain tension over a range of approximately 60° of knee flexion and will then relax to allow the stump to withdraw slightly from the socket with the knee flexed 90°. Try different attachment points until these conditions are satisfied, then mark

the location of the proper attachment points on the socket.



6. Attach the suspension button to the prosthesis at the marked points with self-tapping screws, and button the tabs in place.
7. When trials are complete, attach the buttons permanently with rivets.

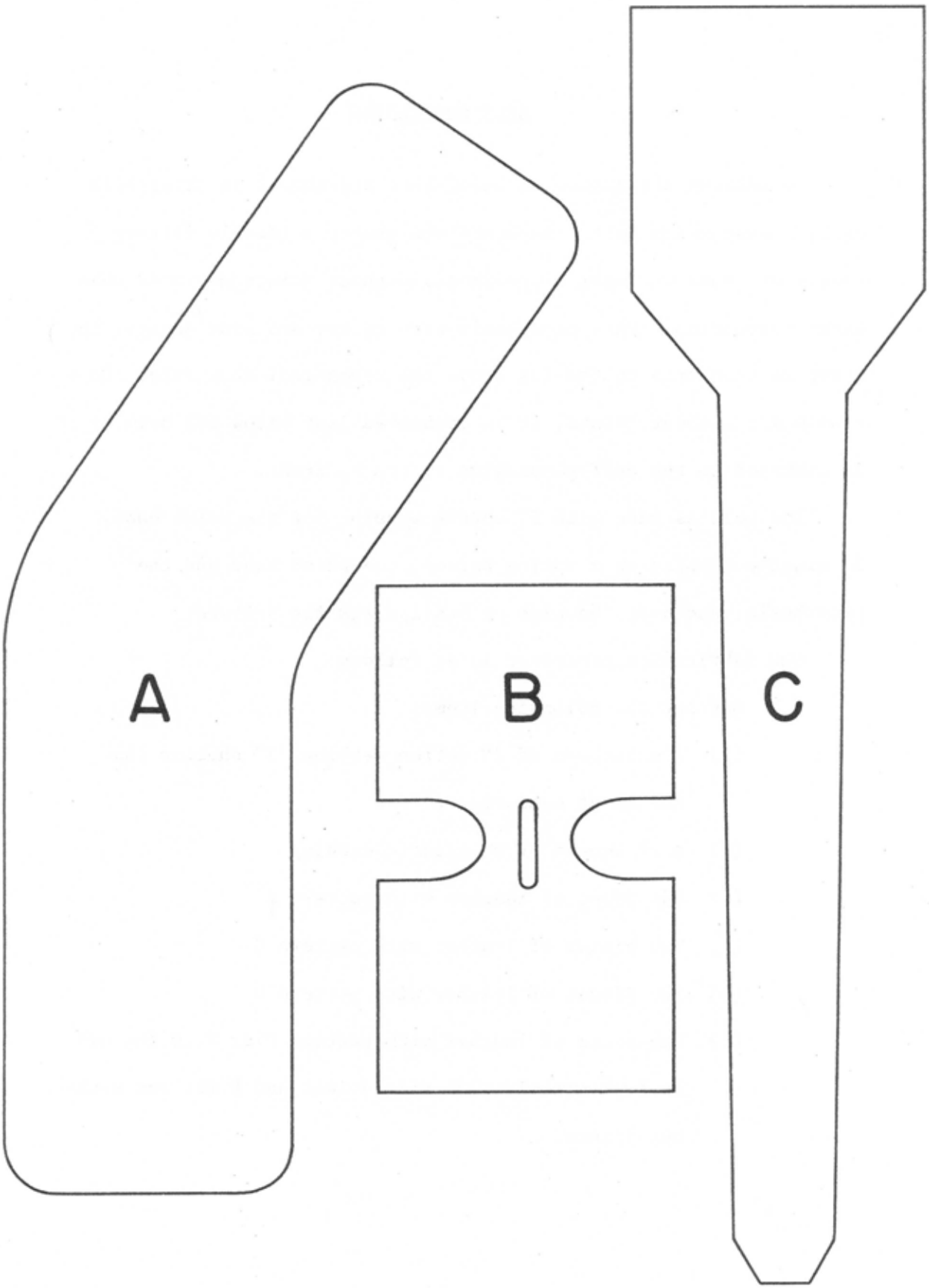
BELT SUSPENSION

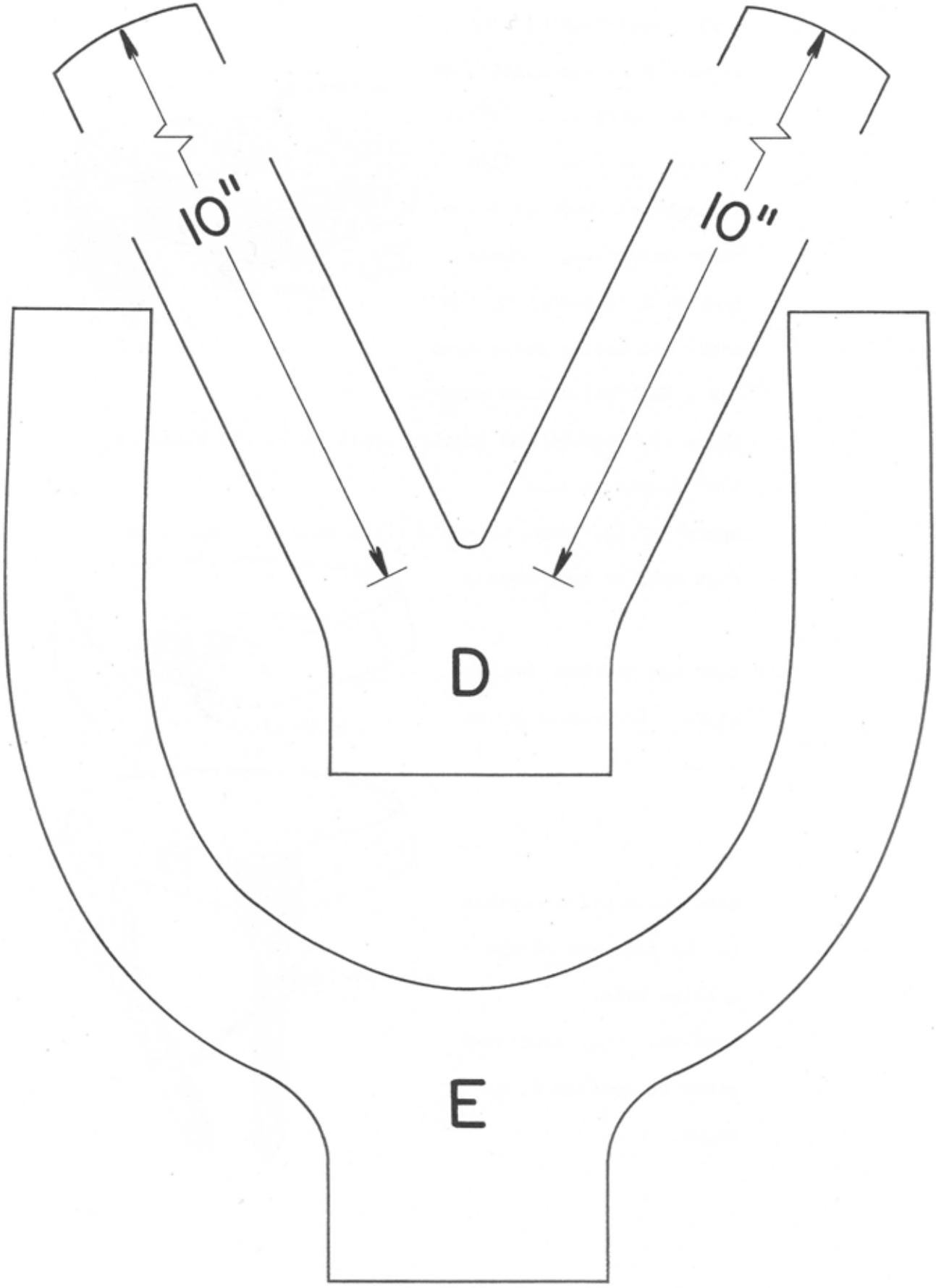
To improve suspension, a below-knee prosthesis is often held on by a suspension belt. Amputees who prefer a loosely fitting corset or those who wear a prosthesis without joints may need this extra suspension. On a prosthesis with corset and side joints, the strap is connected to the leg above the mechanical knee axis. On a prosthesis without joints, it is connected just below the brim or it is fastened to the cuff-suspension system in front.

The belt is made with 2" cotton webbing for the waist band, 2" elastic webbing as a spring between the waist band and the prosthesis, and 6-oz. cowhide or pearled elk for billets.

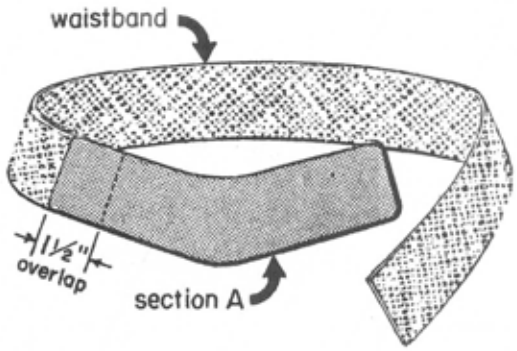
The fabrication procedure is as follows:

1. Cut out the following items:
   (a) A waistband of 2" cotton webbing, 3" shorter than the waist measurement
   (b) A 7" length of 2" elastic webbing
   (c) One piece of leather with pattern A
   (d) Two pieces of leather with pattern B
   (e) Two pieces of leather with pattern C
   (f) One piece of leather with pattern D or E, D for use on a prosthesis with side joints and E for one without joints.


A
B
C


10"
10"
D
E

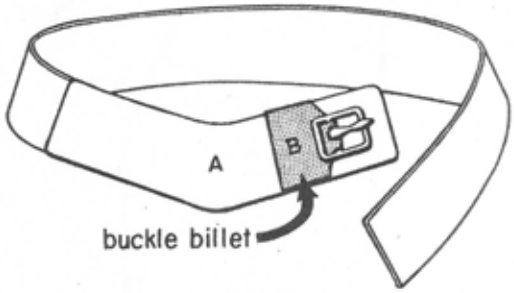
2. With rubber cement, bond section A to the waist band so that there is 1 1/2" of overlap, as shown. (The arrangement shown is for a right below-knee amputee. Section A is bonded to the other end of the waist band for a left below-knee amputee.)



3. Skive the ends of the leather sections B, and thread a 5/8" buckle on each.

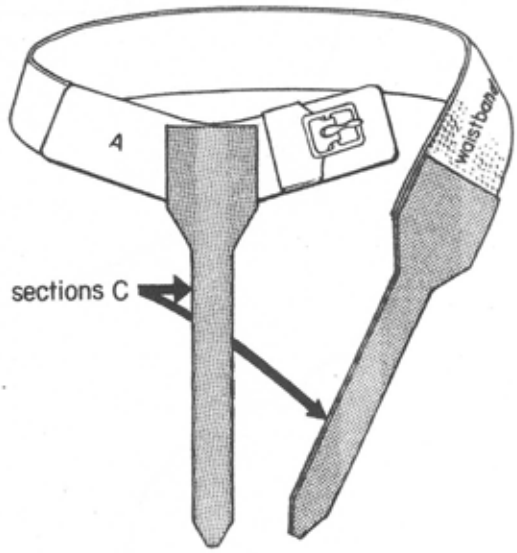
4. Apply rubber cement to their rough surfaces, and fold them over to bond evenly.

5. Bond one of these buckle billets to section A, as shown.

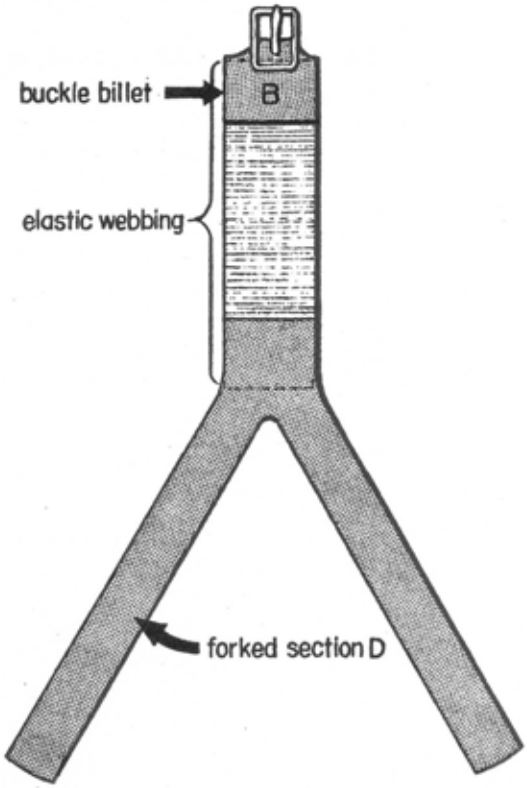


6. Bond one section-C piece to the free end of the webbing belt.

7. Bond the other section-C piece to section A, as shown.

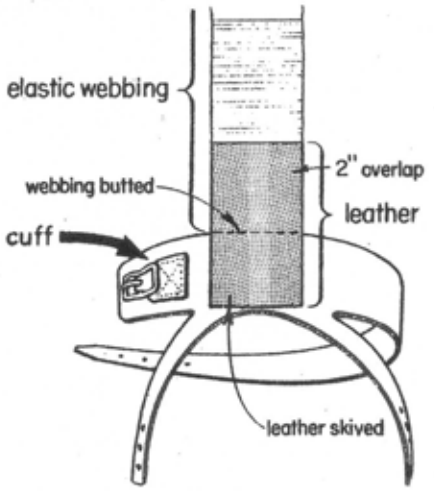


8. Bond the other buckle billet to one end of the elastic webbing, as shown.



9. Bond the forked section (D or E) to the other end of the elastic webbing.

10. If the belt suspension system is to supplement cuff suspension, the forked section is not used. The elastic is bonded to the front of the cuff, as shown.



11. Bond the horsehide backing to all the leather parts, and sew around their edges.

12. Trim off excess horsehide.

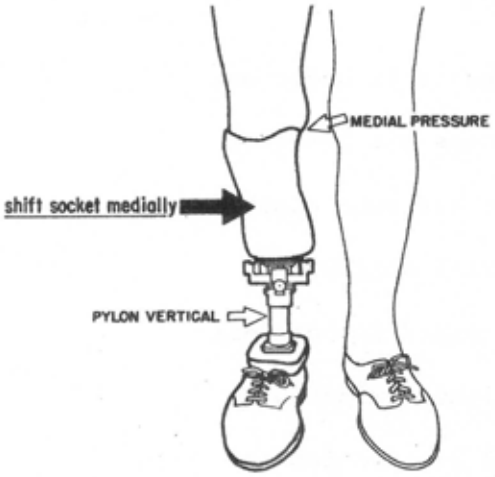
PRELIMINARY DYNAMIC ALIGNMENT

Preliminary dynamic alignment of the prosthesis is based on observation of the amputee as he stands and changes his position over the prosthesis. When preliminary alignment has been completed, the leg will be of correct length, the toe-out will approximate normal toe-out, and the amputee will be able to stand in one position between the walking rails and shift his weight comfortably with control both of mediolateral balance and of knee motion in flexion and extension. The prosthetist should remember that the amputee will be expected to walk with a flexed knee, with weight borne over the middle third of the foot in midstance, and to flex his knee during the push-off phase of walking.

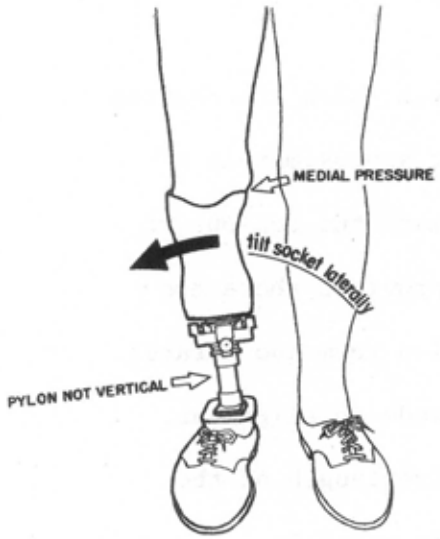
To check toe-out and length of the prosthesis, have the amputee stand with equal weight on each leg and the feet approximately 4" apart at the heels. The toe-out should approximate the toe-out of the normal foot, and the hips should be level, provided there are no abnormalities (check the Prosthetic Information Form and x-rays). Check height periodically if major changes are made in alignment. Anterior socket tilt tends to reduce the effective length of the prosthesis, and posterior socket tilt tends to increase it.

Use the following outline as a guide for correcting deficiencies in alignment.

Lateral Instability

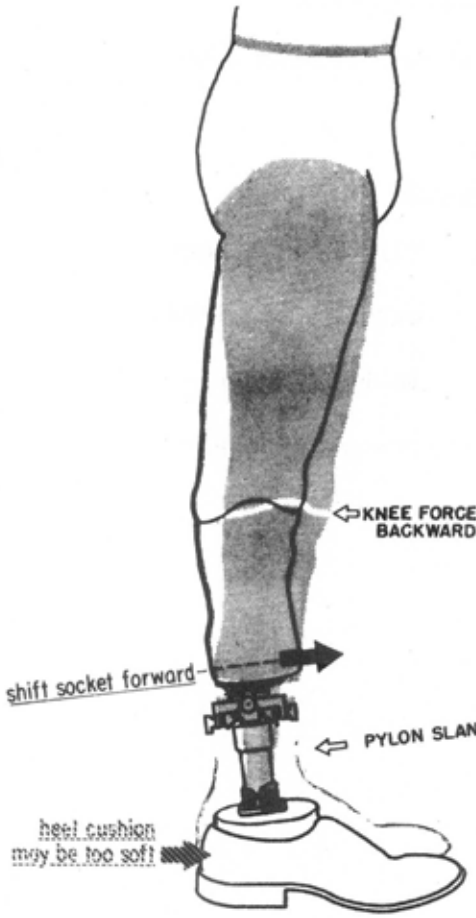


Possible Cause	Remedy
1. Improper mediolateral placement of socket over foot	1. Observe pylon tubing. If tubing is vertical, indicating foot is flat on floor, do not tilt socket. Shift socket medially as required.



2. Improper mediolateral tilt of socket	2. Observe pylon tubing. If tubing is not vertical, tilt socket as required to bring foot flat on floor, then re-check as in 1.

Knee Forced Toward Rear - Pylon Tubing Slanted Toward Rear

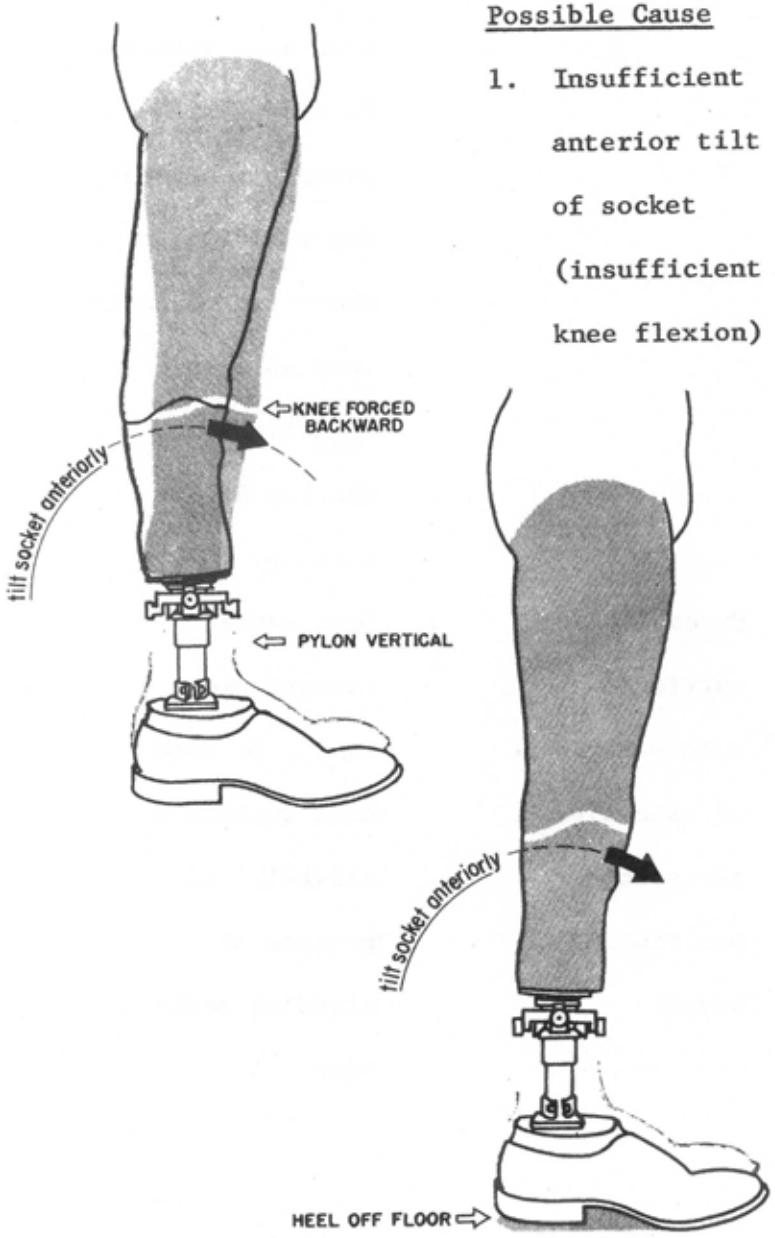


Possible Cause	Remedy
1. Heel cushion not providing sufficient counterpressure	1. Check heel-cushion stiffness against recommended value. Be sure heel cushion is slightly compressed in standing position. Check fit of heel into shoe (see directions for shaping SACH foot, p. 107).
2. Excessive load carried on heel cushion because of excessive posterior positioning of socket	2. Move socket forward over foot. Be sure heel cushion is slightly compressed in standing position.

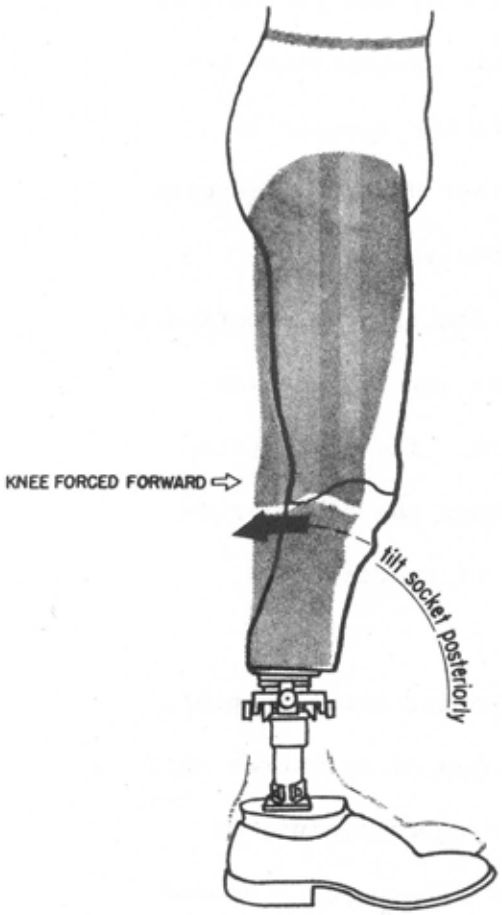
Knee Forced Toward Rear - Pylon Tubing Vertical or Heel Not Contacting Floor

Though conditions tend to force the knee toward the rear, the amputee may compensate by moving the knee forward, putting his weight on the prosthetic toe. Then the heel will not contact the floor or contact it only lightly.

Possible Cause	Remedy
1. Insufficient anterior tilt of socket (insufficient knee flexion)	1. Tilt socket forward as required. Recheck antero-posterior position.



Lack of Knee Stability (Knee Forced Forward)



Possible Cause	Remedy
1. Excessive anterior tilt of socket	1. Check heel-cushion thickness and stiffness by observing orientation of pylon tubing. When foot contact is correct, readjust anterior tilt of socket.
2. Socket too far forward	2. Slide socket back.

When preliminary dynamic alignment is complete, the prosthesis is ready for training the amputee in its use.

PRELIMINARY TRAINING

Preliminary training is given to the amputee by the prosthetist as part of the dynamic alignment procedure. This is necessary because optimum alignment cannot be obtained until the amputee is fairly proficient on the prosthesis. On the other hand, the amputee will not do his best until the alignment is satisfactory. The problem is more difficult for the new amputee than for the experienced amputee, even if the experienced amputee has not worn a patellar-tendon-bearing cuff-suspension prosthesis before. The new amputee has less muscular control of the hip and knee than the experienced prosthesis wearer and must learn a new pattern of coordinated activity.

In either case, as a first step the prosthetist should explain the relationship between socket and stump in terms of pressures that the amputee will feel. This forestalls misleading complaints of pressure when he starts to wear his prosthesis. The amputee should be assured that, if excessive pressures should occur, adjustments can and will be made. He should be encouraged to put up with minor discomforts, but the stump should be examined for pressure points periodically during the training session. The appearance of the stump will usually indicate to the prosthetist what changes, if any, are needed. Unless required changes are obvious, they should not be made at this time. If discomfort is acute, however, training cannot continue until corrections have been made.

If a cast sock is used during the alignment and training period, the new amputee should be told that this is a temporary situation, that, as treatment proceeds, attempts will be made to make adjustments with additional cast socks until he is able to use a wool sock, and that use of a wool sock will greatly increase his comfort.

He should also know that the newly assembled adjustable leg is heavier than his final prosthesis will be and that it is not necessarily optimally aligned. Both factors may contribute to minor discomforts. Tell him that the adjustable unit will allow changes to be made in alignment from time to time until optimum alignment is achieved and that this alignment will be duplicated in his prosthesis, which will be made lighter.

When the suspension system is added, it should be carefully adjusted to minimize the effects of the extra weight of the adjustable leg. If necessary, cuff suspension should be supplemented by belt suspension, at least until the lighter prosthesis is supplied; however, most amputees will not need belt suspension.

Preliminary training is required during the following stages of the dynamic alignment procedure: (1) weight-bearing check of socket fit; (2) installation of cuff-suspension system; and (3) walking trials.

Weight-Bearing Check of Socket Fit

This procedure has two purposes: (1) to insure that no gross fitting errors have been made which result in acute discomfort when the amputee bears weight in the socket and (2) to adjust the pre-

adjusted static alignment to the particular needs of the individual amputee. All observations and adjustments are made with the amputee standing in one position between walking rails.

Have the amputee sit in a straight chair at the end of the walking rails. When the stump is inserted into the socket for the first time, the prosthetist should explain the importance of proper orientation of the stump in the socket and the functional significance of some of the more noticeable socket contours, for example, the closed end, the patellar-tendon protuberance, and the high anterior brim. Next, ask the amputee to stand while the static alignment is rechecked as indicated in the chapter, "Preliminary Dynamic Alignment." The objective is to put the socket in a position relative to the foot which will enable the amputee to use his knee musculature in the control of the prosthesis in as normal a manner as possible. Weight-bearing should compress the heel cushion enough to carry approximately one third of the body weight (about 1/8" compression, depending on the stiffness of the heel cushion used). The knee will be forced into extension slightly during weight-bearing and into flexion as the weight is removed.

After the static alignment is considered satisfactory, the amputee should be instructed to stand between the parallel bars and bear weight in the socket for a minimum of 10 minutes, preferably longer. He should shift his weight from side to side in order to make sure the stump is well seated in the socket.

At the end of this period have the amputee sit down; remove the

socket from the stump, and examine the stump for evidence of poor fit. Before proceeding with the dynamic alignment, install the cuff-suspension system as described in the chapter, "Cuff Suspension."

Installation of Cuff-Suspension System

The dual function of the cuff-suspension system should be carefully explained. If the amputee has worn another type of suspension in the past, he may be skeptical about the new arrangement. Assure him that if cuff suspension is unsuccessful in his case, suspension can be achieved by another type of system. After the cuff-suspension system has been installed, ask the amputee to stand between the walking rails again and bear weight on his prosthesis.

Have the amputee extend his knee, and explain the function of the tabs in preventing hyperextension and in providing proprioceptive sense of knee position. The amputee should be instructed to allow the tension in the tabs to act not as a back check but rather as an indicator of the knee action required to control stability voluntarily. The amputee will soon get the feel of this action with practice, first in the standing position and later during the walking trials.

As a second exercise, have the amputee lift the prosthesis off the floor and flex his knee approximately 60°. The tabs should act in tension to suspend the socket securely on the stump.

Finally, have the amputee sit down. The tabs should relax to allow the stump to rest comfortably in the socket.

The foregoing exercises should now be repeated with the amputee

in the standing position until he appears to have a clear understanding of the functioning of the cuff-suspension system.

Walking Trials

At the time of dynamic alignment, the prosthetist has a most difficult problem. He must be able to see whether the performance of the amputee on his prosthesis is being adversely affected by alignment, fit of the socket, function of such components as the foot or the suspension system, and skill and coordination of the amputee.

As a general rule, the prosthesis should be aligned in a manner consistent with the treatment given other amputees of similar stump length and physical coordination. If training under these conditions produces an atypical performance, the amputee's difficulties should be carefully studied before any major changes are made. The following training procedures have been found useful in helping the amputee develop a normal-appearing gait with his prosthesis.

Probably the most noticeable feature in the gait of a below-knee amputee using a patellar-tendon-bearing cuff-suspension prosthesis is active knee flexion and extension in the weight-bearing phase of the walking cycle. Properly executed, it provides a means of efficiently absorbing the suddenly applied thrust on the prosthesis at heel contact, control of body motion in midstance, and precise control of knee flexion at the time of push-off. The flexion-extension action is easily achieved by most below-knee amputees, since the knee musculature is largely intact and this action is

similar to normal knee motions.

Flexion-Extension Exercise. As a first training exercise, ask the amputee to place the prosthetic foot a short distance (up to 6") ahead of the normal foot. With his knee in extension, instruct him to bear weight continuously on the prosthesis and to allow the knee to flex until the foot is flat on the floor. This procedure is then reversed to bring the knee back into full extension. This should be practiced to give the amputee a feeling of the control he is able to exert with his knee musculature. The prosthetist should explain at this time how the socket has been fitted against the anterior surface of the tibia and against the popliteal area to provide firm support for the stump during this type of maneuver. When this exercise has been mastered, training with the roll-over exercise should be begun.

Roll-Over Exercise. The prosthetic foot is placed forward as in the flexion-extension exercise and the knee again flexed under load to bring the foot flat; then the amputee should step forward with the normal foot and extend the knee on the amputated side, keeping the prosthetic foot in firm contact with the floor. This is the basic action of the prosthesis: controlled knee flexion at heel contact to bring the foot into a stable position flat against the floor, followed by controlled extension of the knee as the amputee rolls over the knee, with the foot providing a stable base in firm contact with the floor. The amputee should not walk between the bars until this exercise has been mastered with reasonable profi-

ciency. He may then proceed to take short steps between the rails.

Short Steps Between Rails. The roll-over exercise should be duplicated on the normal side; then the amputee should be asked to take alternate strides of not more than 6" on each side. The objective of this exercise is to give the amputee an opportunity to compare knee-ankle action on normal and amputated sides and to continue the process of gaining confidence in the strength and control available in the knee joint on the amputated side. When the amputee is able to master short steps between the rails without use of his hands, he may proceed to longer steps outside the walking rails.

Walking Outside Rails. It is only when the amputee can walk vigorously at normal cadence and stride length outside the walking rails that the prosthetist is able to make the final adjustments of the dynamic alignment procedure. Observations and adjustment procedures are outlined in detail in the chapter, "Dynamic Alignment." Training of the amputee will usually proceed rapidly at this point. If fit, alignment, foot function, and suspension are properly adjusted, the amputee will usually adopt a gait pattern which minimizes the loads on the knee by keeping the knee close to the so-called "trigger" position at all times. In this position minimal effort is required to move the knee into extension or flexion as required.

An efficient gait may not be achieved at first, because the stump and knee are not yet conditioned. The duration of the training sessions depends on the particular amputee. He should not be

hurried. Best results are obtained when the amputee is well rested, so that his thigh musculature is not fatigued and the stump is not sore from use. Physical therapy should be considered if weakness seems acute.

Once the amputee has mastered level walking, he can be given training in special activities by the therapist. He should be examined from time to time by the prosthetist while such activities as descending stairs and inclines are being learned, because of the discomforts that may result.

DYNAMIC ALIGNMENT

Once the amputee has become accustomed to standing on the prosthesis, shifting his weight, and walking between the bars, it is possible to refine the alignment. Refinements are based on observations made as the patient walks.

To accomplish the dynamic alignment of a below-knee prosthesis, the prosthetist not only must know what to observe in the way of gait deficiencies or stump discomfort arising from improper alignment but also must be familiar with the causes of certain common difficulties.

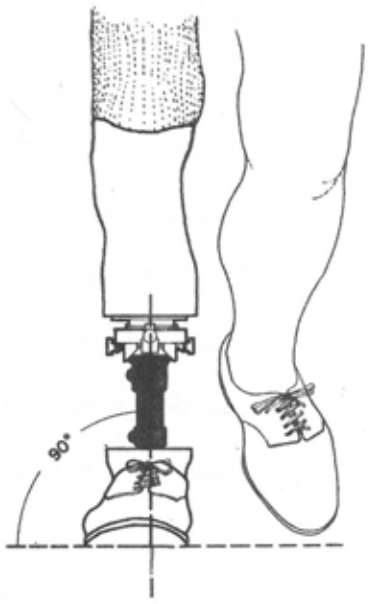
A desirable gait is assumed to have been achieved when the amputee walks effortlessly and comfortably with a relatively natural appearance. His walking base should be narrow, as in normal persons, unless he has an extremely short below-knee stump. His knee should be flexed 10^{o} to 15^{o} when his heel strikes the floor, with the foot rotating smoothly but rapidly into full contact with the walking surface. The sole of the shoe then serves as a secure base for the active and voluntary control of the prosthesis by the stump and knee joint. The knee joint should extend somewhat as the amputee walks over the foot, which remains in contact with the floor, and should remain extended as the weight is transferred to the ball of the foot. Knee flexion at the time of push-off minimizes the strain on

hamstring tendons and other ligamentous structures behind the knee. The swing phase should be natural in appearance, with minimum piston action between stump and socket.

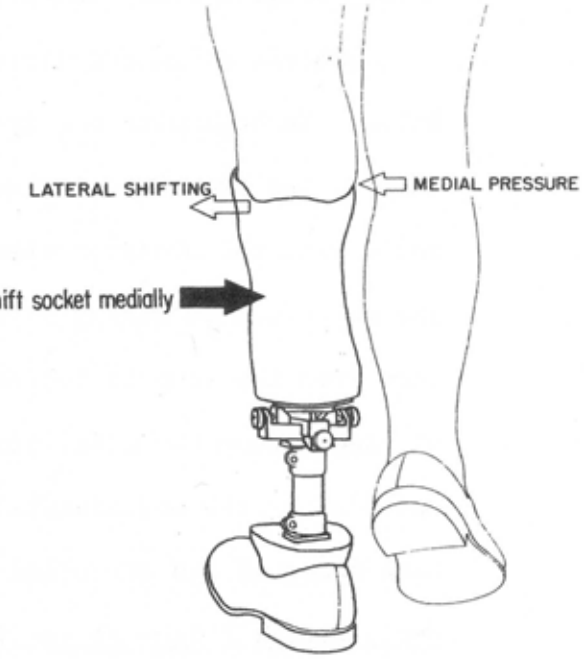
Dynamic alignment deficiencies and their causes are given below. In beginning the dynamic alignment of the below-knee prosthesis, the prosthetist should have the amputee walk between walking rails with the observer viewing the gait from front, back, and side. The procedure of making observations first from front and back and then from the side is logical, since the anteroposterior adjustments, as viewed from the side, are most critical and should not be attempted until after the mediolateral alignment, viewed from the front, has been observed and corrected where necessary.

Mediolateral Alignment (as Viewed from Front and Back)

1. Check foot action. Adjust the mediolateral tilt of the socket until the foot is flat on the floor in midstance, as indicated by the pylon tubing being vertical at that instant. There should be no tendency for the shoe to rotate around the long axis of the foot at heel strike.



2. Check for lateral shift at the socket brim. Lateral shift is reduced by sliding the socket medially. If the socket is well fitted and static alignment is properly done, little shift of this kind should be seen. However, the socket has been fitted to provide lateral stability, and there should be a sensation of firm support because of the medial pressure proximally and lateral pressure distally against the stump.

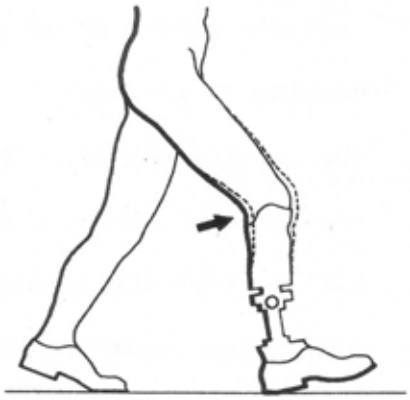


3. Check the mediolateral foot position (inset-outset). The mediolateral position and the mediolateral tilt adjustments are not independent. Therefore, whenever a change is made in one of the adjustments a recheck should be made on the other. After the mediolateral tilt is considered to be optimum, as a final mediolateral adjustment the foot should be positioned medially as required to give a normal-appearing walking base. If the stump is very short, the foot may have to be moved laterally in order to decrease the medial-proximal and lateral-distal forces on the stump. In general, the longer the stump the more medially the foot can be placed.

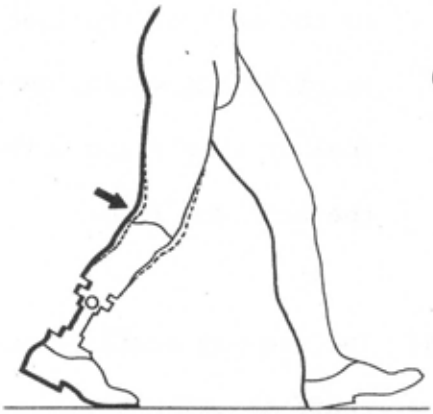
Anteroposterior Alignment (as Viewed from the Side)

1. Adjust the anteroposterior tilt of the socket. The more the socket is tilted anteriorly the greater is the amount of knee flexion as the amputee walks.

   (a) Excessive anterior tilt (i.e., excessive knee flexion) may have two effects:



   (1) The knee may be forced forward and knee flexion exaggerated at heel contact. Loss of knee stability at this phase of the walking cycle is critical and causes development of an erratic gait.



   (2) There may be lack of support and drop at the end of stance phase.

(b) Excessive posterior tilt may have four effects:



(1) The knee may be forced backward, so that there is early arrest of knee flexion after heel strike.

(2) There may be a prolonged and unstable period of weight-bearing on the heel.

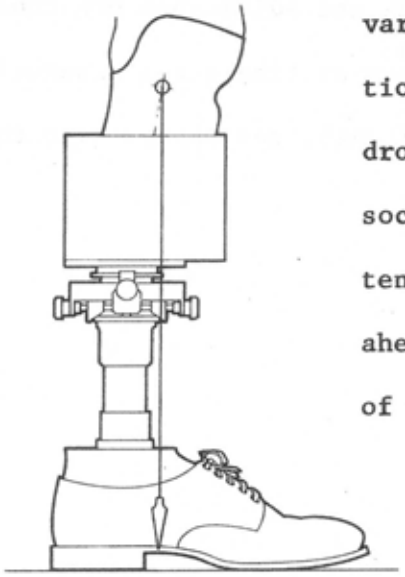


(3) The amputee may have the sensation of "walking over a hill." With the amputee in a standing position, check to see if weight is carried mostly on the ball of the foot with insufficient weight on the heel or even a gap between the heel and floor.

(4) The toe may scuff or nearly scuff in swing phase.

2. Adjust the anteroposterior position of the socket.

(a) The anteroposterior position of the socket should not vary appreciably from a position such that a plumb line dropped from the center of the socket brim at the mid-patellar-tendon level would pass slightly ahead of the breast of the heel of the shoe.



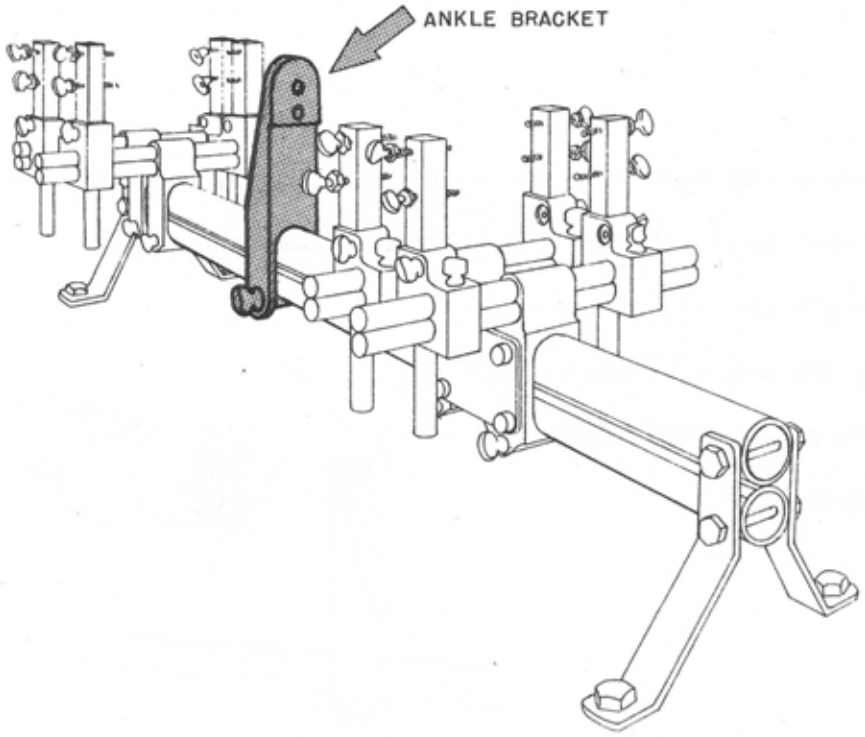
(b) The anteroposterior position should be varied slightly to balance the necessary controlling action of the amputee's stump in the flexion-extension-flexion sequence of knee motion in stance phase. The knee should never lack stability, but, conversely, excessive effort should not be required to control stability or to flex the knee at the end of stance phase.

(c) The SACH foot must be supplied with the proper heel-cushion stiffness for the amputee's weight. Heel rise in the foot should be rechecked and adjusted, if necessary, to give effective heel counterpressure in the standing position.

3. The amputee should walk for a minimum of one hour, after which all adjustments should be rechecked. The total time required for wearing the adjustable prosthesis will depend on many factors, such as time since amputation, prosthetic experience, stump length, and change-over to a new type of fitting.

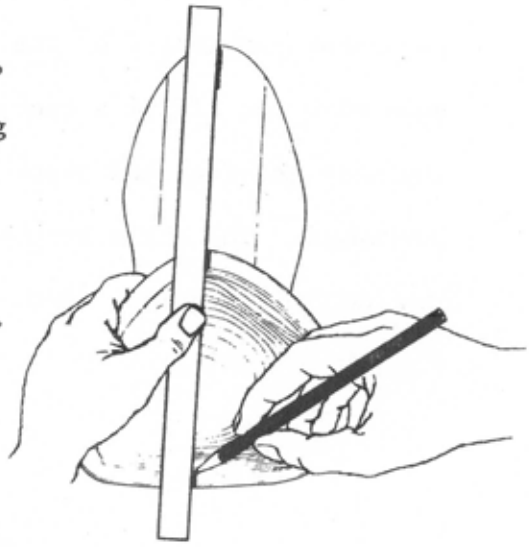
ALIGNMENT DUPLICATION

After the below-knee socket has been aligned over the foot with the adjustable unit, the alignment is transferred to the permanent prosthesis on the above-knee duplication jig. This is done with the aid of a special fixture, the ankle bracket, which replaces the foot and shank clamps on the jig in the duplication procedure. The ankle bracket fits on the base tubes in the same way as the saw guide. Near the top of the bracket is a 3/8" hole,

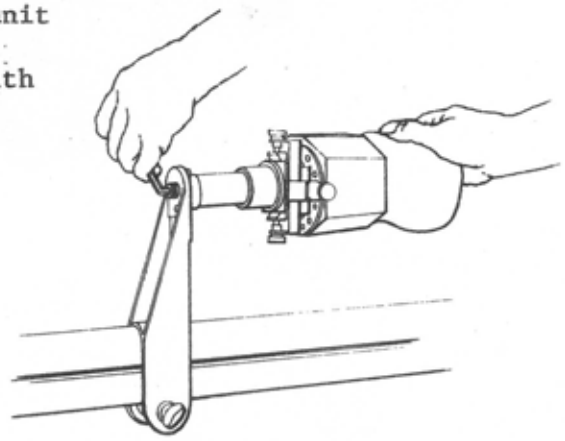


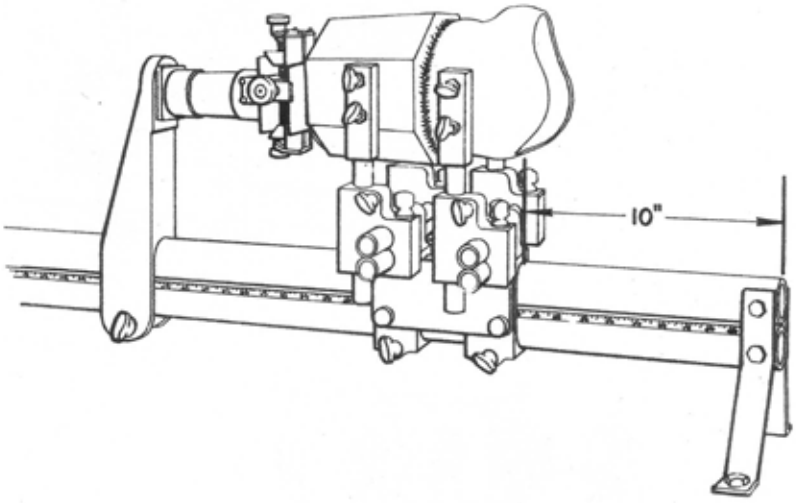
with axis parallel to the base tubes. Thus, when the SACH foot is removed from the adjustable leg and the adjustable leg is attached to the ankle bracket, the axis of the SACH-foot bolt becomes the reference line in the duplication procedure. The procedure is as follows:

1. Make a line on the SACH foot (or use one of the bond lines), and extend the line by sighting along a straightedge to cut the front and back brims of the socket. Mark these points. This will establish toe-out position.



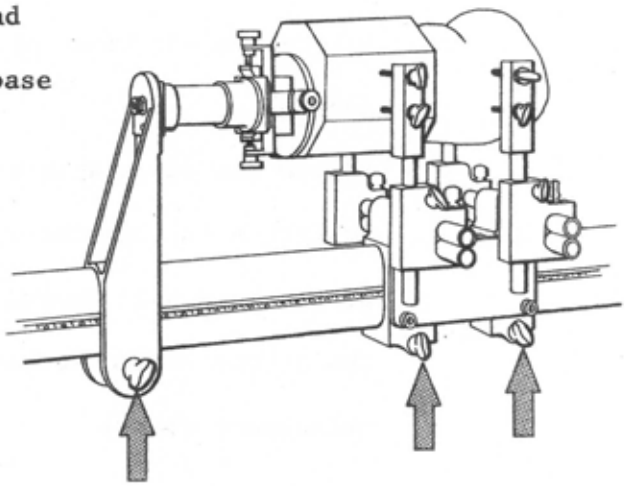
2. Remove the foot from the adjustable leg by unscrewing the socket head screw at the bottom of the foot.
3. Attach the adjustable unit to the ankle bracket with the socket head screw provided.



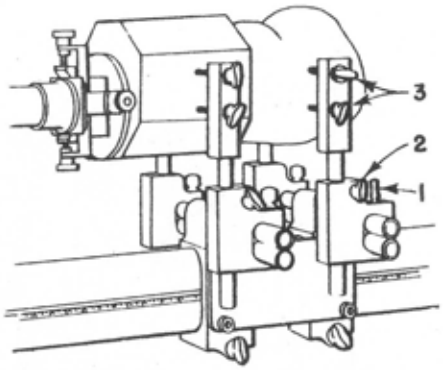


4. Slide the socket clamp assembly away from the end of the jig so that there is 10" of clear base tube, and slide the ankle bracket until the socket is in position between the socket clamps.

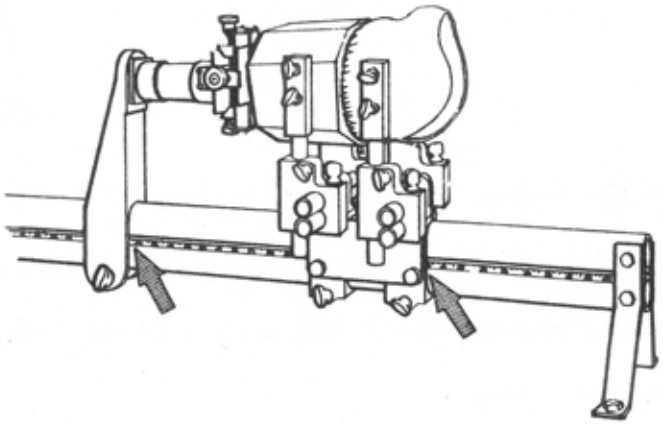
5. Lock the ankle bracket and the socket clamp to the base tubes.



6. Secure the socket in the socket clamps.

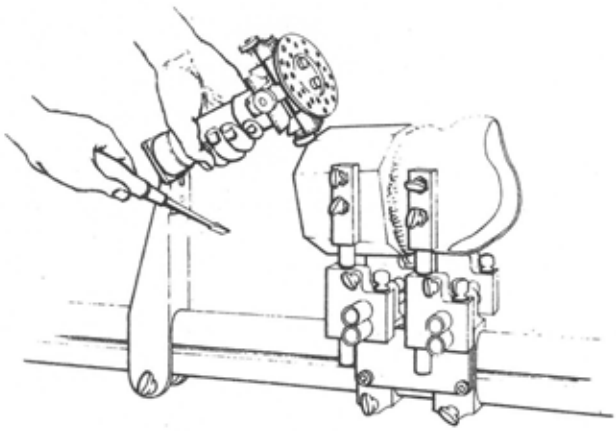


Tighten thumbscrews in this order.

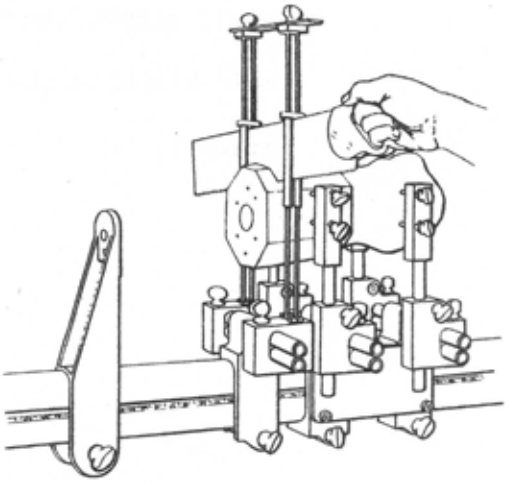


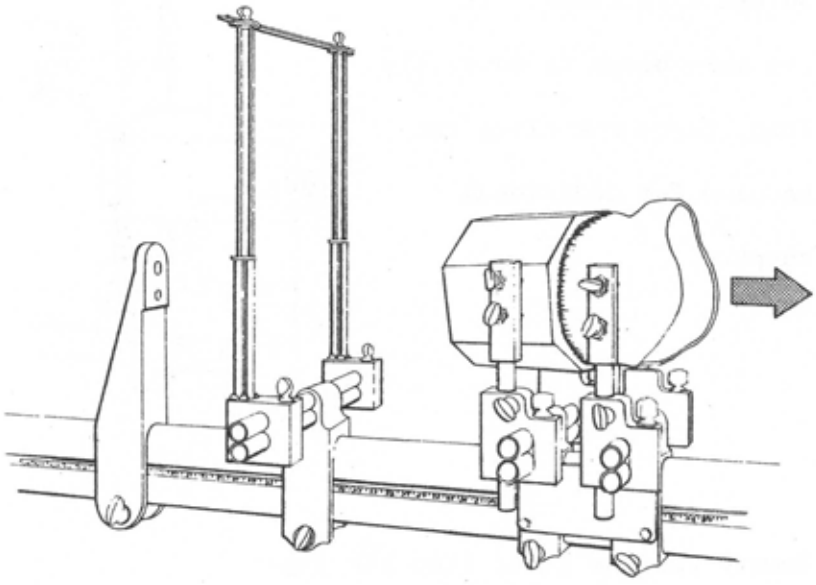
7. Record the positions of the ankle bracket and clamp assembly.

8. Remove the adjustable unit (unfasten it from the ankle bracket and then remove the screws in the socket attachment plate).



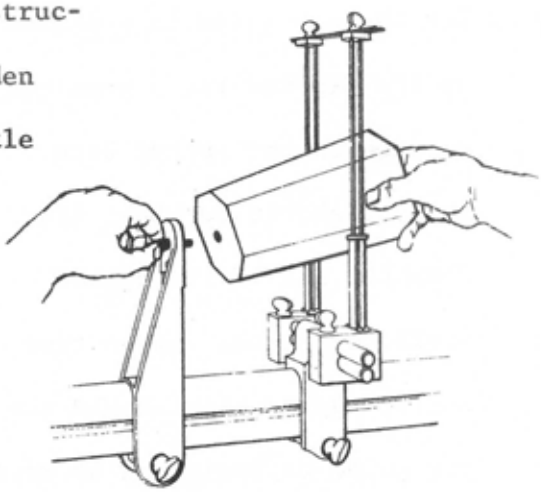
9. Set the saw guide in position on the jig and cut a vertical surface on the socket base. The cut should be about 1/4" from the end of the socket shell. Caution: At no time during duplication should the saw guide be unclamped or moved on the base tubes.



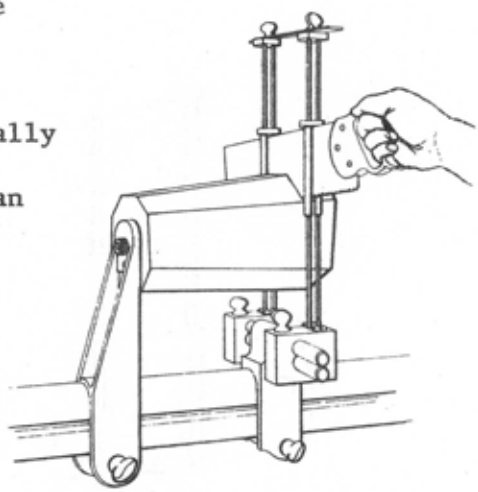


10. Slide the socket out of the way.

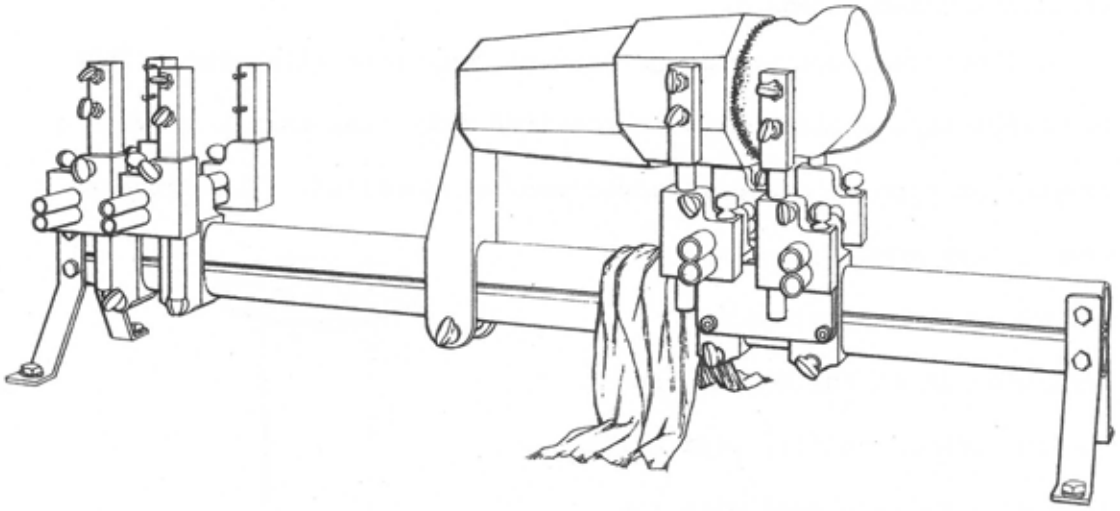
11. For wooden shank construction, attach the wooden shin block to the ankle bracket.



12. Cut the vertical surface on the shin block. If the shin block is unusually long, the shank clamp can be used for additional support.

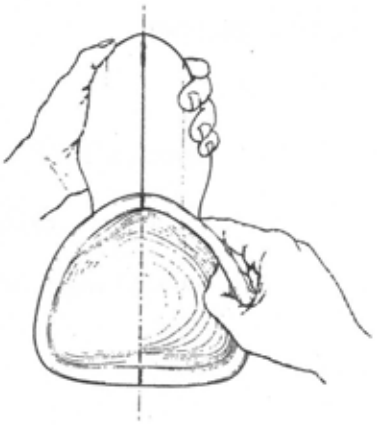


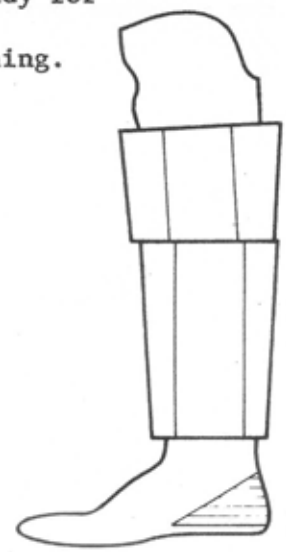
13. Remove the saw guide from the jig.



14. Spot the cut surfaces with glue, and bring them into firm contact with the clamps locked to the base tube. (Cover the base tubes to protect them from dripping glue.)

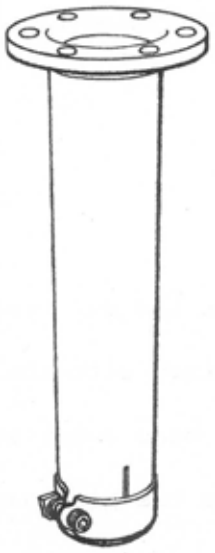
15. When the glue has set, remove the leg from the jig and reattach the foot in its original position. The leg is now ready for shaping and finishing.



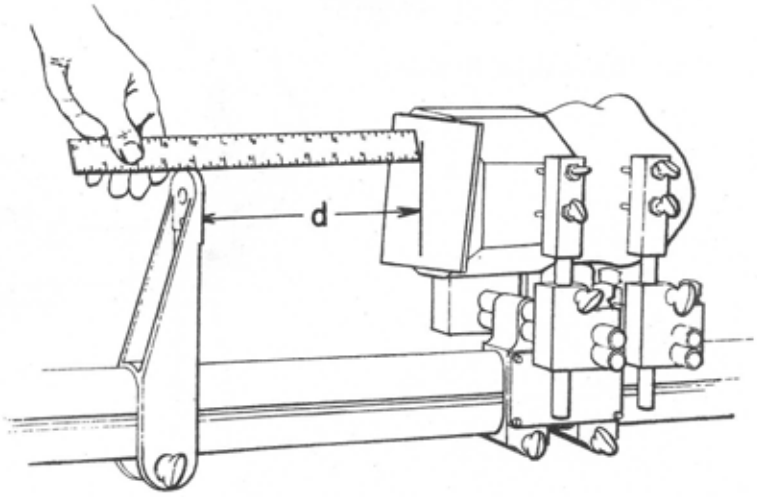


Pylon Shank Construction

Pylon construction can be used to duplicate alignment. This is useful if the prosthesis is required only temporarily or when a crustacean type of cosmetic cover can be installed. The pylon is made of aluminum/ It has a flange at the upper end for attaching it to the socket base and the other end fits over a foot adapter like that used with the alignment device. The end fitted to the foot adapter is split so that it can be clamped tightly to the adapter.

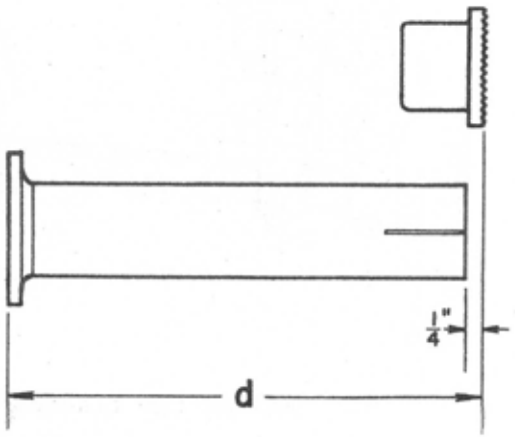


1. Bond a 1/4" edge grain hardwood plate to the base of the socket. This will insure that the screws used to fasten the flange of the aluminum pylon to the base will hold.



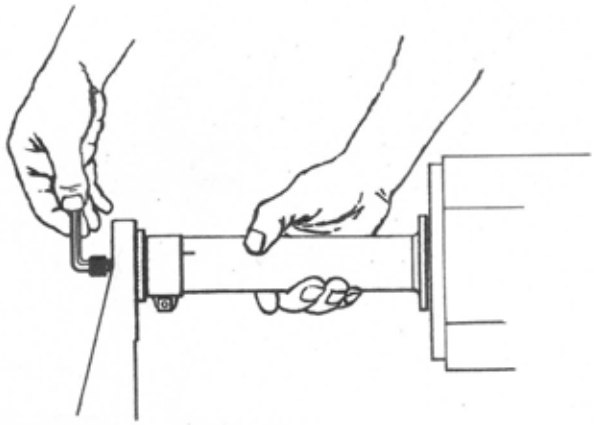
2. Measure the distance d between the surface of the hardwood plate and the surface of the ankle bracket.

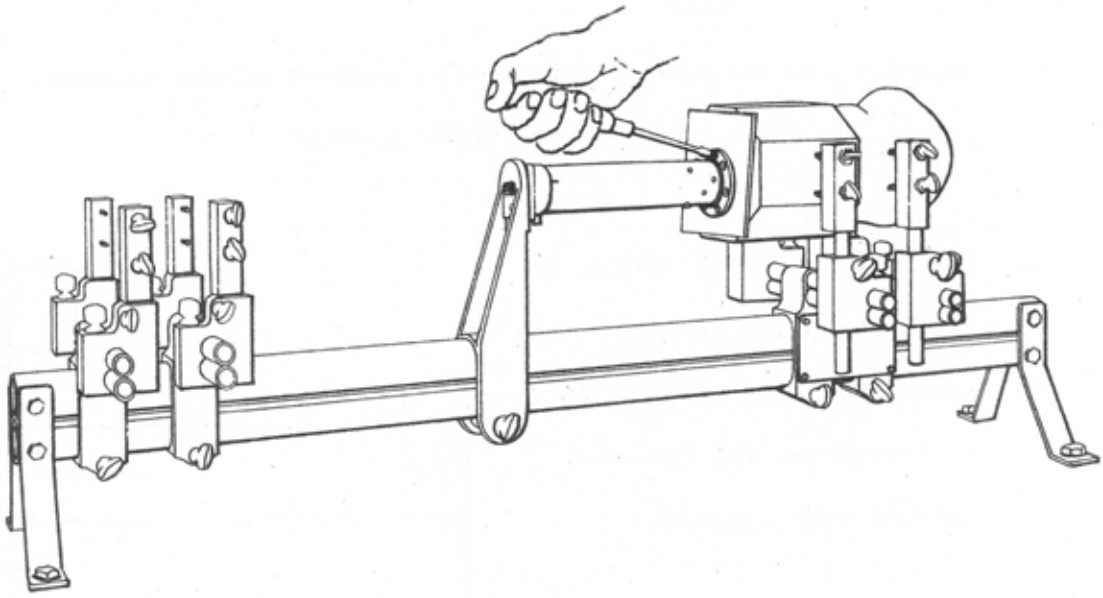
3. Cut off the pylon tubing so that the pylon length is 1/4" less than distance d. This allows space for the base of the foot adapter.



4. Split the end of the tubing about 1 1/4". Without clamping, fit the tubing to the foot adapter, which has been removed from the adjustable leg. (The position of the tubing on the foot adapter will be adjusted when the flange of the pylon is attached to the socket base.)

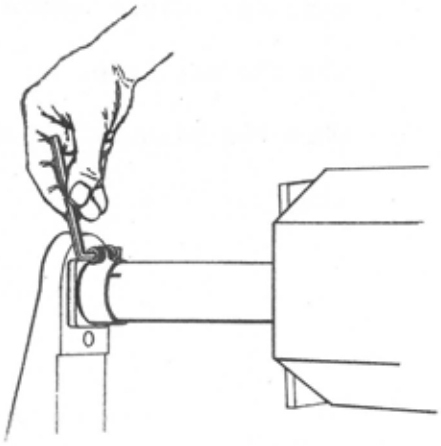
5. Attach the foot adapter to the ankle bracket.





6. Fasten the flanged end to the socket base with wood screws.

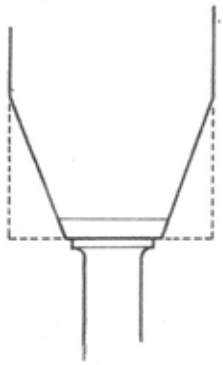
7. Clamp the tubing firmly to the foot adapter.



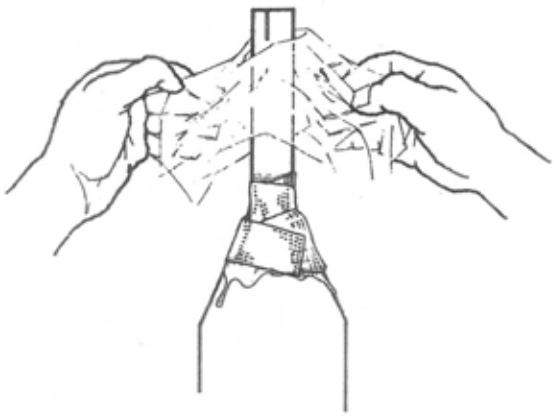
The foot is not attached until the pylon has been bonded permanently to the socket with plastic laminate.

If the temporary pylon leg is to be used extensively, the joint should be reinforced.

8. Shape the socket base to fair in with the flange of the pylon.



9. Wrap three turns of glass cloth around the socket base and flange, and wet it with polyester resin set to gel in 10 or 15 minutes.



10. Pull a slit PVA sheet over the plastic laminate so that the pylon tubing protrudes through the slit. This will

make the reinforcement neat. Pressure-sensitive tape over the PVA may help.

11. When the plastic has cured and has been trimmed, install the foot.

FINISHING THE PROSTHESIS

After the leg has been duplicated, it is shaped, excess wood is removed from the inside, the joints are installed, the leg is reinforced, and its fixtures are installed. The procedure is as follows:

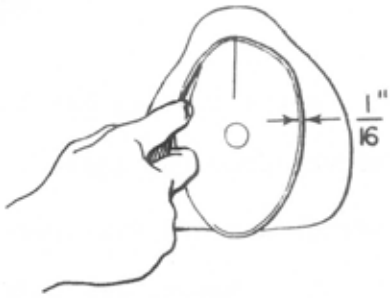
1. Remove the soft insert and the suspension attachments, including the thigh corset and upper side bars.
2. Shape the leg, using traces and measurements of the normal leg as guides.
3. Mark the toe-out position of the foot.



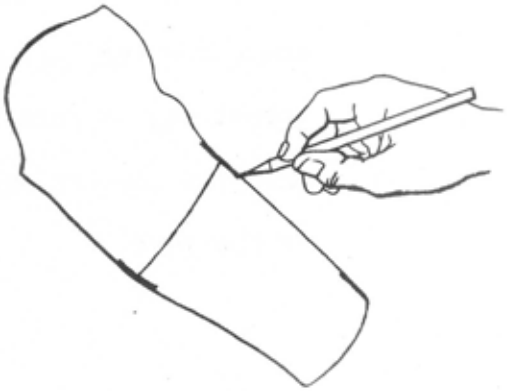
4. Remove the foot, and transfer the toe-out mark to the bottom of the shank with a sharp-edged tool so that it will not be lost during the subsequent steps.



5. Scribe a line 1/16" in from the edge around the surface of the shank where it mates with the foot, and grind the shank down to this line at the ankle. This will allow room for the plastic laminate in the ankle area.

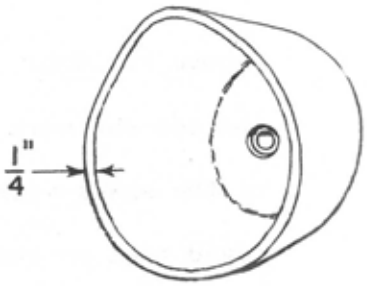


6. Scribe two vertical lines across the glue line between the socket base and the shank block so that the leg can be separated and reassembled without loss of alignment.



7. Break the glue line with a sharp knife.

8. Remove wood from inside the shank with a router or pulling tool until only 1/4" remains around the sides.



9. Glue the leg back together.

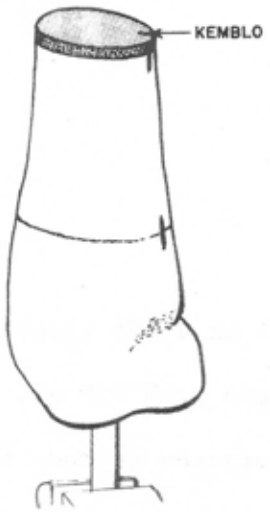
The joints are riveted in place directly to the socket after they have been seated in position with filler.

To make the filler, prepare polyester resin that sets in 15 to 20 minutes. Add the mixed resin to filler material slowly, while stirring, until the mixture can be handled with a putty knife. To protect the joint races from the resin, wrap them with masking tape.

10. Seat the joints in position against the socket with the filler (use sawdust as filler material).
11. When the filler has set, rivet the lower side bars to the socket.
12. The side bars and the socket base are faired into the socket with filler. (Use microballoons, a lightweight phenolic filler, if much filler is required.)
13. When the filler has cured, reshape the leg.

The shank and socket assembly are now reinforced with plastic laminate:

14. Set the shank assembly over a mandrel held in a vise.
15. Bond a piece of Kemblo rubber over the bottom of the shank to protect it and to plug the foot bolt hole.



16. Wrap one layer of 114-181 glass cloth around the shank from the foot base to about 2" from the socket brim.

17. Add two layers of nylon stockinet, and spiral the under layer for increased strength.



18. Tie the stockinet at both ends.



19. Pull on a PVA sleeve, and impregnate the reinforcing fabric with 250 gm. of polyester resin mixed to gel in 20 minutes at room temperature.

20. After the resin has cured and cooled, trim off excess material at the ankle and socket brim.
21. Put the foot in position on the reinforced shank. Make sure the toe-out position is correct.
22. Mark the foot around the shank with a sharp lead pencil.



23. Remove the foot and sand it down to this mark at the ankle.
24. Reattach the foot to the shank.
25. Attach the finished lacer as indicated in the chapter, "Cuff Suspension."

USE OF SIDE JOINTS AND THIGH CORSET

Theoretical Considerations

Single-axis side joints must be aligned on the shank and corset of the below-knee prosthesis so that they effectively stabilize the prosthesis on the amputated leg and allow the amputee to sit comfortably. This is a complicated problem, because the anatomic joint is not a single-axis joint. Any one position of the single-axis mechanical joints on both sides of the knee will give rise to some relative movement between the amputated limb and the prosthesis as the knee and side joints move from the fully extended position to flexion at 90^{o}. The task is to place the joints in a position that will offer the best function and eliminate discomfort resulting from this relative motion; this may be done either by reducing the motion or by having the motion relieve pressures which would otherwise cause discomfort.

The effect of a particular position of the side joints with respect to the socket and corset can best be understood by investigating the effect of making a change from a position assumed to be the optimum one. Since movements result from a combination of several factors, total motion is a complex problem. In a hypothetical situation, it would be possible to have knee flexion occur either with the stump held tightly in the socket and all motion occurring between thigh and corset or with the thigh fixed in the corset and

all motion occurring between stump and socket. Of these two hypothetical situations, the one which will be considered is that in which the stump is fixed in the socket and relative motion occurs between the thigh and upper side arms of the joints. This condition most nearly approximates the real situation and forms the basis for the joint-location procedure described below.

Figure 1 shows a hypothetical situation in which the socket is held fixed and the stump is not allowed to move relative to the socket. In the fully extended position, the upper side bar is parallel to the shaft of the femur and the mechanical joint center is placed directly above the anatomic center. The anatomic center, although it actually varies in position, is assumed to maintain a single axis of rotation. As the thigh flexes 90°, the mechanical side bar tends to move anteriorly on the thigh (distance A) and to be drawn distally along the thigh (distance B). As a result, pressure is created between thigh corset and thigh posteriorly and the stump is forced against the anterior part of the brim (the patellar-tendon area of the stump).

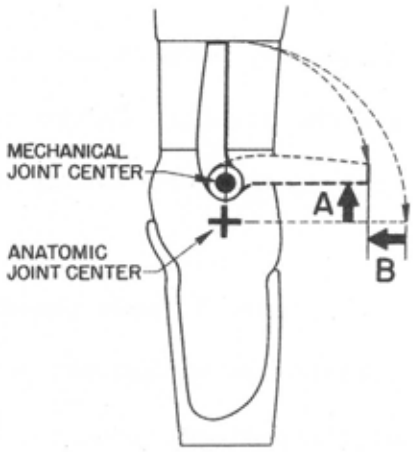


FIG.1 MECHANICAL JOINT ABOVE ANATOMIC CENTER

Figure 2 shows the effects of placing the mechanical joint below the anatomic center. With flexion, the side bar tends to move posteriorly on the thigh (distance C) and to move proximally on the thigh (distance D). As a result, pressure is created anteriorly between corset and thigh and the stump is forced posteriorly, causing pressure in the popliteal area.

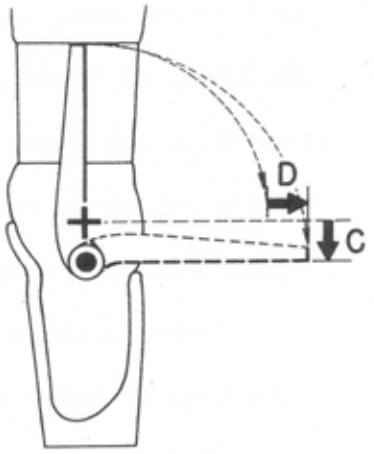


FIG.2 MECHANICAL JOINT BELOW ANATOMIC CENTER

Figure 3 shows the effect of placing the mechanical joint in front of the anatomic center. With flexion, the side bar tends to be forced posteriorly (distance E) and distally (distance F) with respect to the thigh. As a result, pressure is created anteriorly between corset and thigh and the stump is forced against the anterior part of the socket brim.

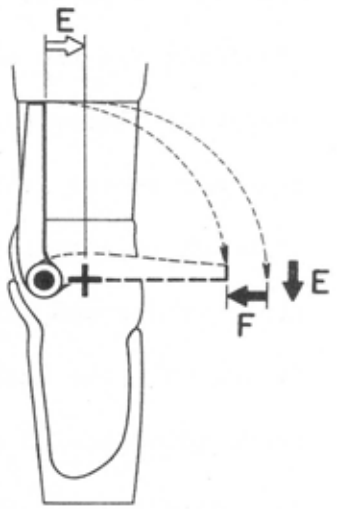


FIG.3 MECHANICAL JOINT AHEAD OF ANATOMIC CENTER

Figure 4 shows the effect of placing the mechanical joint behind the anatomic center. With flexion, the side bar tends to be forced anteriorly (distance G) and proximally (distance H) with respect to the thigh. As a result pressure is created posteriorly between corset and thigh, and the stump is forced posteriorly, causing pressure in the popliteal area.

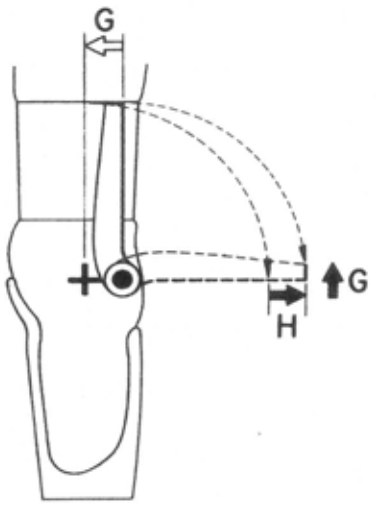


FIG.4 MECHANICAL JOINT BEHIND ANATOMIC CENTER

Figure 5 shows an interesting special case in which the mechanical joint is located on a 45° anterior diagonal through the anatomic center. In this case, the side bar is drawn distally downward on the thigh (distance I) but there is no tendency for the side bar to move either anteriorly or posteriorly with respect to the thigh. This would indicate that the corset pulls the stump anteriorly, causing pressure on the patellar tendon, but that there is no anterior or posterior pressure between corset and thigh.

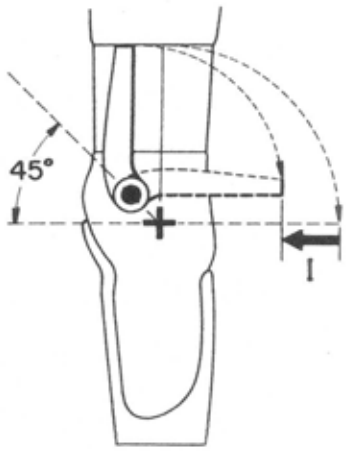


FIG.5 MECHANICAL JOINT ON ANTERIOR 45° DIAGONAL

A similar analysis of the situation shown in figure 6 would indicate that in this situation (posterior diagonal), posterior pressure between corset and thigh would be created by the movement J (anterior movement of the side bar). There would be no tendency for the stump to be pushed anteriorly or posteriorly against the socket brim.

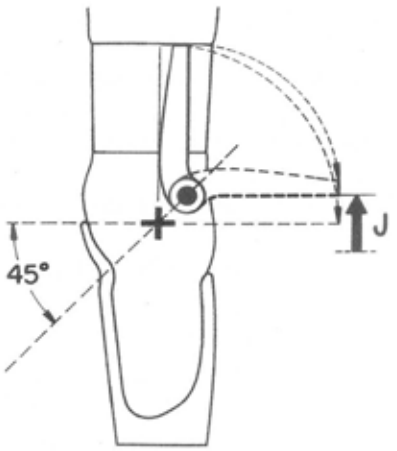


FIG.6 MECHANICAL JOINT ON POSTERIOR 45° DIAGONAL

Optimum Mechanical Relationship Between Joint Axis and Knee Axis

Relative movement in the mechanical joint position as compared with that in the anatomic joint position must first be understood. The prosthetist can then establish the best position for the joint axis by deciding what motions to suppress and what motions to allow. However, when the corset is attached to the upper side arms of the joints, the motion of the side arms will be suppressed and there will be commensurate movement of the stump in the socket. This factor must be borne in mind, as the motions of the upper side arms of the mechanical joints are considered in establishing the best position.

There are two situations in which the motions between the prosthesis and the amputated leg are of particular significance: (1) when the amputee sits and (2) when the leg is swinging through during walking.

Sitting. When the amputee sits, joint movement should draw the stump out of the socket and move it forward so that roll formation and pinching between the corset and the back of the socket are reduced. In order to lift the stump, the mechanical joints must pull the corset up against the back of the thigh as the amputee sits. This will occur when the upper joint arms move anteriorly with respect to the thigh. To move the stump forward as the amputee sits, the upper joint arms should move distally with respect to the thigh. Thus, theoretically, a satisfactory position for the mechanical joints will be directly above the anatomic joint axis, if it is assumed that the amount of forward motion and upward motion should be approximately the same.

Swing Phase. For swing-phase control, there should be little or no motion between the stump and socket. Thus, the mechanical joint axis should be close to the anatomic joint axis.

If the prosthesis is to function satisfactorily both during sitting and during swing phase, the mechanical axis should therefore be above the anatomic axis but not so far above as to introduce too much relative motion between stump and socket during walking.

All the foregoing analyses are based on consideration of the knee as a single-axis joint. But, as was shown in the chapter, "Anatomy of the Below-Knee Stump," the knee joint is actually made up of two complex surfaces: the femoral condyles and the tibial condyles. The femoral condyles are two convex surfaces separated by an antero-posterior groove, and the tibial condyles are two concave surfaces

separated by a ridged area which fits their femoral counterparts.

The femoral condyles roll and slide on the tibial condyles as the knee joint moves. The amount of sliding and rolling determines the axis of rotation of the knee joint at any instant. A shift in the axis of rotation may sometimes help and sometimes oppose required function. If the path of the knee axis were exactly known, the best position for the single-axis knee joint could be positively stated and joints fully satisfying the functional requirements could be designed. However, experience has shown that the mechanical joints can be located accurately enough when the proposed procedures, based on consideration of the knee as a single-axis joint, are used.

A typical relationship between socket, joints, and thigh corset in the finished prosthesis is shown in figure 7. The back brim of

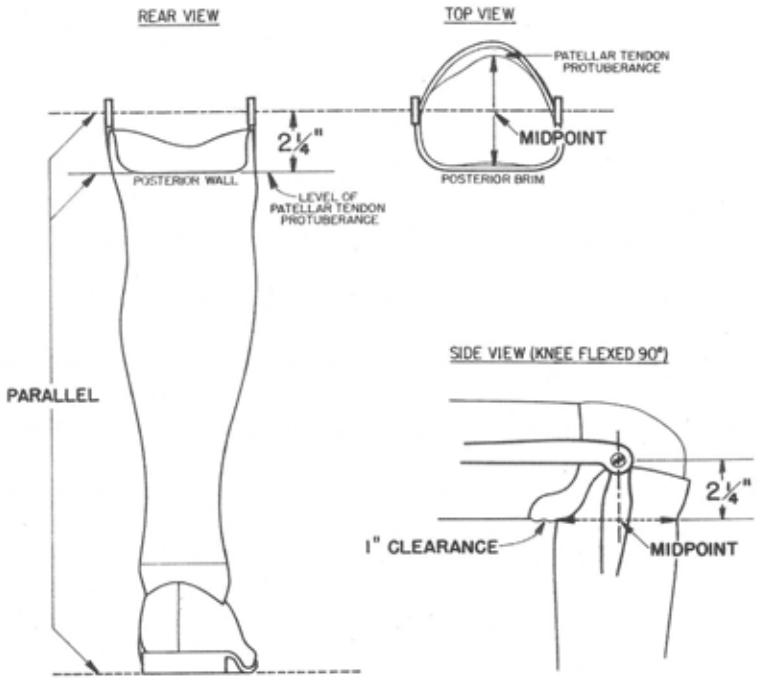


FIG.7 TYPICAL RELATIONSHIP BETWEEN SOCKET, JOINTS, AND THIGH CORSET.

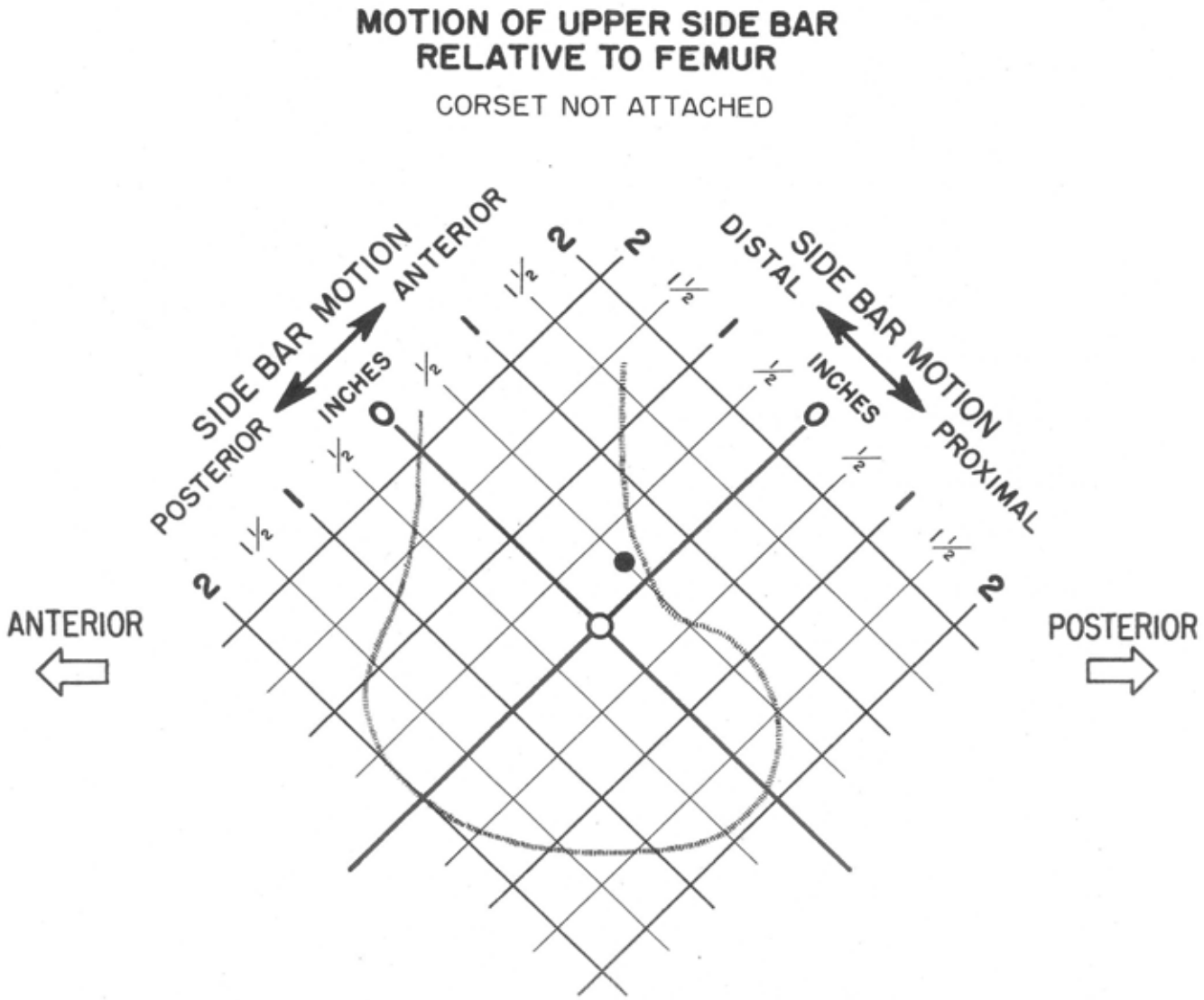


FIG.8 CHART FOR LOCATING SIDE JOINTS

the socket will be trimmed to the patellar-tendon level. With the joints flexed 90°, the posterodistal edge of the thigh corset will be 1" behind the posterior brim of the socket and at the same level as or slightly above the posterior brim of the socket. The joints are approximately on a mediolateral axis parallel to the back wall of the socket, midway between the patellar-tendon protuberance and the posterior wall, and the axis is approximately 2 1/4" above the mid-patellar-tendon level.

Side-Joint Locating Chart

Figure 8 shows a chart based on the theoretical analysis given above. The chart can be used for correct positioning of the side joints on a below-knee prosthesis. It indicates the motion to be expected between the upper side bar (the corset will be attached later) and the femur.

1. Attach the lateral lower side bar to the socket temporarily in the position indicated in figure 7 so that the center of the joint is 2 1/4" above the mid-patellar-tendon level and midway between the patellar-tendon protuberance and the posterior wall of the socket. Use only one attachment point at the bottom of the side bar, and secure it above by wrapping masking tape around the socket. The single attachment point at the lower end of the side bar allows the joints to be moved back and forth during trials and simplifies a change in position up and down. The upper bar is not shaped or attached to the corset at this time.

2. Have the amputee stand and extend the joint. Mark the position of the front and top edges of the side bar with a skin pencil.

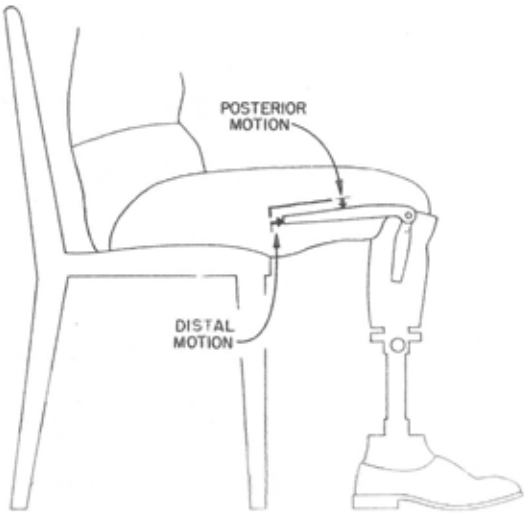


3. Ask the amputee to sit with his knee flexed 90^{o}. Check to see whether the posterior brim of the socket is properly trimmed and the stump is well seated in the stump.

4. While the amputee is sitting in this position move the upper side bar until the front edge is parallel to the line on the thigh marked in step 2. Make a second mark along the front and top edges of the side bar.



5. Measure the relative motion as evidenced by the difference in position of the marks in step 4 as compared with step 2.



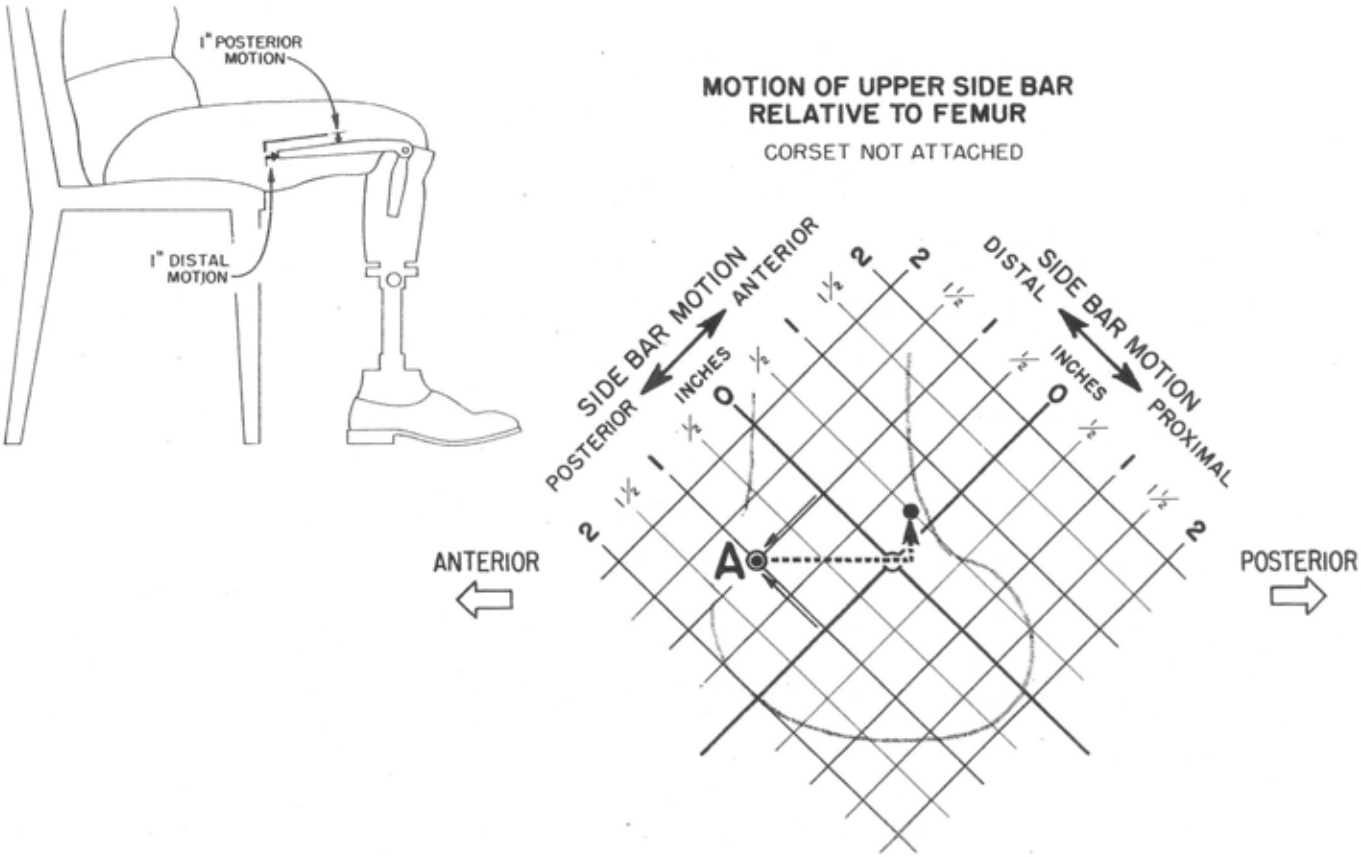
6. Enter on the chart the data obtained in step 5. This information will indicate the approximate location of the mechanical joint center with respect to the femur, as shown in the dotted outline.

7. Estimate the direction in which to move the joint to improve its position. The optimum position is located a short distance above and slightly behind the average anatomic center. The upper side bars of the mechanical joint should move distally on the thigh approximately 1/4" with 90° knee flexion. A motion of between 1/4" and 1/2" is allowable. Motion greater than 1/2" results in the stump being forced forward excessively after the side bars are attached to the corset. The upper side bars should move toward the front of the corset approximately 1/2" with 90° knee flexion. This motion is equivalent to a stump withdrawal with knee flexion after the side bars are attached to the corset.

If the movements are not within the suggested limits, move the joint as indicated by the chart to bring them within these limits.

When the joint has been properly located, rivet both side bars to the socket so that a line connecting the centers of the joints would be parallel to the floor and to the posterior wall of the socket. Shape the upper side bars to fit the thigh, keeping the joints coaxial. Pay particular attention to the shaping of the upper bars over the femoral condyles, because a close fit here helps

to suspend the prosthesis. At this point the corset is cut to shape and is temporarily attached to the upper side bars of the joints with binding screws.



Example

1. Step 5 indicates a relative motion of 1" posteriorly and 1" distally along the thigh.
2. Enter data on chart as shown to locate point A. Point A represents the probable position of the mechanical joint

relative to the femur.

3. The femur outline is actual size. Therefore the movement required to relocate the joint in the assumed optimum position B may be scaled directly from the drawing. In this example, the joint axis shown is moved rearward a distance a = 1 1/8" and upward a distance b = 3/8".

Corset Fabrication and Finishing

While cuff suspension can be used successfully for the majority of below-knee amputees, a corset and side-joint system is sometimes needed.

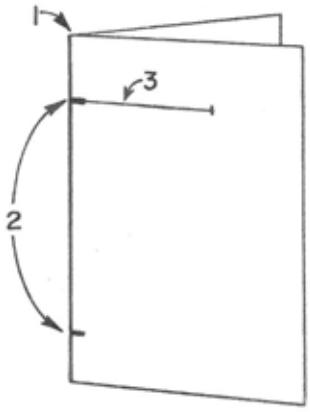
The measurements required to make the corset are recorded on the Prosthetic Information Form. Use the thigh circumference at the level 2" above the midpatellar level for the bottom end of the corset.

For the top end of the corset, use the thigh measurement at the appropriate level. This level, for an amputee of average height, is usually 8" above the midpatellar level.

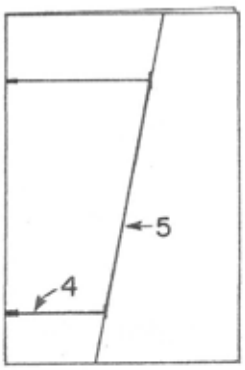
These measurements are used to lay out the corset pattern. Proceed as follows:

1. Fold a 2' by 2' piece of paper in half.
2. Along the folded edge mark two points corresponding to the distance from the top to the bottom of the corset.

3. From one mark draw a line perpendicular to the folded edge one half the length of the upper thigh circumference.

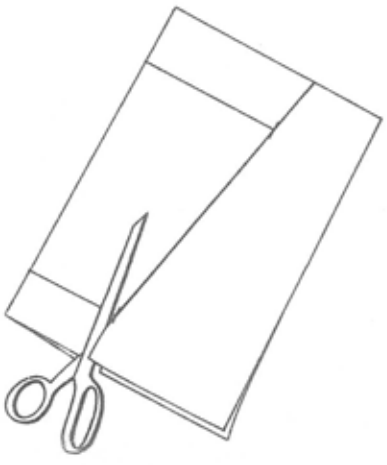


4. From the other mark draw a perpendicular line one half the length of the circumference just above the patella.

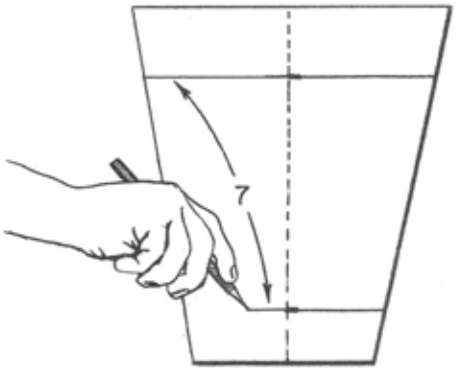


5. Draw a line to join the far ends of these two lines.

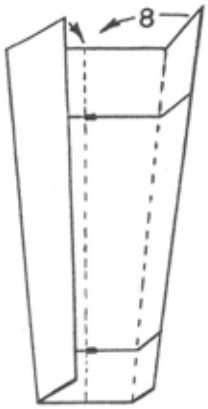
6. Cut the folded pattern paper along this last line and open the pattern.



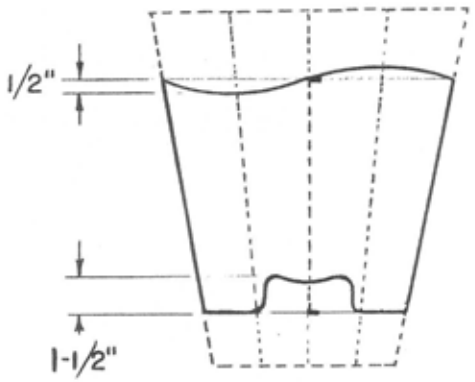
7. Continue the lines across the blank paper pattern.



8. Refold, and crease each half of the pattern so that the two edges lie along the original crease. This second crease will be a guide line on the corset for positioning the attachment of the side bars.

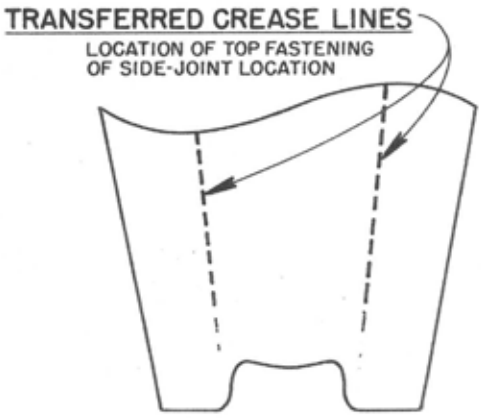


9. Shape the pattern top and bottom as shown in the illustration.



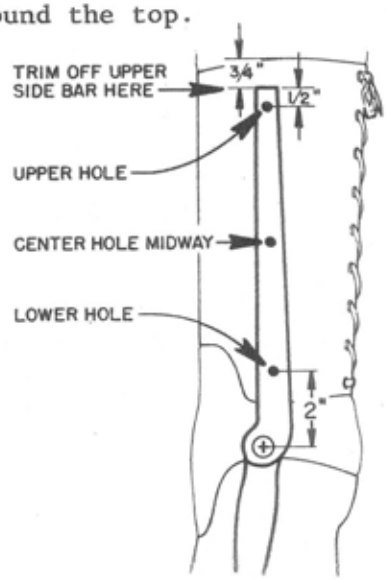
Cutting and Fitting the Corset and Attaching the Joints. Using the pattern, cut the corset from cowhide leather or its equivalent.

Transfer the second crease lines from the pattern to the corset. Later, the upper side-joint bars will be fastened to the corset in three places, about 1" from the top and bottom and in the middle; the top fastening will lie along these second crease lines.



(a) Top.

1. With the prosthesis on the amputee and the amputee standing, wrap the corset around the thigh.
2. Shape the upper side bars as close as possible to the condyles and thigh for good pick-up and stabilization.
3. Mark and trim off the upper side bars about 3/4" below the top of the corset. This will leave as much of the side bars as possible for leverage and yet allow enough room to sew around the top.
4. Drill three holes through the side bars as follows: Drill a hole 1/2" from the top of the side bar. Drill a second hole about 2" above the race center, avoiding bends in the

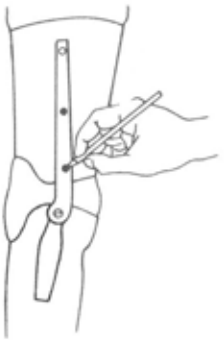


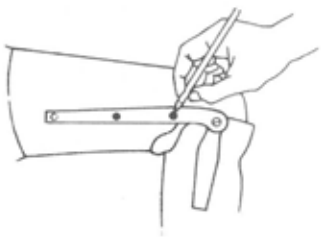
metal where it was shaped. Drill a third hole midway between the two.

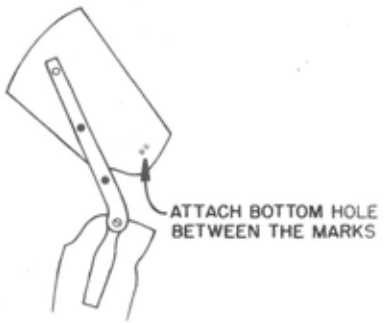
5. Place the top side-bar holes directly over the pattern crease lines.
6. Mark the corset through the top side-bar holes.
7. Punch holes through the corset at these marks.
8. Attach the side-bar tops to the corset with screw-type fasteners.

(b) Bottom.

9. With the amputee standing, mark on the corset the bottom hole of each side bar.
10. Mark the same holes with the amputee sitting.
11. Attach the bottom hole of the side bars to the corset midway between these two marks. Since this is a temporary attachment, do not fasten the bar at the middle at this time.



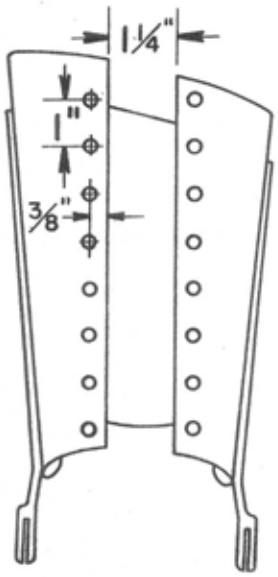




(c) Corset Fitting.

1. With the prosthesis on the amputee, close the corset around the thigh.

2. To allow enough separation for the leather to stretch, mark the front edges so that, when trimmed, they will be 1 1/4" apart.



3. Trim the corset along these lines.

4. Cut eyelets 1" apart and 3/8" from both front edges of the corset. The holes on the two sides should be exactly opposite. If stiffer leather, such as English bridle or domestic cowhide, is used, the distance between the holes can be as much as 1 1/2".

5. Have the amputee put on the prosthesis and lace up the corset.

6. With the amputee standing, mark the front-bottom trim line just at the top edge of the patella. The corset should fit closely along the patella and knee flare

to help suspend the prosthesis.

7. This is a good time to check joint position. If the back edge of the corset falls below the back brim of the socket when the amputee sits, the joints are too low.

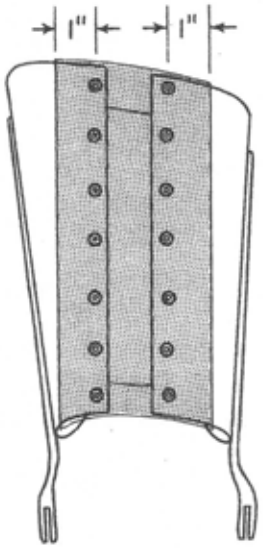
8. When the joint alignment is safisfactory but the skin bunches at the corset bottom in back, trim the corset here.

The same kind of leather is used for both corset and tongue. A medium-weight horsehide serves for the lining.

(d) Tongue.

1. Cut the leather as long as the corset and wide enough to reach 1" beyond the rows of eyelets on either side.

2. Skive one of the long edges of the tongue.



(e) Lining.

The edge of the tongue will be sewn to the corset down one front side. This strip of corset must first be lined.

1. Cut a piece of horsehide as long as the corset and 2 1/2" wide.

2. Skive one of the long edges.

3. With rubber cement bond the strip of horsehide on the inside of the corset, placing the skived edge 2 1/4" in from the corset edge.
4. With its smooth side facing the inside of the corset, lay the skived edge of the tongue along the skived edge of the lining, making a gradual build-up. Sew along the skived edge of the tongue.

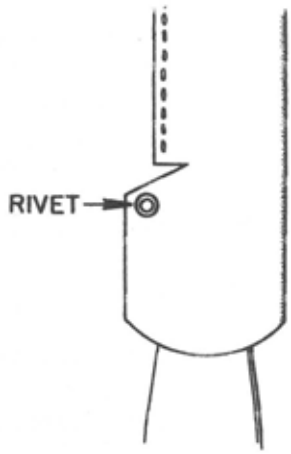
Horsehide now lines the surface of the corset that faces the tongue. The rest of the corset may now be lined.

5. Lay the corset on the bench inside, or rough side, down.
6. Lay a piece of horsehide over the corset, rough side up, large enough to cover completely the corset and tongue.
7. Sew along the top of the corset. The seam line will start where the tongue joins the corset and will end 1" short of the opposite corner.
8. Turn the corset over, bringing the liner over the top edge evenly and snugly.
9. Pull the horsehide over the inside of the corset, and bond the inside surfaces of liner and corset together with rubber cement.
10. Sew around the other edges of the tongue and corset. Trim the liner close to the seam.

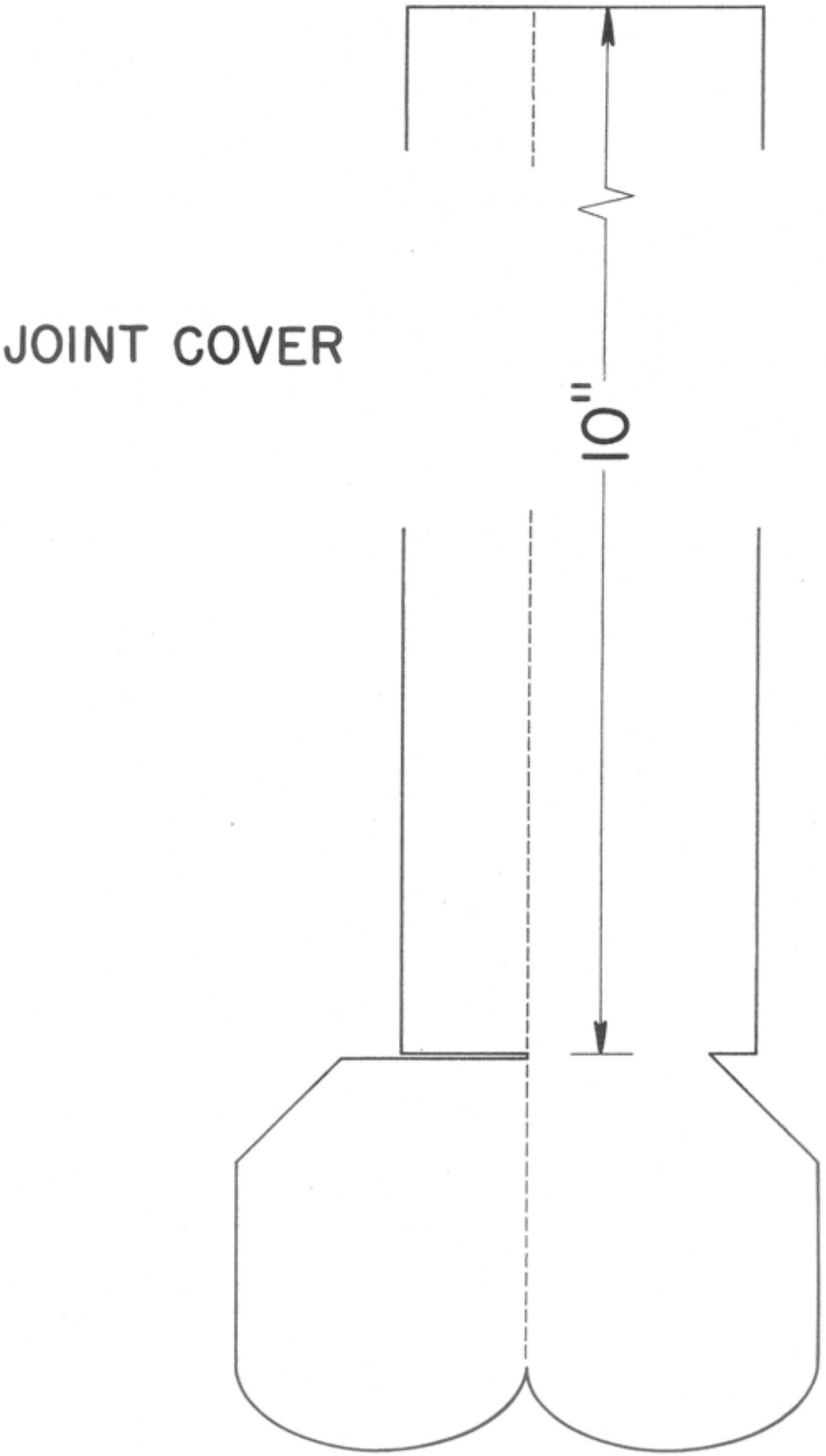
11. On the side opposite the tongue, sew a seam down the corset inside the line of the eyelets, flanking the eyelets evenly by the two seam lines.
12. Cut the eyelet holes through the horsehide liner.

To protect clothing, the upper side bars and the races are covered with leather one third the thickness of the corset.

1. Make a paper pattern for the joint covers, as illustrated.
2. Cut a leather cover for the right and left sides.
3. Fasten the side bars to the corset permanently. Use 1/8" copper rivets at the top, middle, and bottom, as marked.
4. Bond the covers over the side bars with rubber cement.
5. Sew around the upper side-bar covers.
6. Trim off any excess material.
7. Attach a speedy rivet at the corner of the race cover, as pictured.



Next, the metal eyelets and the corset lace are installed.


JOINT COVER
10"

1. Attach the metal eyelets.
2. Cut a leather lace or a piece of nylon parachute cord long enough to lace all the holes and leave a foot to spare on each end. If nylon is used, burn both ends to prevent fraying.

Finally, as proof against moisture and bacteria, coat the leather with nylon solution.

PROSTHETIC PROBLEMS

This chapter will deal with problems which face the prosthetist or clinician as he examines amputees who may be wearing prostheses that are so old as to be decrepit, of recent construction but of antiquated design, or, perhaps, of recent design but functionally unsatisfactory. Thus, reference will be made to appliances other than the patellar-tendon-bearing cuff-suspension prosthesis and to conditions not likely to be associated with wearing this prosthesis.

Many of the factors involved in below-knee prosthetic problems are common to all levels of amputation: the individual physical and psychological characteristics of the amputee, the adequacy of the prosthesis (in respect to type, construction, and fit and alignment), and the condition of the stump.

Yet certain factors are peculiar to the below-knee amputee. In contrast to the above-knee patient, he has greater control over the prosthesis. Therefore, his activity level is usually high. The stump itself, however, being bony and vulnerable, offers little area on which pressure can be exerted to stabilize the prosthesis. Furthermore, these areas that support body weight are sloped, so that a much larger force must be applied at right angles to the weight-bearing region to give adequate support.

Throughout the walking cycle, support of the body by the prosthesis is constantly complicated by problems of movement, such as

impact at heel contact and leverage just before toe-off. If movement shifts the stump out of its position, the areas for force-transfer are reduced and pressure on the areas in contact with the socket is correspondingly increased. The problem becomes more acute when the socket fits poorly or the prosthesis is badly aligned. Under these more severe conditions of high pressure and increased movement, damage may occur to the stump. Such damage will be manifested by abrasions, blisters, calluses, infected areas, or cysts, which may be painful enough to make use of the prosthesis impossible.

It is in the study of these stump-socket pressures, or forces, and movements that clues to treatment are to be found. In this report, therefore, each below-knee prosthetic problem will be considered whenever possible in terms of the effects of force and movement on the stump.

Initial Examination

In the initial examination, the prosthetist is guided by the amputee's immediate complaint. As the amputee becomes more experienced with the problems involved and more aware of the comfort and function he wishes to attain, his subjective interpretations become increasingly meaningful.

If the amputee is wearing his artificial leg, the logical first step is to watch his gait to see how much movement there is between the prosthesis and the stump and to observe the alignment of the socket over the foot. For checking weight-bearing and the fit of the lacer, the amputee should be observed while standing, to determine

the depth to which the stump settles into the socket. He should then be observed while sitting, to check the position of the prosthesis on the leg (see chapter, "Use of Side Joints and Thigh Corset"). As he sits, there should be no painful pressure against the anterodistal surface of the tibia, on the hamstring tendons, or against the upper edge of the tibial tubercle.

The stump should be studied for signs of infection, location of abraded areas, and other evidence of stump damage. The prosthetist can relate his observations to socket fit by comparing the measurements and shape of the socket with those of the stump or, better, with those of a modified plaster model of the stump.

Evaluation of Gait

Important variables which affect the gait of the below-knee amputee include (1) mediolateral position of the socket over the foot (foot inset-outset), (2) anteroposterior position of the socket over the foot, (3) anterior or posterior tilt of the socket with respect to the shank (socket flexion), (4) inversion or eversion of the foot, (5) foot function, (6) shoe, (7) length of the leg, (8) suspension, and (9) socket fit.

Foot Inset-Outset. Effects of mediolateral foot-socket position can be seen from the front or back. An excessively inset foot tends to pull the top of the socket away from the stump laterally and the top of the lacer in against the medial aspect of the thigh. Thus, although this inset placement tends to shift the stump toward the socket areas designed for contact, it may increase socket forces to

an uncomfortable degree on the medioproximal and distolateral areas of the stump and give the amputee an insecure feeling with regard to mediolateral stability. The better the stump has been fitted in the socket, however, the more the foot can be inset without producing insecurity, discomfort, or an unnatural gait. A good inset placement results in comfortable pressure on the weight-bearing medial flare of the tibia, reduces pressure in the area over the head of the fibula, provides effective lateral stabilization of the tibia, and results in a narrow-based gait.

The opposite forces operate with an excessively outset foot. The medial side of the socket top and the medial side of the corset top pull away from the stump. The disadvantages of this placement are that the area over the medial tibial flare tends to pull away from the socket, thus bearing weight less effectively, and that forces tend to concentrate where the proximolateral portion of the socket presses against the stump.

Anteroposterior Foot-Socket Position. The influence of the anteroposterior foot-socket position on gait can be seen from the side. When the socket is placed too far back, the amputee walks with his knee extended and bears weight for an excessively long time on the heel. The toe may be elevated at the instant of heel contact. Posterior placement increases the pressures under the patella, reduces control of the knee, and causes an unnatural gait.

When the socket is placed too far forward, the amputee walks with an asymmetrical gait. There is exaggerated knee flexion after

heel contact, drop at the end of stance phase, and a reduced period of weight-bearing on the prosthetic side. During the weight-bearing phase, the amputee holds the knee against flexion, so that the socket pressures against the stump are increased high in back and low in front, thus causing discomfort over the anterodistal part of the tibia. Throughout the rest of the walking cycle, however, anteroposterior forces on the stump are reduced.

The final anteroposterior position depends on the length and strength of the stump. A long stump has more leverage and can cope better with high forces than a short stump. The optimum position permits smooth transition between heel contact and toe-off.

Anterior or Posterior Tilt of the Socket. The angle between foot and socket is viewed from the side. When too much posterior tilt of the socket is present, the amputee first extends, then flexes, his knee at heel contact; flexion is prematurely arrested as he meets the resistance of the toe. This premature stopping of knee flexion is distracting to the amputee and lessens his control over the knee. At the end of stance phase he feels as though he is climbing a hill.

Too much anterior tilt of the socket forces the knee into exaggerated flexion as the amputee bears weight on the heel; it throws him forward at heel contact and then allows him to drop after mid-stance.

The best position of the socket over the foot allows the amputee to stand or walk with the knee controlled so that he can either flex or extend his knee to control the prosthesis with his stump.

Inversion or Eversion of the Foot. If the foot tends to contact more on the inside or on the outside, the effects on the amputee will be similar to those of placing the socket medially or laterally. There is usually foot or shoe wear as evidence.

Foot Function. With the SACH foot, the only variables are the stiffness of the heel cushion and the length of the keel. These are dictated by the weight and size of the amputee. If the heel cushion is too stiff, the prosthesis functions as it does when the socket is positioned too far forward over the foot and, if it is too soft, as though the socket were positioned too far to the rear. If the toe break is too long, the amputee has a hill-climbing sensation, and (although this is rarely a problem), if it is too short, he drops at the end of stance phase. The foot function should always be rechecked if the alignment varies markedly from the typical.

Shoe. Stiff, new shoes or shoes in a state of disrepair will cause a change in foot function. Shoe wear may show evidence of the force pattern on the foot of the prosthesis.

Length of the Leg. If the prosthesis appears short, the stump may be sinking into the socket. This is checked by observing the position of the patella in relation to the socket brim while the amputee stands.

Suspension. If there is excessive up-and-down movement of the stump in the socket as the amputee walks, the suspension is at fault. Check to see whether the tabs of the cuff-suspension system have stretched, the attachment points are incorrectly located, or the thigh

has atrophied under the cuff above the patella in such a way that the cuff does not anchor correctly on the knee and is forced downward. If the tabs have stretched or the thigh musculature under the cuff has atrophied, use the next hole on the tabs. If the location of the attachment points is at fault, correct it as indicated in the chapter, "Cuff Suspension." When prominent thigh musculature reduces the effectiveness of the cuff-suspension system, it may be necessary to provide a waist belt as auxiliary suspension.

Socket Fit.

(a) Settling. The stump settles deeper into the socket when stump volume diminishes, when the thigh atrophies, or when the lacer stretches and sags. Reduction in stump volume may be the result either of loss of edema or of true atrophy of the tissues. With shrinkage of the stump, the skin overlying the bony prominences and tendons becomes abraded as they slip down and out of relief pockets. In an effort to correct this condition, the amputee may sometimes add stump socks to take up the slack in the socket. However, the use of stump socks tends to defeat its own purpose, since the socks fill the relief pockets, allowing less space for the unchanged contours of the bony prominences.

To check whether the stump has settled too far into the socket, the prosthetist should compare the anteroposterior and mediolateral dimensions and shape of the socket with those of the modified plaster stump model and the position of the patella with respect to the socket brim. If it is necessary to raise the stump in the socket, material

is added where the proximal 2" to 3" of the socket contacts the gastrocnemius and where the socket contacts the patellar tendon and the medial flare of the tibia.

(b) Tight Fit. Only when a socket is new or when more than one stump sock is being used is the socket likely to fit too closely over bony prominences and tendons. Tightness may be remedied by enlarging the relief pockets; if too many stump socks are being used by the amputee in an effort to make the socket fit more snugly, socket dimensions should be checked. If the discrepancy between stump and socket is too great, the fit should be adjusted by adding or removing material from the socket so as to improve weight-bearing or, if this cannot be done, the socket should be replaced.

(c) Stabilization. The stump moves excessively in the socket when it is not securely fitted or when excessive forces result from poor alignment. Such movement is an important factor in stump abrasion. It may occur from back to front, from side to side, or as twisting, depending on the directions in which the stump is poorly stabilized.

(1) Anteroposterior Movement. Anteroposterior movement causes abrasion at the anterodistal end of the tibia, the lower border of the patella, and the patellar tendon. The socket is less likely to move if it extends high on the stump and is closed at the end, with the greatest possible length of stump being used for leverage. However, even a well-fitted socket will move excessively posteriorly, if the leg has been poorly

aligned. To reduce moments, the socket should be moved forward over the foot. If a standard wooden foot is used, the forefoot length may be shortened, the foot may be dorsiflexed, or a soft dorsiflexion stop may be added. When the SACH foot, which has a standard forefoot length, is used, the foot should appear dorsiflexed, the socket forward, and the stump flexed.

(2) Mediolateral Movement. Mediolateral movement causes abrasion over the head of the fibula and, sometimes, the medial condyles of the tibia. The socket should extend as high as possible on the sides, especially medially, and fit closely to the sides of the stump down its entire length and at the end; it should also provide adequate relief pockets. Insetting the foot will relieve proximal pressure laterally.

When the foot is inset, the medial flare of the tibia (a weight-bearing area), the lateral aspect of the distal surface of the stump, and the medial aspect of the stump should be well anchored. The medial tibial condyle may be protected from pressure by provision of a relief pocket and by a high and close fit of the socket to the stump above the condyle.

If the stump has little length against which to stabilize the socket, the prosthetist must compromise on foot inset-outset.

(3) Axial Torque. When the socket is not securely fitted to the stump, rotatory movement about the long axis of the shank will cause abrasion over bony prominences and tendons. Torque

occurs through the normal rotation of the femur on the amputated side in stance phase. To compensate, the amputee may deviate from his normal gait. The resulting mediolateral body momentum presents a torque problem if the lines of force acting on foot and prosthesis cause the prosthesis to twist on the stump as the foot pivots from heel or toe. Torque can also result from failure to align the side joints coaxially or to locate them to allow natural shank flexion during swing phase (see chapter, "Use of Side Joints and Thigh Corset"). Excessive toe-out, which moves the heel in, excessive resistance to plantar-flexion action, and foot inset also contribute to the torque.

Stump Examination

The amputee's stump usually bears the stump-sock pattern on it, especially in areas where the stump presses against the socket. This pattern shows the prosthetist how forces are distributed and may indicate high-pressure areas or the level where the thigh or stump is being constricted.

Other signs of pressure resulting from poor fit and alignment are color changes, abnormal skin temperature, tender and painful areas, abrasions and other skin disorders, and edema.

Color Changes. Skin normally blanches when it is pressed briefly and recovers color readily after pressure is removed. However, the stump is subjected to continuous pressure in the course of the day. When the socket is first removed, small stresses may be revealed by reddened areas on the stump, while greater stresses may

blanch the tissues temporarily. A high local force leaves a blanched indentation on the stump.

Constriction may change the color of the stump skin for a longer period of time, depending on how long the stump has been constricted and how great the pressure has been. Brown discolorations usually mark areas where pressure has been high for prolonged periods, i.e., weeks or months. At the distal end of the stump dark discolorations usually indicate long-term edema which has been brought on by constriction at some higher level. Tissue that has been discolored for a long time is also usually firmer than the normal tissue around it.

In the dark-skinned patient, pressure spots may darken because of deposition of melanin in the traumatized area. This, of course, is different in origin and composition from the browns, greens, and yellows resulting from oxidizing pigments left in the tissues by blood from ruptured vessels, as in a patient with chronic stump edema.

The temperature of the skin of the stump may be an indication of the circulatory condition (however, it must be remembered that this temperature tends to vary with environmental temperature). An unusually cold stump may mean impaired circulation; severe constriction may be the cause. A hot stump may mean infection or inflammation.

Pain. When the patient complains of tenderness or pain in the stump, the prosthetist must determine whether the pain is the result of mechanical forces exerted by the prosthesis or of a pathological condition in the stump.

Pressure of the prosthesis on a muscle belly, over the cut end of bones, or on deep nerves gives rise to a dull pain. If it is not too severe, a dull pain may be tolerated; it often diminishes rapidly.

Sharp pain may be produced by constriction of the peroneal nerve, which passes over the posteroinferior edge of the head of the fibula. The saphenous nerve, which passes under the medial condyle, may also give rise to sharp pain if pinched, as well as a pins-and-needles sensation. The pain is sometimes felt in a part other than the spot pressed; this is known as "referred" pain and may also be described as felt in the phantom leg. Pain caused by nerve constriction can be relieved if the stump is held securely in the socket to limit movement and if relief pockets are made large enough to eliminate pressure on areas where the nerves are superficial.

Sometimes there is hypersensitivity at the distal end of the stump, either localized or general. Usually a stump in which palpation gives rise to pain will tolerate continuous, even pressure such as can be applied with cupped hands, although spots around the cut bone ends may trigger involuntary withdrawal. This tolerance suggests that many such stumps may be conditioned to sockets which contact the stump end, since continuous stimulation appears to reduce hypersensitivity.

When edema forms in the stump end, it may cause a painful pulling sensation.

If the side joints are too low and too far forward, pinching will occur between the back of the socket and the corset when the

amputee sits. The joints should be placed so that at 90° flexion the lower back edge of the corset is at least 1" from and level with or above the back edge of the socket. Pinching may also be caused by a fold in the stump sock (see chapter, "Use of Side Joints and Thigh Corset").

Abrasion. Abrasion is the first sure sign that the stump is not securely held by the socket and that excessive pressures are being exerted on it by the prosthesis. Areas commonly subject to abrasion are those over tendons and bones that are only lightly covered with tissues, such as the head of the fibula, the tibial tubercle, the anteromedial and anterolateral condyles of the tibia, the anterodistal end of the remaining tibia, and the hamstring tendons. These abrasions occur when the stump settles deeper into the socket, when there is up-and-down movement of the stump in the socket, when the socket moves anteroposteriorly or mediolaterally (bell-clapper action) on the stump, when the socket twists around the stump, or when the stump fits too closely over the vulnerable areas.

Skin Disorders and Bursae. Persistent skin disorders and painful bursae should be treated by a physician. However, since treatment often consists of prosthetic changes, it is essential for the prosthetist to recognize the symptoms of the more common disorders.

Any stump abrasion may become secondarily infected. Infection may involve not only the bony prominences but also the soft-tissue areas, such as the back of the knee, the area surrounding the patella, and the distal surface of the stump.

Poor stump hygiene may be a factor in surface infection, although surface infection does not necessarily imply poor stump hygiene. The prosthetist should stress the importance to the amputee of changing his stump sock at least once a day and of washing and rinsing both stump and sock thoroughly.

Most superficial bacterial infections of the stump are temporary, perhaps induced by unusual activity, and the amputee should be encouraged to use the hygienic methods indicated and to bear some discomfort for a short time. A temporary inconvenience may be less hazardous than a new force pattern introduced by changes in the socket. Conservative treatment with a reduction of activity while the prosthesis is worn will often clear infections.

Stimulated by friction between tissue layers, existing bursae may become irritated and adventitious bursae may form over the bony prominences, around tendons, and under the edges of the patella. They may become distended, tender, and infected.

Epidermoid cysts appear as hard nodules within and under the skin. Infected cysts appear as puffy swellings. Old cysts often form sinuses to the skin surface and drain when they become inflamed or infected.

When skin disorders are the result of allergic reactions, the prosthetist may help the amputee by changing the materials of the prosthesis to eliminate the allergenic substances.

Edema. Edema is one of the major problems affecting amputees. It is seen as a hard swelling at the end of the stump where fluids

have collected in the tissues. A residual sign that edema has been present may be that the distal stump skin is darker than normal. After prolonged edema, especially when it has been severe, the skin may become furrowed like orange peel and the discoloration may persist. The skin is purplish if the damage is fairly recent and dark brown if the damage has been long-present. After the edematous phase the skin may become scaly. Loss of hair and thin, shiny skin are danger signals; referral to the physician is indicated. Eventually, under the joint assault of pressure and reduced nourishment, the skin may break down and become infected. Or, if it remains scaly, the furrows may deepen and the skin assume a horny, leathery appearance. It may become covered with wart-like excrescences which encrust the edematous area, producing deep fissures and discharging a straw-colored serous material or, if infected, a foul-smelling, yellow pus.

The fluid content of the tissues is normally kept at a nearly constant level. In the amputee, the return of fluid from the tissues may be disturbed by two main factors: (1) atrophy of muscles whose activity is essential for normal flow of lymph and for venous return and (2) constriction by the prosthesis proximally, causing a backing-up of venous blood and a resulting increase in intracapillary pressure at the venous end of the capillary bed.

The first step in treatment of the edematous stump must be to reduce constriction above the area of edema by a better distribution of forces around the stump.

The thigh corset is a potential constrictor in the patient with

a below-knee prosthesis. If laced too tightly, it may (1) constrict the entire thigh, (2) constrict the region just above the knee, or (3) crowd the roll of flesh against the back brim of the socket when the amputee flexes his stump.

If the thigh corset is generally tight, an ill-fitting socket may be causing the amputee to depend on the lacer to take the weight off the socket. When the socket fit is improved, the need for dependence on the corset is eliminated.

The amputee may tighten the corset just above the knee to improve suspension on the patella and the flares of the femoral condyles. A yoke strap that passes over the knee and is joined to the upper side bars is sometimes part of the corset system. When the leg is swung through, this yoke strap catches the top of the patella, improving suspension. However, the strap can be the cause of constriction when the amputee sits. In addition to binding against the top of the knee, it forces the stump down into the socket so that the back socket brim presses against the popliteal space. If the corset and side joints are properly fitted over the flares of the femoral condyles, the yoke strap is not needed.

The roll of flesh at the posterodistal border of the corset may develop in one of three ways: (1) the anterior edge of the corset may force the stump down into the socket, (2) the posterior edge of the corset may come too close to the socket brim, or (3) the front of the corset may force the stump against the posterior brim of the socket. These are all the results of incorrect joint placement. The

prosthetist can check joint placement by observing the prosthesis when it is removed from the amputee. With the knee flexed at a 90^{o} angle, the posterior edge of the corset and socket should be at the same level or else the corset edge should be slightly above the socket edge, with a space of at least 1" between them in this position. The posterior brim should fit well up into the popliteal crease, with relief channels for the hamstring tendons to give sitting comfort. (For further ideas on joint location, see the chapter, "Use of Side Joints and Thigh Corset").

Constriction causing edema may also result from stump changes. As the newly amputated stump shrinks, particularly in the region of the gastrocnemius muscle and portions distal to this, it sinks deeper into the socket. This sinking constricts the stump around the proximal or middle portions while the distal end is still held loosely.

When the posterior brim of the socket is too low it increases pressures on the stump, since there is less area for stump support. Too great an anteroposterior distance between the patellar-tendon protuberance and the posterior inside edge of the socket allows the stump to become wedged into the socket. The socket shape and dimensions should be compared with those of the modified plaster model.

Another cause of edema is a poorly fitting stump sock. Amputees with open-end sockets sometimes pull their stumps in by means of a strong or lace attached to the end of the sock. The end of the stump does not then contact the socket, and, as a result, distal pressure is low. A stump sock should be the correct size and free of holes

distally. It should be worn snugly against the stump end.

An amputee may be predisposed to edema either because of his general circulatory condition or because of a local condition in the amputated extremity. A frequent predisposing factor is redundant tissue at the distal end of the stump.

To control or correct edema, pads of sponge rubber may be placed under the end of the stump. By providing back pressure on the fluid-filled tissues and reducing the pressure difference between the stump end and the constricted levels of the amputated leg, these pads usually bring the stump back to its more normal shape.

When the stump is again normal, further steps in treatment can be taken. If unsupported tissue at the end of the stump is the source of trouble, the sponge pads in the socket may be made a permanent part of the prosthesis or a new socket may be made to enclose the stump end. If the edema is caused by tightness proximally or looseness distally, the necessary socket changes may then be made gradually or a new well-fitted socket may be provided.

General Principles of Treatment

The choice of treatment will depend on the problem presented, but a few rules apply generally. One principle must be stressed: It is sometimes important to make no change. Of course, when the adjustments required are obvious and give immediate and satisfactory relief, the problem is clear. However, when the extent or nature of prosthetic adjustment is uncertain, the changes that are made should be conservative and carefully planned. Major adjustments may give

dramatic relief in one place but trouble elsewhere.

When the patient has been referred to the prosthetist by a physician, a report of the amputee's condition will be provided, as well as an outline of a course of medical treatment to parallel the prosthetic treatment. If the prosthetist is the first to see the amputee, and damage to the patient's stump appears serious or the cause of the damage is not clear, he should refer the amputee for medical treatment.

Sometimes the amputee's difficulties are such that it is even necessary to decide whether or not he should wear his prosthesis. In a case of this type the amputee will undoubtedly be under medical care, and the physician should participate in the decision. The best procedure is to have the amputee wear the prosthesis throughout treatment but be less active. This will keep the stump shape stable so that either a new prosthesis or the original prosthesis will fit the stump after treatment, without a period of adjustment. Should the amputee be unable to wear his prosthesis because it is too defective, he should have medical treatment, his stump should be wrapped, and he should be provided with a new prosthesis as soon as possible. If the stump shape is not kept stable, a new prosthesis made to fit the changed stump becomes less serviceable as the stump returns to normal.

Postfitting Adjustments

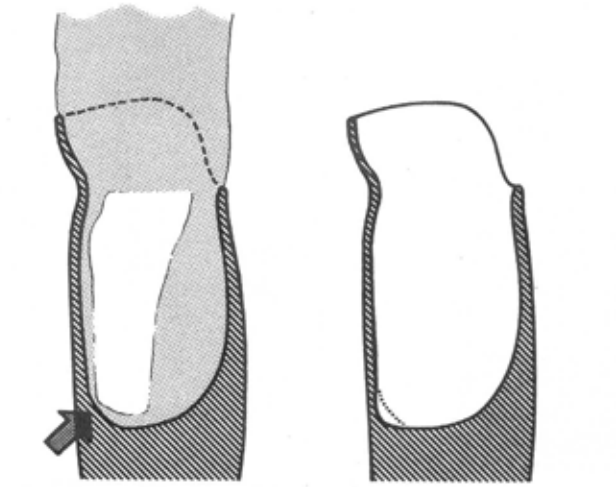
Soon after the amputee begins to wear his patellar-tendon-bearing cuff-suspension prosthesis routinely, unforeseen difficulties may appear and require adjustments to be made. These difficulties result

from inadequate socket fitting or from changes in the stump.

Stump Changes. Because the patellar-tendon-bearing cuff-suspension prosthesis imposes a different pressure pattern and perhaps increased forces on certain areas of the stump, significant changes can occur even in a seasoned stump. Shrinkage may occur because the stump was edematous when fitted, or there may be a reduction in fatty tissue because of pressure or a general weight loss. If the shrinkage occurs rapidly--within a day or so--edema is probably responsible; otherwise, other factors are involved. Since the significant shrinkage occurs at areas used the support and stabilize the stump in the prosthesis, these areas in the socket must then be built up until the fit is restored. In extreme cases, a new socket may be needed.

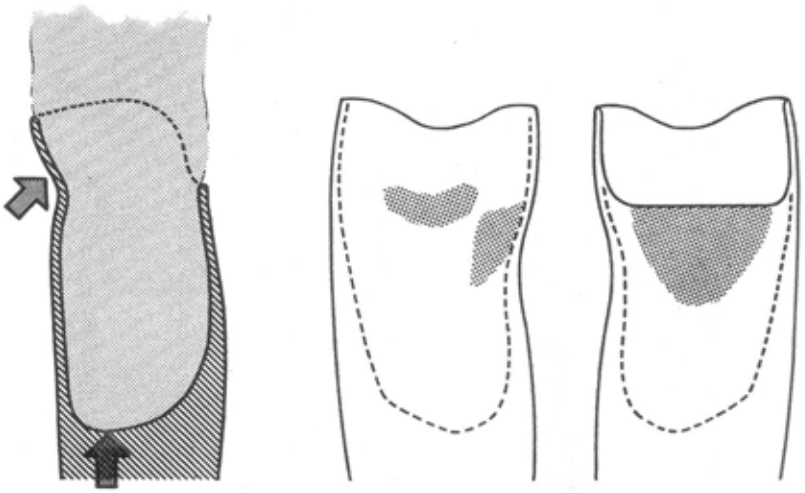
An outline of the trouble spots and some indications of how the trouble can be corrected follow. One should not be too quick to modify a socket, especially for shrinkage, if the socket has been considered comfortable; perhaps the stump has merely stabilized to the shape and size that is best suited to the socket fit and alignment. Both alignment and suspension should be considered as possible causes of discomfort before changes in the fit are made.

(a) Distal End. The amputee has discomfort on the end of the stump when the bone makes too firm a contact with the socket at the end or when the end of the stump works back and forth across the bottom of the socket. Too firm a contact results if there is not enough space for the end of the tibia in the socket or if



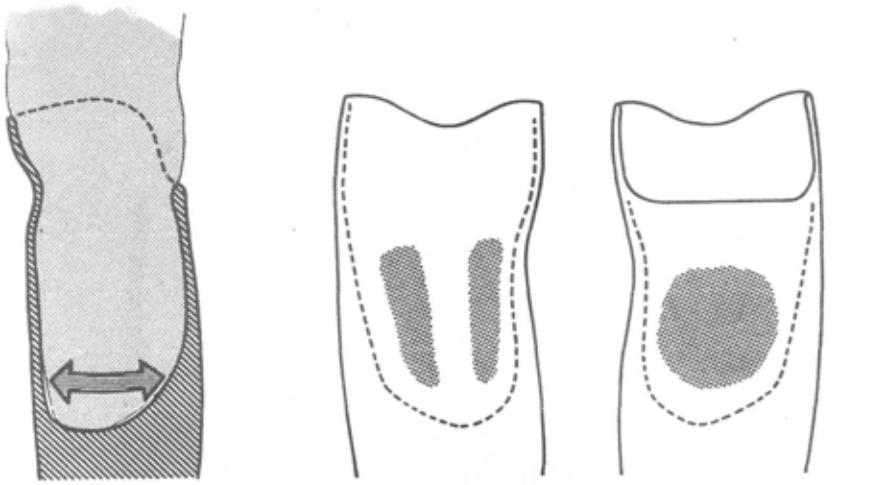
Insufficient space for end of tibia Remove material to enlarge space

the stump settles deeper into the socket. To increase space for the end of the tibia, material is ground out of the socket. To correct settling, material is added to the weight-bearing areas of the socket and over the popliteal area. To reduce movement of the stump end across the bottom of the socket, material is



Discomfort due to settling of stump into socket

Add material to weight-bearing areas

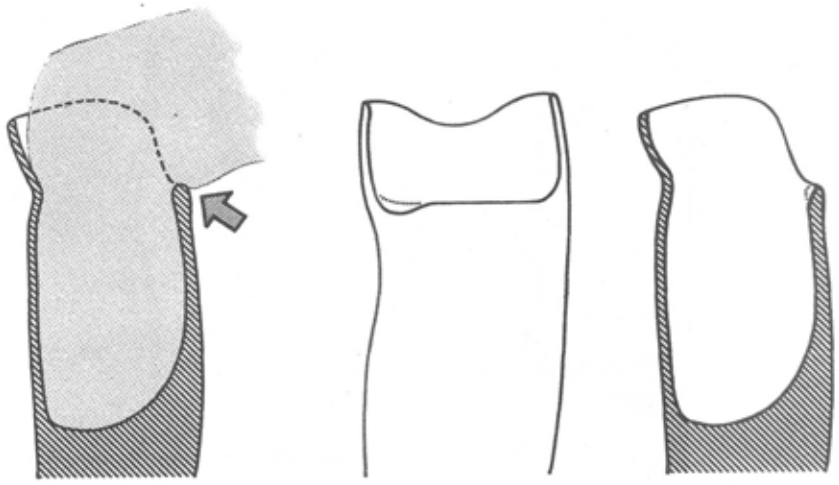


Motion of stump end

Add material on either side of tibial crest and over gastrocnemius and popliteal area

added to increase pressure on either side of the tibial crest and over the gastrocnemius-popliteal area.

(b) Medial Hamstring. When the amputee sits, the medial hamstring catches on the edge of the socket if the relief groove does not extend far enough or if the flare over the posterior edge of the socket under the hamstring is not generous enough.

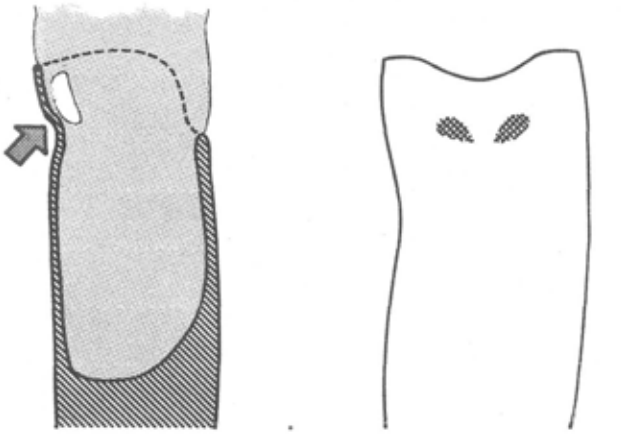


Medial hamstring catches on brim when amputee sits

Lower relief groove

Increase flare of posterior brim

(c) Patella. When the lower edge of the patella catches on the front of the socket, it may be that the stump has settled deeper into the socket or the indentations on either side of the patellar-tendon protuberance were made too large or too high. When settling is corrected by addition of material over the weight-bearing areas of the socket and over the popliteal area, pressure on the patella will be relieved if settling is the problem. If the problem is caused by large or high indentations on either side of the patellar-tendon protuberance, pressure on the patella will be relieved when material is removed from the socket.



Pressure on patella from too large or too high patellar-tendon protuberance

Remove material from upper part of patellar-tendon protuberance

Socket Adjustments. The simplest way to reduce the volume of the type of socket described in this manual is to add Kemblo to the Kemblo of the soft insert. When a piece of the required size has been secured in place with adhesive, the edges are skived and the thickness is adjusted on a sanding drum. If firmer support is required at any point, a more rigid material may be added to the inside of the socket shell.

When the socket is too tight, material may be carved from the socket shell or, if shell thickness is limited, rubber may be ground from the insert. The former procedure is preferred. Changes in the socket should be made in increments not exceeding 1/8".

Psychological Considerations. Proper orientation and frequent checks will help the amputee over the transition phase with his new prosthesis. He may find the absence of thigh corset and side bars, the flexed-knee gait, and the changed force pattern disturbing at first. He should be assured that his difficulties are typical and that he will probably adapt to the new prosthesis in about a month.