Functional Considerations in the Fitting of Above-Knee Prostheses

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IN THE fitting of any artificial limb, the goal of the prosthetist is simply to restore to the amputee the ability to perform everyday activities in an easy, natural, and comfortable manner. The basic requirements are therefore three in number—comfort, function, and appearance, the latter embracing both cosmetic appearance and appearance in use. Unless a prosthesis is reasonably comfortable, the amputee will be unable to wear it. Unless it performs the necessary functions with reasonable ease and dexterity, the amputee is not apt to find the device very useful. Unless it is reasonably acceptable cosmetically, and unless it can be operated in a natural manner, the limb is likely to be disagreeable both to the wearer and to his friends and associates.

But this seemingly simple set of requirements is vastly complicated by the fact that the three are all mutually interrelated. That is to say, the degree of satisfaction attained in one condition is influenced greatly by the situation prevailing with respect to the other two. Cosmetic appearance, for example, is necessarily limited by details of mechanism, and vice versa. No matter how elaborate a prosthetic device may be, it cannot be made to function properly unless it can be manipulated with ease and without discomfort. And conversely, no device can be comfortable in use unless its functional characteristics are properly integrated with the residual biomechanics of the wearer. Any change aimed at improvement in one condition unavoidably affects the other two—sometimes favorably, sometimes unfavorably.

In the lower extremity, cosmesis presents no serious problem. Since it is comparatively easy to fashion an artificial leg to an external shape and appearance more or less like that of its normal counterpart, and since in both sexes the lower extremity may be concealed beneath some sort of clothing, the actual cosmetic properties of a lower-extremity prosthesis amount to refinements to be added after all other requirements have been met. More critical in the lower extremity are comfort, function, and appearance in use. The leg prosthesis is in almost constant service, and it must provide both adequate support and a natural-appearing gait with as modest consumption of energy as possible. In fitting an above-knee limb, therefore, correct practices based on established biomechanical principles are mandatory if success is to be had.

Because during all activities the suction-socket above-knee leg *(3,4,19)* is controlled by the amputee through the use of remaining hip musculature, every effort must be made to ensure that these muscles are used to the fullest possible extent without causing discomfort. The intent here[2] is to present the basic concepts that apply to the fitting of all

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[2] It should be understood that no new theory of alignment is intended, that the aim is simply to explain logically some of the problems facing prosthetists in the construction of above-knee legs and to provide rational solutions for those problems. The views presented are the combined result of experience gained at the University of California Prosthetic Devices Research Project during limbshop trials of the adjustable leg and alignment duplication jig *(8,9,10)*, of a study of methods presently in use by the artificial-limb industry, and of a survey of information presented in the German literature *(15,16,17)*.

above-knee prostheses, regardless of type of suspension, but which have particular application to the suction-socket above-knee leg. Although the details of fitting must necessarily be modified as dictated by the individual case, the basic features apply to all cases.

THE PRINCIPLES OF ABOVE-KNEE ALIGNMENT

MEDIOLATERAL STABILITY

When one watches the walk of a typical above-knee amputee, two characteristics of gait often are particularly apparent. First, sidesway, *i.e.*, lateral movement of the torso from side to side, is exaggerated. Second, the amputee usually walks with his feet farther apart than does a normal individual of similar build. The average individual walks in such a manner that the lateral distance between successive points of heel contact is from 2 to 4 in. In order for the gait of an amputee to appear as normal as possible, therefore, he must walk with a base equally narrow. The amputee with a walking base of from 6 to 12 in. never can achieve a normal gait appearance. If such an amputee is asked why he walks with a wide base, he usually gives as the reason that it is more comfortable or that he feels more secure with his feet farther apart.

This circumstance is accounted for by the fact that, as an amputee attempts to walk with his feet closer together, certain functional requirements are placed upon the fit of the socket and upon orientation of the socket in space. In general, these requirements are not fulfilled in a prosthesis aligned for a wide-base gait. If an attempt is made to use such a prosthesis with a gait of narrow base, difficulties arise because certain forces come into play that cannot be accommodated by the stump in a comfortable manner. Although a poorly fitted prosthesis may be reasonably comfortable for many months provided the amputee walks so as to compensate for errors in fit and alignment, the same prosthesis may be very uncomfortable if the wearer attempts to change to a more normal-appearing gait. It is, however, possible to construct for the average above-knee amputee a prosthesis that allows a reasonably normal gait, that is comfortable in all normal activities, and that eliminates common points of stump irritation such as those in the crotch area and near the end of the femoral stump.

The Weight-Bearing Line

One of the most common terms used by the prosthetist in the fitting and alignment of an above-knee prosthesis is the "weight-bearing line." It serves as the guide for many phases of setting up the prosthesis, but its exact position is subject to considerable difference of opinion. One prosthetist may use a weight line drawn from the ischial tuberosity through the center of the ankle joint; a second may select a line falling along the medial side of the foot; and a third may advocate use of a line drawn from the geometric center of the socket at the ischial level to the center of the heel. It is possible to get many other definitions of the weight-bearing line. As a matter of fact, they probably are all equally helpful in the alignment of prostheses. In considering the manner in which the weight-bearing line is used, it becomes apparent immediately that such a line actually serves as a "reference line" or "construction line."

In the discussion that follows, the term "weight line" is used to establish a mental picture of a theoretical line in space along which the force of the body weight acts. This concept differs from "weight-bearing line" in that "weight" is due to the gravitational attraction of the earth, whereas "weight-bearing" refers to the transmission of a force through the structural elements of the anatomy and the prosthesis. Although it would appear difficult to establish any one line which accounts for the net effect of the weight of the various and widely separated parts of the anatomy, that can be done in a theoretical, idealized way by defining a point within the body at which the effect of all body weight can be assumed to be concentrated. This point is usually designated as the "center of gravity" of the body as a whole. With all the weight assumed to be concentrated at the center of gravity, the body weight must then always be considered as acting directly downward from this point, as though it were a plumb bob suspended on a string hanging from the center of gravity. The string would represent

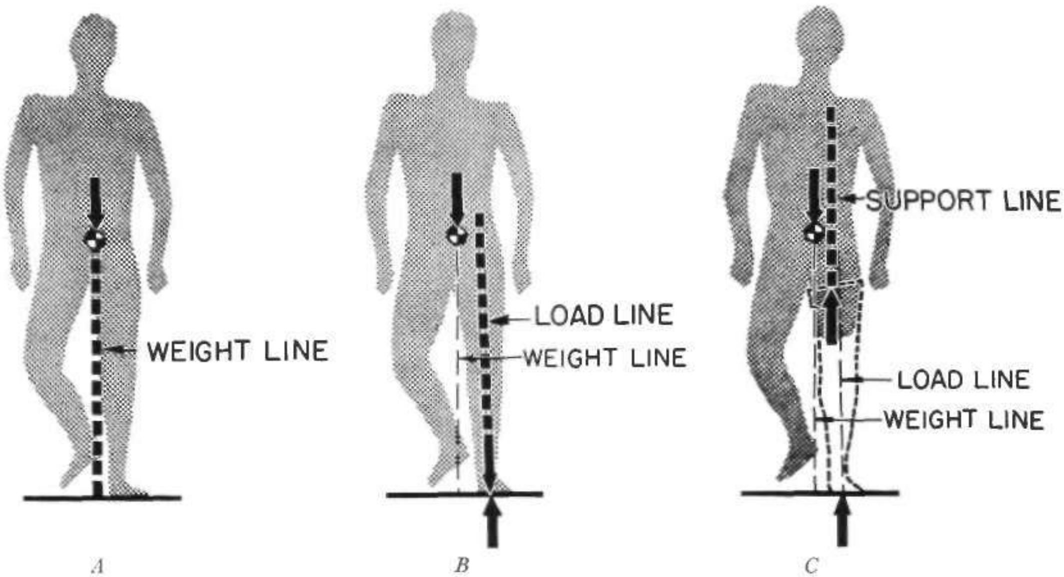


Fig. 1. Definitions in alignment of the lower-extremity prosthesis. *A,* The "center of gravity" of the body is a point at which all body weight can be assumed to be concentrated. The effective body weight passes through the center of gravity and acts vertically downward along the "weight line." *B,* The "load line" is a line along which the force between the foot and the floor acts. In general, it is not perpendicular to the floor surface, since this force has two effects. First, it supports the body weight in a vertical direction, and second, it provides the horizontal forces necessary to cause motion of the body in the forward and medial directions. *C,* The "support line" is a vertical line along which the effective supporting force exerted between the rim of the socket and the stump of the amputee is assumed to act. In general, the support line does not pass through the center of gravity or through the center of foot pressure.

the body weight line. A short definition of the weight line as shown in Figure 1A might read as follows: *The weight line of the body is a line through the center of gravity along which the body weight can be assumed to act vertically downward at all times.*

Variations in Vertical Force

Thus far we have considered only the effect of the body weight acting downward. For either an amputee or a person with two good legs, the body weight must be supported by the contact between foot and floor. For many reasons, the force of contact between foot and floor is very difficult to measure accurately because, for either foot, the contact force is extremely variable over the short time the foot is supporting weight. Shortly after the heel strikes the floor, the leg receives an initial load which, because of the slight reduction in the rate of progression of the body as a whole, quickly increases to a value greater than body weight. During the mid-portion of the stance phase, as the center of gravity of the body is reaching the lowest point in its path of motion, the load on the leg decreases to a value somewhat less than that of body weight. As the body is being elevated and propelled forward into the next step, the load builds up again to a value greater than that of body weight.

Forces in Shear

While all this is occurring, the person also is swaying from side to side and varying in speed slightly as he walks. This condition requires that the contact force must also provide some horizontal frictional forces along the floor, as everyone has realized after slipping on ice or when making a sharp turn. The forces acting on the foot during walking are, then, of two kinds—those acting perpendicular to the floor, which support the body weight, and those acting parallel to the floor, which are necessary to provide resistance to the impetus of the body moving forward, backward, or sideways.

Floor Reaction and Load Line

The total force exerted on the sole of the foot—the combination of all these effects—is known as the "floor reaction." It acts along the same line as does the total force exerted by the amputee on the socket of the prosthesis. The floor-reaction force is the load which the leg, whether normal or prosthetic, must transmit upward from the floor. In general, the line of these forces, known as the "load line" (Fig. 1*B),* is not perpendicular to the floor but is directed upward, inward, and forward or backward with an inclination that varies continually during the time either foot is supporting the body. It is very definitely not a line drawn from the center of the hip joint through the knee and ankle joints. A line so drawn should, instead, be designated as the "mechanical axis of the lower extremity."

The Support Line

An additional necessary concept is that of the "support line" (Fig. 1C). In order to define the support line, it is necessary first to identify a "support point," which may be defined as the center of action of all the vertical supporting forces at the top rim of the socket, including the ischial-bearing force, support in the gluteal region, and support in other weight-bearing areas around the socket rim. Where such a point lies is very difficult to establish, its actual location depending largely upon the individual prosthetist's methods of fitting. In a typical ischial-bearing socket, the support point is probably somewhere anterior and lateral to the point of contact of the socket with the ischial tuberosity. The support line is defined as a vertical or plumb line, passing through the support point, along which the effective supporting force between the socket rim and the stump can be assumed to act. In general, the support line coincides neither with the weight line nor with the load line.

Use of the Hip Abductors

Figure 2 presents a rear view of an above-knee amputee, walking with a narrow base, at an instant during the walking cycle when the full weight is carried on the prosthesis. During the stance phase, the amputee, like the normal individual (5), keeps his pelvis

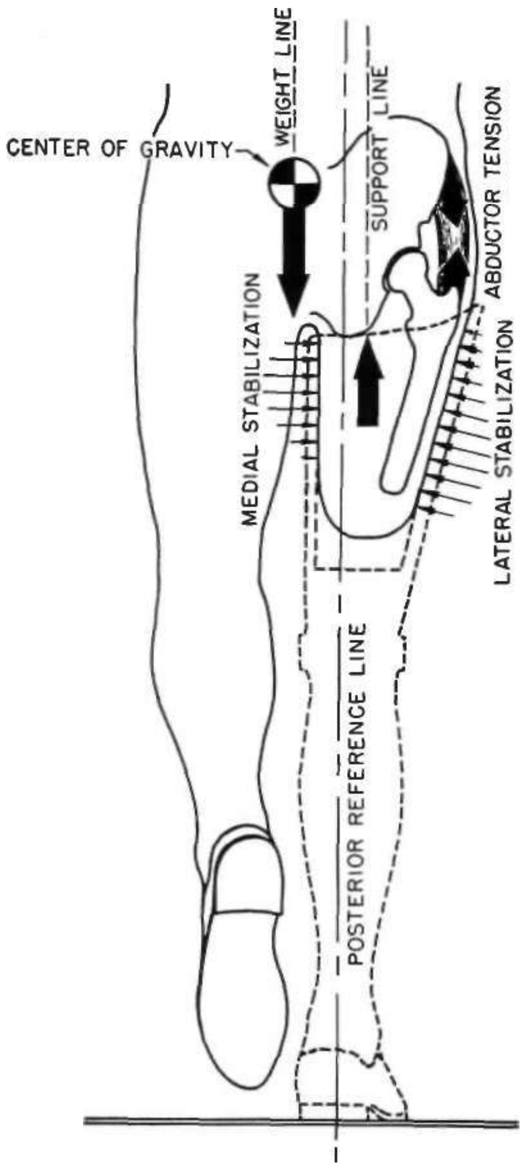


Fig. 2. Use of the hi]) abductors for lateral stabilization of the pelvis.

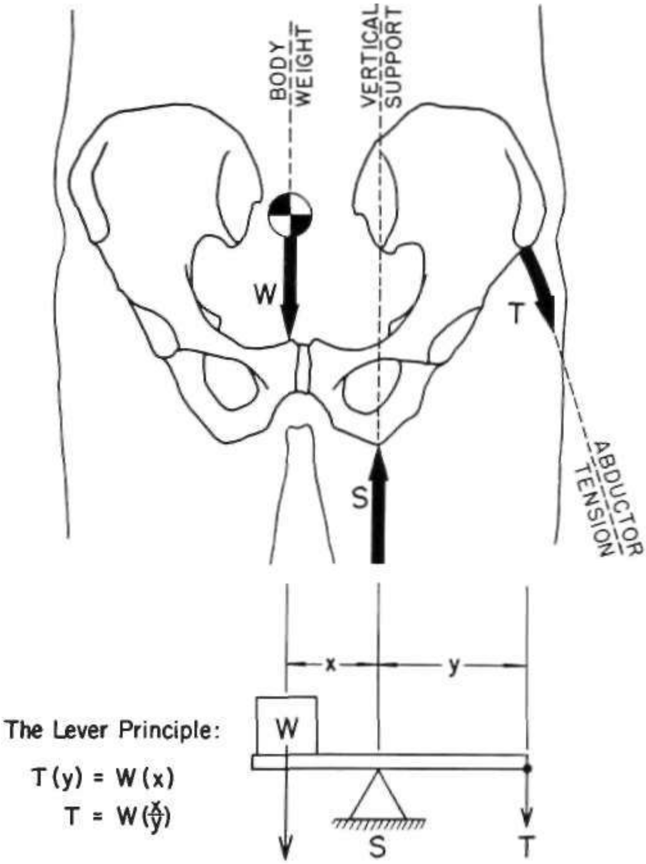


Fig. 3. Lever action of the pelvis in stabilization of the torso,

horizontal primarily by action of the hip abductors on the supporting side, as shown by abductor tension in Figure 2. If, for one reason or another, the hip abductors are unable to exert the necessary force, the pelvis has a tendency to drop toward the unsupported side. When, therefore, the above-knee amputee stands upon his prosthesis, his pelvis may tend to drop toward the normal side owing either to inadequate hip abductors or to inadequate support on the lateral side of the stump—support which is necessary to stabilize the femur and to form a firm base for action of the hip-abductor musculature.

Dropping of the pelvis toward the normal side generally results in an increase in pressure in the crotch area. It often allows the pubic ramus to come into contact with the medial wall of the socket and .an therefore be extremely uncomfortable. Anticipating this action, the amputee makes appropriate compensation. He maintains his balance either by leaning over the prosthesis, which results in the familiar amputee list, or by walking with a wide base and swaying from side to side. In the alignment of an above-knee prosthesis, then, one of the most important objectives is to construct the prosthesis in such a way that the hip abductors may be used in a normal and comfortable manner to prevent this tendency toward pelvic drop, torso list, or sidesway, and to allow a reasonably normal and comfortable gait.

The Pelvic Lever

As indicated in Figure 1*A*, the center of gravity of the body is defined as the point at which the entire weight would have to be concentrated were it to have the same effect on the body as a whole as does the actual weight distribution. On the strength of this concept, the pelvis can be assumed to act as a lever in the stance phase while the amputee supports his weight on the prosthesis (Fig. 3). Using the ischium as a supporting pivot or fulcrum, the pelvic lever supports the body weight (which acts vertically downward through the center of gravity and along the weight line) by the balancing action of the hip abductors, the process being similar to normal hip action in which vertical support is through the hip joint. If this lever action is to prevent dropping of the pelvis toward the unsupported side, the tension in the hip abductors must be sufficient to balance the body weight. The abductor muscle force can perform this function only if abduction of the stump is prevented by firm contact against the lateral wall of the socket. Otherwise the muscle action would simply cause abduction of the femoral stump inside the socket.

Distribution of Lateral Pressure

The necessary stabilization of the stump against the lateral wall of the socket can be accomplished comfortably if the stabilizing pressure is distributed widely over the lateral side. For a stump of average length, stabilization is achieved by fitting the lateral wall snugly over its entire length. A slight flattening of the lateral wall, with relief near the distal end of the femur, usually ensures that the stabilizing forces are not only comfortable but that they are directed medially as required (Fig. 2). If, with the stump improperly supported against the lateral wall, an attempt is made to use the hip abductors for pelvic stabilization, the result may be a gap around the lateral brim and a painful concentration of pressure near the end of the stump.

Considerations of Mechanical Advantage

Two other factors enter into the lateral stabilization of the pelvis by the hip abductors. First, in balancing the body weight on the ischial fulcrum, the tension in the hip abductors has greatest mechanical advantage when the lever arm between the abductor tension and the support point is as long as possible. Support of a substantial portion of the body weight by the ischial seat and of a smaller amount by the gluteal musculature gives the abductor tension sufficient mechanical advantage to balance the body weight with little or no conscious effort on the part of the amputee. The characteristics of this lever system are shown in the schematic diagram of Figure 3, where the required tension T is reduced by decreasing the distance x and increasing the distance y.

Adduction of the Stump

A second factor in making allowance for normal use of the hip abductors is the degree of stump adduction in the socket. The "rest-length" theory of muscle action *(1,6,7,11,12, 13,14)* has shown that the muscles of the body act most efficiently when they are at approximately their normal rest length. To make the action of the hip abductors efficient, the stump, when fitted in the socket, must be adducted in such a manner that the outward movement of the femur within the muscle mass of the stump is anticipated and that the normal pelvic-femoral angle is maintained as closely as possible while the body weight is being supported on the prosthesis. For the average amputee, this requirement can be met in a practical way by aligning the medial wall of the socket perpendicular to the floor, the lateral wall being sloped definitely inward. Although exceptions are necessitated on the basis of stump length, the short stump being aligned with less adduction, every effort should be made to adduct the stump as much as conditions permit.

An additional advantage of alignment in adduction becomes apparent immediately. As a result of the accompanying decrease in tension of the adductor musculature, pressure in the crotch area is decreased. As a result of this relaxation, the pressure in the crotch or medial area (Fig. 2) is then predominantly lateral rather than vertical and no longer causes painful pressure on stretched adductor tendons or in the region of the ramus. It should be emphasized here that a socket properly fitted and aligned carries little or no weight on the medial wall.

Foot Position

Alignment of the foot in a medial position, a fundamental consideration if the amputee is to walk without excessive sidesway or torso list, helps to ensure that the body weight will be borne chiefly on the ischial seat. The average amputee walks well with the centerline of the foot located directly below the ischium during the time the prosthesis is supporting the entire body weight. But this rule-of-thumb, illustrated by the reference line shown in Figure 2, must vary depending upon the capacity of the amputee to use his hip abductors. If an amputee with a very short stump attempts to use it for lateral stabilization, he cannot tolerate the increased and usually localized pressure resulting from the short stump length and the concentration of force in a small area. He must, therefore, walk with more limited use of his hip abductors, and compensation is effected by leaning over the prosthesis to shift the weight line closer to the support line and by walking with a wider base, an expedient which increases lateral stability but leads to excessive sidesway. Because of these factors, and because of the probability in such cases of some degree of abduction contracture, the amputee with a very short stump should have his prosthesis aligned to accommodate a gait of wider base.

Recapitulation

In summary, mediolateral stabilization of the pelvis accompanied by a decrease in the amount of sidesway and list can be achieved by alignment of the foot in a medial position relative to the socket, by fitting the stump in an adducted position where possible, and by providing firm support for the stump against the lateral wall of the socket to allow efficient use of the remaining abductor musculature of the hip.

KNEE CONTROL

Involuntary Control

Generally, the tendency of the articulated knee joint of the above-knee prosthesis to collapse under load is controlled involuntarily through alignment or by mechanical devices which lock or restrain flexion while the body weight is being transferred through the prosthesis *(20)*. Although involuntary control is desirable as an aid in achieving a smooth and natural-appearing gait, a proper balance must be obtained between the amount of involuntary and voluntary control of knee stability, taking into account the amputee's coordination and age and the condition of his stump.

Involuntary control of knee stability during weight-bearing is made possible by so placing the knee axis that it is at all times posterior to the load line of the prosthesis *(10)*. A prosthesis with the socket placed well forward on the knee block or aligned in hyperextension and with the knee joint located posterior to the ankle joint is said to have a high degree of "alignment stability." That is to say, under load the knee joint is forced to extend until the extension stop makes contact and prevents further motion. This expedient often is necessary for amputees who have a fear of falling or when it is required because of age, insufficient stump power, excessive weight, or the prevailing terrain. But it has the disadvantage of making the prosthetic knee hard to flex under even a light load and thus results in poor gait and difficulty in negotiating stairs and slopes.

Voluntary Control

An attempt should therefore always be made to minimize the amount of involuntary alignment stability and to provide for a maximum of voluntary knee control by stump action because this type of functioning results in the smoothest and most effortless gait possible. The average above-knee amputee has a reasonable amount of strength remaining in his hip flexors and extensors and is able to extend and flex his stump throughout an appreciable range of motion, and it is important that the fullest use be made of this musculature in voluntary control of knee stability. That this control may be exercised in the most efficient manner possible, the stump should never approach the limits of its motion as the amputee performs normal activities. If, for example, the stump is able to extend a maximum of 20 deg. to the rear, then at push-off any forced extension in excess of the 20 deg. results in a forward rotation of the pelvis. To compensate for such a forward pelvic rotation, the amputee must arch his back, an expedient which leads to the development of lordosis. Alignment of the socket in a position of initial flexion, as shown in Figure 4, eliminates much of this difficulty.

Initial Flexion

When the socket is aligned with initial flexion, several other advantages become apparent. Since the length of the hip extensors is increased by the additional degree of hip flexion, the amputee has greater control of knee stability during the entire stance phase of the walking cycle. Since the extensor muscles are thus elongated slightly, they are able to develop the required tension easily. With much less conscious effort on the part of the amputee, therefore, the stump is able to exert the force necessary to keep the prosthetic knee back against its extension stop.

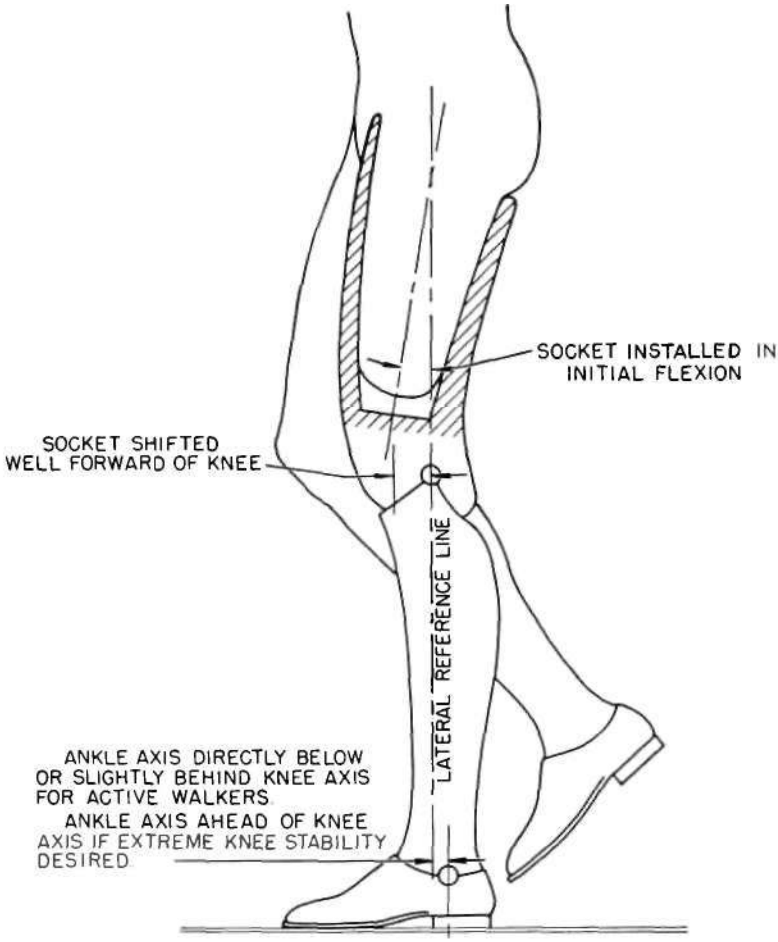


Fig. 4. Influence of alignment on control of knee stability, socket aligned in initial flexion to avoid exces. sive pelvic rotation.

Again, in an amputee with overdeveloped hamstring musculature there often is a tendency, as the stump extends at push-off, for the muscles to force the tuberosity of the ischium off the ischial seat, thereby causing pressure on the hamstring muscle and attachments and against the anterior brim of the socket. Initial flexion of the socket reduces this tendency and allows a portion of the body weight to be borne comfortably upon the hamstring attachments.[3]

If the same degree of alignment stability is to be maintained, initial flexion of the socket must be accompanied by a shifting of the socket anterior to the knee axis. Merely changing the extension stop to decrease knee extension never can achieve the desired end-results. But less alignment stability is necessary under these conditions because of the increased voluntary control of the knee. Anterior positioning of the socket relative to the knee axis allows the prosthetic knee to be flexed a great deal more easily as weight is transferred from the prosthesis to the normal leg at the end of the stance phase. The result is a smoother gait. Although increased use of the hip extensors owing to their greater

[3] Too much initial flexion results in a decrease in stride length, which may be undesirable in some cases.

working length produces some decrease in the power available in the hip flexors, the loss is not serious since during ordinary activities the hip flexors never approach the limit of their range of flexion and since the force requirements are small as compared with those of the hip extensors.

Ankle Position and Toe Break

Another important factor in achieving the proper amount of knee stability is the fore-aft position of the ankle joint relative to the knee joint. For the active above-knee amputee, it usually is desirable to have the ankle joint directly below or slightly posterior to the knee joint, as shown in Figure 4. Such an arrangement has several effects. First, as the foot is moved to the rear, the distance out to the toe break decreases to give the foot more of a "rocker" action and to allow the knee to flex easily at the end of the stance phase. Second, the major portion of the weight can be carried on the ball of the foot while standing. And third, the amount of toe clearance during walking is greater for a given angle of knee flexion. To move the ankle joint too far to the rear, however, results in instability at heel contact and excessive shortening of the stride.

Many of these advantages can be achieved by use of a double toe break *(i.e.,* a flexible forefoot), which also gives the foot more of a rocker action and decreases the amount of vaulting over the prosthetic foot. But too much flexibility or too short a distance from ankle to toe break causes the leg to feel too short at the time of push-off.

DYNAMIC ALIGNMENT

For the major part of the time that the amputee is supporting himself on the prosthesis during the stance phase, the motions are relatively smooth, and the forces act on the prosthesis in essentially the same way as if the amputee were standing still with all weight carried on the artificial leg. During the swing phase, however, and during the times of transition from stance to swing and from swing to stance, the behavior of the prosthesis is influenced largely by dynamic forces varying rapidly with time. It is often relatively easy to fit an amputee so that he is comfortable in the stance phase, but in many cases it is more difficult to construct the prosthesis so that the amputee is able to walk with a smooth, natural-appearing, effortless swing-through. The first requirement for a smooth swing phase is a smooth transition from stance to swing, since, if the prosthesis is to swing properly, it must be given a good start.

Knee Stability and Toe Break

Of particular importance during these transition periods are knee stability, as affected by alignment and by the stiffness of dorsifiexion and plantar flexion at the ankle, and the combined effect of toe-out and orientation of the toe break in the foot. For security, the knee axis should be positioned far enough behind the hip-ankle line so that the amputee is conscious of a stable knee while standing. The amount of security desired depends upon the particular amputee. If, as the amputee attempts to walk, the knee feels insecure, the dorsiflexion position and stiffness in the ankle should be investigated as a possible additional cause of knee instability.

In general, placing a stiff dorsiflexion bumper in the ankle and having the foot plantar-flexed in the neutral position, close to the point where the amputee has the sensation of "walking over a hill," produces the most desirable knee stability and allows smooth flexion of the knee at the start of the swing phase. The amount of toe-out usually is adjusted to the individual amputee. In all cases, however, the toe break should be at right angles to the line of progression to prevent insecurity resulting from the rapid shifting of the center of pressure during push-off.

Whip in the Swing Phase

One of the more obvious indications of poor dynamic alignment is the so-called "whip" of the prosthesis during the swing-through (Fig. 5). This lateral movement of the knee accompanied by medial movement of the foot, or vice versa, usually is caused by an incorrect amount of adduction for the particular socket being fitted, an improper angle of the knee axis with respect to the

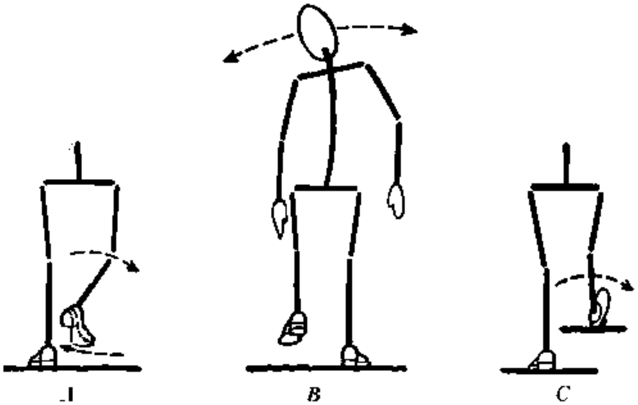


Fig. 5. Common indications of incorrect alignment. *A*, Whip of the prosthesis during the swing phase. *B*, Mediolateral instability. C, Rotation at heel contact. For specific causes of these difficulties, see Radcliffe *(10)*.

frontal plane, the natural tendency of the femoral stump to twist inward as it is brought forward, or a combination of these factors.

An above-knee prosthesis often is "knocked" at the knee to position the foot laterally for greater stability while standing. Sufficient two-leg standing stability thus can be attained, but a stable, narrow-base gait is not then possible. The tendency of the prosthesis to whip also is aggravated because, as it swings like a pendulum, the leg has a natural tendency to swerve medially after toe-off and then to swerve out again just before heel contact. A prosthesis having the foot aligned medially for a narrow base during the stance phase need only move forward in a straight line from toe-off to heel contact.

Rotation of Knee Axis

Studies of normal human locomotion *(2,18)* show that the femur rotates an average of 3 to 4 deg. medially as the hip is flexed to bring the knee forward. Medial rotation of the femur causes a lateral displacement of the foot, as can be verified easily by observation of a person standing and flexing the hip while the shank hangs vertically. Accordingly, the knee axis in an above-knee prosthesis usually is rotated laterally to compensate for the tendency of the femur to rotate medially as the hip is flexed.[4] When the prosthetic knee axis is aligned in a position laterally rotated with respect to the socket, the foot moves somewhat medially with knee flexion, thus compensating for lateral movement of the foot caused by the medial rotation of the socket during the swing phase and allowing the foot to travel in a straight path.

Ankle Stiffness

The stiffness of plantar flexion at the ankle determines, to a large degree, the stability of the knee at heel contact. A stiff ankle does not allow the foot to rotate forward into the stable flat position and thus tends to cause the knee to buckle forward as the weight is transferred to the prosthesis. An ankle joint with insufficient plantar-flexion stiffness, however, allows the foot to slap at heel contact. A proper balance between these two effects must therefore be attained for the individual amputee. Proper swing-through is achieved by proper dynamic alignment, which, in turn, is effected by a comfortable, stable, and functional prosthesis in the stance phase; a smooth transition from stance to swing phase; proper ankle stiffness; and adjustment of the knee axis in lateral rotation to compensate for medial rotation of the stump during hip flexion.

SOCKET SHAPE AND ORIENTATION

Considered thus far are the means by which the amputee can make most efficient use of the remaining hip musculature to control body movements and to control the prosthetic knee during the stance and swing phases. There are, however, many functional details of socket shape and fit which make it possible for the amputee to derive these benefits comfortably.

[4] The amount of medial rotation in the stump depends upon the inherent physiological characteristics of the hip joint and upon the loss of muscular function after amputation. Some amputees have even been observed to have lateral rotation of the stump upon hip flexion.

The Lateral Wall

As already indicated, for the amputee having sufficient stump length and power, sidesway and leaning over the prosthesis during the stance phase can be eliminated almost entirely by making provision in the socket for full use of the remaining abductor muscles of the hip, primarily the gluteus medius. This can be achieved in two ways. First, the stump is adducted in the socket so that the lateral wall is sloped downward and inward, the medial wall remaining essentially vertical. Second, a slight flattening of the lateral wall, and undercutting for relief of pressure points where necessary, ensures a comfortable distribution of the pressure directed medially against the stump. The hip abductors then can develop tension as needed because the excursion of the femur is blocked comfortably against the lateral wall of the socket. If, after the fit of the lateral wall is considered satisfactory, the socket is too tight, relief should be provided along the medial wall of the socket to avoid disturbing the fit required to block excursion of the femur.

The Anterior Wall

The lateral pressures, acting with the horizontal counterpressures in the upper portion of the medial wall, tend to maintain the ischium on its seat medially. To hold the ischium in place still more firmly, it is necessary to provide stabilization at the front of the socket. Accordingly, the anterior wall of the socket should fit the stump firmly in the area of Scarpa's triangle, and a very accurate measurement should be made of the distance from the ischial tuberosity to the tendon of the adductor longus so that the anteromedial apex may be fitted snugly around the adductor tendons. The socket brim should be rounded and fitted high on the anterior side. If fitted properly, the anterior brim usually can be brought up to the level of the inguinal crease without producing discomfort when the wearer is seated. The actual height of the anterior brim varies with the individual and is limited by contact with bony prominences. It usually extends from 2 to 2-1/2 in. higher than the ischial seat, but it should extend at least high enough so that the brim will press into the abdominal muscles rather than pinch a roll of flesh near the top of the stump. Distributed over the upper portion of the entire anterior wall of the socket, such anterior counterpressure easily can prevent the ischium from sliding into the socket and can prevent the discomfort that would result in the crotch area.

The Adductor Region

Incorporation of the proper distance from the adductor tendons to the ischial tuberosity, combined with a well-fitted, high, anterior brim, usually eliminates entirely any unwanted pressure in the crotch area. Some lateral counterstabilization by pressure in the crotch area is unavoidable, but it should be predominantly by lateral rather than by vertical pressure, and it can be tolerated comfortably if distributed over the widest possible area. Flattening the medial wall of the socket is one means of ensuring a comfortable distribution of pressure in the adductor region.

The Anteroposterior Dimension

Weight-bearing in the gluteal region makes it possible to reduce the size of the ischial seat. If the anteroposterior dimension is shortened, the socket may be widened in the mediolateral dimension, a feature having several advantages. First, it allows a greater area for gluteal weight-bearing on the posterior rim of the socket. Second, the ischium is moved laterally, allowing the ramus to be carried within the brim of the socket and thus easing a major source of irritation. Finally, because the ischium bears no weight in the posteromedial apex, there is less tendency for crowding of the adductor and hamstring musculature. Relaxation in this area owing to stump adduction also helps to relieve uncomfortable vertical pressures.

Shape at Ischial Level

As a result of these functional requirements, the socket shape shown in Figure 6 has evolved. When coupled with the proper alignment, it has proved to be extremely beneficial to the average amputee. As with any method of fitting, variations in shape must be made in

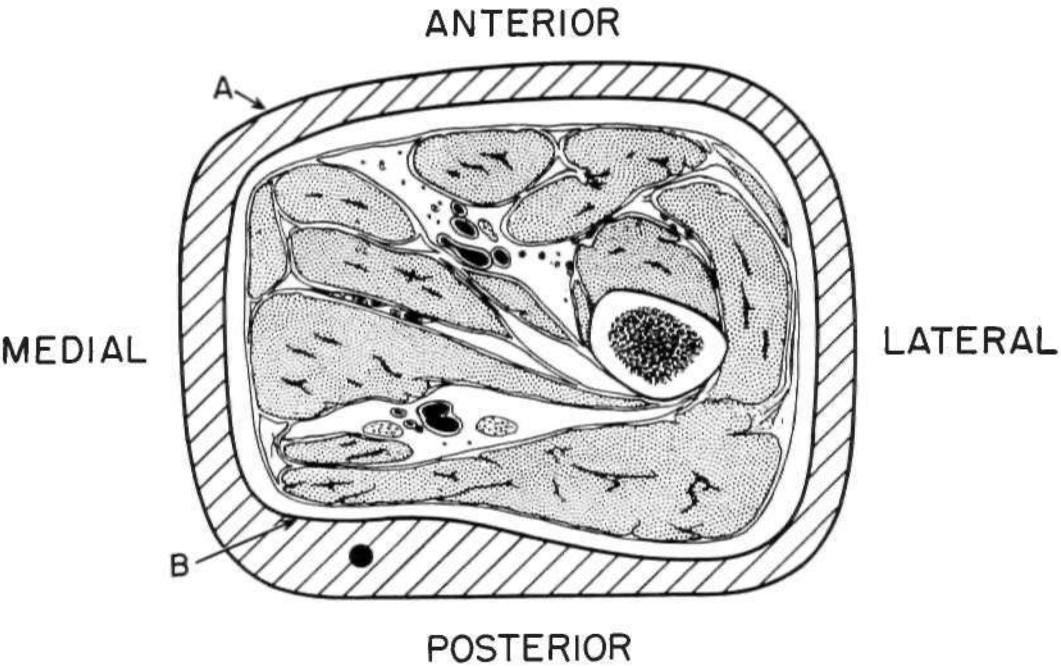


Fig. 6. Anatomical features of an above-knee stump in weight-bearing, shown in cross section 1/2 in. below schial level.

accordance with the muscular development and condition of the individual stump. The influence of muscular development at the ischial level is shown in Figure 7.

Entrances of the adductor tendons in the anteromedial apex, shown as *A* in Figure 6, can be made more comfortable by a slight flaring of the socket brim in this region. Flaring of the socket brim in the hamstring area *B* has no function while the amputee is walking, but it contributes remarkably to his comfort while sitting. Many amputees experience a burning sensation while sitting because the hamstring attachments attempt to stretch over an ischial seat located high or medially, especially when the ischial seat has been placed diagonally across the posteromedial apex. The socket shape shown in Figure 6, however, allows the ischial seat to be placed laterally to provide relief in the hamstring region and does not disturb the functioning of the limb during walking.

CONSTRUCTION OF THE SOCKET

STUMP EXAMINATION AND MEASUREMENTS

Before construction of an above-knee prosthesis is started, it is essential that a very careful evaluation be made of the amputee and his stump. A prosthesis may thus be planned and constructed to take full advantage of the individual patient's capabilities. Of particular importance is a thorough examination of the stump with regard to its functional characteristics. Answers to the following questions are helpful in planning the prosthesis, and they should be included in the examination data:

1. What degree of stump flexion contracture is present?
2. What degree of stump abduction contracture is present?
3. Is the stump musculature soft, average, or hard?
4. Is the hamstring group soft, average, hard, or prominent under tension?

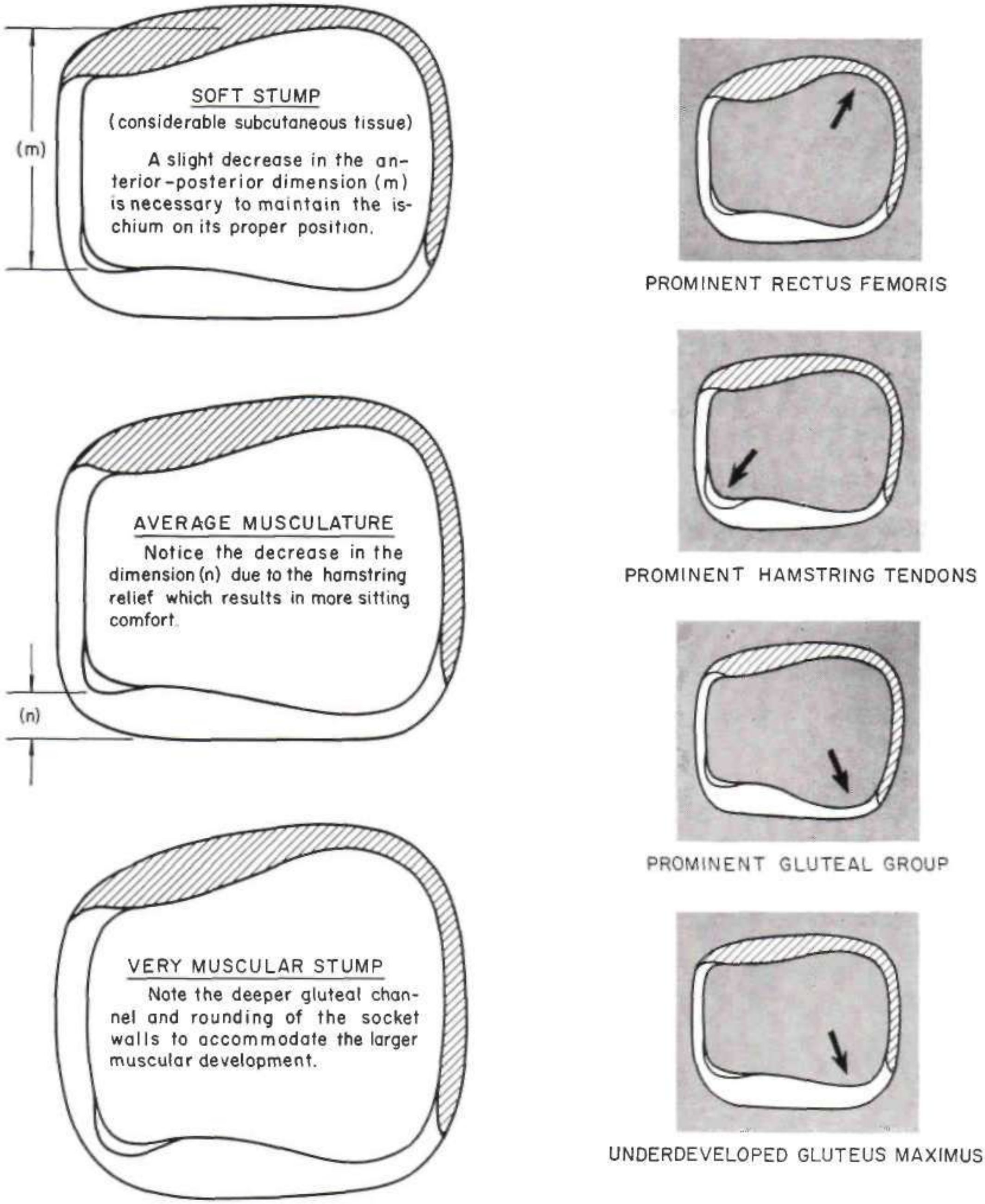


Fig. 7. Influence of stump muscular development on socket shape at ischial level.

5. Is the gluteal group soft, average, hard, or prominent with stump extension?
6. Is the stump contour along the lateral side convex, concave, or essentially flat?
7. Is the rectus femoris muscle prominent with stump flexion?
8. Is the adductor longus soft, average, or hard?
9. Is the ischium toughened, pressure sensitive, padded with muscle, or prominent?
10. Has the amputee been accustomed to ischial-bearing?
11. What is the amount and location of redundant tissue?
12. What is the extent, location, and adherence of scars?
13. Are there areas of prior irritation as shown by blisters, boils, pimples, scars, darkened skin areas, and so forth?
14. Are there areas which are sensitive because of bone spurs or other prominences?
15. Is there any prior history of edema?

In addition to this general information about the condition of the stump, which can be recorded on a form such as Figure *8A*, the series of measurements indicated in Figure *8B* should be recorded carefully.

PLANNING THE SOCKET SHAPE

After the information gathered during the examination is recorded, the limbfitter is ready to begin planning the prosthesis, a phase essential to proper fit. The socket contours and the over-all alignment to be incorporated into any lower-extremity prosthesis depend upon the interrelation of many factors. First, the amputee's general physical condition must be determined. Will the amputee be an active walker? Will ease of walking be more important than knee security, or vice versa? Has the amputee developed gait habits that require corrective training? Second, the stump must be evaluated on a functional basis. In terms of its potential usefulness in control of the prosthesis and of body movements, is it classed as short, medium, or long? Is there a normal range of motion in all directions? Are there any sensitive areas that restrict stump function? The answers to these questions affect the alignment of the prosthesis as well as the fit of the socket.

It is important to plan for alignment before the socket contours are considered because the orientation of the socket on the stump and the alignment of the socket on the prosthesis may affect considerably the method of fitting the socket. Shown in Figure 9 are some general features of alignment based upon the functional capacity of the stump—short, medium, and long. There are exceptions, of course, and these illustrations should serve only as a guide.

After the general type of alignment has been decided upon, the necessary features can be incorporated into the orientation of the socket on the stump, a matter requiring a decision regarding the approximate amount of initial flexion and adduction to be anticipated in the final alignment. The socket contours are determined by reference to the information on stump muscle development recorded during the examination. Figure 7 shows a typical socket shape for an amputee of average musculature and indicates the variations possible with different types of stump muscle development. Undersize patterns for use in roughing out the socket contours are shown actual size in Figures 10 and 11. The dimensions shown along the medial side of the patterns are typical measurements of the distance from the ischial tuberosity to the anterior aspect of the adductor longus tendon. The perimeter measurements shown correspond to actual stump dimensions. But these patterns may require modification to provide for individual stump characteristics, an example of such a pattern modification being shown in Figure 12.

MATERIALS

The primary features required of a material to be used in making a suction socket are ease in forming to the proper shape, adaptability to a surface finish which is nonirritating and easy to keep clean, and ease in making alterations as required by changes in the stump. Wood and plastic laminates have, so far, proved to be the most satisfactory. But major changes in the size of the stump often take place during the first several months of wear. Hence, wood is recommended for the first socket because it is relatively simple to shape and allows alterations to be made as required. After the stump size is stabilized, a socket can be made of plastic laminates, which seem better than wood because of their flexibility, their ability to stand cleansing with soap and hot water, and their greater resistance to the action of perspiration.

SHAPING THE WOODEN SOCKET

The three stages in shaping a typical socket are shown in Figure 13. In the first, the posteromedial shelf is cut after laying out the socket pattern on the top of the socket block. The ischiogluteal shelf is cut in such a way as to be horizontal when the socket is oriented vertically in space. For the average socket, the medial wall is parallel to the vertical reference line (Fig. 2), and therefore the horizontal ischiogluteal shelf is cut at right angles to the medial wall of the socket. After the ischiogluteal shelf is cut, the missing portion of the socket pattern line is transferred down to the ischial level.

The second construction stage shows the roughed-out socket, where considerable extra wood has been left above the ischial level to allow for the protrusion and flaring of the anterior brim in this area. The finished socket is shown in the third stage with all areas of the socket brim flared and rounded to prevent irritation of the stump, especially important in the anteromedial apex where the adductor longus tendon enters the socket.

Figure 6 indicates the principle muscle groups and other anatomical features considered in preparing the patterns used as a guide in the preliminary layout of the socket outline. Because of the atrophy of certain muscle groups in the above-knee stump, and because the cross section shows the stump in the weight-bearing condition, the shape differs slightly from that of the normal. When the stump is bearing weight, it is necessarily compressed slightly in areas of relatively soft tissue which support load, such as the gluteal channel.

The Lateral Wall

The lateral side is always higher than the level of the ischial seat. In most cases, it is possible to extend it over the trochanter. To do so is especially important when the slump is short and when the height of the socket in this region may be required to maintain suction. If the muscular development requires it, the lateral side of the socket is, in some cases, undercut above the ischial level. Examination of the amputee determines the amount of undercut required, and, if it is necessary, it should be done with caution. The lateral wall should taper in acutely below the ischial level to provide adduction and lateral support for the femur upon weight-bearing above the distal end. Because the femur has been established as the body stabilizer during the stance phase, an undercut below the ischial level may distribute the pressure unevenly and thus allow most of the pressure to be taken at the top of the socket and near the distal end of the stump. The lateral wall should be shaped to fit the stump accurately and should, if necessary, be flattened to distribute the lateral-support pressure over a large area so that it can be tolerated comfortably.

The Medial Wall

The length of the crotch-line area that receives the adductor longus, gracilis, and adductor magnus muscles should be determined accurately by skeletal measurements. As indicated in Figure 12, the measurement from the anterior aspect of the adductor longus tendon to the weight-bearing portion of the ischial tuberosity, less about half an inch, gives the approximate length of the medial side of the socket. In general, the upper third of the medial wall is flattened, and the superior brim is flared to prevent skin irritation.

In almost every case, the crotch-line height varies with respect to the level of the ischial seat, but it should always be as high as is tolerable. In the typical socket, the crotch area is from 1/8 to 1/4 in. lower than the ischial seat. A pelvic tilt lowers the ramus of the ischium and may require a lowering of the medial side of the socket. In a properly fitted ischiogluteal weight-bearing socket, little or no weight should be borne on the medial side. From the ramus to the anteromedial apex, the medial brim can be raised as governed by comfort. If a medial adductor roll is present, the socket is enlarged slightly (never lowered) on the medial side to accommodate the excess tissue, which then is pulled into the socket and eventually diminishes.

PROSTHETIC INFORMATION — ABOVE-KNEE PROSTHESIS

A. STUMP DESCRIPTION

Amputee ______________________________ Date ______________

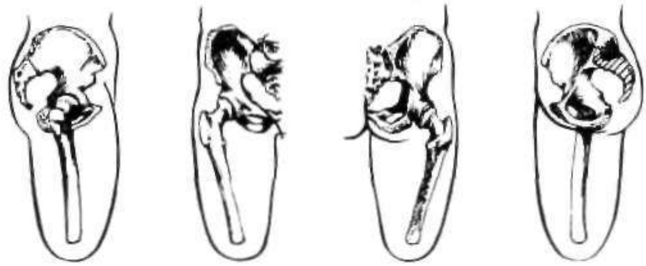
Height ________ Prosthetist ______________

Weight ________

Age ________

Sex ________

Show location of stump details, identifying with letter code:



Lateral Anterior Posterior Medial

A. Abrasion
B. Boil
BS. Bone Spur
D. Discoloration
E. Edema
I. Irritation
M. Muscle Bunching
P. Pressure Point
R. Redundant Tissue
S. Scar
T. Trigger Point

Ischium: Toughened ( ) Pressure sensitive ( )
Muscle padding ( ) Prominent ( )
Previous ischial bearing? yes( ) no( )

Subcutaneous tissue: Heavy ( )
Light ( )

Skin condition: Tough ( )
Thin ( )

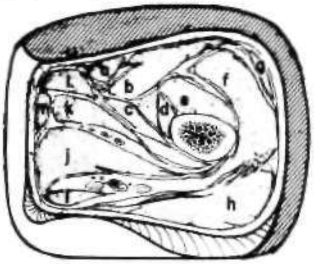
Stump lateral contour: Convex outward ( ) Flat( ) Concave inward ( )

Stump Musculature	Soft	Average	Hard	
General				
Hamstring Group				Prominent with stump extension?
Gluteal Group				Prominent with stump extension?
Rectus Femoris				Prominent with stump flexion?
Adductor Longus				

Stump flexion contracture: ______degrees; abduction contracture:______ degrees

Show modification of basic socket shape, if required:

Muscle code:
a. Sartorius
b. Rectus femoris
c. Pectineus
d. Vastus medialis
e. Vastus intermedius
f. Vastus lateralis



g. *Tensor fasciae latae*
h. Gluteus maximus
i. Hamstrings
j. Adductor magnus
k. Adductor brevis
l. Adductor longus
m. Gracilis

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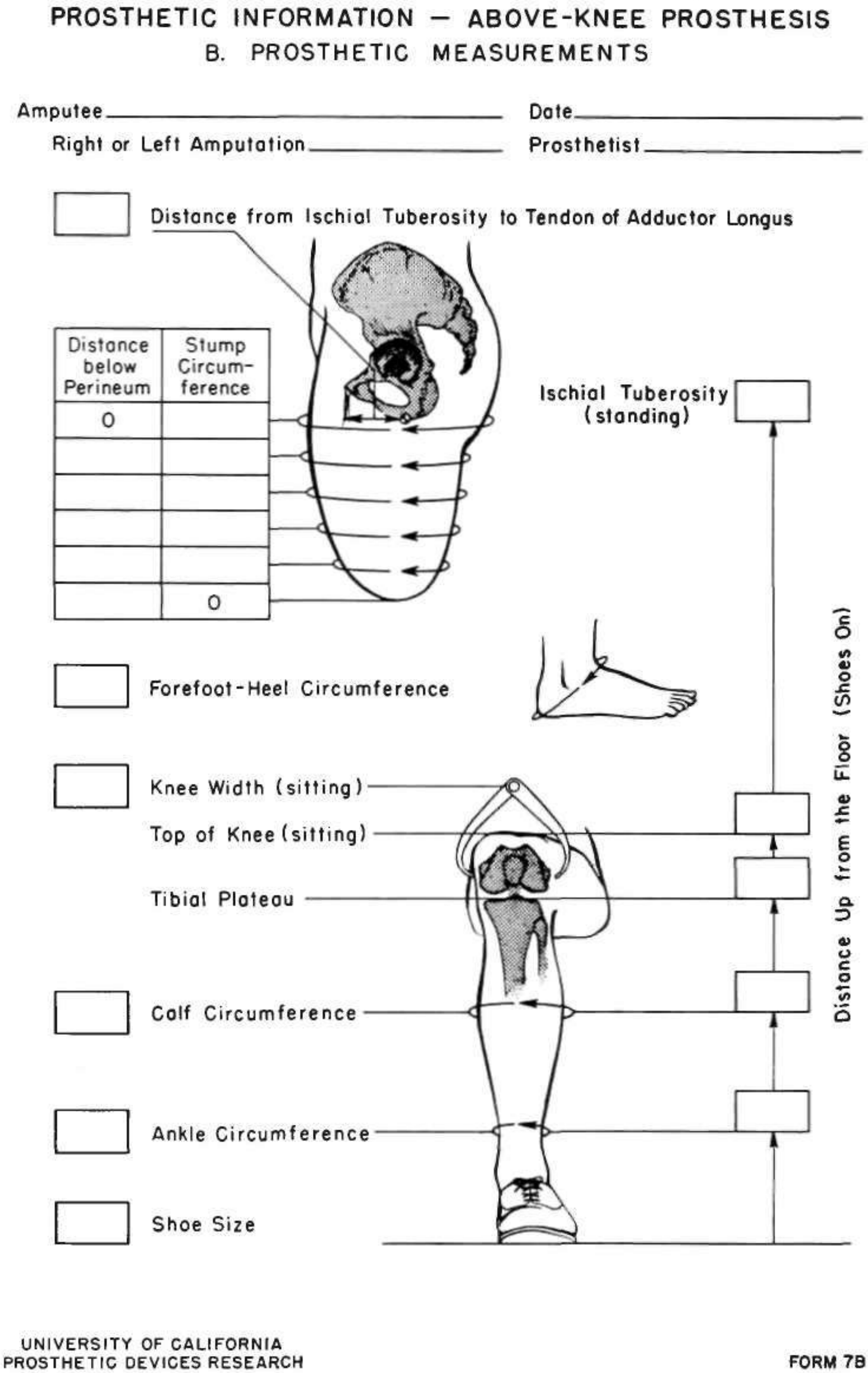
FORM 7A

Fig. 8/1. Form used at the University of California for recording stump characteristics and measurements in above-knee fitting.



PROSTHETIC INFORMATION — ABOVE-KNEE PROSTHESIS

B. PROSTHETIC MEASUREMENTS

Amputee ______________________ Date ______________________

Right or Left Amputation ______________________ Prosthetist ______________________

Distance below Perineum	Stump Circumference
0	
	0

Fig. 8B.

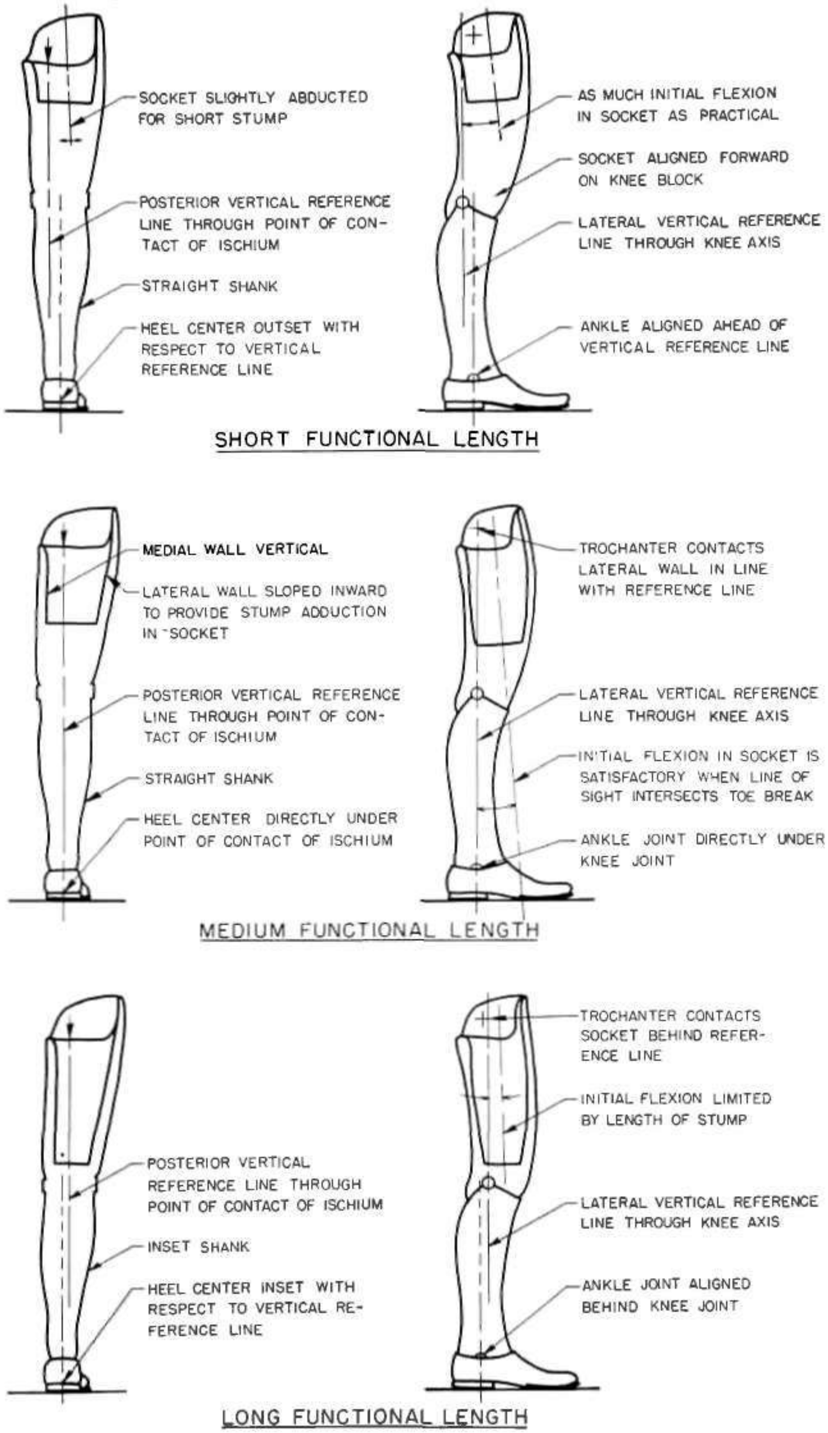


Fig. 9. Variations in alignment to accommodate stumps of different functional lengths. With the short stump, the slow or hesitant walker, having limited use of the hip abductors and extensors, needs considerable alignment stability. The moderate walker, with stump of medium functional length, has average use of the hip abductors and extensors. Alignment for the long stump is for an active walker having good use of the hip abductors and extensors.

The Anteromedial Apex

The socket shape at the anteromedial apex (Fig. 6) should conform to the contour of the adductor longus and gracilis muscles. The shape varies in each case, however, because these muscles form a cordlike tendon which must be fitted accurately. Tightness in this region, a common source of irritation in suction sockets, usually is caused by excessive length of the medial side of the socket. This condition allows the ischium to slide forward into the socket and to wedge the stump into the anteromedial apex. If tightness in the anteromedial apex persists, it is apt to be due to inadequate support of the stump across the anterior brim and down the anterior aspect of the adductor group.

The Anterior Wall

The primary function of the anterior brim of the socket is to maintain the ischium in place on the ischial seat so that ischial weight-bearing causes no discomfort. In many cases of amputees who are unable to tolerate ischial weight-bearing, the trouble can be traced to improper contact between ischium and socket. Ischial bearing on the edge of a flat ischial seat is especially uncomfortable. To maintain the ischium in place properly, considerable counterpressure from the front of the socket is required. Since, by and large, the portion of the stump in contact with the region of the anterior brim is soft tissue, some compression of the stump is necessary. This is accomplished by a flattening and inward protrusion of the anterior brim in the area of Scarpa's triangle.

The upper portion of the anterior brim is fitted 2 to 2-1/2 in. higher than the ischial seat and with a generous flare along the superior brim. When the socket is fitted with such a "high front," the anterior brim can hold the ischium in place comfortably. The high front does not interfere with sitting or with the amputee's ability to bend over far enough to tie his shoes. As the stump is flexed, the higher brim of the socket is accommodated by the abdominal musculature and does not pinch a roll of flesh on the upper portion of the thigh. The brim should be lowered only as necessary to prevent contact with bony prominences such as the anterosuperior spine. A channel should be provided below the brim for the rectus femoris muscle, which usually becomes prominent with stump flexion.

The Posterior Wall

The back of an ischial-bearing socket deserves particular attention. Channelization for the gluteus maximus muscle depends on the individual, but, in most cases where there has been little atrophy or distortion, this region of the socket should be kept on the same level as the ischial seat with a gradual enlargement in the posterolateral apex. The gluteus muscle should carry a considerable amount of body weight on a flared socket brim.

Relief for the adductor muscles or the crotch line often can be made by relieving the gluteus maximus. Too tight a fit over the gluteus maximus can cause crowding of the adductor muscles in the crotch section. If the space for the gluteus muscle is lowered and widened, the ischial tuberosity can be moved posteriorly and laterally on the ischial seat of the socket. Lowering this section, however, increases pressure on the ischial tuberosity and should, therefore, be avoided. Should additional room be needed within the socket, the lateral side of the gluteal region can be made wider. The gluteal area should be widened instead of cut deeper posteriorly because a deeper section forms a hump or radius on which the leg rotates during sitting and thus causes a burning sensation of the skin over the ischial tuberosity.

The outside shape of the socket in the posterior region is important to sitting comfort, but no attempt should be made to complete its shaping until the inside has been made comfortable and until the leg has been aligned properly and tested by walking. After these things are done, the back then is flattened for comfort and alignment while sitting.

The Ischial Seat

The ischial seat cannot be overemphasized. It should be located accurately under the ischial tuberosity, and, in the determination of its location, individual variations in anatomy must be taken into account. The seat should be adequate but not so wide as to cause discomfort while sitting. Slipping of the ischial tuberosity either to the inside or to the outside

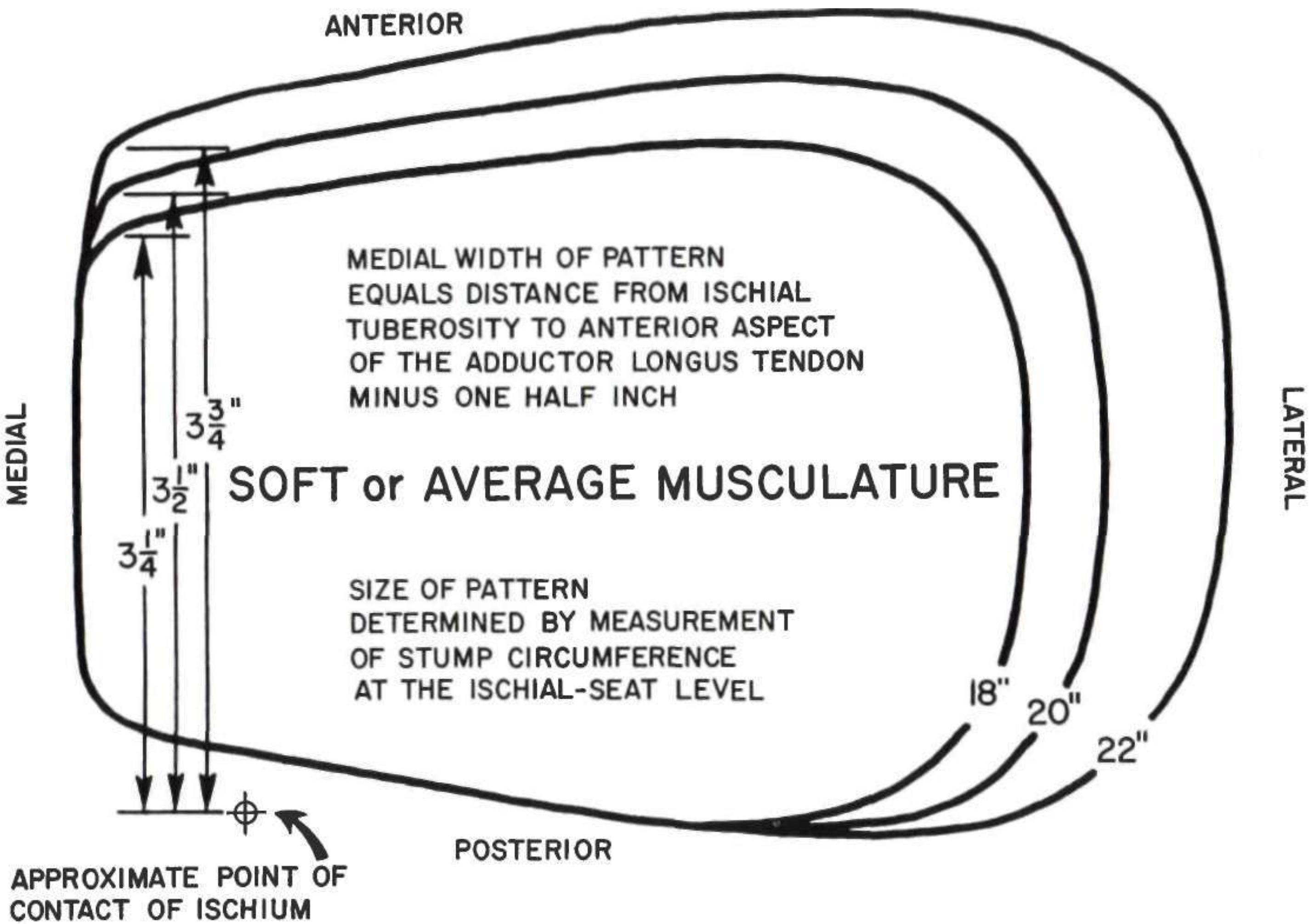


Fig. 10. Undersize socket patterns (shown actual size) for stump with soft or average musculature,

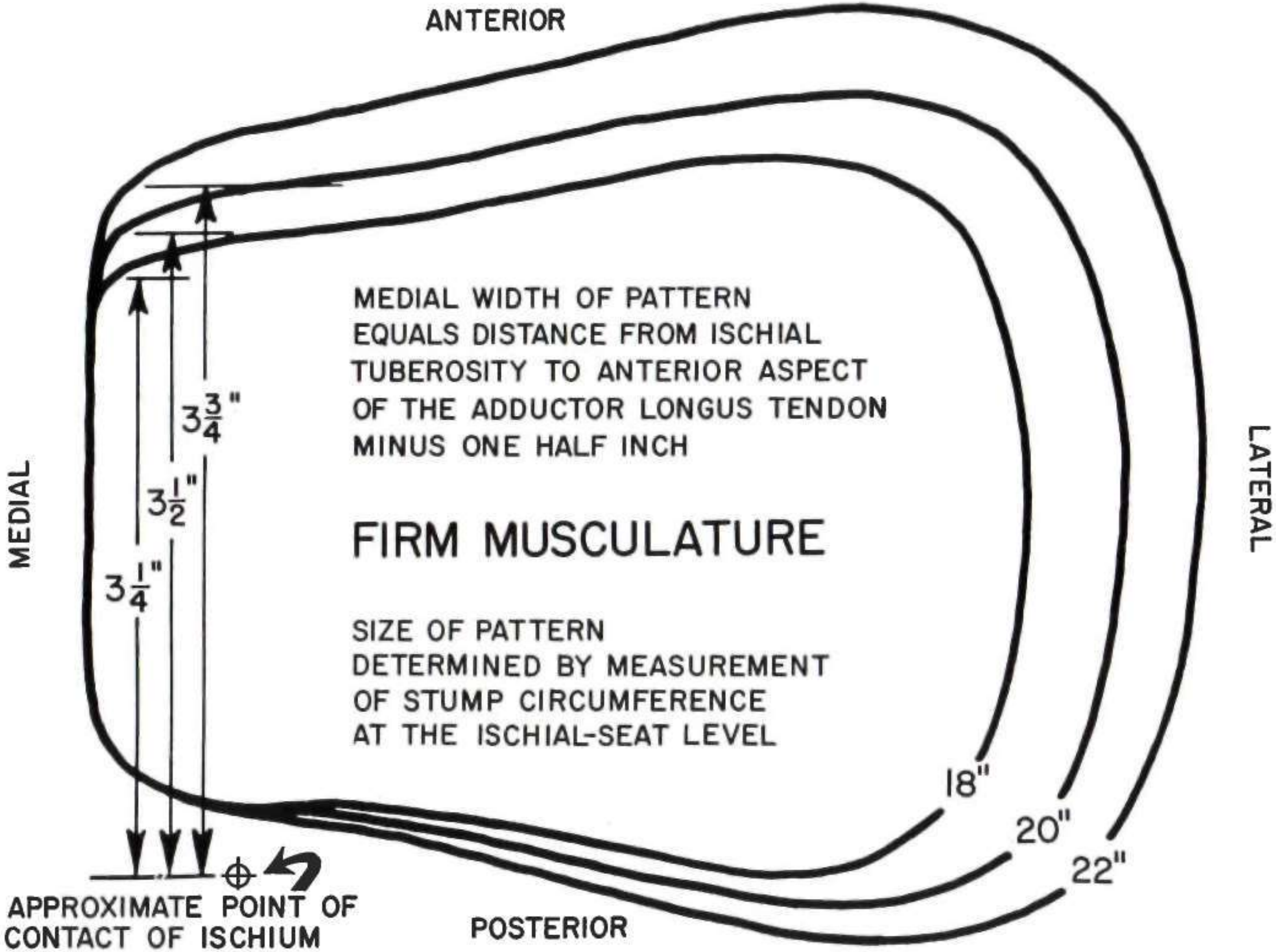
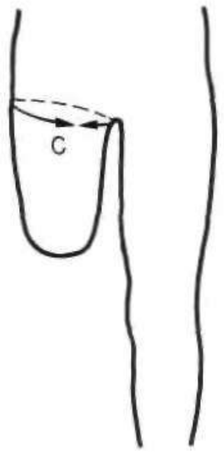


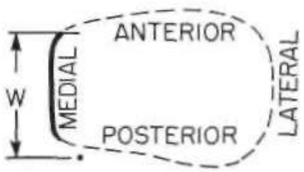
Fig. 11. Undersize socket patterns (shown actual size) for stump with firm musculature.



BASIS OF LAYOUT OF SUCTION-SOCKET PATTERN:

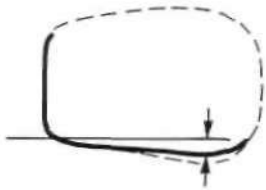
1. Muscular development of stump
2. Circumference of stump at ischial level (C)
3. Medial width of stump, measured from adductor longus tendon to tuberosity of the ischium (W)

A.



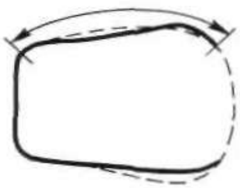
Choose from Figure 7 the pattern which most nearly conforms to muscular development and ischial circumference of the stump. Alter medial width of pattern if necessary. Medial width of pattern should be one half inch less than distance from adductor longus tendon to the tuberosity of the ischium.

B.



Estimate depth of gluteal channel required. This figure illustrates modification of basic pattern for stump with soft or flabby gluteal musculature.

C.



Modify anterior contour as necessary. This figure illustrates modification for stump with soft adductor musculature and prominent rectus femoris muscle.

D.

Cut pattern and vary over-all width to give a pattern circumference of from 2" to 3" less than measurement of stump ischial circumference. The socket contours will be enlarged as necessary during the fitting.

Fig. 12. Modification of socket shape to accommodate individual stump characteristics.

of the seat, conditions which create a great deal of discomfort, can be prevented by shaping the bearing surface in such a way that the seat slopes slightly toward the inside of the socket to render it more comfortable. Sloping increases the radius of the edge of the ischial seat and lessens the burning sensation of the skin in this region.

If the ischial seat is too prominent, or if the ischium rides on the edge of the seat, a jabbing sensation or a marked increase in pressure is felt near the end of the stance phase. Lowering the ischial seat allows more weight to be distributed to the gluteal region and, if the ischial tuberosity is located properly on the seat, results in less discomfort and a shorter break-in period.

Amputees with highly developed stump muscles may not require a well-defined ischial seat. In some cases, the muscles may push the ischial seat away from the tuberosity of the ischium and cause the weight to be carried by the muscles around the top of the socket. Such a condition is not objectionable, provided that the socket is designed with proper modification of the ischial seat. Indeed, such a design may be necessary in unusual cases, as for example those with end-bearing stumps.

SPECIAL CONSIDERATIONS IN THE SUCTION SOCKET

Tightness of Fit

In the case of the suction socket, better results are obtained by having proper contours than by having a tight fit *(3).* If, in the course of donning the leg, much difficulty is encountered in removing the sock, the fit is too tight. The superior brim of the socket should fit the contour of the stump while the muscles are tensed, and the fit should be so accurate that the socket can be suspended for short periods by skin friction without the aid of negative pressure *(i.e.,* without a valve).

Free Space Below the Stump End

The volume of unoccupied space at the lower end of the suction socket is not critical in obtaining sufficient suction. In most cases, it is convenient to have approximately 2 in. of space below the end of the stump to provide room for installation of the valve and for elongation of the soft tissue. In general, the

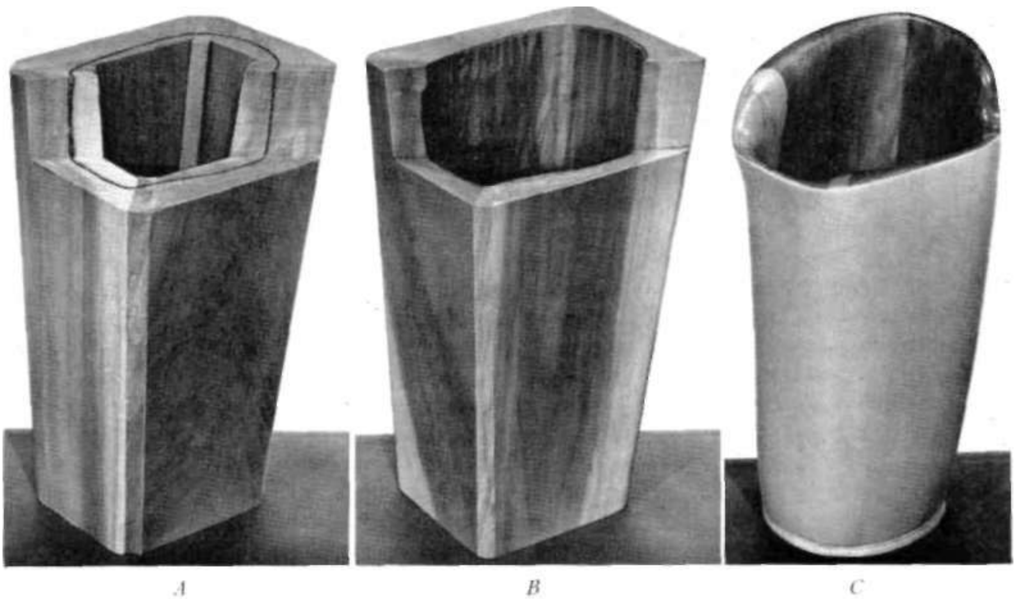


Fig. 13. Three stages in the construction of a wooden socket. *A,* Block cut to form posteromedial shelf. *B,* Roughed-out socket. C, Completed socket with inside finished and rawhide covering on outside.

smaller the volume in the end of the socket the less the excursion, but in itself the amount of free volume has no significant effect on the magnitude of the negative pressure.

End-Bearing

If it can be tolerated, end-bearing is recommended because it relieves the load on the ischium. Felt or foam-rubber padding placed in the bottom of the socket permits comfortable end-bearing, the thickness of the padding governing the amount of weight carried on the end of the stump. Although little free space remains in the socket, adequate suction and control are not affected. For example, Gritti-Stokes amputations, which are principally end-bearing, have been fitted successfully.

Inside Finish

No single recommendation is made regarding adequate nonirritating finishes. Industrial and perspiration-resistant lacquers common to the limb industry are being used routinely. Some subjects have reported slipping of the socket because of perspiration. In some cases, perspiration also has caused the lacquer finish to deteriorate and to produce a roughness resulting in skin irritation. In general, however, these industrial lacquers have proved satisfactory when applied according to manufacturers' specifications. In cases of excessive perspiration, the socket may have to be refinished every few months. Whenever perspiration creates a severe problem, the amputee should be referred to a dermatologist for possible treatment.

Bottom Seal

The bottom of the socket should be sealed with a piece of hard wood 1/8 in. thick or more, cut so that the surface goes along the grain, and sealed with a waterproof glue. The bottom may be given additional protection by applying a thin coating of one of the thermosetting plastics common to the limb industry.

Control of Negative Pressure

Several different types of valves have been used in suction sockets with good results. A simple type of plug valve with a manual suction release is satisfactory. Automatic expulsion valves permit some change of air in the socket, a beneficial feature during hot weather and at times when the amputee perspires. They have proved successful in all cases and are now in general use.

The valve opening should be positioned for ease in removing the fitting sock when the leg is donned and for convenience in operating the manual control, and it should be placed where the distal end of the stump is least likely to touch the inner face of the valve. The optimum location is toward the front on the medial side below the stump end.

The magnitude of the negative pressure or suction required to hold a suction socket in place is only slightly greater than the value given by dividing the weight of the prosthesis by the cross-sectional area of the stump near the distal end—in most cases about 1-1/2 lb. per sq. in. With the additional support given by contracting the stump muscles during each step, a negative pressure of 1-1/2 lb- Per sq. in. is sufficient. Some amputees prefer somewhat greater suction, with its accompanying feeling of security, but excessive suction may cause edema. A negative pressure greater than 1-1/2 lb. per sq. in. indicates the presence of forces tending to pull or push the leg off the stump. This action may occur when the stump muscles are contracted, or it may be caused by an improper fit resulting in constriction of the muscles. Use of a gauge for measuring the maximum negative pressure at the time of the rough and the final fittings serves as a check on the quality of fit and is essential to good and consistent results.

Accurate records should be made of the variations in pressure inside the suction socket during normal walking. With the automatic expulsion valve now in general use, these records should show a small positive pressure during weight-bearing and a negative pressure when the leg is in the swing phase. Figure 14 is a record of the pressure variations in a suction socket during two complete walking steps, the valve used during this test permitting automatic exhaust starting at a positive pressure of 1/2 lb. per sq. in.

The stiffness of the spring in the valve has, in itself, no direct effect on the magnitude of the maximum negative pressure. It does,

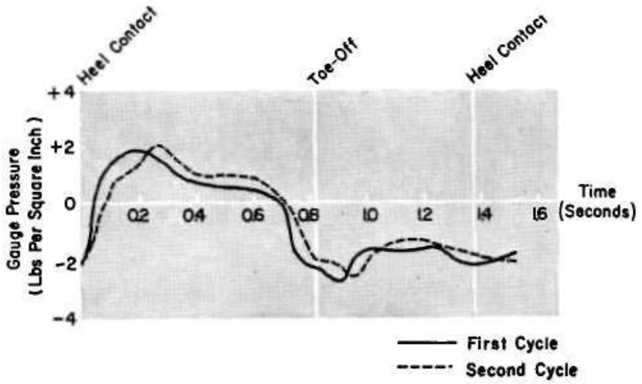


Fig. 14. Typical pressure variation in an above-knee suction socket during level walking. Body weight: 145 lbs.

however, allow a greater or lesser amount of air to be expelled with each step and thereby affects the amount of positive pressure developed during weight-bearing. Fairly high positive pressure within the socket during the stance phase generally is found desirable because it increases the pavex action of the socket on the stump, with consequent benefit to the circulation. High positive pressures help to control edema and to give the amputee a sense of "walking on air." But, as already mentioned, too great a positive pressure in the stance phase may tend to push the leg off or to increase the piston action of the stump in the socket. Springs permitting expulsion at a positive pressure of 1/2, *1-1/2* or 2 lb. per sq. in. now are commercially available. The choice should be based upon individual circumstances.

Some leakage generally occurs either in the valve or between the socket wall and the stump. A regulated amount of leakage is, however, desirable because it relieves the suction during periods of inactivity. If the leak rate is too great, the leg may fall off or the piston action may be excessive and cause discomfort. If the leak rate is too small, however, edema may result. A good test for leak rate is to measure the time required for the negative pressure to drop to half its initial value while the prosthesis is suspended on the relaxed stump. If the time is 50 to 80 sec, the leak rate is satisfactory, but if it is greater than 100 sec, the manual release should be used during periods of inactivity.

CONCLUSION

In summary, then, it may be restated that, in the construction of an above-knee artificial leg, the objective of the prosthetist is to provide the wearer with optimum security in standing and walking, the best possible walking pattern, a minimum requirement for expenditure of energy in usual activities, and a generally comfortable leg that can be used more or less continuously without injuring the stump and without causing undesirable postural deformities. The above-knee prosthesis is called upon to replace as nearly as possible the functions of the normal leg, but it must do so under the influence of a residual motor mechanism deficient in power and sensory control. The necessary features are therefore to be obtained only by observance of certain functional rules established on the basis of anatomical, physiological, and mechanical considerations.

Of first importance is that the prosthetist well understand the mutual interdependence of the details of alignment of the various components and of the fit and orientation of the socket. Since, unlike the normal limb, support in the above-knee prosthesis is not through the shaft of the femur but through some other axis, due cognizance needs to be taken of the new set of musculomechanical relationships and of the influence of these relationships on the static and dynamic characteristics of the artificial replacement. When proper compensation for these factors is made by the limbfitter, undesirable compensation by the amputee is avoided, while the requirements of comfort, function, and acceptable gait are satisfied. In no other way can so much satisfaction be afforded the above-knee amputee.

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