Prosthetics and Orthotics International, 1990, 14, 9–21

Biomechanics and shape of the above-knee socket considered in light of the ischial containment concept

C. H. PRITHAM

Durr-Fillauer Medical Inc., Chattanooga, Tennessee

Abstract

In recent years considerable interest has been generated in the United States and abroad about new style above-knee prosthetic sockets, variously referred to as Narrow M-L, NASNA, CAT-CAM and SCAT-CAM. More than a little confusion has attended the process. Moreover, the impression has been created that they are not governed by the basic biomechanical rules identified by Radcliffe as affecting the quadrilateral socket. Attention has come to be focused on the role of ischial containment and the term Ischial Containment (IC) socket is enjoying widespread use. This paper reviews many of the critical features of such sockets with the goal of first demonstrating that many of these features are dictated by the requirements of ischial containment, and second that the principles set forth by Radcliffe are fully applicable. The paper concludes with a brief discussion of the alignment principles associated with Long's Line.

Introduction

In 1974 Ivan Long became involved in a project to evaluate radiographically the femoral alignment of above-knee amputees (Long, 1975; 1985; Mayfield et al, 1977). This has come to have profound effects not only on Long's practice but also on the practice of many prosthetists. In the process considerable confusion has caused many of the issues involved to be obscured; and somehow or another, the perception that the new style sockets are different from quadrilateral style sockets and unaffected by the principles of above-knee prosthetics as explained by Radcliffe (1955; 1970; 1977) has crept into popular consciousness. Recently, however, some semblance of order has begun to emerge (Pritham, 1988; Schuch, 1988) and attention has come to be focused on the role of the ischium. It is the author's contention that most if not all of the major factors influencing the shape of the newer sockets can be explained in terms of the principle of ischial containment. Further, it is the author's belief that this principle is fully compatible with Radcliffe's biomechanical analysis of the function of the quadrilateral socket and that the varying socket configurations are not at odds but rather are separate but related entities in a continuum labeled "above-knee sockets."

The goal of this article is to explore and clarify the issues involved. A wide variety of claims for the new socket configuration have been made. While there is a certain body of anecdotal subjective evidence to support some of them, the author is not aware of large scale objective scientific studies to substantiate any of the claims. However, for purposes of advancing the argument many of these contentions are accepted as given.

The problem

To understand properly the problem it is perhaps best to turn to Long's own statement (1985).

"Most above-knee amputees walk with a wide base and lurch to the amputated side. Only 100 per cent concentration can change that pattern. We looked at 100 x-rays of above-knee amputees standing in their prostheses and found 92 out of 100 to have a difference in angle of the femur. In 91 of 92, the difference was towards abduction."

"Abduction was caused by the quadrilateral socket being entirely too large in the M-L dimension and too tight in the A-P. The ischium sits on top of the seat at best, and a couple of inches above it in most fittings. The x-rays show the lateral wall to be several inches

All correspondence to Mr. C. H. Pritham, C.P.O., Technical Coordinator, Durr-Fillauer Medical, Inc., P.O. Box 5189, Chattanooga, Tennessee, 37406, USA.

away from the femur except at the most distal point. When the femur exerts force against the lateral wall in weightbearing, the quadrilateral socket moves laterally immediately, because the ischium has no effect on stopping this shift. With the more narrow socket and increased A-P, the ischium is inside the socket, preventing lateral shifting of the socket during weight-bearing."

Of course, socket fit was not the only factor considered by Long and his co-workers. Apparently the initial focus of their investigations was not socket shape but alignment of the prosthesis (Long, 1975). Alignment will be considered separately at the end of this paper.

Mayfield (Mayfield et al, 1977) described the findings in an initial group of 38 amputees (presumably a sub-group of the 92 mentioned above by Long). Seventy-nine per cent of them were in abduction or neutral, and 13 per cent were in less adduction than the sound side. Only 8 per cent were in adduction equal to or greater than the sound side. Twenty of the 38 were refitted with revised techniques and an improvement in femoral alignment and gait. Another group of 13 new patients were fitted utilizing the new techniques and similar results were achieved.

In short, in the majority of cases examined by Long the prosthesis was ineffective in maintaining the proper relationship between the femur and the socket.

The solution

The solution as stated above is to prevent the proximal socket from shifting laterally by using ischial containment (also called bony or skeletal lock). To understand this solution properly it is perhaps best to start with Radcliffe's principle of lateral stabilization (1955). This may be summarized as follows:

1. The weight of the amputee's body, acting through the centre of gravity, tends to cause the pelvis to dip towards the sound side during stance phase on the amputated side.
2. This converts the pelvis into a lever with the supporting point, lateral of the ischium, acting as the fulcrum (Fig. 1).
3. The tendency of the pelvis to dip is resisted by the gluteus medius exerting a counteracting moment to the pelvic lever.

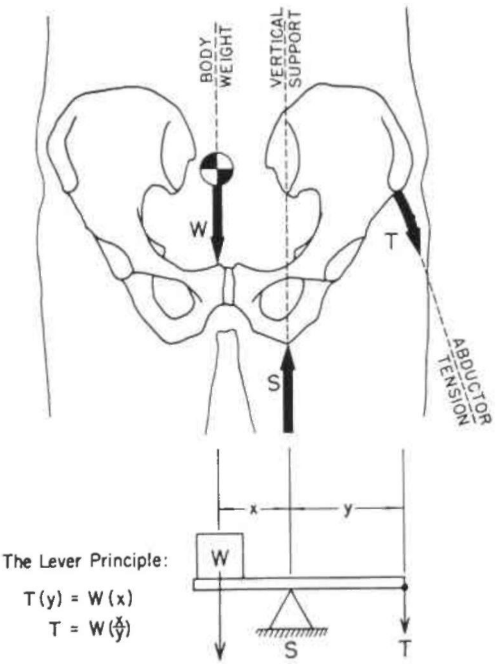

Fig.1. Moments acting about the support point in the frontal plane in lateral stabilization of the pelvis (Radcliffe, 1955).

4. For the gluteus medius to work at maximal physiological efficiency it must be maintained close to its normal rest length.
5. This is achieved when the femur is at its normal position of adduction.
6. The lateral wall of the socket must be shaped to maintain this position, anticipate the outward movement of the femur under load, and to distribute the pressure comfortably.
7. As a result of these forces acting against the shaft of the femur laterally, a counterpressure is created by the medial brim of the socket pressing against the stump so that "pressure in the crotch or medial area is then predominantly lateral rather than vertical" (Radcliffe, 1955). That is to say, a compressive force is exerted by the medial wall against the medial proximal tissues of the limb (Fig. 2).
8. This in turn creates a shearing force in the soft tissues trapped between the medial brim of the socket and the medial structures of the pelvis (Fig. 3).

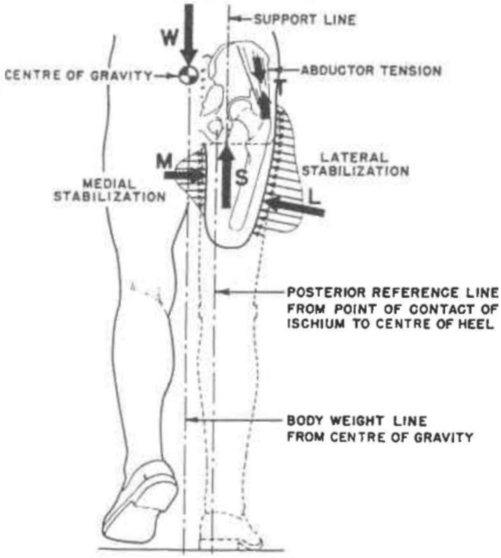

Fig. 2. Lateral stabilization of the pelvis (Radcliffe, 1970).

The basic principle, as described by Radcliffe, is contained in numbers one through seven above. Point number eight is an addition to the basic principle added in response to comments like that of Long previously quoted.

Haberman (1963) performed a very similar analysis and attributed the shearing force to the medial displacement of the prosthetic support point (ischial tuberosity, about which the stump rotated on the prosthesis) relative to the physiological centre of rotation, the hip joint. To reduce this shearing to a minimum he advocated maintaining the support point as far laterally as possible in order to align it as closely as possible with the physiological centre of rotation. How this was to be accomplished is not apparent from Haberman's paper, although presumably it could be done by reducing the amount of ischial weightbearing and increasing the amount on the gluteus maximus.

Radcliffe, (1955) by way of contrast, was considerably more sanguine about the consequences of exerting laterally directed pressures in the perineum, although he did say "Flattening the medial wall of the socket is one means of ensuring a comfortable distribution of pressure in the adductor region" and "Providing efficient medial-lateral stabilization will also minimize medial shifting of the ischial tuberosity which might result in painful skin

Fig. 3. Socket displaced laterally (solid) from its original resting position (dotted). This can result in a shearing force being exerted against the tissues between the medial bones of the pelvis and the medial brim of the socket.

abrasion in this important weightbearing area" (1970).

Radcliffe also pointed out that the closer the support point is to the centre of gravity the less the moment tending to cause pelvic dip and the more efficient the countermoment of the gluteus medius on the femur. He apparently seemed to have considered any concomitant increase in shear forces as a small price to pay and well within the manageable limits.

The reasons for this sangiuneness are perhaps worth considering. Radcliffe's work was part of a larger effort initiated in response to the needs of World War II amputees, who at that time were for the most part young and healthy. It is to be presumed that much of his practical experience was gained with such amputees. Working with this group who had firmer tissues and stronger muscles than those that prevail with today's more typical patient, may well have masked problems that are more prevalent in today's practice. Another contributing factor that cannot be dismissed outright is Radcliffe's assertion that many of the problems described by Long and others may well be the results of poorly fitting sockets (Radcliffe, 1989), i.e. not made according to the principles outlined by the University of California team.

Leaving this last point aside, it may be presumed that the laterally directed shearing force in the perineal area and the inability of the soft tissues to withstand it causes discomfort and contributes to malalignment.

The solution that has emerged, and that was clearly apparent to Long, is to extend the medial brim upward so that pressure is brought to bear against the ramus. (Fig. 4). to quote Radcliffe (1989) "the medial counterpressure on the pubic (ischial) ramus clearly is capable of providing medial counterpressure which supplements the medial pressure on the adductor musculature. Since the socket slopes downward and inward along the entire medial brim this contour is faired into the medial wall of the socket which gives the impression of exaggeration of the medial counterpressure in the upper one-third of the socket."

This is the principle of ischial containment and many of the determining features of the newer designs derive from the desire to make ischial containment possible. It would seem logical to consider these features in a point-by-point fashion proceeding around the periphery of the socket.

Medial-lateral dimensions

The medial brim of the IC socket is an oblique sloping surface, upon which the ischium occupies a somewhat tenuous perch. To quote Radcliffe (1989).

"In taking advantage of the weightbearing potential on the medial aspect of the ramus the prosthetist is creating a situation much like weightbearing on the seat of a racing bicycle. To prevent the ramus from sliding laterally and downward into the socket the prosthetist must exaggerate the counterpressure from the lateral side. This has been done by a reduction in the M-L dimension particularly in the area just distal to the head of the trochanter."

Hence the emphasis on the M-L dimension of the IC socket. However, it has become clear at only a relatively late stage that the dimensions at more than one level are involved (Fig. 5).

Proximally the socket in the area at about the

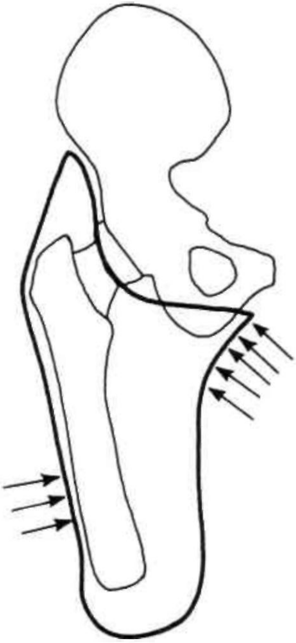

Fig. 4. Medial forces borne by bones of the pelvis and soft tissues, the principle of ischial containment.

Fig. 5. Skeletal and soft tissue M-L dimensions of the Ischial Containment Socket (Hoyt et al, 1985).

level of the medial brim must be wide enough to accommodate the bones of the pelvis and the greater trochanter. Given that the ischial and pubic ramus pass obliquely (in the direction of internal rotation) from the ischial tuberosity to the pubic symphysis, it would seem logical that the M-L dimension in this area must be at least as large, if not larger, than the equivalent dimension of the quadrilateral socket.

At a level about 4cm distal to the ischial tuberosity, the M-L dimension is considerably reduced. As Radcliffe points out this is in order to bring pressure to bear on the femur on the area distal to the greater trochanter. It may also serve to load the tissues medially and thus play a role in creating the laterally directed counterforce necessary for lateral stabilization of the socket.

The dimension at the level of the ischial tuberosity is variously referred to in current texts as the Ischial Tuberosity (IT) M-L or the skeletal M-L (Hoyt et al, 1987; Prosthetic Consultants, 1987). The more distal diameter is called the Soft Tissue M-L or the Distal Ischial Tuberosity (DIT) M-L, and is either derived from the values given in Long's chart relating it to the circumference distal to the ischial tuberosity (Long, 1985) or is very closely related to these values, in most techniques.

Much of the confusion and the unfortunate sobriquet "Narrow M-L" would seem to have grown up over this latter dimension. A failure to appreciate the role of ischial containment and the need for different M-L dimensions at different levels coupled with a desire to emulate a poorly understood technique has led to more than one improperly fitting AK socket. Focusing on the lateral gapping in a quadrilateral socket and reducing the M-L dimensions in response would seem to be treating the symptom rather than the cause of the ailment.

Anterior-posterior dimension

For any particular fitting the volume of the patient's stump is a given (constant) regardless of the shape of the socket that the prosthetist wishes to fit. To quote Radcliffe (1989) again: "The soft tissues must be accommodated. Therefore, the A-P dimension is correspondingly increased as compared to the quadrilateral socket." Hence it can be seen that the major dimensions of the IC Socket are dictated by the imperatives of ischial containment. Other, secondary, rationales for a wide A-P dimension have been presented. It has been postulated that the greater A-P dimensions of the IC Socket better accommodate the major muscle groups of the thigh, permitting them to function more effectively (Long, 1985; Sabolich; 1985). Second it has been suggested but never proven that a concentration of pressure in the Scarpa's Triangle has a deleterious effect on circulation in the distal tissues (Sabolich, 1985).

With regard to the first point, Radcliffe (1977) clearly understood the necessity of allowing sufficient room for functioning muscle groups. "Regions of firm musculature such as along the rectus femoris muscle are channeled to avoid excessive pressure as required". "The socket contours are determined by reference to the information on stump muscle development recorded during the examination (Radcliffe, 1955). With these statements in mind there would seem to be no contradiction in principle between the quadrilateral socket and the IC Socket. Rather it would seem to boil down to a difference of opinion between advocates of both about which does the better job.

The second point is considerably more problematic. It seems self-evident that if any fundamental problem (such as adverse effects on circulation resulting from pressure in the Scarpa's Triangle) were to exist with the quadrilateral socket, there would have been considerable hue and cry and the design would have fallen into disfavour very early on. Yet the basic socket design has been in widespread international use for more than 25 years. Writing in 1964, Hall, stated: "Properly applied pressure is well tolerated by neurovascular structures. This is an interesting concept for orthopaedic surgeons, who have been painfully aware of the results of unrelieved plaster-of-Paris cast pressure over neurovascular tracts. Surprisingly, these vessels and nerves will tolerate firm pressure over extended periods of time if it is applied properly, while the same degree of pressure over a functioning muscle will prove to be intolerable. As considerable force must be applied over a sufficient area in the socket wall to stabilize the stump, and since those areas overlying contacting muscle bellies are not feasible, the ability to utilize zones superficial to neurovascular structures becomes most important." No convincing evidence has been advanced, even at this date, to challenge this assertion.

Contrary to the apparent opinions of some, Radcliffe never advocated application of all of the anterior counterpressure in the Scarpa's Triangle. What he did say was: "Distributed over the upper portion of the *entire anterior wall* (present author's emphasis) 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." (Radcliffe, 1955). Clearly it was his intent that forces be distributed over the widest possible area, while taking due notice of the nature of the tissues involved and their response to pressure. "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."

Interestingly enough in recent months at least one of the most vocal advocates of Skeletal Contoured Adducter Trochanteric-Controlled Alignment Method (SCAT-CAM) fitting techniques, Sabolich, has begun using more contouring in the Scarpa's triangle than was formerly his practice. This is being done to improve anterior-posterior control and rotary stability. While this necessarily results in some reduction in the A-P diameter, the intent is most emphatically not to reduce the diameter to the same value that would be achieved in a quadrilateral socket. It is perhaps best thought of as channeling or contouring and not as a reduction in diameter. Sabolich remarks that quite often it is accompanied by an increase in the depth of the rectus channel laterally.

Regardless of amputation level or socket style, the underlying principles remain the same. Force should be distributed over the widest possible area with due recognition of the volumetric relationships to be effected, functioning muscle groups, and the response of tissues to the load. Confronted with conflicting claims from advocates of differing socket designs about which more effectively fulfills the same purpose, and in the absence of objective evidence to support one position or the other, it would seem necessary to give equal weight to both positions. Ultimately the only necessary justification, and indeed the only compelling one, for a wide A-P in the IC Socket is the necessity of preserving the proper volume to accommodate the limb.

Medial brim

The desire to distribute at least a portion of the laterally directed thrust of the proximal socket to the ischium has major implications for the shape of the medial brim. The medial border of the ischium is to be loaded, while at the same time the adductor longus tendon and the pubic ramus, which are not pressure tolerant, are not to be loaded. Hence, the medial brim is high enough posteriorly to bear against the ischial ramus and dips lower as it passes anteriorly to clear the pubic ramus and adductor longus tendon (Fig. 6). Since it is desired to distribute pressure as evenly as possible, the brim parallels the course of the ischium as it goes from posterior to anterior and is therefore internally rotated when viewed in the transverse plane. These are the general criteria for shape of the medial brim. Specific details vary with fitting philosophy and with patient characteristics.

The height of the medial brim and the amount of ischium encompassed would seem to

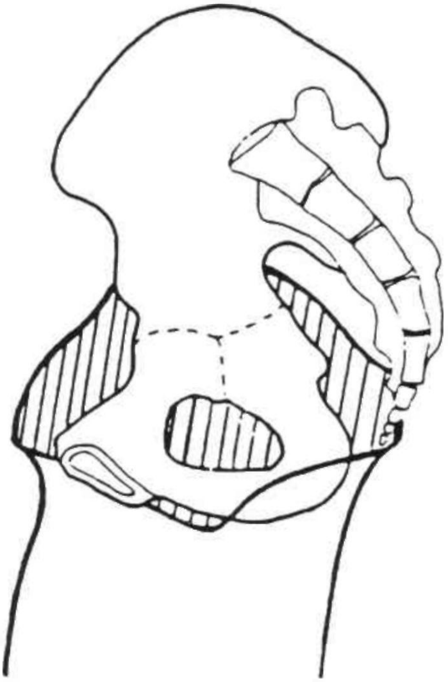

Fig. 6. Medial view of the Ischial Containment Socket in the sagittal plane showing relationship between the proximal edge of the medial wall and the bones of the pelvis (Hoyt et al, 1985).

be influenced primarily by the prosthetist's fitting philosophy. Above-knee sockets can be characterized by the amount of ischial containment from none (quadrilateral) to "maximal" (Pritham, 1988). Advocates of SCAT-CAM style sockets, at the maximum end of the scale, believe that it is both possible and desirable to bring the medial brim as far proximal as possible. Those individuals who believe in the broader group of moderate ischial containment socket designs are less emphatic about the need for height.

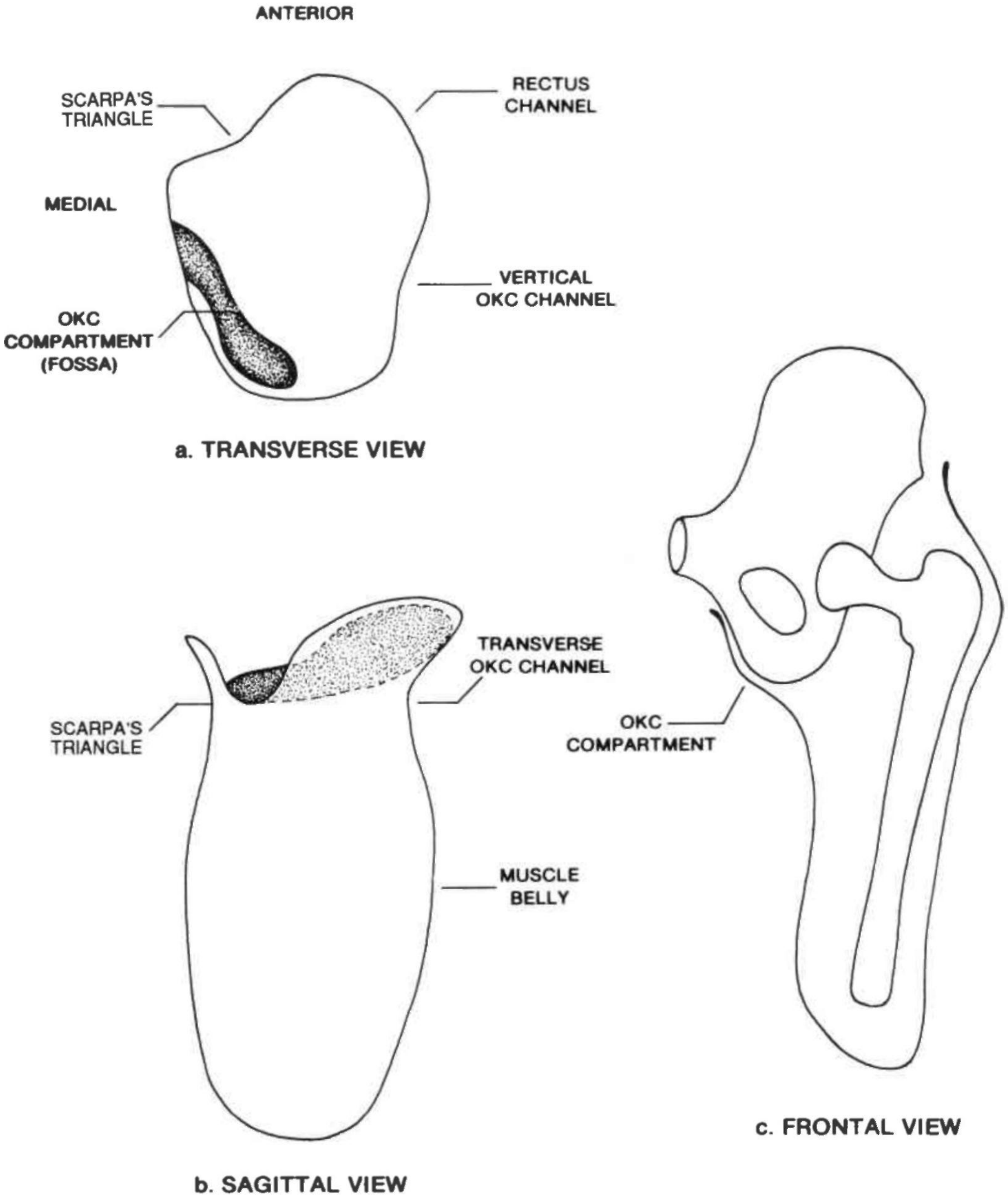

Fig. 7. The SCAT-CAM socket as described by Sabolich. Redrawn from an original by him to clarify some points. According to him some contours are exaggerated for emphasis, but not by much.

Those prosthetists that advocate higher brims are generally of the opinion that the increased height is made possible by flexible thermoplastic sockets. The general scheme is that the more flexible the brim, the more comfortable the patient, and the higher the brim can be. However, the question must be asked, what really is the role of the brim under these circumstances? Are the higher brims with their increased flexibility actually firm enough to be distributing an appreciable compressive load to the patient's tissues? Or, is the brim so flexible that it is acting only as a "shear distributor" to reduce the shear forces that are built up around the edge of the device in the transitional zone between the rigid socket wall and the relatively soft flesh of the patient? This latter concept is one that was developed by Murphy (1971) and Bennett (1971) in a series of theoretical articles published a decade ago. The practical implications of these articles and their potential impact upon prosthetic/orthotic design have never been fully appreciated.

In many instances the medial brim is not a flat oblique surface but rather is corrugated or channeled in cross-section as it goes from posterior to anterior. This is done to increase the amount of the ischium bearing against the brim and thus decrease the unit pressure. The amount of channeling that is needed would seem to be determined primarily by tissue properties. The softer the tissue, the more the load borne by the ischium and the more prone is the patient to discomfort. In an attempt to relieve this discomfort, the point of contact between the brim and ischium is relieved. When done correctly this results in a channel. The softer the tissue the more the brim is convoluted in cross-section and corrugated. This forms a concave inner surface. The firmer the tissue, the more the load that is borne by the soft tissue, the less that is borne by the ischium, and the flatter the brim can be in cross-section. The extreme of this case would be the patient who can bear all of the laterally directed load on the soft tissues without any reliance on the ischium. It would seem logical to consider a quadrilateral socket for such a patient. Nevertheless, it could be argued that comfort for such a patient, particularly one engaged in stressful athletic activities, could be enhanced by including the ischium in the socket.

Sabolich (1985) has described the channeling in the medial brim as an OKC (Oklahoma City) fossa. Most recently the fossa has been deepened and accentuated in the shape to become the OKC Compartment (Fig. 7.). "This Compartment ideally contains all the tuberosity and most of all the ramus except for the exiting symphysis pubis. As in the original article (Sabolich, 1985), the ramus is in a better location to include both in a compartment which makes the best possible use of medial superior containment both vertically and horizontally. This compartment is specifically contoured for these bones. This is the tough part."

Anterior brim

The impression has been created that the anterior brim of an IC Socket is lower than the anterior brim of a quadrilateral socket. In reviewing the literature, however, it is difficult to see how this impression has come about. The height of the anterior brim was not addressed in Long's (1985) article but was described in the Chicago Workshop (Pritham, 1988) as following the inguinal crease. Shamp recommends that the anterior brim be at the same level as the posterior brim (Prosthetic Consultants, 1987). The UCLA-CAT-CAM manual prescribes a brim just proximal to the inguinal crease (Hoyt et al, 1987). The consensus of the Chicago Worship was that generally it should follow the inguinal crease.

Radcliffe (1955) stated: "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 can be seen then that in height at least there is no real difference between the anterior wall of an IC Socket and a quadrilateral socket.

Lateral wall

Most descriptions of IC Style sockets describe them as extending quite high above the greater trochanter and with a great deal of contouring around that bony prominence (Hoyt et al, 1987; Long, 1985; Pritham, 1988; Prosthetic Consultants; 1987). This can perhaps best be explained as an offshoot of the demands of ischial containment. As has been previously discussed, one of the primary functions of the

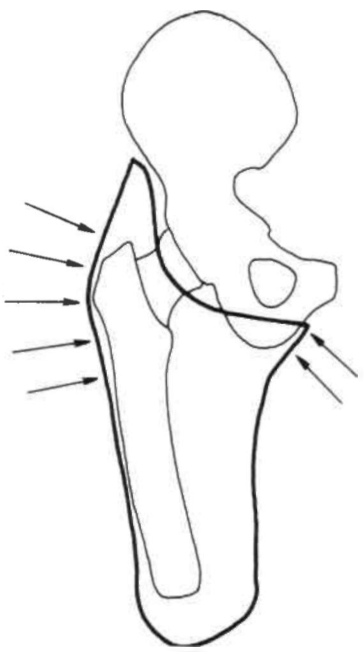

Fig. 8. Counterpressure generated by the lateral wall.

lateral wall is to generate the counterpressure necessary to maintain the ischium on the sloping medial brim (Fig. 8). The height and contouring of the lateral wall about the greater trochanter can be seen as necessary to distribute the load over a wide area and in an equitable fashion so that all the force is not concentrated on the most prominent lateral projection of the greater trochanter.

The other prominent feature of the various IC style sockets, when viewed in the transverse plane, is the extreme obliquity of the area posterior to the greater trochanter (termed the "wallet hollow" area by some) when compared to the comparable area of the quadrilateral socket. This is partly due to the demands of the counterpressure mechanisms and different fitting philosophy just discussed above. It can also be the result of trying to accommodate patients who are not as muscular and firm in this region as some. In many quadrilateral fittings it is necessary to create the same sort of contour just to preserve total contact. Radcliffe in his oral comments at the Miami meeting mentioned the necessity of this when working with older less physically fit patients than the young veterans he had experience with. This portion of his comments does not appear in any of the written accounts of his remarks (Radcliffe, 1989a; Radcliffe, 1989b; Schuch, 1988).

Whatever the socket style, firm pressure and contouring in this region posterior to the greater trochanter does more than generate the previously cited counterpressure. By compressing the gluteal muscle it helps create gluteal weightbearing, and by locking in around the greater trochanter it plays a role in providing rotary stability in the transverse plane. This contour is extended distally into the depths of the socket and, as will be seen, fulfills other roles at these levels.

Posterior brim

The posterior brim of the IC designs is described as being located 4 cm or so proximal to the ischial tuberosity so that the ischium is inside the socket. (It is doubtless this greater height of the posterior brim, as compared to the quadrilateral socket, that creates the impression of a low anterior brim). While it has been claimed that fitting the ischial tuberosity inside enhances a number of biomechanical functions (Prosthetic Consultants, 1987; Sabolich, 1985) the simplest explanation for the posterior brim's greater height is that it is a side effect of ischial containment and the increased height of the medial brim.

Function in the sagittal plane during gait

Radcliffe identified two separate force patterns (Fig. 9) that were exerted on the socket by the

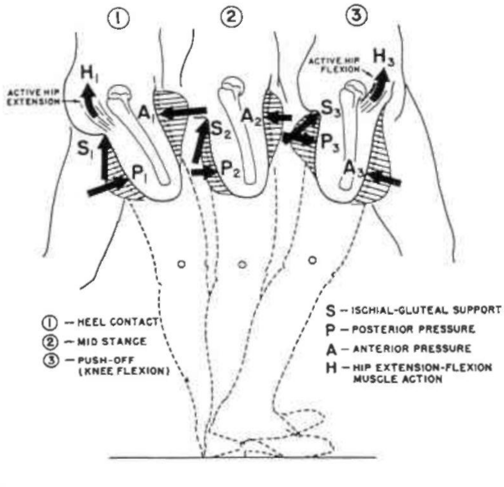

Fig. 9. Force patterns generated in the sagittal plane during gait (Radcliffe, 1970).

stump and which were the results of using the hip musculature to stabilize the knee in the early part of the stance phase and to initiate knee flexion in the later part. The first instance, knee stabilization, creates a situation where force is concentrated on the anterior proximal brim and the distal posterior portion of the socket. It is considered essential by Radcliffe (1970) to fit the anterior brim as high as possible into the inguinal crease so as to use the maximum effective stump length in this situation. With regard to the demands placed on the distal portion of the socket, he said "At the same time, the fitting must anticipate the movement of the femur stump within the soft tissue as the femur first presses posteriorly to maintain knee stability then moves anteriorly to initiate knee flexion in the swing phase". Such socket modification as the previously mentioned flattening of the area posterior to the shaft of the femur and the OKC Channel (Sabolich, 1985) can be seen as attempts to provide for effective transmission of force from the femur to the prosthesis postero-distally in order to stabilize the knee.

The force pattern is essentially reversed later in stance phase during the initiation of knee flexion. It should be borne in mind, however, that the forces required to initiate knee flexion are considerably less than those required to stabilize the knee in early stance phase. For this reason it will be appreciated that the functional demands placed on socket design are less. Undoubtedly this is what Shamp had in mind, when he said of the OKC Channel "Our experience is that the anterior channel is not necessary and may only serve to diminish the volume of the socket." (Prosthetic Consultants, 1987). Sabolich apparently has come to much the same conclusion for in a telephone conversation with the author in September 1988 he stated that it was currently his practice to remove considerable material from the area posterior of the femur and essentially none from the anterior region.

Proximally, much the same situation prevails. It may be argued that enclosing the posterior portion of the ischial tuberosity inside the socket enhances function in the saggittal plane. However, when the functional demands involved, i.e. those related to initiation of knee flexion in late stance phase, are considered, it can be appreciated that it really is not necessary. So, the prime criterion for extending the posterior brim of the socket proximal of the ischial tuberosity remains that of ischial containment. It is interesting to note, that while Radcliffe did not dwell on the work of Schnur, as did Lehneis (1985); he was aware of it, mentioned it in passing, and applied the principles in socket design. In 1955 he said that "conditions which create a great deal of discomfort can be prevented by shaping the bearing surface in such a way that the seat slopes 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" (Radcliffe, 1955).

In a somewhat related matter Sabolich describes an indented horizontal channel immediatley distal to the ischial tuberosity. This channel, which he terms the Transverse OKC Channel, touches the ischial tuberosity tangentially and presses against the hamstring tendons. Distal to the channel the socket wall flares outward to accommodate the muscle bellies of the hamstring group. This channel continues the contours of the medial wall posterior and laterally to where it blends in the contours around the femur. Sabolich contends that the transverse OKC Channel enhances A-P Control, while the hamstring relief distally improves the function of those muscles.

Weightbearing

Of weightbearing in the quadrilateral socket Radcliffe (1970) has stated: "In the ischial-gluteal-bearing type of above-knee socket it is assumed that the contact against the ischial tuberositiy is the major source of vertical support. In addition, perhaps one third (33 per cent) of the vertical support is provided by firm contact pressure acting upward on the gluteus maximus. Other areas of the socket, such as the anterior brim also contribute to the vertical support in varying amounts, depending upon the individual fitting".

If "major" is interpreted to mean more than 50 per cent it can be concluded that something in the nature of 83 per cent (50 per cent ischial weightbearing plus 33 per cent gluteal) or more of the patient's weight is borne by ischial-gluteal weightbearing with the remaining 17 per cent or less borne by the anterior brim and other areas. The question is, how does this differ in the IC Socket?

As has been stated by Sabolich (1985) one of the goals of CAT-CAM fittings has been to increase the amount of weight borne by the femur, and that is at least one of the justifications he cites for increasing the adduction angle. This is in contrast to the more commonly stated goal of striving to fit the amputee in a postition of normal adduction, inclined eight degrees or so, from the vertical. At eight degrees, or even if the limb is adducted to the maximum possible, the femur is still so near the vertical that the large majority of the force exerted against it is directed horizontally. Thus, force exerted by the lateral wall creates the previously described lateral counter-pressure necessary to maintain the ischium on the medial brim and relatively little of the force is exerted in the vertical plane to provide weightbearing. The weightbearing potential of the femur is further limited by the cross-section of the femoral shaft and head. It might be mentioned in passing that studies have been conducted, by Gottschalk (1989), of Dallas Texas, that suggest that the femur in an IC socket is no more likely to be adducted than it is in a quadrilateral socket.

It is an article of faith by prosthetists that if the soft tissues of the stump are properly compressed and contained in a socket that weight can be borne by the tissues (hydrostatic weightbearing). It has been one of the goals of Sabolich (1985) and others to employ this concept in fitting the newer style sockets. The concept has been the subject of a study by Redhead (1979), who labeled it Total Surface Bearing and who reviewed his work in this area at the Miami Meeting (Schuch, 1988). Unfortunately, the concept was roundly condemned by Radcliffe and other engineers present at that meeting and, in light of the controversy, it would seem that no definitive statement about the role of soft tissue weight-bearing in IC Socket can be made.

In remarks made in Miami, Radcliffe (1989 b) suggested that the ischial ramus as well as the tuberosity was bearing weight in the IC Socket. When this was discussed in Chicago (Pritham, 1988) it was pointed out that the medial brim was so oblique and nearly vertical that only a small component of the force exerted by it would be in a vertical direction and thus the contribution of the ramus to weightbearing was questioned.

The matter of weight distribution in the socket is of more than academic interest. It may well be that the various proponents of IC fitting techniques, with their emphasis on weight-bearing on structures other than the ischial tuberosity, have succeeded in shifting the support point laterally. As was pointed out in the discussion of the principle of lateral stabilization, the closer the support point of the socket is aligned with the physiological hip joint axis, the less shear will be created by the medial brim. Redhead (1979) in his discussion of the Total Surface Bearing Socket made much the same point.

In the end however, it would seem that no more conclusive statement about weight-bearing in the IC Socket can be offered than that made by Radcliffe about the quadrilateral socket. It seems likely that something more than 50 per cent and less than 100 per cent of the weight is borne by the ischial tuberosity in the IC Socket, and that, in descending order, weight is also borne by the gluteus, the femur, and the anterior brim.

Alignment

In all the furore and debate over socket design one fundamental fact is often overlooked. Long's original objective was to study alignment of the prosthesis, not socket configuration. In a recent private commun-ication he states—

"The original radiographical study in 1974 was to study femoral alignment — not socket shape. This study proved how little we knew about proper alignment of the above-knee prosthesis and led to the use of Long's Line for improved adduction angle. These x-rays were all with Quad sockets.

The need for a different socket shape became apparent. Not to achieve adduction, we could achieve adduction in the Quad socket, but we then had lateral gapping and discomfort.

I have never claimed that the socket shape gives you proper adduction. It does help to maintain it."

From this work in 1974 was spawned the concept of Long's Line (Long, 1975). This states that the normal femoral adduction angle can be approximated by positioning the end of the femur under the femoral head (the centre

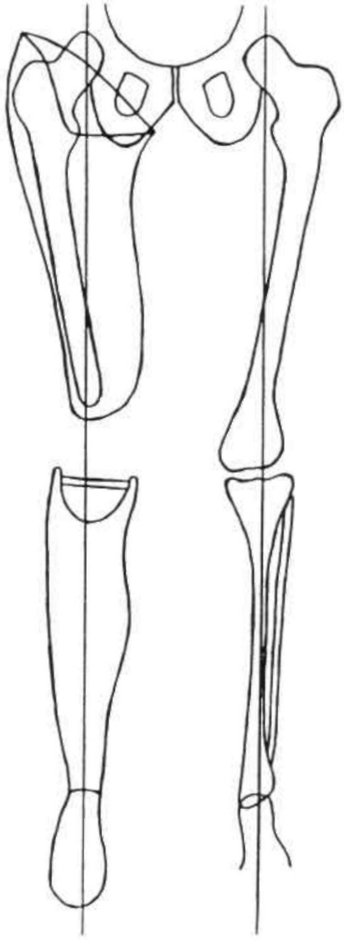

Fig. 10. Long's Line from: fabricating the Long's line above-knee prosthesis. (Long, 1985.)

of the head is approximated by bisecting the M-L dimension of the socket proximally). Further it maintains that a vertical line through these two points should be used for alignment in the frontal plane so that the knee is displaced laterally and the foot is centred on the line (Fig 10). The principle would seem to be that this comparative outset not only provides incentive for the amputee to adduct the femur as he strives to bring the foot in under him for proper balance, but it also provides clearance between the two legs thus permitting increased adduction.

The line described by the centres of the hip, knee, and ankle is of course the mechanical axis of the lower limb and was first described in the last century. Radcliffe (1955) alludes to alignment systems that centre the M-L dimension of the brim over the foot. What would seem to be original to Long is the concept of locating the femoral end on the line as well as the femoral head to determine the adduction angle.

From the foregoing, and from the work of Gottschalk et al. (1989), it would seem that quite quite possibly the operative factor influencing adduction angle in the frontal plane is alignment rather than socket design. Gottschalk would of course give primacy to efficient adductor muscles, while others would give the nod to socket design). Changes in socket configuration initially were made to ameliorate deficiencies in fit that emerged as a result of realigning the prosthesis, and to assist in maintaining the desired position. Eventually the process of reconfiguring the socket came to eclipse the matter of alignment. This brings us full circle and to consideration of ischial containment concepts.

Conclusion

The fundamental biomechanical principles governing behaviour of a prosthesis remain the same, independent of socket style. What differs is the strategy for dealing with these principles. An alteration in one or more basic features of a socket design affects others, and in a chain reaction, one socket configuration is inevitably transformed into another. The goal of this paper has been to demonstrate that once the decision to employ ischial containment in the AK socket has been made, the quadrilateral socket is inevitably changed into something different yet related. While different in shape and application of pressure, the two are related in that they both obey the principles of AK prosthetic behaviour, as described Radcliffe. In exploring this thesis, a variety of the crucial criteria describing an IC Socket have been discussed, but no attempt has been made to be exhaustive or all encompassing. It is hoped that this exercise will serve to put events of the past few years in perspective and clarify some of the issues involved.

It should be amply evident that a wide variety of issues remain unresolved. What is the support point in the IC Socket? What is the weightbearing distribution? Can the controversy over hydrostatic weightbearing be resolved? Can the questions raised by Dr.

Gottschalk's work be resolved? Can the claims made by advocates of IC style Sockets be verified? For whom is the IC Socket indicated? Contraindicated? What patient best benefits from which height and style brim? And last, but not least, can a readily applicable and teachable technique be developed so that the benefits of the IC Socket be made available equitably? These and a host of related questions would seem to give scope for investigators for quite some time to come.

As has been previously discussed, a good many of the claims made for the IC style sockets, while accepted as true for purposes of this article, remain unsubstantiated by objective scientific investigation. There is sufficient experience, however, from a good many practitioners to support the claim that it is possible to fit a patient comfortably and functionally with such sockets. This body of evidence also shows that it is considerably more difficult to fit a patient with an IC socket than it is to fit him/her with a quadrilateral socket, and that considerably more experience is necessary in order to learn how to do it properly. The ultimate issue that must be resolved is whether or not the results justify the increased effort and aggravation.

Acknowledgements

Finally, the author would be remiss if he did not acknowledge with gratitude the contributions of the following people who reviewed the manuscript in its gestation: Carlton Fillauer, C.P.O., Gunter Gehl, C.P., Christopher Hoyt, C.P., Ivan Long, C.P., John Sabolich, C.P.O., Michael Schuch, C.P.O., and Daniel Shamp, C.P.O.. A particular note of gratitude is due to John Michael, C.P.O and A. Bennet Wilson, Jr., who reviewed and edited the article several times and made many helpful suggestions.

REFERENCES

Bennet, L. (1971). Transferring load to flesh — Part II. Analysis of compresssive stress. *Bull. Prosthet. Res.* **10 (16)** 45–63.

Gottschalk, F., Kourosh, S., Roberts, J., Stills, M., McClellan, B. (1989). Does socket configuration influence the position of the femur in above-knee amputation? AAOP Annual Meeting, February 3, Orlando, Florida.

Haberman, H. (1963). Above-knee prosthetic techniques in Germany. *Orthop. Prosthet. Appl. J.* **17,** 15–26.

Hall, C. B. (1964). Prosthetic socket shape as related to anatomy in lower extremity amputees. *Clin. Orthop.* **37,** 32–46.

Hoyt, C., Littig, D., Lundt, J., Staats, T. (1987). The UCLA CAT-CAM above-knee socket. Third Edition — Los Angeles: UCLA Prosthetics Education and Research Program.

Lehneis, H. (1985). Beyond the quadrilateral. *Clin. Prosthet. Orthot.* **9,** 6–8.

Long, I. A. (1975). Allowing normal adduction of femur in above-knee amputations. *Orthot. Prosthet.* **29, (4)** 53–54.

Long, I. A. (1985). Normal shape-normal alignment (NSNA) above-knee prosthesis. *Clin. Prosthet. Orthot.* **9, (4)** 9–14.

Murphy, E. F. (1971). Transferring load to flesh — Part I. Concepts. *Bull. Prosthet. Res.* **10 (16)** 38-44.

Mayfield, G. W., Scanlon, J., Long, I. (1977). A new look to and through the above-knee socket. *Orthop. Trans.* **1, (1)** 95.

Pritham, C. H. (1988). Workshop on teaching materials for above-knee socket variants, *J. Prosthet. Orthot.* **1, (1)** 50–67.

Prosthetic Consultants. (1987). Manual for the use of the Shamp brim for the narrow M-L above-knee prosthetic socket — Sterling, Ohio; Ohio Willow Wood.

Radcliffe, C. W. (1955). Functional considerations in the fitting of above-knee prostheses. *Artificial Limbs.* **2, (1)** 35–60.

Radcliffe, C. W. (1970). Biomechanics of above-knee prostheses. In: Prosthetic and Orthotic Practice edited by G. Murdoch, London: Edward Arnold. 191–198.

Radcliffe, C. W. (1977). The Knud Jansen Lecture, above-knee prosthetics. *Prosthet. Orthot. Int.* **1,** 146–160.

Radcliffe, C. W. (1989 a). A short history of the quadrilateral above-knee socket In: Report of ISPO workshops. Edited by R. Donovan, C. Pritham, A. B. Wilson Jr. Copenhagen: ISPO. 4–12.

Radcliffe, C. W. (1989 b). Comments on new concepts for above-knee sockets In: Report of ISPO workshops. Edited by R. Donovan, C. Pritham, A. B. Wilson Jr. Copenhagen: ISPO. 31–37.

Redhead, R. G. (1979). Total surface bearing self-suspending above-knee socket. *Prosthet. Orthot. Int.* **3,** 126–136.

Sabolich, J. (1985). Contoured adduction trochanteric-controlled alignment method (CAT-CAM). *Clin. Prosthet. Orthot.* **9 (4),** 15–26.

Schuch, C. M. (1988). Report from: international workshop on above-knee fitting and alignment techniques. *Clini. Prosthet. Orthot.* **12 (2),** 81–98.