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Report From: International Workshop on Above-Knee Fitting and Alignment Techniques

by C. Michael Schuch, C.P.O.

An "International Workshop on Above-Knee Fitting and Alignment Techniques" was held in Miami, Florida, May 15–19, 1987. Conceived and organized by A. Bennett Wilson, Jr. and Melvin L. Stills, C.O., the workshop was supported and sponsored jointly by the International Society for Prosthetics and Orthotics and the Rehabilitation Research and Development Service of the Veteran's Administration. Hosting the workshop was the Prosthetics and Orthotics Education Program of the School of Health Sciences, Florida International University, and more specifically, Dr. Reba Anderson, Dean of Health Sciences and Ron Spiers, Director of Prosthetic Orthotic Education. Approximately 50 invited professionals attended the workshop, representing the United States, England, Scotland, Denmark, Sweden, Israel, the Netherlands, and Germany. Invited professionals included physicians, engineers, educators, and researchers, as well as prosthetic practitioners, all known to be active in the field of prosthetics.

The intent of the workshop was an organized sharing and discussion of information and experiences relative to the management of above-knee amputees. Above-knee socket design variables, specifically the accepted and established quadrilateral design and the newer ischial-containment designs known by various acronyms (CAT-CAM, NSNA, Narrow M-L), were discussed in great detail. Goals were to determine differences/similarities, advantages/disadvantages, indications/contraindications, as well as to develop recommendations for future action with respect to the various socket designs. While many prosthetists and/or clinics may have considerable experience with the newer above-knee socket designs within the United States, it is true that there are still many questions and concerns on the part of consumers, prescribing physicians, third party paying agencies, and educators in the U.S., as well as a great curiosity on the part of our international colleagues abroad.

After introductory remarks from Dr. Anderson, Dean of Health Sciences at Florida International University, Mr. John Hughes, President of ISPO, and Dr. Margaret Gianninni, Director of the Rehabilitation Research and Development Service of the Veteran's Administration, the program began with a presentation by A. Bennett Wilson entitled, "Recent Brief History of AK Fitting and Alignment Techniques." This paper began with the advent of the suction socket in the U.S. shortly after World War II and proceeded with the development of the total contact quadrilateral socket in the early 1960's. The audience was reminded that the total-contact quadrilateral socket, with or without suction suspension, was the socket design of choice from 1964 until very recently, when ischial-containment socket designs emerged. It was noted that, at present, the three senior prosthetic education programs in the U.S. (UCLA, Northwestern University, and New York University), in addition to teaching the application of the standard total contact quadrilateral socket, are offering special courses in what at first glance appear to be radical departures from the quadrilateral design. The technique at UCLA is known as CAT-CAM (Contoured Adducted Trochanteric-Controlled Alignment Method), based on work by John Sabolich, C.P.O., and inspired by Ivan A. Long, C.P. The technique being presented at Northwestern University is said to be based more directly on the Ivan Long technique and is known as NSNA (Normal Shape-Normal Alignment). The technique taught at New York University is usually referred to as the narrow ML socket design based on a special tool designed by Daniel Shamp to facilitate casting. Mr. Wilson concluded his remarks by saying "unfortunately, none of these techniques has been subjected to an evaluation program independent of the development group, and a great deal of confusion exists among clinicians responsible for amputee care. I hope that this workshop can be helpful in clearing away some of the confusion, and point the way for action that will bring order to the present day practice of above-knee prosthetics."

The next speaker on the agenda was Charles Radcliffe, Professor of Mechanical Engineering at the University of California, Berkeley. Professor Radcliff's presentation was entitled, "Review of UCB Quadrilateral Socket and Alignment Theory." Having been a member of the Prosthetic Devices Research Project of UC Berkeley in the 50's and 60's, Professor Radcliff is still a strong proponent of the quadrilateral socket. He presented a detailed review of the history and development of the quadrilateral socket and summarized this section of his presentation with the following comments. "The net result of all of this work in the 1950–1963 period was a better understanding of the complex interrelationships between the functional capability of the amputee, the rehabilitation goals, the prosthetic components required in the prescription, the gait of the amputee, the biomechanical forces generated, the socket shape, and the alignment. The socket was no longer described as a cross-section shape at the ischial level, but rather a three-dimensional receptacle for the stump with contours at every level which could be justified on a sound biomechanical basis. . . . It should be emphasized again that the quadrilateral type of fitting is not just a socket, it is a complete system which includes the amputee as a most important component. The socket is the interface between stump and prosthesis, and its primary functions are to provide for weight-bearing in the stance phase, allow the use of the stump and hip musculature to control motion and posture of the upper body in the stance phase (Figure 1), and to provide for control of the prosthesis in the swing phase of walking."

The next section of Professor Radcliffe's presentation focused on biomechanical and alignment principles of a prosthesis with a quadrilateral socket. Here he related his feelings that many of the biomechanically related claims made by proponents of the newer non-quadrilateral socket designs are equally attainable in the quadrilateral socket if the original biomechanical principles are followed. "Regardless of the fitting method employed, the socket for any patient must provide the same overall functional characteristics, including comfortable weight-bearing, a narrow base gait, and as normal a swing phase as possible consistent with the residual function available to the amputee after amputation. It is possible to provide this with a quadrilateral socket and it is being done routinely in many facilities." Professor Radcliffe went on to say, "In most of the recent articles that I have read, statements have been made which indicate clearly that the author is comparing very poorly fitted quadrilateral sockets to the results obtained using the new technique. They show diagrams of typical fittings and gait deviations which can only be described as a complete list of horror stories describing what not to do in fitting a quadrilateral socket. Any prosthesis with the problems listed in these articles should never have been delivered. If the average prosthetist in the United States is having the problems described by Long, Shamp, and Sabolich, then I must suggest that something is wrong with the methods being taught and used

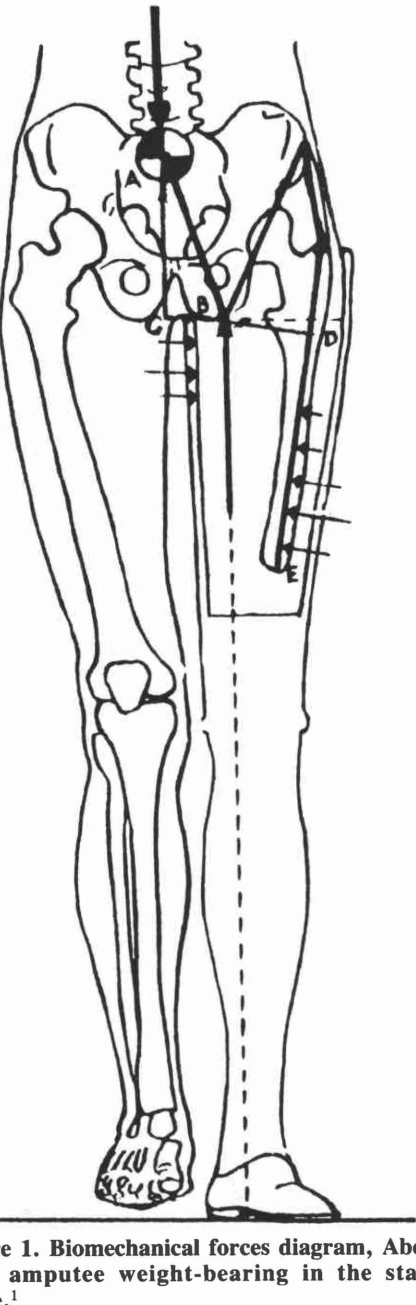


Figure 1. Biomechanical forces diagram, Above-knee amputee weight-bearing in the stance phase.[1]

in daily practice. I am aware that the schools have made significant changes in the way that the principles are taught, with each school emphasizing different aspects of the problem. I suspect that there may have been a shift away from the fundamentals of teaching of overall objectives, including the interrelationships of amputee evaluation, components prescribed, biomechanics, and why sockets are fitted with particular contours."

Following Professor Radcliffe was Tim Staats, Director of the UCLA Prosthetics Education Program. Mr. Staats' presentation was on the "UCLA CAT-CAM." UCLA began teaching CAT-CAM above-knee prosthetics with a pilot course in March 1985, which included both John Sabolich and Tom Guth as course instructors. Mr. Staats made it clear that the UCLA CAT-CAM philosophy of 1987 has departed from that of Sabolich, Guth, et al. and that the UCLA philosophy has now evolved to the point where a third edition of a teaching manual was published in March, 1987. To quote Mr. Staats as he spoke about this new manual, "the third edition of the UCLA CAT-CAM Above-Knee Prosthesis teaching manual integrates much additional material, covering the anatomy/socket relationship and how this is best achieved—material not yet fully understood and synthesized at the time of preparation of the previous edition. The UCLA CAT-CAM above-knee socket is a variation of the CAT-CAM design developed by John Sabolich, C.P.O., and Tom Guth, C.P., and the NSNA AK prosthesis of Ivan Long, C.P. Through countless hours of literature search, discussion, and intensive training given in this and nine foreign countries, and through the results of over 200 students who have fabricated and fit over 1,000 sockets under the guidance of our staff, a new insight has been developed. Our staff has refined the techniques of measurement, casting, and model modification to the point where it is a clearly teachable and viable above-knee fitting method. It is with great respect that we continue to recognize the published contributions of John Sabolich, C.P.O., Tom Guth, C.P., and Ivan Long, C.P., to the development and evolution of the UCLA technique. We would hope that this manual captures, blends, and enhances their philosophies. We recognize that our technique and CAT-CAM evolved from NSNA and we hope that these professionals can appreciate our efforts to refine and further evolve their clinical approach into a methodical step-by-step teaching manual."

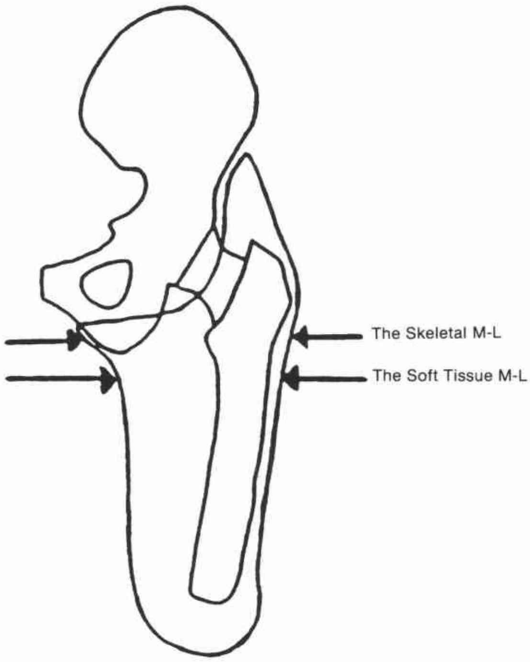


Figure 2. UCLA CAT-CAM medial-lateral diameter measurements.[2]

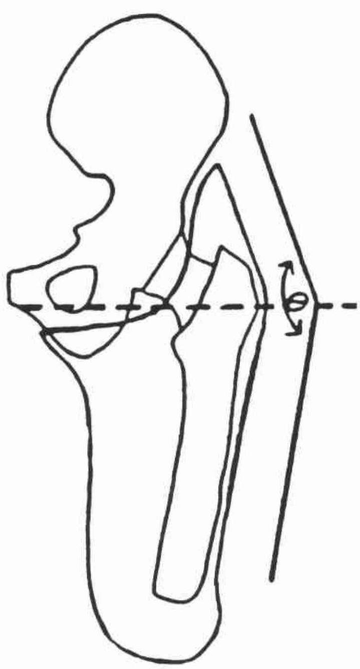


Figure 3. Ilio-femoral angle, as measured for UCLA CAT-CAM.[2]

At this point I will briefly review the highlights of the UCLA CAT-CAM sequence, beginning with patient evaluation and measurement and proceeding through model modification and bench alignment. For the details, I suggest referencing the third edition of the UCLA manual.

The recommended evaluation/measurement protocol is very complete and detailed, covering many of the procedures with which we should all be familiar. Adduction and flexion analysis of the residual limb are emphasized. Some new measurements and/or evaluations are introduced and illustrated:

- Skeletal ML dimension, actually measured on patient (Figure 2)
- Soft tissue ML dimension, taken from Ivan Long's chart of circumferences and related ML values (Figure 2)
- Ilio-femoral angle, actually measured on the patient (Figure 3)
- Public arch angle, evaluated by palpation and captured in the wrap cast (Figure 4)
- Ischial inclination, evaluated by palpation and captured in the wrap cast (Figure 5)

The wrap cast is taken with the patient in a standing position, and all shaping of the cast is accomplished by hand molding. The goal is good definition and containment of the medial and posterior aspects of the ischial tuberosity and ischial ramus within the wrap cast and subsequent socket, as well as allowance for the pubic ramus to exit the socket near the midline of the medial wall (Figure 6).

The initial trimlines for the resultant socket are as follows:

1. Anteriorly, just proximal to the inguinal crease. The anterolateral brim must clear the superior iliac spine when the patient is sitting.
2. Laterally, the brim extends approximately 3″ above the trochanter. The final height of this wall will be determined during fitting.
3. Posteriorly, the trim line should begin at least 1″ above the level of the inferior border of the ischial tuberosity. The curve that defines the posterior to lateral trim line normally begins at a point between the lateral third and the midline of the socket ML dimension at ischial level.

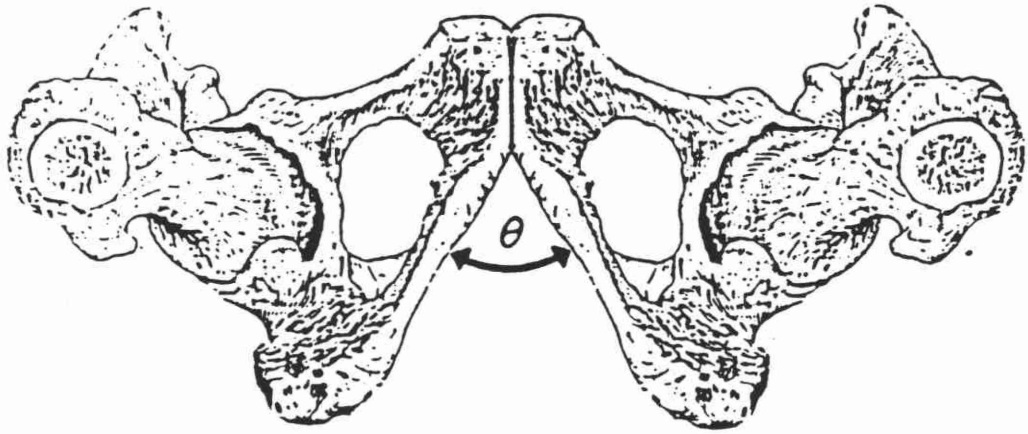


Figure 4. The pubic arch angle, as evaluated for UCLA CAT-CAM.[2]

Figure 5. The ischial inclination angle, as evaluated for UCLA CAT-CAM.[2]

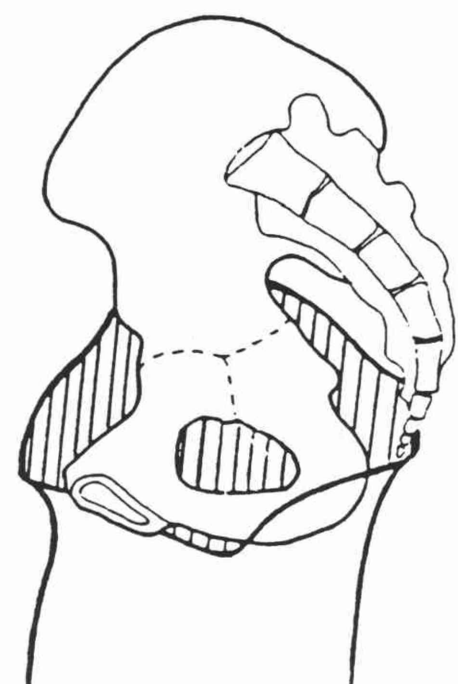


Figure 6. Medial view of pelvis-socket relationship, UCLA CAT-CAM.[2]

4. The medial proximal brim will be "V" shaped, with the vortex of the "V" located at the point where the pubic ramus crosses the medial wall. This trim line projects upward from the vortex, posteriorly to encapsulate the medial aspect of the ischial ramus and tuberosity. (Figure 6) A circumference reduction chart is used to attain suction suspension. The values used in this chart are slightly less than those normally used in quadrilateral suction sockets.

For bench alignment, the following references are used:

1. Posteriorly, bisect the socket at the level of the soft tissue ML, this reference line should fall as a plumb line to the center of the heel.
2. Laterally, bisect the socket AP dimension at ischial level, this reference line should fall as a plumb line between 0″ and 1″ anterior to the foot bolt.
3. Socket is set in measured adduction, and measured flexion plus 5°.
4. The distal aspect of the medial wall should be on the line of progression.
5. The knee bolt is externally rotated 5°.
6. The top of the foot, as well as the prosthetic shank should lean medially 4°, or alternatively, the socket is hyper-adducted 4° beyond measured adduction with the foot parallel to the floor and the shank perpendicular to the floor.

The UCLA CAT-CAM can be fabricated using rigid socket or flexible socket techniques. If a flexible socket or brim system is desired, the proximal medial trimline in the ischial area must be more aggressive during casting to allow for the linear shrinkage factor known in most thermoplastics.

A final comment: the manual reflects the accumulated experience of the UCLA staff and includes a section on problem solving the difficulties that might be experienced in the CAT-CAM socket.

Next to speak was Gunther Gehl, C.P., Director of Prosthetic Education at Northwestern University in Chicago. Northwestern has been teaching the NSNA AK techniques of Ivan Long for several years now, and it was Mr. Gehl's task to report to the workshop on NSNA and Long's Line. He said that he and his staff taught NSNA as presented by Ivan Long with no changes. Ivan has been fitting Long's Line, now known as NSNA, for more than 12 years, and his approach has been consistent, with few changes. Perhaps changing the name from Long's Line to NSNA in July, 1985 is the most significant change. Mr. Long has published three technical papers describing his technique: "Allowing Normal Adduction of the Femur in Above Knee Amputees," (*Orthotics and Prosthetics,* December, 1975); "Fabricating the Long's Line Above Knee Prosthesis," (1981); and as a reprint of the Long's Line article with new title, "Normal Shape-Normal Alignment (NSNA) Above Knee Prosthesis," (*Clinical Prosthetics and Orthotics,* Fall, 1985). These articles were the basis for Gunther Gehl's presentation to the International Workshop.

I will attempt to review and highlight the NSNA philosophy as I did the UCLA CAT-CAM. Again, within the limitations of this report, this will only be an overview. With the widespread availability of Ivan's publications, it does not seem necessary to go into details.

NSNA is less detailed regarding evaluation and measurements, placing great emphasis on the wrap cast, subsequent model modification, and alignment, all based on Long's Line, which is defined as a straight line, starting approximately at the center of a narrow socket, passing through the distal femur, and on down to the center of the heel (Figure 7). Long's Line is not always vertical because it shifts constantly when the amputee goes from a standing position to a walking position.

The wrap cast is taken with the patient in a standing position. The important points about the wrap cast procedure are identification of the ischium and proper alignment. The hand will be held to indicate the medial and posterior surface of the ischium, but not forward of the ischium. The amputee then adducts as tightly as possible and extends his thigh to tighten the hamstrings. At this point a lateral reference line is established.

The resultant cast model is oversized and will require considerable modification. Practically all modification will take place on the lateral wall. Following is a brief description of modification goals and resultant trimlines, taken from Mr. Gehl's presentation and from Mr. Long's publications.

1. The lateral wall is to be shaped to give support over a wide area, and particularly the lateral-posterior aspect of the socket.
2. The medial wall will be lower than seat level, and the wrap cast will be the guideline as to how low.
3. Depth of the socket will be the same as the measured length of the thigh.
4. The seat will be at a right angle to Long's Line.
5. Long's Line is drawn from the center of

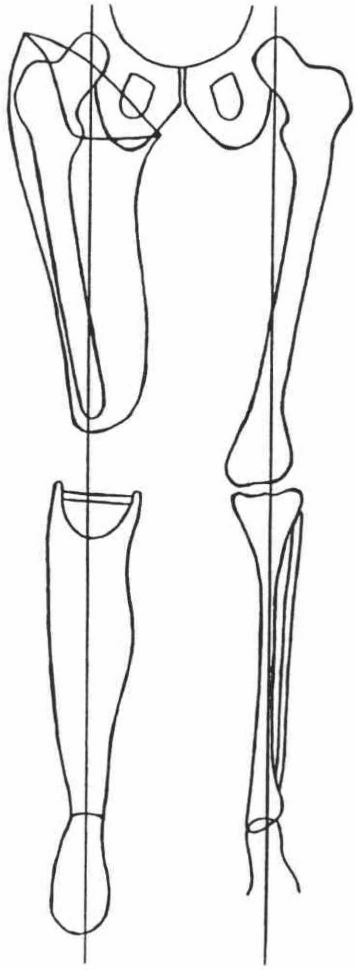
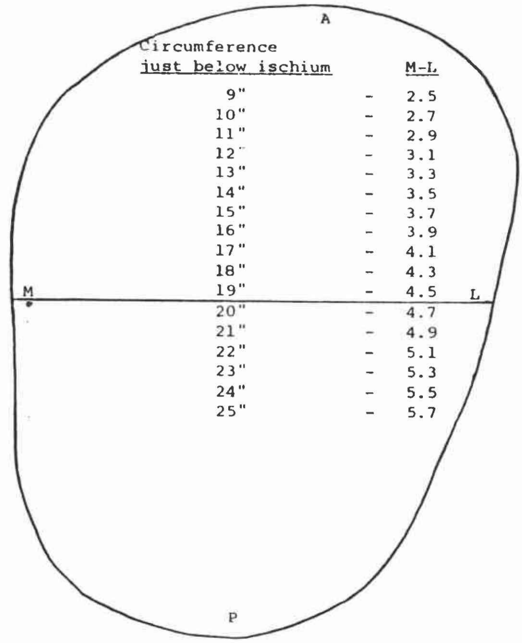


Figure 7. Long's Line.[3]



Circumference just below ischium		M-L
9"	-	2.5
10"	-	2.7
11"	-	2.9
12"	-	3.1
13"	-	3.3
14"	-	3.5
15"	-	3.7
16"	-	3.9
17"	-	4.1
18"	-	4.3
19"	-	4.5
20"	-	4.7
21"	-	4.9
22"	-	5.1
23"	-	5.3
24"	-	5.5
25"	-	5.7

Figure 8. Table of M-L values determined from circumference just below ischium, used in NSNA.[3]

the seat level ML to the center of the distal femur. The distal femur will be very close to the lateral surface, probably only covered by skin.

6. The top 1″ of the medial wall will flare outward at 45°.
7. The lateral wall extends above the trochanter.
8. The ischium will bear on the flare of the socket, both medially and posteriorly.
9. The cast is taken down in the ML as though the trochanter does not exist. In order to achieve the desired ML, many casts will be reduced 2″ or more. The desired ML dimension is taken from Ivan's chart of ML values related to the thigh circumference just below the ischium (Figure 8).

Circumference reductions for suction suspension begin at 1″ of tension proximally, reducing to ¾″, then ½″, with the remaining tensions at ¼″.

Mr. Long does not advocate use of an alignment device. Bench alignment is critical and is based on Long's Line. The center of the lateral wall is marked at seat level for TKA and the vertical reference line established during casting should parallel the TKA line. Long's Line is marked on the posterior of the socket. For the male, the socket is mounted with the inner aspect of the medial wall (which follows the pubic ramus angle) in 30° internal rotation to the line of progression (the outer edge of the medial trimline is on the line of progression), and with the knee bolt axis 4° higher on the lateral side. This is the same as adding 4° additional adduction to Long's Line. For the female, the socket is mounted with the inner aspect of the medial wall in 40–45° internal ro-

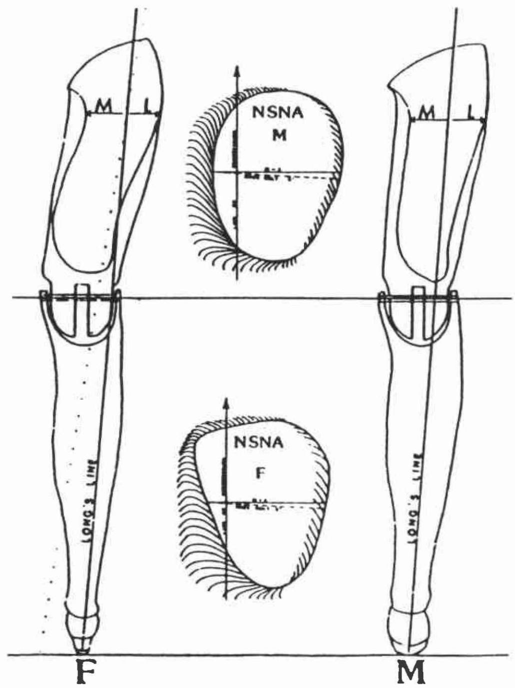


Figure 9. NSNA socket shape and alignment diagram, male and female.[4]

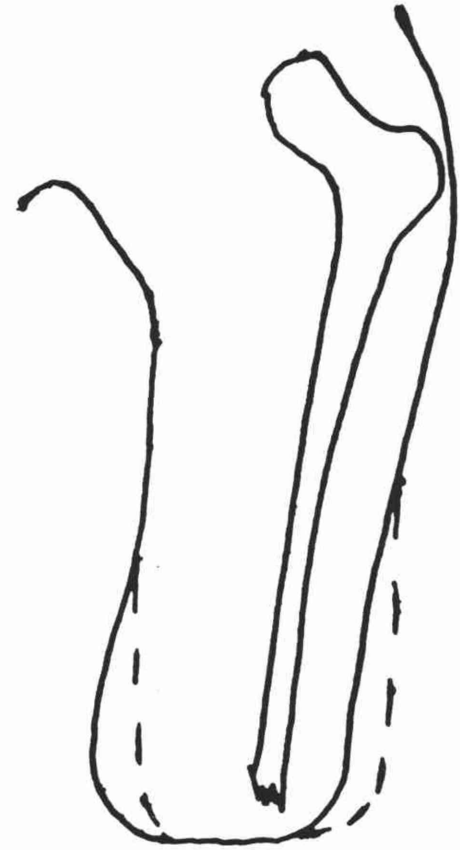


Figure 10. Centralization of the femur, as proposed by Dan Shamp for Narrow ML Socket.[5]

tation to the line of progression (again, the outer edge of the medial trimline is on the line of progression), and with the knee bolt axis 7° higher on the lateral side (Figure 9). Mr. Long emphasizes that it is not necessary to change the alignment. When the amputee is allowed time to adjust to the new prosthesis, then alignment changes will not be necessary.

Following Gunther Gehl was Daniel Shamp, C.P.O., presenting, "The Shamp Brim, For the Narrow ML Above-Knee Prosthetic Socket." Mr. Shamp's system of brim casting and evaluation is currently the content of a special short course offered by New York University's Prosthetic and Orthotic Education Program.

Long and Sabolich, as well as UCLA, advocate that the hand casting technique is the most successful in their experience with the narrow ML, wide AP, or ischial-containment socket for above-knee amputees. In response, Mr. Shamp stated, "Experience with the Shamp Brim system has proven to make the procedure more uniformly successful and more easily learned and applied by the practitioner who has spent years working with the brim method for quadrilateral socket casting and modification." Mr. Shamp went on to present detailed biomechanical rationale for the narrow ML socket. Biomechanical descriptions such as bony lock on the ischium, ischial containment within the socket, retention of normal adduction, etc., are consistently relevant to Mr. Shamp's socket system, as well as all of the latest ischial-containment socket designs. Two noticeably different aspects of Mr. Shamp's technique are (1) the brim forming system itself, which allows for evaluation of brim design under weight bearing conditions before proceeding with the wrap cast, and (2) what Mr. Shamp refers to as centralization of the femur. To accomplish centralization of the femur, during the casting procedure, the prosthetist pulls the distal medial tissue in a lateral direction while stabilizing the femur with the other hand by means of a 45° force against the lateral shaft of the femur (Figure 10). Mr. Shamp stated that this centralization procedure is essential to prevent a large medial-distal bulge with resultant cosmetic problems when the femur is maintained in a position of maximum adduction in the AK prosthesis.

Again, I will present an overview of the Shamp Narrow ML technique, summarizing from Mr. Shamp's presentation and from the "Manual for use of The Shamp Brim," which was provided for the workshop attendees. This manual was produced by Prosthetic Consultants, Incorporated of Akron, Ohio in cooperation with the Department of Prosthetics and Orthotics, New York University Post-Graduate Medical School, and is published by the Ohio Willow Wood Company.

The measurement and evaluation procedure includes a careful observation and recording of the characteristics, lengths, and circumferences requested on the Narrow ML AK Information Chart. Review of this information chart will show the practitioner who is familiar with the technique for the quadrilateral socket that only a small number of measurements are different for the Narrow ML socket. It is important to note that three ML measurements must be taken precisely as follows:

1) Distal Ischial Tuberosity (DIT): firm ML measurement of the anatomy taken 1″ to 2″ distal to the ischial tuberosity (Figure 11).
2) Oblique ML (OB): firm ML measurement taken from the medial side of the ramus of the tuberosity to a point just superior to the greater trochanter of the femur (Figure 12).
3) Ischial Tuberosity ML (IT): firm ML measurement taken from the medial border of the ramus of the ischial tuberosity to the subtrochanteric area of the femur (Figure 13).

The Shamp Brim, which is compatible with the Berkley brim stand, is now set up and adjusted to the patient's measurements. As stated earlier, the brim allows for weight-bearing evaluation of the patient with regard to socket design before the actual wrap cast is taken.

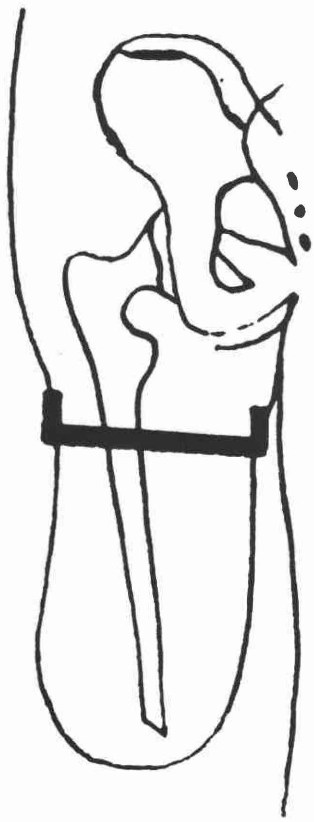


Figure 11. Distal Ischial Tuberosity (DIT), medial-lateral diameter measurement for Narrow ML Socket.[5]

As with all of the ischial-containment socket designs discussed at the Workshop, the location of the ischial tuberosity in the socket is essential to both a comfortable fit and a stable femur in maximum adduction. For the Shamp technique, the ideal location is ½″ inside the medial-proximal wall of the prosthesis and indicates the area referred to as the IT ML measurement. The medial wall has a 45° angle that assists the wedge effect in stabilizing the femur and so the location of the tuberosity on this slope is important. The trimlines are similar to both NSNA and the UCLA CAT-CAM, including the low anterior wall with clearance for the ASIS, the relatively horizontal posterior wall, and the high lateral wall, which extends

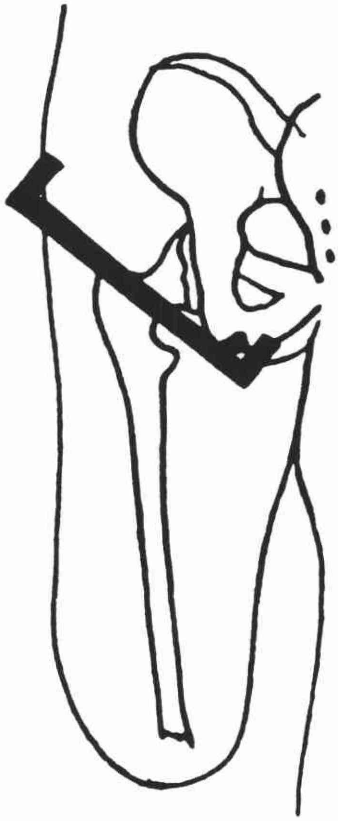


Figure 12. Oblique ML (OB), medial-lateral diameter measurement for Narrow ML Socket.[5]

Figure 13. Ischial Tuberosity ML (IT), medial-lateral diameter measurement for Narrow ML Socket.[5]

generously above the trochanter. Although, not as exaggerated as the UCLA CAT-CAM, the medial wall is lowered as it approaches the anterior wall, allowing for the pubic ramus to pass from within the socket.

Alignment follows generally accepted quadrilateral alignment principles for TKA and knee bolt external rotation. For alignment in the frontal plane (posterior view, ML plane), Mr. Shamp advocates the principles of Long's Line.

Dr. Hans Lehneis, C.P.O., of the Rusk Institute of Rehabilitation Medicine was the next speaker and his presentation covered work done at the Rusk Institute and the New York Veterans Administration. Dr. Lehneis and associates are investigating anatomical, physiological, and biomechanical characteristics of geriatric above-knee amputees in an attempt to develop a set of design criteria for geriatric above-knee sockets. As this project is still in the developmental stages, I will not elaborate on this subject.

Following Dr. Lehneis was Ossür Kristinsson of Iceland. As the developer of the flexible socket-rigid frame system, he was the first to speak on flexible sockets. Mr. Kristinsson reported that he was continuing development of flexible sockets, including walls and brims. He is conducting an extensive materials search in hopes of finding the materials that will make possible the ultimate flexible socket design.

Mr. Kristinsson went on to say that we need some simple definition of flexible socket characteristics. "To label a socket as flexible, I would say that you should be able to deform it by your hands, and the material should not be elastic enough to stretch under the loads it will be subjected to." Concerning flexible socket design, Mr. Kristinsson stated, "When designing a flexible socket system, the most critical aspect for the comfort of the wearer is how the frame is designed. It has to be capable of supporting the flexible socket, preventing permanent deformation, and the socket-frame combination has to be structurally strong and stable enough to counteract the reaction forces." Mr. Kristinsson made a final, important point: "There may be doubt among professionals and users about the value of the flexible wall. I am, however, totally convinced that the flexible socket is here to stay. If anything, I think it will get more flexible as we gain access to more suitable materials than we are using today, and some obstacles on the way to proper understanding of the socket-stump interaction are overcome."

Continuing the flexible socket presentations was Norman Berger of New York University's Prosthetic Orthotic Program. Mr. Berger's presentation was the ISNY (Icelandic-Swedish-New York) flexible socket design as taught by NYU. Mr. Berger described the socket and frame fabrication technique used in the ISNY. Three interesting points are worthy of mention:

1. The flexible socket is fabricated with polyethylene, which has a known shrinkage factor.
2. The desired wall thickness of the flexible socket is 60/1000″.
3. Lateral distal support for the femur is not provided for by the frame.

The final presentor on the topic of flexible sockets was Charles Pritham, C.P.O. of Durr Fillauer Medical Company. A co-author and co-developer of Durr-Fillauer's flexible socket technique, Mr. Pritham described the biomechanical function of the flexible walled ischial-gluteal bearing quadrilateral socket as follows:

1. Ischial/gluteal weight bearing;
2. Stabilization of the distal femur laterally;
3. Total contact; and
4. Flexible walls.

Note the mention of stabilization of the distal femur laterally; this is provided for by the frame design of the Scandinavian Flexible Socket. Mr. Pritham went on to say, "It will be appreciated that the design is actually not fundamentally different, flexible walls aside, from a similarly designed socket in the rigid walls. Indeed one of the factors that undoubtedly hastened its acceptance was the fact that previously learned methods of casting and fitting quadrilateral sockets were fully acceptable when fitting a flexible walled socket. While the advantages cited are formulated with the quadrilateral socket in mind, there is no reason to suspect that they are significantly different from non-quadrilateral above-knee sockets. Indeed, flexibility is often considered by the designers of one another of the various designs as an integral factor in their success."

Mr. Pritham listed advantages of flexible walled sockets as:

1. Flexible walls;
2. Improved proprioception;
3. Conventional fitting techniques;
4. Minor volume changes readily accommodated;
5. Temperature reduction; and
6. Enhanced suspension.

Indications for use of the flexible wall socket are:

1. Mature stumps (where frequent socket changes are not anticipated);
2. Medium to long stump (where a significant portion of the wall will be left exposed and flexible); and
3. Suspension is not a factor.

While the use of flexible wall sockets has been well accepted, Mr. Pritham pointed out that questions have arisen in at least three areas.

Material

Both Surlyn® and low density polyethylene (in a variety of types and name brands) have been used successfully and each has its advocates. Mr. Pritham and colleagues at Durr Fillauer prefer Surlyn® for three reasons: clarity, no shrinkage, and ease of rolling the edge.

Thickness

Originally socket walls of 30/1000″ thickness were specified, however, this proved to lack durability. Subsequently, thickness in the neighborhood of 80–90/1000″ were specified and are preferred. (Note: NYU prefers 60/1000″.)

Frame configuration

At least three different configurations have been described for quadrilateral sockets. The differences center on the lateral wall and the amount of support considered necessary for the femur.

A variety of designs have been put forth in order to achieve specific features in non-quadrilateral sockets, including the well known total flexible brim.

Mr. Pritham concluded his presentation by saying, "the crucial point would seem to be that flexibility is independent of socket shape and can be modified to provide specific design features in a socket-frame system. The specific configuration depends upon the prosthetist's experience and fitting philosophy and the needs of the individual patient."

Rounding out the first day of presentations was Dr. Robin Redhead, Senior Medical Officer at the Roehampton Limb Fitting Centre in London. Dr. Redhead's paper was entitled "Experience With Total Surface Bearing Sockets." This presentation centered more on weight-bearing distribution and biomechanics than on socket design or shapes. Dr. Redhead and associates maintain that regardless of socket shape or design, well distributed weight-bearing can eliminate the need for single point, bony weight bearing (such as ischial weight-bearing). This system of well distributed weight-bearing was referred to as a total-surface-bearing socket. It infers a hydrostatic type of socket fit utilizing the incompressibility of the fluids in an above-knee residual limb.

This presentation brought a reaction from of Professor Radcliffe, who doesn't agree with the hydrostatic concept of weight-bearing in prosthetics. He stated that "you need a closed system for hydrostatics and the AK residual limb is not a closed fluid system. With an open fluid system, the fluids are pushed out."

There was considerable discussion on this topic, both pro and con, and it was never resolved.

Beginning the morning of the second day, John Sabolich, C.P.O., from Oklahoma City, and Glenn Hutnick, C.P., from New York, presented another view of CAT-CAM. As stated earlier, Tim Staats, C.P.O. reported that the UCLA CAT-CAM is evolving independently of the CAT-CAM technique of the original developers.

Sabolich and Hutnick report that the original CAT-CAM is continuing to evolve and develop. Sabolich stated that, "it took five to six years to develop the current medial wall design, which has become increasingly more aggressive in enclosing and capturing the ischial ramus." They advocate use of the total flexible brim. "The key is the flexible brim system—it is totally flexible in the proximal area, where most patients complain." Aside from 100% use of the total flexible brim, the Sabolich/Guth CAT-CAM differs from NSNA and the UCLA CAT-CAM by not advocating the 4° to 7° medial lean of the foot, pylon, and knee bolt in bench alignment as proposed by Long and UCLA. John Sabolich went on to say "this additional adduction or tilting of the knee bolt is a cover-up for lost stability due to inadequate ischial containment." Mr. Long's response was that this was incorrect. Probably the most noticeable aspect of design that separates the Sabolich/Guth CAT-CAM apart from the other recent ischial-containment designs is the earlier mentioned aggressive capture of the ischial tuberosity and ramus. Sabolich claimed that they are enclosing more and more of the ischial ramus, as much as possible and still allow pubic ramus comfort. This ramus enclosure provides two biomechanical functions: (1) a medial bony stop for ML stability, and (2) rotational control, especially on soft fleshy residual limbs. Other than these departures, the Sabolich/Guth CAT-CAM differs very little from the UCLA CAT-CAM, especially in terms of brim shape, trimlines, and biomechanics. Sabolich, unlike Long, does advocate the use of dynamic alignment devices.

At this point in the Workshop, Professor Radcliffe returned to the podium in an attempt to present and clarify the comparative biomechanical principles of both quadrilateral and ischial-containment sockets. The following biomechanical analyses are taken from Professor Radcliffe's discussion and from the paper he later submitted reviewing his presentations.

"It has been demonstrated that pressure against the medial aspect of the pubic ramus can be used to supplement the weight-bearing on the tuberosity of the ischium and contribute to medial stabilization in the upper one-third of the above-knee socket. In taking advantage of the weight-bearing potential on the medial aspect of the ramus, the prosthetist is creating a situation much like weight-bearing 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. The soft tissue must be accommodated. Therefore, the A-P dimension is correspondingly increased as compared to the quadrilateral socket. As compared to the quadrilateral fitting, the height of the anterior brim is typically lowered and flared and the gluteal area is filled in and fitted higher as a result of the ischium being encased deeper into the socket."

"The medial brim of the socket must slope forward and downward to the point where the pubic ramus crosses the medial brim and emerges from the socket. The 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 flared 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."

"The adduction of the socket and the use of lateral stabilization should not differ from that achieved by a properly fitted quadrilateral socket. There is an apparent exaggeration of the modification of the lateral wall, but this is primarily limited to the area just below the trochanter where the M-L dimension has been reduced to insure that the encased pubic ramus and ischium are maintained in the desired position on the medial brim. The exaggeration of the medial flare and reduction of the M-L dimension in the upper third of the socket leads to the impression of a greater angle of femur adduction, but the actual angle of the femur should be similar in both types of fittings if the quadrilateral socket is properly fitted and aligned."

"Long's Line as proposed by Ivan Long is the anatomical axis of the lower extremity as described in anatomy textbooks. Placing the femural stump in an advantageous position for normal use of the hip musculature by adduction and flexion of the socket has been a part of good prosthetic practice for at least 40 years in the United States and perhaps longer in certain European centers. Mr. Long's Line appears to be most useful in the cast taking procedure and subsequent modifications of the model rather than have any fundamental bearing on the alignment of the prosthesis. It appears to offer no new concepts useful in the bench or dynamic alignment of the prosthesis."

Professor Radcliffe told the Workshop attendees that the use of "catchy names" should be avoided, and he therefore proposed the terminology of Ischial-Ramal weight-bearing socket, as well as Ischial-Gluteal weight-bearing socket.

Professor Radcliffe continued his biomechanical analysis by saying "The biomechanics of the ischial-ramal weight-bearing socket are similar to the ischial-gluteal weight-bearing quadrilateral socket. The major differences are in the manner in which the ischium is maintained in position within or on the brim of the socket. In each case, there must be vertical support with a combination of lateral and anterior counterpressure to maintain the ischium in position" . . . "Some of the socket shape diagrams I have seen published are so crude and inaccurate as to be almost meaningless. The level of the cross section shown is often not indicated and a section at ischial level is sometimes compared to a section which is obviously higher or lower." Professor Radcliffe then sketched on the blackboard what he believed to be a more accurate comparison with emphasis on the three-dimensional shape both above and below the level of the tuberosity of the ischium. In each case, he showed a cross section of the socket at, (1) ischial level with the medial wall projected upward to this level; and (2) the outline of the highest points on the brim (Figures 14 and 15).

This concluded all presentations of current fitting techniques. The remaining presentations were concerned with evaluation techniques. Bo Klasson of Een-Holmgren Company in Sweden

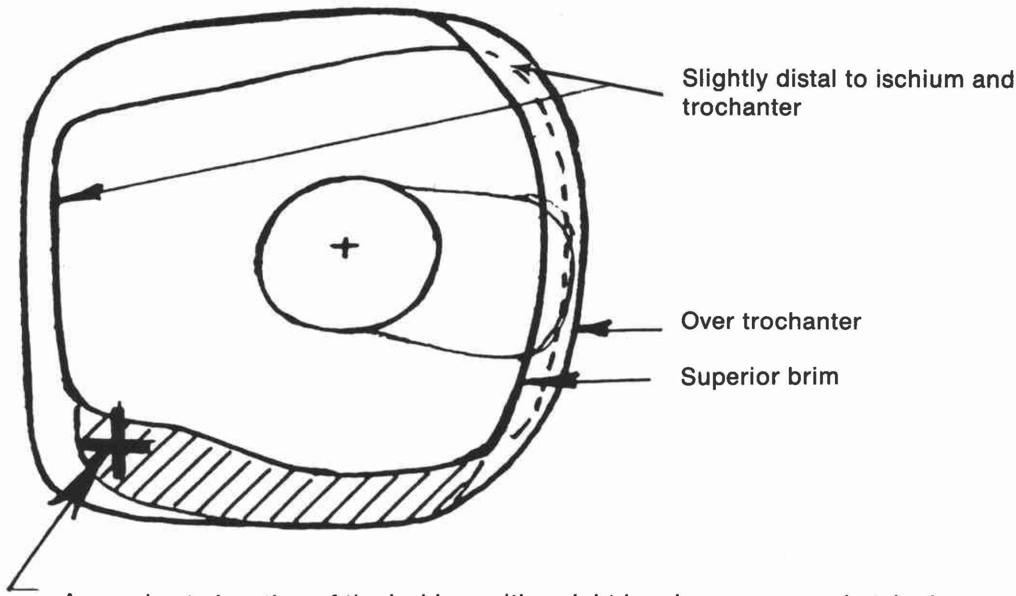


Figure 14. Socket contours for an Ischial-Gluteal weight-bearing socket using the UC Berkeley Brims.[6]

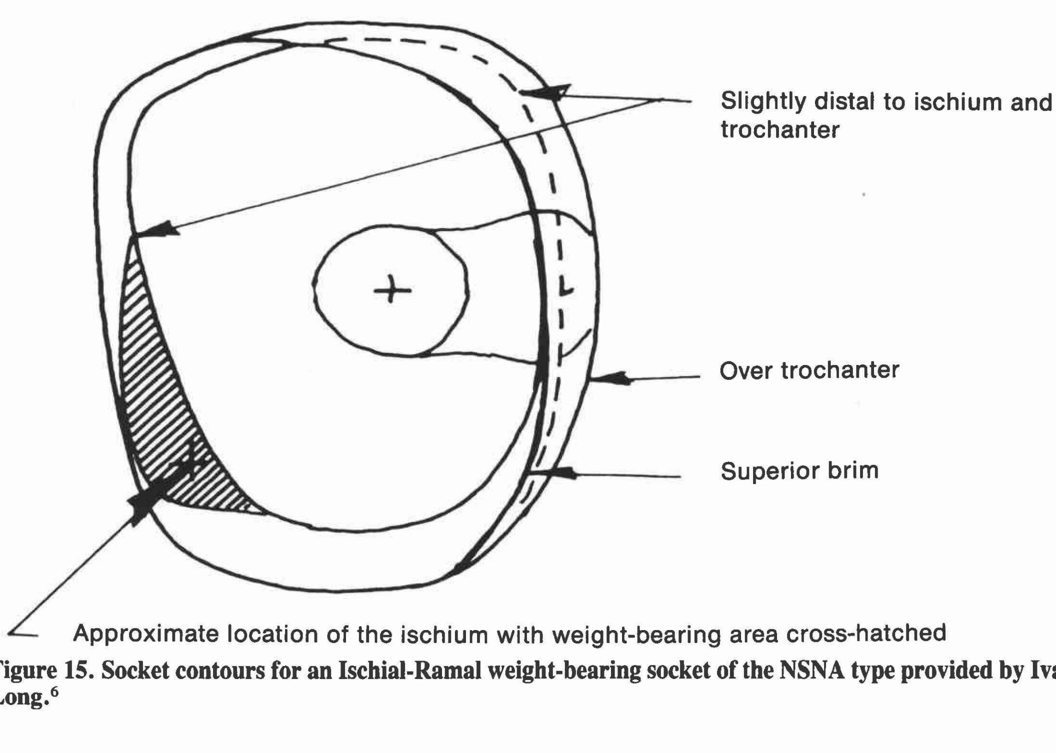


Figure 15. Socket contours for an Ischial-Ramal weight-bearing socket of the NSNA type provided by Ivan Long.[6]

presented on "Socket Fit With Reference to Soft Tissue Force Transmission." Briefly, Mr. Klasson's theory is that we should attempt to design sockets with physical characteristics that match the physical characteristics of the residual limb. In other words, where the tissues of the residual limb are firm, so should the matching area of the socket material be; where the tissues are soft and flexible, so should the socket be. Mr. Klasson refers to this as "surface matching."

The next speaker was Professor George Murdoch of Dundee, Scotland, presenting "A Method for the Description of the Amputation Stump." Professor Murdoch's paper was based on his premise that there is a need for an international classification system for residual limbs to be developed in order to compare one publication with another, one patient with another, one fitting technique with another.

The final presentation was made by A. Bennett Wilson on "Physiological Monitoring Equipment in Evaluation of Lower Limb Prosthetic Components and Techniques." He reported on a system of physiological monitoring originally developed by MacGregor of the University of Strathclyde in the 1970's. Recently modified for use by the University of Virginia Division of Prosthetics and Orthotics, this system consists of a compact tape recording component worn on a waist belt that records electronically, step count, walking velocity, standing versus sitting, and heart rate, plotted against time up to 24 hours. The tapes are then analyzed by a special micro-computer program, which subsequently prints the information in digital and graphic format.

Under some circumstances the heart rate data can be useful in providing an energy index, but probably more importantly, the step count, standing versus sitting, and velocity data provide specific information about the activity of the subject. Mr. Wilson and colleagues have recently developed a solid state device which is less costly and more reliable. The new system has 17 information gathering channels. Mr. Wilson concluded by saying, "At this point, we do not have sufficient experience to know how many subjects have to be monitored and how much data is needed to show significant differences, but it certainly appears that at last we have a breakthrough in instrumentation for evaluation of prosthetic devices and other treatments involving the function of the musculoskeletal system.

With all presentations complete, the plenary group was divided into six panels of six to nine members with the following charges:

1. Determine similarities
2. Determine differences
3. What is the role of flexible walls?
4. Indications and contraindications
5. Recommendations for future action
   a. Evaluation
   b. Education
   c. Application

This first group of panels reported back on Sunday morning. The reports were quite consistent among the different panels. A synopsis of these reports will be presented in concluding this report.

On Monday, new panels were formed to restudy the rationale for and possibly develop protocol for evaluation. The reports from this second group of panels was heard in plenary session on Tuesday morning.

The meeting was adjourned Tuesday, May 19, 1987 at noon.

What follows here is a synopsis of the conclusions and recommendations of the panel reports.

I. Similarities & Differences

A. *Biomechanics*

1. Ischial Containment:
   a. similarities:
      –all ischial containment sockets advocate and utilize varying degrees of ischial containment
   b. differences:
      –quads do not utilize ischial containment
      –ischial containment sockets, amount of ischial containment
2. Weight Bearing Distribution:
   a. similarities:
      –ischial containment sockets, combination of ischial tuberosity and ramus, and peripheral (soft tissue)

b. differences:
   –quads, ischial-gluteal weight bearing
3. ML Stability—maintenance of adduction
   a. similarities:
      –goal of all AK socket systems
      –greater success and maintenance in ischial containment sockets due to ischium acting as bony stop or lock
   b. differences:
      –quad, soft tissue lock only, no bony lock
      –less successful maintenance of adduction, thus less ML stability
4. Socket Shape—ischial level cross section
   a. similarities:
      –ischial containment sockets, narrow ML, wider AP, concave post-trochanteric shape
   b. differences
      –quad, wider ML, narrower AP
5. Trimlines:
   a. similarities:
      –ischial containment sockets, generally; especially anterior, posterior, and lateral wall trimlines
   b. differences:
      –quads, especially higher anterior, lower posterior and lateral wall trimlines
      –medial wall of CAT-CAM
6. Suspension:
   a. similarities:
      –all compatible with suction
   b. differences:
      –ischial containment sockets, unclear about auxiliary suspension
7. Alignment:
   a. similarities:
      –all but NSNA utilize alignment devices
      –ischial containment sockets, medial wall not on line of progression
      –NSNA & UCLA CAT-CAM, tilting of knee bolt in bench alignment
      –Shamp Narrow ML & NSNA, use of Long's Line
      –ischial containment sockets, TKA bench alignment, socket midline
   b. differences:
      –NSNA does not use dynamic alignment device
      –quad medial wall on LOP
      –not all tilt knee bolt
      –NSNA, varying degrees of knee bolt tilt, 7°, female, 4°, male
      –quad, bench alignment, more stable TKA, T reference point is located at posterior ⅓ of socket
8. Rotational Control:
   a. similarities:
      –ischial containment sockets, bony lock of Ischium and post-trochanteric concavity
   b. differences:
      –quad, muscular-soft tissue cross-section

B. *Method of Obtaining Cast*
   a. similarities:
      –quad and Shamp Narrow ML utilize a casting brim
      –UCLA CAT-CAM & Sabolich/Guth CAT-CAM, hand molding technique
      –NSNA & UCLA CAT-CAM, standing
   b. differences:
      –CAT-CAM & NSNA, hand molding technique
      –Sabolich/Guth CAT-CAM, sometimes cast lying down

C. *Anatomical Considerations*
   1. UCLA CAT-CAM detail about pelvic differences:
      – ischial inclination
      – pubic arch angle
      – ilio-femoral angle
   2. NSNA male, female alignment differences:
      – bolt tilt

II. Role of Flexible Walls
   – not linked to any one philosophy of designing an AK socket
   – vital to the success of the Sabolich/Guth CAT-CAM

- improved sitting comfort
- improved proprioception
- better heat dissipation
- improved muscle activity
- reduced weight
- ease of socket change within frame, no loss of alignment
- enhanced suspension, if suction suspension

All participants agreed there is great need for improved flexible materials.

III. Indications and Contraindications

- there were no specific contraindications noted for any socket design
- some advocated not changing successful quad wearers
- quads are most successful on long, firm residual limbs with firm adductor musculature
- ischial containment sockets are more successful than quads on short, fleshy residual limbs
- ischial containment sockets are the better recommendation for high activity/sports participation/running
- lack of agreement on best recommendation for bilateral above-knee

IV. Recommendations

The panels' conclusions and recommendations were remarkably consistent. Most consistent was the recommendation for improved terminology, lumping what I have referred to as ischial containment into a single, workable term. Suggestions ranged from "Narrow ML" to Ischial/Ramus Containment (IRC) and Non-Ischial Containment (Non-IRC). Due to time constraints, arguments about this recommendation were never resolved. It is hoped that all recommendations can be addressed in a future workshop or through some other form of action.

A. *Evaluation*

There was unanimous agreement for formal evaluation of the newer above-knee techniques (NSNA, CAT-CAM, Shamp Narrow ML) as well as evaluation of implications of the inferiority of the quadrilateral technique.

1. A program for scientific/laboratory evaluation should be set up at a center or multiple centers, depending upon resources. This study might include: cinematography, force plate, motion analysis, gait mat and other "gait lab" studies as well as radiographical data on alignment and containment, physiological data, residual limb/socket force analysis, and/or any other relevant laboratory studies.
2. A program of clinical evaluation, based on previous fittings and continuing fittings in clinics already utilizing new fitting techniques. This would be a more subjective study, and would require a greater effort for coordination and pooling of data.
3. Complete manuals should be developed for each individual technique, unless the developers can find it mutually agreeable to work together and blend the new techniques. The panels found the latter option to be most desirable.
4. Evaluation should be independent of the developers.
5. Any evaluation needs to be coordinated by an authoritative group. ISPO and/or the U.S. Veterans Administration were recommended. The American Academy of Orthotists and Prosthetists should also be involved.
6. Possible funding sources within the states include the Veterans Administration and the National Institute on Disability and Rehabilitation Research (NIDRR).

B. *Education*

The post-graduate, specialized courses for experienced practitioners appear to be most appropriate for teaching these newer techniques at this time. Incorporation into entry level education programs should follow as well written, experience based manuals are developed. Any teaching course should include "hands-on", patient contact, fitting, and management as part of the curriculum.

C. *Application*

The application of these new techniques, while certainly not as widespread and accepted as the quadrilateral technique, or even the flexible socket technique, is occurring at this time. Growing acceptance and application will most certainly follow. It is hoped that this workshop, as well as future workshops, will aid in safe and proper application of these and future advances and developments in prosthetics.

References

[1] UCLA AK Teaching Manual, 1977–1978.

[2] *UCLA CAT-CAM Above Knee Prosthesis,* Teaching Manual, Third Edition, March 1987.

[3] *Fabricating The Long's Line Above-Knee Prosthesis,* by Ivan long, 1981.

[4] Ivan Long's business card.

[5] *Manual for use of THE SHAMP BRIM for the Narrow ML Above-Knee Prosthetic Socket,* The Ohio Willowwood Co., 1987.

[6] By Charles Radcliffe. Re-drawn by A. Bennett Wilson, Jr.

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