Clinical Prosthetics & Orthotics

New Concepts in AK Sockets

Volume 9, Number 4 Fall, 1985

The Academy would like to gratefully acknowledge the contributions of the individuals below whose generosity helped make possible the publication of this issue of *Clinical Prosthetics and Orthotics*.

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Clinical Prosthetics & Orthotics

Clinical Prosthetics and Orthotics (ISSN 0279-6910) is published quarterly by the American Academy of Orthotists and Prosthetists, 717 Pendleton St., Alexandria, VA 22314. Subscriptions: $15.00 domestic, $20.00 foreign, $30.00 air mail. Second-class postage paid at Alexandria, Virginia and additional mailing offices. POSTMASTER: Send address changes to *Clinical Prosthetics and Orthotics,* 717 Pendleton St., Alexandria, VA 22314.

TO: ORTHOTISTS AND PROSTHETISTS
FROM: EDITOR, *CLINICAL PROSTHETICS AND ORTHOTICS*
RE: INVITATION TO CONTRIBUTE TO THE *C.P.O.*

As professionals, we are obligated to do what we can to advance the state-of-the-art and share new developments with our colleagues. The most efficient way to transfer information, and the way that has the greatest impact, is through the written word. But, for many professionals, writing is a task that often becomes monumental to the point that we succumb to inertia. Writing, however, is not such a monumental task if we break it down into smaller, simpler tasks which we can complete one at a time.

The initial and most difficult problem every writer faces is how to organize the material. The quickest way to organize material is through use of an outline. In its most basic form, an article is divided into three parts—introduction, body, and conclusion. The introduction states the subject and gives pertinent background information that is necessary in order to understand the topic. The main body of the article then presents the topic in as much detail as possible. At the heart of every article is the intent to inform and answer a variety of questions. The body can include subheads, such as review of literature, method, clinical materials, discussion, and results. The conclusion restates the main points presented in the article.

Clinical Prosthetics and Orthotics addresses broad, philosophical issues, and as such invites a more subjective style. Each issue of *C.P.O.* centers on a main topic. Usually, an issue will contain a lead article, an editorial, and one or more technical articles pertaining to the topic. Authors are solicited by the Academy editorial board; however, *C.P.O.* also accepts unsolicited articles. Unsolicited articles need not cover the topic at hand and may be of a more technical and objective nature. All articles are submitted to the editor, a professional in the field, who checks every article for accuracy, terminology, format, and references. The articles are then forwarded to the publications staff at the Academy National Headquarters for production and printing.

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Volume 9, Number 4 **Fall, 1985**

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From the Editor:

Opinions expressed in *Clinical Prosthetics and Orthotics* are solely those of the authors. No endorsement implied or explicit is made by the editoral staff, or by the American Academy of Orthotists and Prosthetists.

Letter to the Editor

Dear Editor,

I have read in detail the Summer issue of *Clinical Prosthetics and Orthotics* and find it to be an excellent treatise on the current advanced clinical practice in lower-limb prosthetics along with references to current development work that is apt to affect further clinical practice. All concerned are to be congratulated, with special recognition going to the editor for putting it all together in a coherent package.

In reading the various articles, several thoughts come to mind that may be of interest to the Academy as a body and to members as individuals.

First, it seems so obvious that an effective clinical evaluation program is needed to sort out the relative values of the new devices and techniques that are emerging from the various research and development efforts. Both NIHR and the VA have come to realize that an effective clinical evaluation program would accelerate progress and result in a more efficient use of both research and service funds, but unfortunately neither group seems to be able to carry out the tasks needed. NIHR doesn't seem to be interested in prosthetics and orthotics and the VA program hasn't in nearly two years been able to complete one project. Even if the VA in-house program does become efficient, there is so much work that needs to be done that there is still need for another effort. The Academy is the natural body to conduct this work, and I believe it could carry out this task more efficiently than any other group.

A second item that comes to mind is the lack of reference to the need for improved techniques for achieving the best alignment for individual patients. I feel that this is an area that needs attention, but I know of no work going on in this country on alignment and fail to see any value in the work going on in Great Britain.

All in all, I believe that this issue will provide the inspiration for those who are using advanced practices and for research personnel to continue to forge ahead as well as provide encouragement to other practitioners to investigate new procedures as they emerge from research and development efforts.

Sincerely,
A. Bennett Wilson, Jr.
Associate Professor

From the Editor:

In the Summer, 1985 issue of *Clinical Prosthetics and Orthotics* (Volume 9, Number 3), the Academy featured a series of articles by members of the staff of Newington (Conn.) Children's Hospital and others, on various aspects of gait analysis. The excellent articles these authors produced will greatly enhance the existing body of knowledge on gait analysis.

While space considerations did not allow us to list each author in the series on the front cover of the issue, we do wish to acknowledge the many hours of work and research by James R. Gage, M.D.; Ramona Hicks, R.P.T., M.A.; Scott Tashman, M.Eng.; David J. Jendrzejczk, C.P.; David E. Krebs, M.A., P.T.; and Robert S. Lin, C.O.—as well as their support staff.

These contributions by such dedicated professionals can only add to the stature and prestige of *Clinical Prosthetics and Orthotics*. The Academy and Editorial Board thank the authors for their submitted articles.

Charles H. Pritham, C.P.O.
Editor
Clinical Prosthetics and Orthotics

Editorial

Basic Changes in Lower Limb Prosthetics

by Alvin L. Muilenburg, C.P.O.

After several years of very little change in above knee amputee fitting, we now have a *C.P.O.* issue with four papers on current advanced clinical practice in lower limb prosthetics. Some of these advances can be brought into use without too much difficulty while others require much more training and careful follow-up.

The techniques that involve materials and fabrication are usually not too difficult to try. But even changes in these techniques can give us problems that we didn't expect, and require extra caution during initial use.

Alterations of socket shape to adapt to more difficult amputations or congenital deficiencies is something where we also look for improvements. Papers that are written giving experience and suggestions on how to solve these problems give us help that is needed in our day to day fitting. This usually does not alter our basic method of alignment and cast model alterations.

The discussions concerning basic changes in socket shape and alignment cause us much more concern by whatever name they may be given. There is a new way to fit an AK amputation, that is certain. I cannot question the results; patient acceptance has been proven.

New information, however, does not always come easily. These new methods have been brought to the public view only through a considerable amount of publicity, which then stimulates us to get more information. Traditionally information and results have been passed on from one prosthetist to the other; usually by visiting the developers and exchanging new ideas.

Educational institutions have provided a valuable learning ground. U.C.L.A. had a one week course in March and a few seminars have been held elsewhere. However, many details on how to teach the new methods have created controversy. We must support our educational institutions and help them to determine what should be taught.

I believe we need a working group of a few prosthetists who are already involved in the new methods to develop guidelines for teaching. Perhaps the Academy could organize this. Clinical evaluation programs have been discussed but communication between prosthetists involved seems to have adequately covered that area.

I want to express my appreciation to the publishers in this issue for all the work that has been done. Having this information published enables us to sort it out and make better decisions on improving our own care of the AK amputees.

Editorial

Beyond the Quadrilateral

by Hans Richard Lehneis, Ph.D., C.P.O.

Earlier this year I had the pleasure to be invited to the Academy Midwest Chapter Symposium entitled, "AK Design Principles: Beyond the Quadrilateral." I found the latter half of the title so intriguing and expressive of contemporary thinking and rethinking in AK socket prosthetics that I chose it as the title of this commentary. I hope that the organizers of the Chicago Symposium do not mind my borrowing this title.

One of the earliest and major break throughs in AK socket design in this century was the concept of ischial weight bearing. At first glance this appears to be a sound approach and certainly one that has improved general comfort over other sockets. If, however, one analyzes that concept more closely, i.e., biomechanically, it becomes clear that ischial weight bearing is not a reality through all phases of gait. It must be appreciated that the socket and, thus, the prosthesis as a whole during walking is controlled by movement emanating from the center of rotation of the residual hip joint. At heel strike, when the hip is flexed, the distance from the ischial tuberosity to the ischial seat of the socket increases with the angle of hip flexion (Figure 1). Obviously, at this point in the gait cycle, there cannot be any ischial weight bearing. Yet, the need to support weight is greater than at any other point during locomotion. Body weight, plus the force of impact must be transmitted. How is this possible without direct skeletal support?

I believe that, by what in German is called "verspannung" of the musculature, a stable interface is achieved. This is a phenomenon which every AK amputee must learn to prevent the prosthetic knee from buckling.

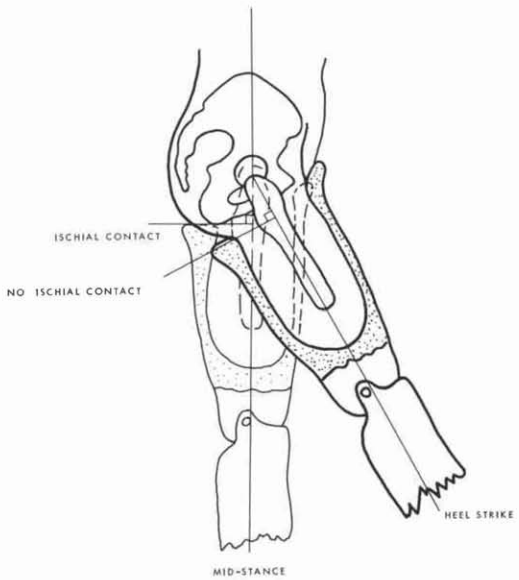

Figure 1.

Unlike normal locomotion in which there is phasic interaction of the musculature to produce controlled hip and knee flexion (eccentric contraction), the AK amputee must learn out-of-phase contraction of the hip musculature, i.e., the hip joint must produce an extension moment prior to heel strike so that the knee joint is in full extension at heel strike. Such muscular activity causes "verspannung," an increase in cross sectional volume, which in turn increases the tangential forces in the socket to equal the vertical forces generated at this point in the gait cycle.

While it is clear that reasonably comfortable ischial weight bearing is indeed possible in the midstance phase, ischial weight bearing cannot

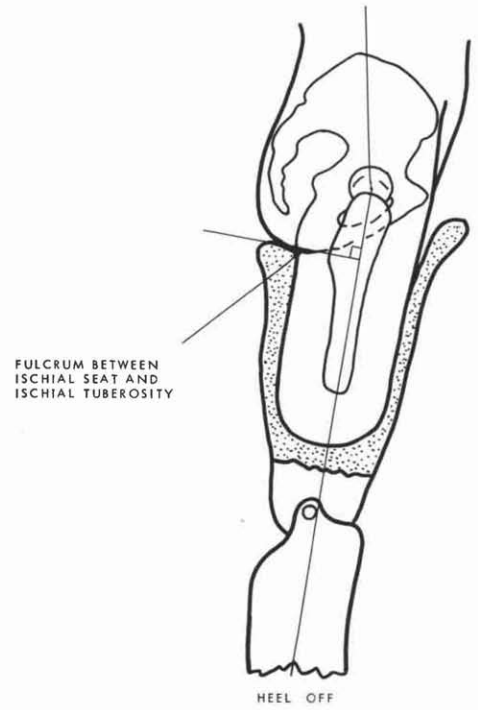

Figure 2.

be comfortably maintained at heel off. When the hip joint is extended, the perpendicular distance between the axis of rotation of the hip and the ischial seat of the socket is less than in the mid-stance phase (Figure 2), yet the distance from the hip joint to the ischium remains constant throughout all phases. Thus, hip extension causes increasing pressure on the ischial tuberosity, which now becomes the fulcrum about which the prosthesis tends to rotate. This results in the stump being pulled out of the socket, gapping of the anterior brim, elevation of the body on the involved side, and discomfort. Clinically, prosthetists have relieved this problem by increasing the radius of the anterior portion of the ischial seat. This maneuver allows the socket and seat to move posterior to the ischium as the hip is extended.

Personally, I have always advocated that the ischial seat is sloped forward and downward such that it is tangent to a radius from the hip joint to the ischium (Figure 3). This not only increases comfort at heel strike, since it reduces the sharpness of the anterior portion of the ischial seat, but at heel off, it allows the ischial tuberosity to be inside the socket and pressure

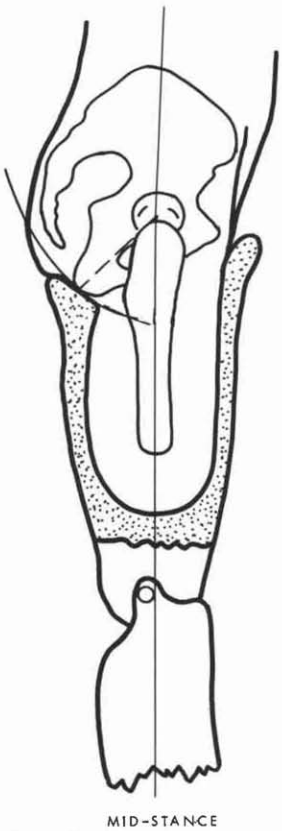

Figure 3a.

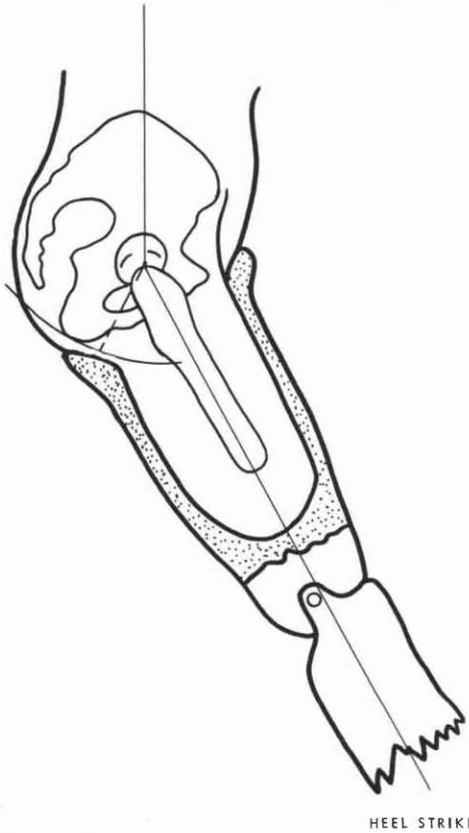

Figure 3b.

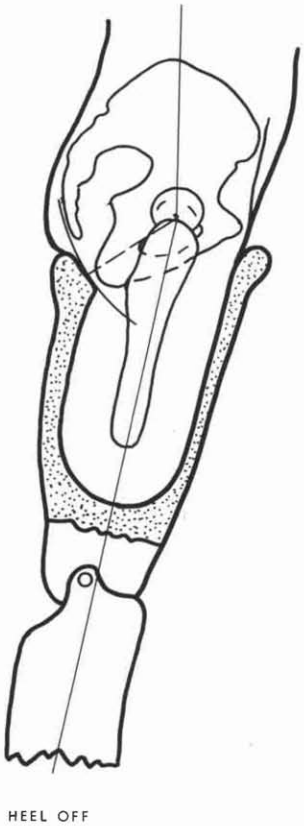

Figure 3c.

to be transferred to the much larger part of the ischium and gluteus maximus. Placing the ischial tuberosity on the anterior portion of the ischial seat also results in greater comfort, since it reduces skin tension in that area.

While one might argue that placing the ischial tuberosity squarely on the seat was a necessity with open-end sockets; it is amazing that this theory continued to persist past the advent of total contact sockets. Under certain conditions, Pascal's law may be applied to total contact sockets, i.e., a hydrostatic condition exists which would eliminate the need for ischial weight bearing. In other words, the quadrilateral shape of AK sockets has remained unchanged despite the fact that total contact has resulted in a different application of the laws of physics which makes ischial weight bearing less important than originally conceived.

Practitioners familiar with the fitting of prostheses to patients with Proximal Femoral Focal Deficiency (PFFD) know that the quadrilateral socket is inappropriate for these patients. A more appropriate socket shape resembles that of a flower pot in which the ischium is contained within the socket. In addition, the largest patient population for which the quadrilateral shape must be revised is the geriatric AK amputee. These patients, as a rule, become amputees due to Peripheral Vascular Disease (PVD), often compounded by diabetes. They usually present diminished sensation, reduced muscle tone, poor skin quality, and sometimes senility. Generally, they suffer from great discomfort when fitted with a prosthesis. Although most of this can be ascribed to the problems presented, it appears that some of this discomfort is due to the quadrilateral socket shape, particularly when the patient is provided with a manual knee lock. Unlike amputees who are fitted with an open knee and who must, and are able to, contract the residual muscles prior to heel strike, the geriatric amputee with a manual knee lock simply steps on the prosthesis. This simulates the effect of stepping on a rake (Figure 4). As a result, the tissue below the ischium is compressed (poor muscle tone), resulting in excessive skin tension, anterior proximal gapping of the socket, and the ischium to be far posterior to the socket.

In summary, it seems to me that in light of the change in patient population (overwhelmingly geriatrics) with all the physical problems they present, one should, indeed, think beyond the quadrilateral. One should also note that with the advent of total contact, the concept of ischial weight bearing needs to be re-visited and re-assessed. Designs such as CAT-CAM and work supported by the Veterans Administration at the Rusk Institute of Rehabilitation Medicine hold promise to go beyond the quadrilateral to improve patient comfort.

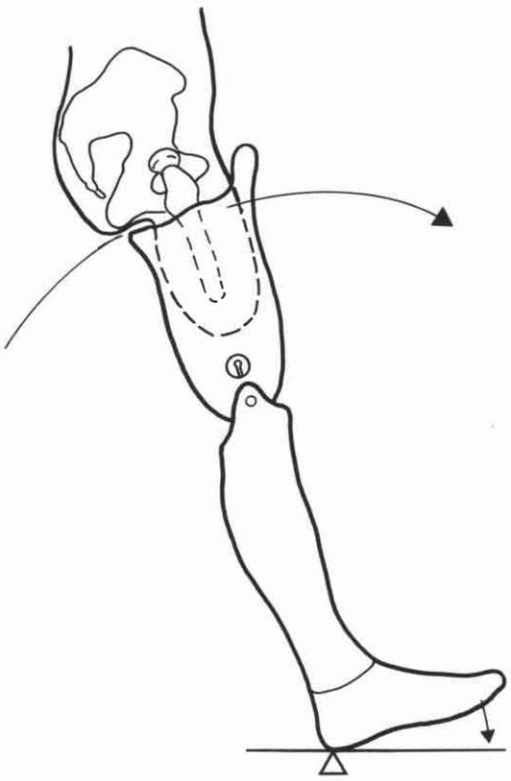

Figure 4.

ACKNOWLEDGMENTS

This is to acknowledge that certain concepts presented in this paper are based on, *Schnur*, J., DAS KUNSTBEIN—Messen und Bauen. Köthen-Anhalt: Buchdruckekel Hans Greiner.

I am also grateful to Robert Wilson, M.S., research scientist, designer and medical illustrator, Orthotics & Prosthetics Research for the illustrations in this text.

AUTHOR

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Lead Article

Normal Shape-Normal Alignment (NSNA) Above-Knee Prosthesis

by Ivan A. Long, C.P.

On March 13, 1974, I saw the first x-ray of an amputee standing with his prosthesis, equal weight on both feet, heels 2″ apart and toes 3″ apart. (See Figure 1. Notice the two zippers on the boots.) After seeing the amputated femur in such abduction, I realized that the quadrilateral socket and standard alignment procedures were not adequate for an above-knee limb. In December 1975, *Orthotics and Prosthetics*, the journal of the American Orthotic and Prosthetic Association, published my article, "Allowing Normal Adduction of Femur in Above-Knee Amputations."

On February 2 and 3, 1981, I presented a demonstration and the booklet "Fabricating the 'Long's Line' Above-Knee Prosthesis" at Sabolich, Inc. in Oklahoma City. Shortly thereafter, news of a CAT-CAM socket available through Sabolich was announced.

For the last 11 years, I have been fabricating only above-knee limbs and all have "Long's Line." The following article is presented so that prosthetists can provide the above-knee amputee with a limb that has a comfortable socket and alignment that allows him to walk in a normal fashion without drawing attention. Recently, it has been decided to call this work "Normal Shape-Normal Alignment" (NSNA) above knee prosthesis.

WHAT IS WRONG WITH OUR PRESENT A/K PROSTHESES?

Most above-knee amputees walk with a wide base and a lurch to the amputated side. Only 100 percent concentration can change that pattern. We looked at 100 x-rays of above-knee amputees standing in their prostheses and found

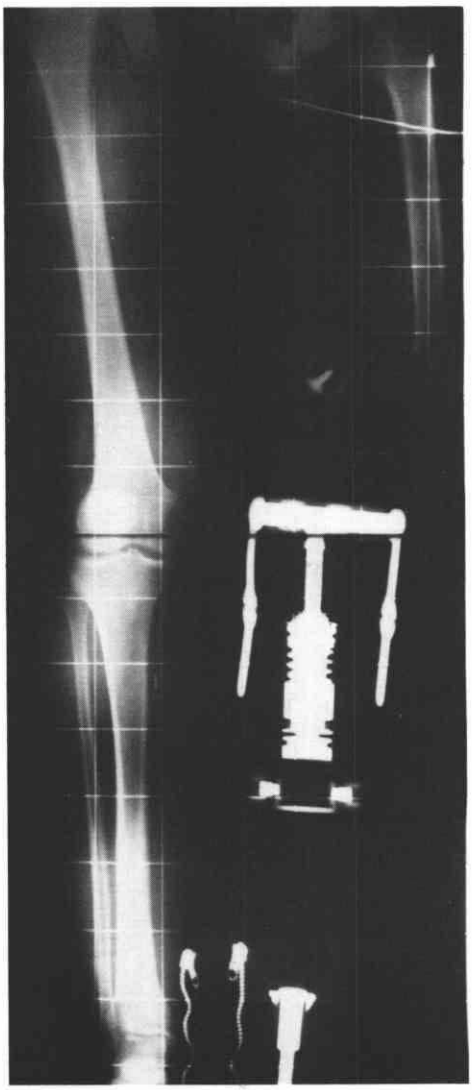


Figure 1. X-ray of standing patient showing relative abduction of amputated femur as compared to normal side.

92 out of 100 to have a difference in angle of the femur. In 91 to 92, the difference was towards abduction. (In this article, the angle of the sound femur is considered normal and movement away from the midline will be called abduction.) Most amputees would have to cross their legs to put the amputated femur in normal position while wearing the standard quadrilateral socket made all over the United States.

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 away from the femur except at the most distal point. When the femur exerts force against the lateral wall in weight bearing, 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.

To insure proper angle of the femur, the distal femur is brought directly under the head of the femur. This allows hip musculature to work in a normal fashion. The narrow socket with a well shaped lateral wall will support this angle, and the ischium will secure the socket from shifting laterally, which destroys femoral support.

Balance is dramatically improved when the foot is placed directly under the head of the femur rather than under the ischium. The amputee will immediately bring his feet closer together when he starts to walk, as opposed to a widened position when the foot is placed under the ischium.

Long's Line is a straight line from the head of the femur (located approximately at the center of a narrow socket), through the distal femur, and down to the center of the heel. This line is not always vertical because it constantly shifts when changing from a standing position to a walking position.

In order to support the femur, it is necessary to narrow the M-L dimension of the socket. The resulting greater A-P allows muscular function which is not possible with the crowded effect of a narrow A-P. Table I is used as a guide in establishing the width of the finished positive model. The figures were taken from approximately 500 sockets made in this facility, and may of these sockets have now been worn eight years. Very few, if any, sockets have been replaced because of shrinkage. Many sockets have been replaced as muscles return to normal and the thigh takes on its original shape and size increases. Most of the increase in size will take place in the A-P dimension, with very little change in M-L. Increasing the M-L dimension by anything more than 1/4" will result in a lateral gap at the top of the socket.

Circumference just below ischium	Goal 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

Table I.

TECHNIQUE

Thigh is measured as to length and circumference as high as possible and every two inches.

Taking a cast: Take two pieces of 6" wide cotton stockinette, 32" long. Cut 17" into each piece and sew together to make undergarment for casting (Figure 2). Measure length of thigh and sew one leg of garment to fit thigh. Cut small holes in front and back of top of garment and insert cord to tie up over amputee's shoulder to help hold garment securely in place. With a snug fitting undergarment on the patient, and with the seam as near center as possible, the prosthetist will work from the side and completely circle the pelvis above the trochanter with a single wrap of 4" non-elastic plaster bandage. Pull it snug, for this wrap is to prevent downward slippage of the cast as more wraps of plaster are applied around the thigh. Work quickly so your finger can be placed around the ischium to mark its location and proper depth of cast before the plaster sets. This spot will be

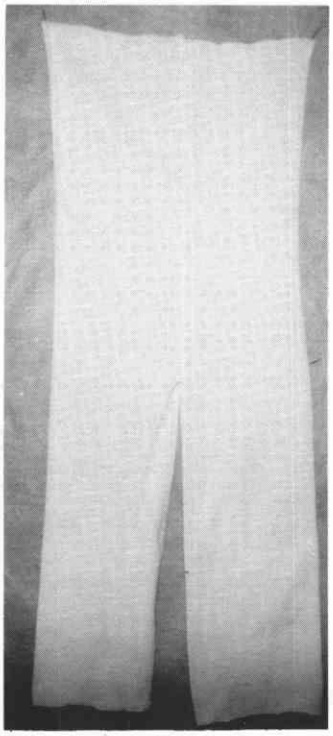


Figure 2. Casting garment.

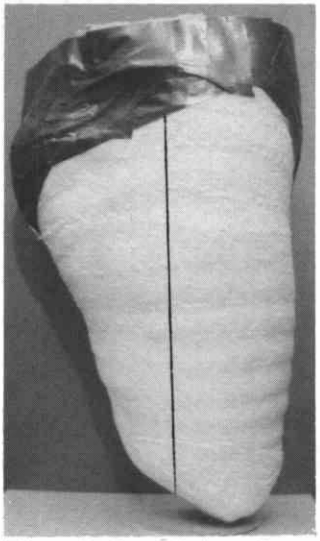


Figure 3. Lateral view of cast ready to pour.

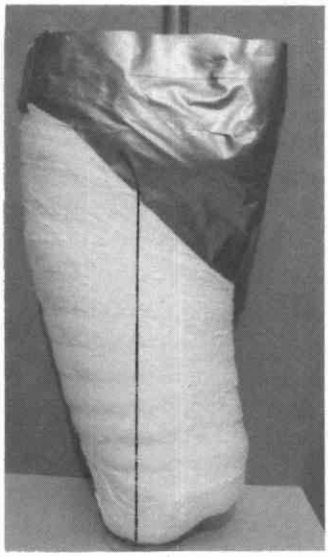


Figure 4. Anterior view of cast.

used to measure length to floor, pelvis level. The hand should be held to indicate the medial and posterior surfaces of ischium. Do not push forward of ischium. Ask the amputee to bring his knees together as tightly as possible and to extend his thigh to tighten the hamstrings. Hold this position until the plaster sets. Now place a vertical mark on lateral surface, with muscles tightened in extension (Figure 3).

Tear the single wrap of plaster than encircles the pelvis. The cast will drop away. Immediately check depth of cast and location of ischium.

Prepare cast for filling by adding duct tape around top to make top level. Pipe must be parallel with lateral mark, and tipped to medial to approximate Long's Line angle (Figure 4).

Now pour the cast full of plaster and let it set.

When the plaster bandage and stockinette are peeled away, we now have a grossly oversided model (Figures 5 and 6) that must be reduced in size. Practically all the reduction will take place on the lateral wall.

Referring to Table I, the socket M-L will be 4.5″ for a 19″, 0 circumference level measurement of the amputee.

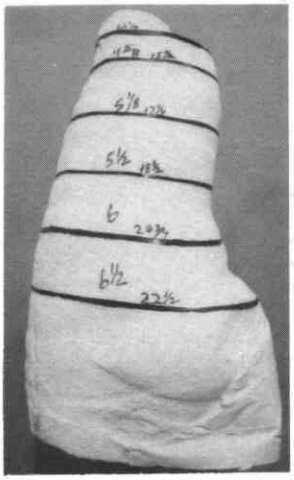


Figure 5. Posterior view of unaltered model.

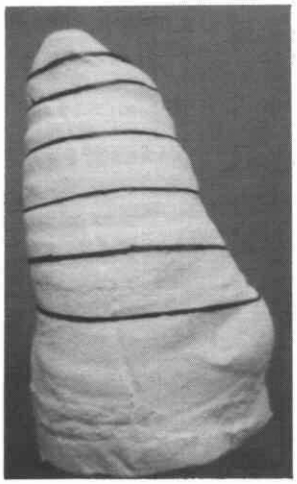


Figure 6. Lateral view of unaltered model.

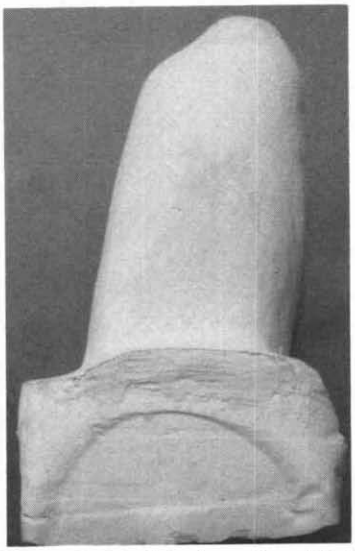


Figure 7. Medial view of modified model.

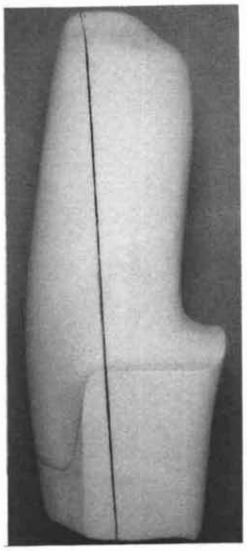


Figure 8. Posterior view of modified model.

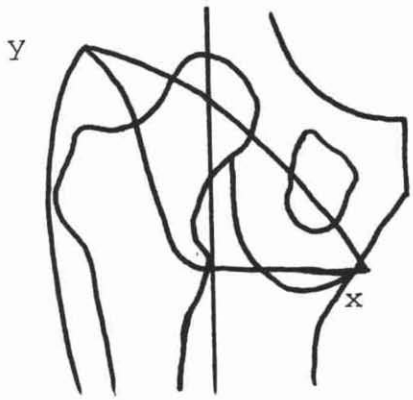


Figure 9. Anterior view showing relationship of medial brim (point X) to ischium and of lateral wall (point Y) to greater trochanter.

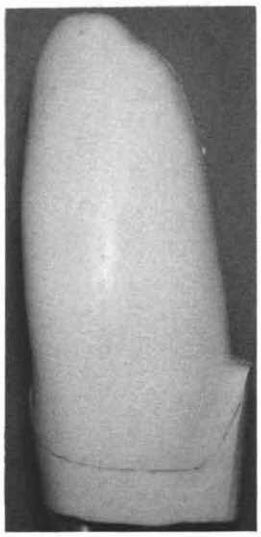


Figure 10. Lateral view.

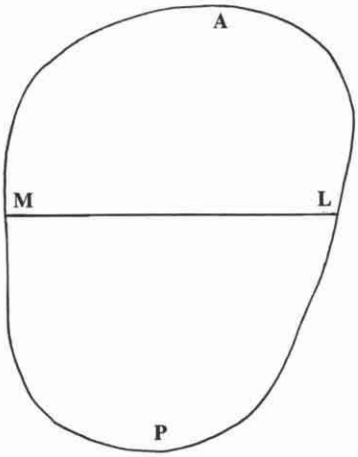
SOCKET MODIFICATION

1. Lateral wall is to be shaped to give support over a wide area, and particularly the lateral posterior aspect of socket.
2. The medial wall will be lower than seat level, and the cast will be the guide as to how low (Figure 7).
3. Depth of the socket will be the same as measured length of the thigh.
4. The seat will be at right angle to Long's Line.
5. Long's Line is drawn from center of M-L (see chart) to center of distal femur (Figure 8). (Distal femur will be very close to lateral surface, probably covered only by skin.)
6. Top 1″ of medial wall will flare outward at 45° (Figure 9, point Y).
7. Lateral wall is higher than usual. Do go above the trochanter (Figure 9, point Y).
8. Seat need not be wide, but sharp edges must be avoided (Figure 10). The ischium will bear on flare of socket, both medial and posterior.
9. Do not worry about the socket touching the greater trochanter. Take the cast down as though the trochanter does not exist. Practically all sockets gap in this area. In order to achieve the desired M-L, many casts will be reduced 2″ or more (Figure 11, Table II).

Example of Shaping the Positive Mold for a Particular Patient:

Amputee Circumference Measurements	Unaltered Plaster Mold	Finished Plaster Mold
0″–19″	22 1/2″	18 1/4″
2″–18 3/4″	20 3/4″	17 1/2″
4″–17 1/2″	18 1/2″	17″
6″–16 1/4″	17 1/4″	16″
8″–14 1/4″	15 1/2″	14 1/4″
9″–13″	13 1/4″	13″

Table II.



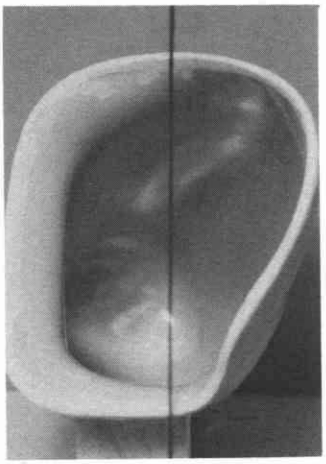


Figure 11. Proximal view of socket and socket pattern for thigh measuring 19″. Actual measurement of the pattern is 18″.

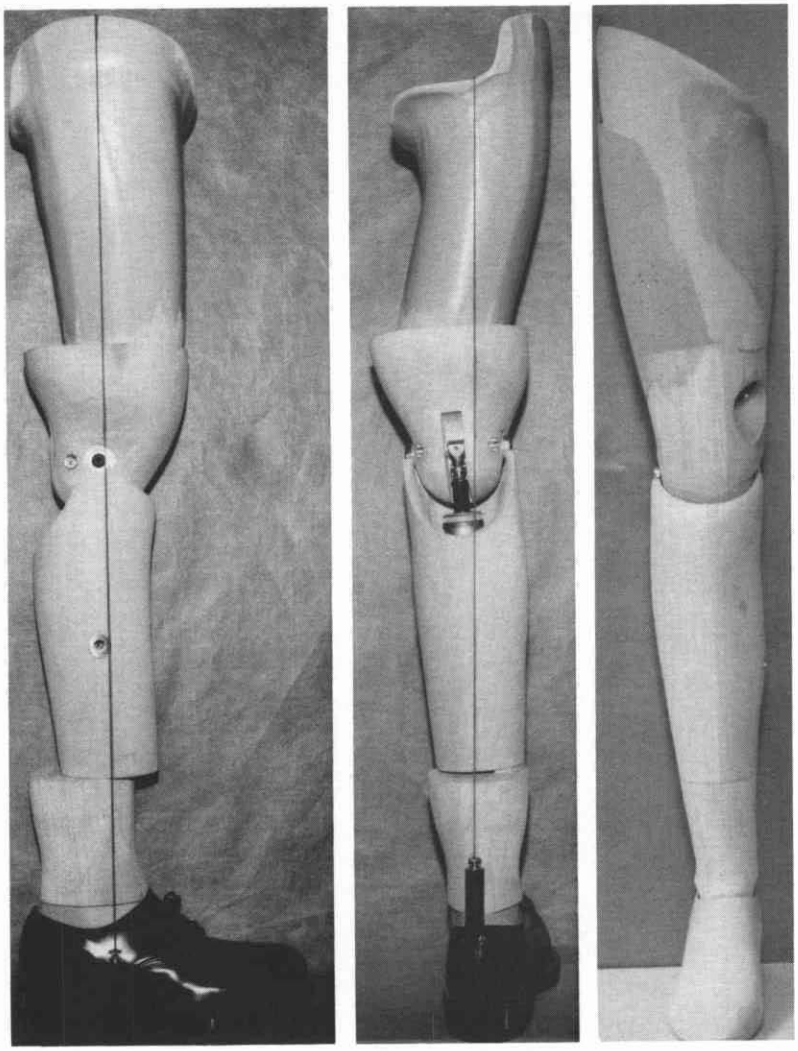


Figure 12. (left) Lateral view of bench aligned prosthesis.

Figure 13. (center) Posterior view of bench aligned prosthesis.

Figure 14. (right) Anterior view of prosthesis following completion of shaping.

10. Many sockets require fill added distally on medial side, only because I failed to remove enough material in this area when modifying the model.
11. Laminate socket using two layers of 1 oz. dacron felt plus extra felt around top.
12. Remove socket from cast and trim excess plastic.
13. Mark the center of the lateral wall at seat level for TKA. TKA should be parallel to lateral cast mark lines (Figure 12).
14. Mark Long's Line on posterior of socket (Center of M-L through distal femur) (Figure 13).
15. When using a standard wood set-up, knee bolt should be 4° higher on lateral side when Long's Line is vertical. Long's Line will thus not be in center, but towards lateral side.
16. Mount socket on set-up so that lines are straight (Figures 12 and 13) and medial wall checks out for height.
17. Install valve and walk amputee.

DO NOT change the alignment. Allow the amputee to take a few steps and watch the foot come in to a narrow base normal gait pattern. Notice level knee bolt while walking.

DO expect the amputee to have much more difficulty in readjusting to his old prosthesis. He will need to widen his base and may experience vertigo at first due to lack of support and extreme inward location of the foot.

To finish shaping of the thigh, material is added to the knee block to widen the knee block in front of medial joint. This must not limit full extension (Figure 14).

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Lead Article

Contoured Adducted Trochanteric-Controlled Alignment Method (CAT-CAM): Introduction and Basic Principles

by John Sabolich, C.P.O.

Since 1969, it has become increasingly evident that quadrilateral sockets have serious biomechanical problems. Even my old-timer above-knee prosthetic patients seem to be more comfortable in their ancient plug sockets, although transverse rotational stability was not as good. Fundamental to these objections is the lack of adequate stabilization in the frontal plane, which results in the gluteus medius gait most AK amputees demonstrate.

In order to stabilize the upper trunk and pelvis in normal gait, the gluteus medius and abductors on the stance side must fire vigorously when the contralateral side is in swing phase. However, we are dealing with a pathomechanical situation when we consider the case of the above-knee amputee. No longer are bones and ligaments positively connecting the hip to the floor. There is an intervening pseudojoint, "the patient socket interface." We now have part of the femur inside a gelatinous semifluid mass, the human thigh.

When the abductors fire, what is most likely to occur in a rectangular socket with a wide M-L dimension and no bony areas for the socket to lock against medially? The answer we have discovered, is that the femur tends to abduct. In quadrilateral sockets, the ischial tuberosity is sitting on top of the ischial seat and is free to shift about (Figure 1). As the gluteus medius pulls the femur into abduction, the pelvic slides medially on the ischial seat and makes the abduction worse. The unsupported femur has little choice than to drift into an abducted attitude within the wide M-L quadrilateral container.

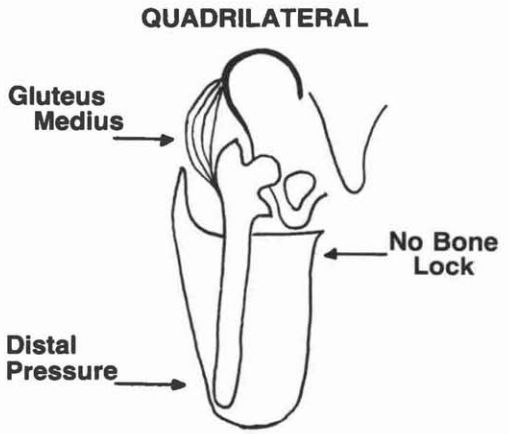

Figure 1. No bone block and no real force system to prevent femoral or ischial drift. Ischial tuberosity acts as a fulcrum. Pelvis can rotate as well as the femur abduct.

Pain at the distal femur and at the proximal medial area is due to this abducted position and excessive soft tissue pressure medially.

We now have a perfect set-up for the classical above-knee "lateral trunk leaning" gait familiar to prosthetists. The patient has to lean to the side to position his upper torso over the base of support (the abducted distal femur) during stance phase, since the prosthesis is falsely placed under him (Figure 2). The patient executes this maneuver to prevent excessive pressure on the lateral distal femur and the medial proximal soft tissue. In essence, the patient must walk in a fashion similar to a person who has two sound legs with one leg out to the side in abduction.

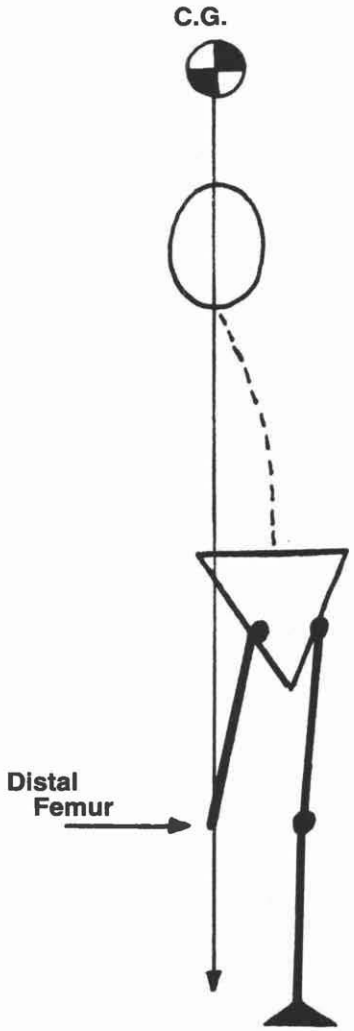

Figure 2. Patient must lean lateral over distal abducted femur, use inertia, or muscular tightening to prevent pain on lateral distal femur.

To the best of my recollection, I began questioning the validity of the quadrilateral socket theory in 1969 when I was a student at New York University. Dr. H. Richard Lehneis, C.P.O., of that institution taught that it is not necessary to put most of the patient's weight on the ischial tuberosity and, if the truth were known, most of the weight is probably borne by the peripheral tissue and gluteal masculature. Moreover, at heel strike, when the largest inertial forces are placed on the above-knee residual limb, the ischial tuberosity is not on the ischial seat due to the flexed hip.[†]

This concept was reinforced in my mind by the idea that if the majority of the amputee's weight was borne by the ischial tuberosity on the quadrilateral socket's flat ischial seat, one would only be able to obtain a tangental force at best, which would bring to bear tremendous force on a very small part of that bony prominence, and consequently cause great discomfort. Placing extra force in the neurovascular bundle anteriorly, Scarpa's triangle, with the purpose of pushing the ischial tuberosity up onto the ischial seat, has never made much sense to me. This seems to be the worst place to apply pressure and can not have a positive effect on circulation. These thoughts confirmed my concern that the quad socket theory had serious biomechanical problems and spurred my subsequent efforts.

We began to close the M-L dimension of the socket by adding material to the lateral and medial sides to try to force the femur into adduction. We also began opening up the A-P dimension, not only to reduce the pressure on the neurovascular structures of the Scarpa's triangle, but also to compensate for the reduced diameter in the M-L dimension, and thus to maintain the original circumference. (Prosthetists naturally tend to be fearful of such modifications since they have been taught to tighten the A-P to keep the ischial tuberosity on the ischial seat.) In addition, I began to slant the ischial seat in the frontal plane upward laterally at about a 30° angle, rather than leaving it horizontal, so as to increase the weight bearing of the gluteal muscles, and thus rely less on the ischial tuberosity. These are some examples of early attempts to change the quadrilateral design and may be considered as our first generation efforts.

In early 1981, the Sabolich Prosthetics Center sponsored a seminar to investigate non-quadrilateral alternatives for A.K. management. Participating in this seminar, among others, was Ivan Long, C.P., developer of the concept of Long's Line and an associated socket design.[1] The information learned from Mr. Long was of the greatest benefit in advancing our efforts. However, for reasons that

[†] Dr. Lehneis states that the first person to indicate that the ischial tuberosity was more efficient biomechanically if it was in the socket proper was a German man by the name of Schnur in the early 1950's.

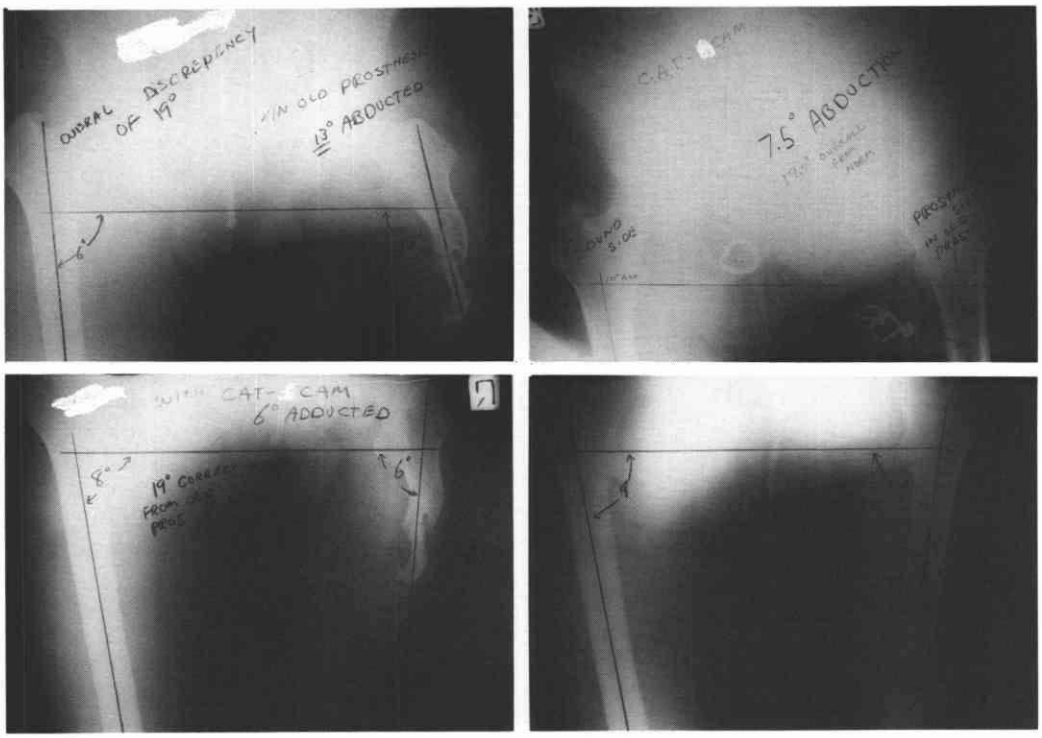

Figure 3. Weight bearing x-rays comparing CAT-CAM and quadrilateral sockets.

will become apparent in this article, we found it essential to proceed on a different track that experience has shown was necessary to make this program work for us. After this seminar, the Sabolich Center continued research study of non-quadrilateral above-knee designs.

Over 900 non-quadrilateral sockets have been fit on a documented basis in Oklahoma City to patients ranging from six months to 103 years of age. X-rays (Figure 3) and Xerography have been impressive, showing the femur to be in a much improved adduction attitude. We have made major changes in shape and contour, especially in the last three years. We have coined the acronym CAT-CAM, which stands for Contoured Adducted Trochanteric-Controlled Alignment Method, to describe the second generation design which is covered in the remainder of this article.

This design includes undercutting of the trochanter and a special fossa in which the ischial tuberosity and descending ramus can rest, giving this bony prominence three-dimensional support within the socket. No more consideration is given to the transverse angle of the posterior wall relative to the medial wall (Figure 4). The Scarpa's triangle is virtually eliminated,

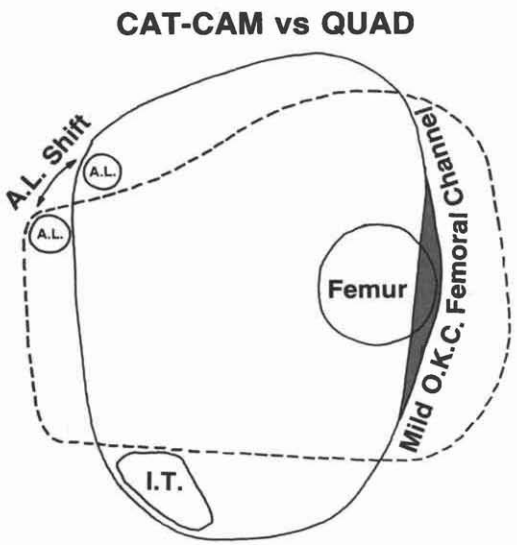

Figure 4. Comparison of CAT-CAM and quadrilateral sockets in a transverse view. Since the femur and ischial tuberosity are fixed in position, the adductor longus tendon has to shift a small amount. Note mild O.K.C. (Oklahoma City) channel about the femur.

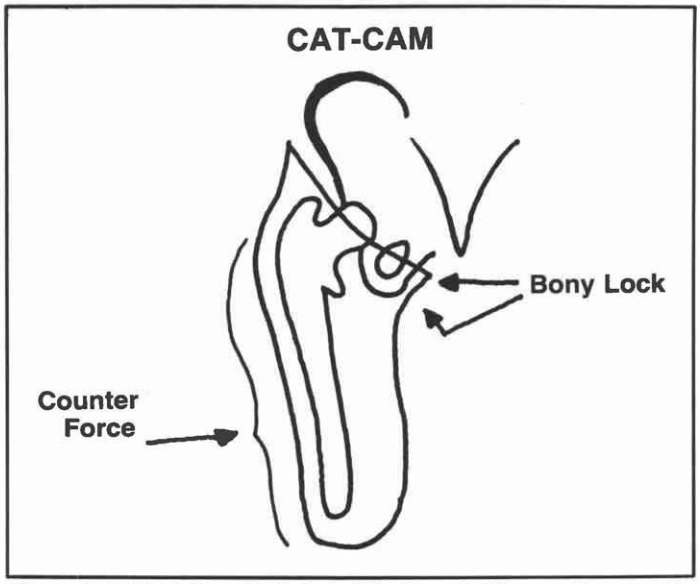

Figure 5. Ischial tuberosity is locked in the socket to provide a counter force against femoral shift.

as are the adductor longus and rectus channels, and the ischial seat. The ischial tuberosity still bears some measure of vertical loading since it rests on an angled surface. The old principles of the quadrilateral design simply do not function, since we are dealing with a completely different design in shape, contour, and biomechanical principles. The socket is so different that it looks somewhat like a quadrilateral socket turned sideways with a large A-P and narrowed M-L.

A number of prosthetists have come to our facility to learn these techniques on a one-on-one basis. We have gained much information and feedback from the other prosthetists who have participated in these informal educational efforts. However, this process is not altogether appropriate and has come to be tremendously time consuming. We feel that in the future, education should be administered to several prosthetists at once in an organized and structured course by one or another of the schools. In March, 1985, a preliminary course was taught at UCLA after two years preparation and the writing of a manual. This effort confirmed, in the minds of those involved, the necessity of such a course, and also the necessity of further efforts upon the part of the teaching staff involved to perfect techniques and teaching material. Moreover, it should be borne in mind that the acronym CAT-CAM embraces a number of varying concepts advanced by a number of prosthetists working in common directions and these differences must be reconciled into one technique to be taught. In the strongest possible terms, and in view of the problems some prosthetists have had, we can not recommend using the CAT-CAM method without a hands-on instructional course.

CAT-CAM THEORY

The CAT-CAM holds the femur in adduction primarily by two means. First, the ischial tuberosity and part of the inferior ramus of the ischium rest inside the socket proper, and bear laterally directed forces which work in conjunction with medially directed forces borne by the femur (Figure 5). Medially directed forces bearing on the proximal portion of the femur in the trochanteric and sub-trochanteric region act to hold the ischial tuberosity on an inclined medial-posterior surface within the socket, while forces on the mid and distal portion of the femur act to maintain the proper adduction angle. Actually, it could be described as a wedging or "locking effect." (Imagine yourself holding the ischial tuberosity of a skeleton in the cupped palm of your hand and pushing the femur into adduction with your opposing hand; thus, the "locking effect.") The lateral surface of the socket proximal to the greater trochanter is contoured intimately into the soft tissue distal of the iliac crest. It is hypothesized that medially directed forces in this area, working in conjunction with the medially directed forces on the lateral surface of the femur and laterally directed forces borne by the ischial tuberosity,

create a three-point pressure system to lock the femur into adduction and reduce motion that can occur when the ischium is free to shift about.

Second, the narrow socket means that the pressure bearing areas of the socket bear directly against the skeletal elements, thus reducing motion lost through intervening soft tissues. A wide socket M-L cannot provide this locking phenomenon since the femur can fall away from the supporting surfaces.

In the transverse plane, the medially directed force of the ischial tuberosity is posterior to the laterally directed force of the trochanter and femoral shaft. One might assume, therefore, that the socket would twist or whip about its long axis. This does not happen, and apparently the adductor longus tendon and other medial proximal tissues anteriorly generate enough counter force to resist this tendency. Also, the ischial tuberosity creates a posteriorly directed force (since it is nestled in the posterior medial corner of the socket), resisting this tendency. Last, this tendency is checked by a new medial trimline (described later) which captures the medial portions, or the inferior ramus of the ischium, which are almost exactly opposite the trochanter.

The exact weight bearing mechanism of the CAT-CAM socket with its wide A-P diameter and decreased emphasis on ischial tuberosity weight bearing is unclear. However, it is assumed that the femur is capable of bearing some measure of the patient's weight due to the increased adduction angle. It is also assumed that hydrostatic weight bearing plays an important role and that the ischial tuberosity still bears a measure of weight.

In general, we have discovered that the prosthetic foot should be placed considerably lateral of a plumb line through the ischial tuberosity, but not always under the center of the hip joint or distal femur as with "Long's Line." This line changes position with how well the ischial tuberosity is locked in the socket and how narrow the mid and distal M-L dimensions can be molded. This alignment line also changes from patient to patient and depends on gluteal muscle strength, ischial ramus shape, femoral length, and subcutaneus tissue thickness. The prosthetist is now able to align the prosthesis in a normal physiological and anatomical fashion because the femur is no longer in abduction.

The Berkeley Adjustable Shank is very useful in determining this critical relationship. By outsetting the foot more than with quadrilateral designs, the patient must adduct his femur to get his feet close together again. With the femur in abduction, as in the quadrilateral socket, a patient would be standing with his prosthesis scissored over his sound leg if he tried to stand with his femur in normal adduction angle. One cannot use a standard unchangeable line and always obtain the same adduction angle as with the contra-lateral femur, since the shorter the femur, the greater the adduction angle must be in order to place the distal femur under the center of the hip joint resulting in hyper-adduction. This was the reason I abandoned this line in favor of an adjustable line utilizing the Berkeley Adjustable Shank. This has resulted in much better alignment.

One may ask, "If everything is stabilized in the M-L direction, then what about in the A-P plane?" Afer all, this is of the utmost importance at heel strike in order to stabilize the prosthetic knee and to help propel the patient over the foot. Our experience has not shown this to be a problem. In fact, if anything, an increase in A-P stability has been noted. We hypothesize two ways by which this might be explained.

First, the majority of the muscle activity about the hip is in the A-P direction. The flexors and extensors are allowed to expand naturally, filling the socket quickly, and thus firmly stabilizing it (Figure 6). Also, this change in contour allows the A-P muscles to function naturally, increasing their size and strength. We have noted many cases of hypertrophy of the A-P muscle groups rather than atrophy. No longer are these muscles being squeezed, stifling their motion and effectiveness. Even suction sockets seem to hold on better since the tissues are not being deformed in an unnatural fashion, causing air pockets and channels to form. Second, the ischial bone is inside the socket, creating a solid posterior stop as opposed to simple soft tissue pressure, aiding A-P control at heel strike (Figure 7). Distally, CAT-CAM's become more round, again aiding A-P control.

We have noted several interesting phenomenons during this research effort. The first I have dubbed the "lateral pylon lean syndrome." Sometimes during dynamic alignment on the adjustable shank, the pylon has to lean laterally in order for the patient to be comfortable. The pylon can be brought vertical by increasing the socket adduction. This turns out to be a temporary solution and does not solve the real problem. This eventually results in pain in

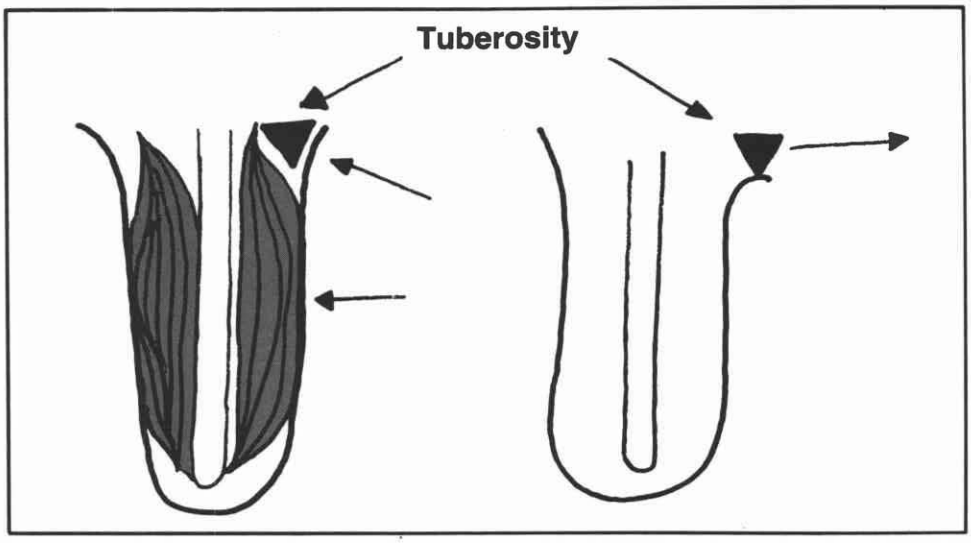

Figure 6. Most muscles function in the A-P plane. The CAT-CAM socket gives these muscles room for their normal dynamics.

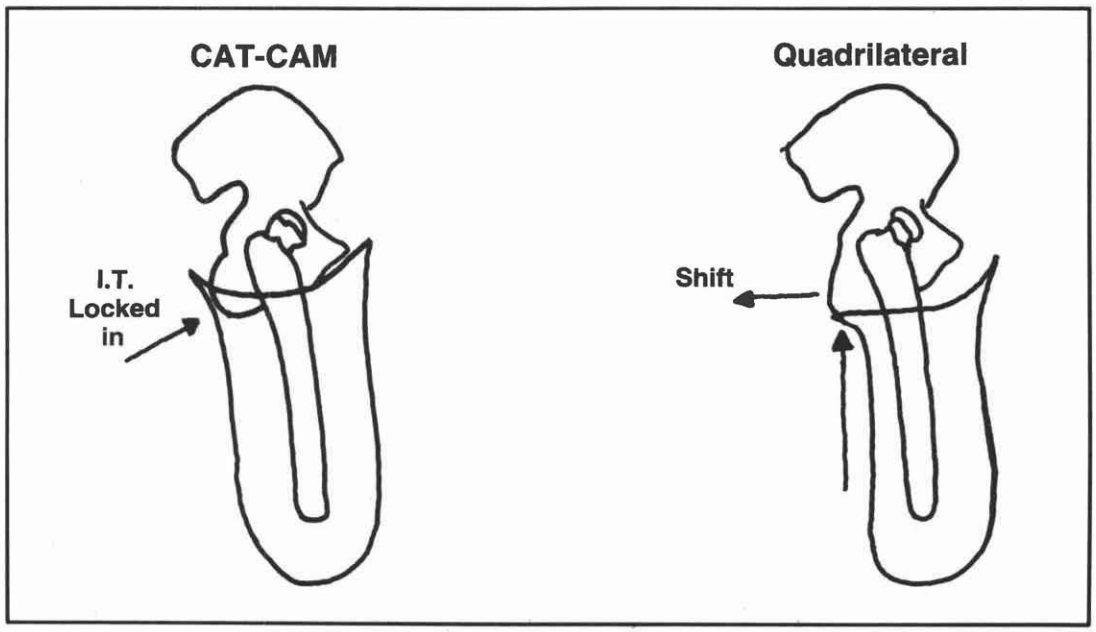

Figure 7. The ischial tuberosity is free to shift about in the A-P plane as well as the M-L plane when sitting on top of the ischial seat.

the perineum. What is actually happening is that the ischial tuberosity is slipping out of the socket proper and migrating medially on the proximal brim. As a result, the femur falls into abduction, or more realistically, the superior lateral portion of the socket drifts laterally on the patient, the medial superior brim digs in, the pylon leans laterally, and the proximal lateral brim gaps. The problem is not one of alignment at all, but of ischial containment (Figure 8). This happens when the socket is too tight in the M-L plane. This happened with sockets fitted after the 1981 seminar when circumference charts were used to determine socket M-L. These resulted in the ischial tuberosity being on top of the medial brim and that is why the brims of such sockets were so wide and thick. The intention was to get the ischium in the socket, but in actual practice it invariably ended up on top. This is no longer necessary due to

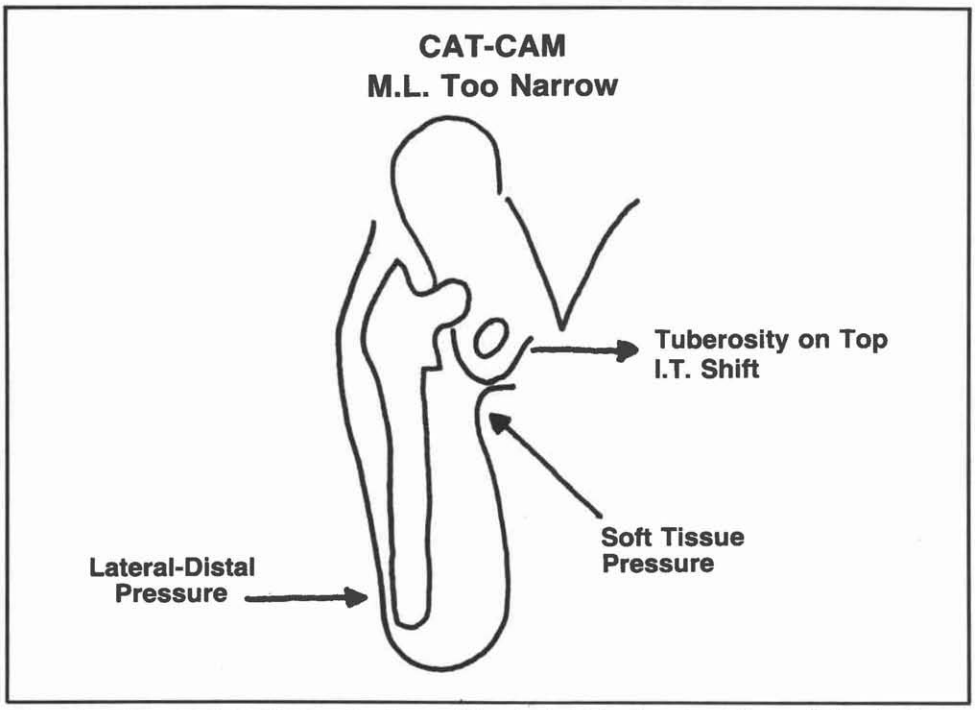

Figure 8. When the CAT-CAM socket is too tight, the ischial tuberosity shifts medially, the femur abducts and the lateral superior brim gaps.

improved measurement techniques used to determine true M-L.

Secondly, it seems that the shorter the femur and the greater the volume of the residual leg, the more noticeable is the "CAT-CAM effect." This is due to the favorable comparison of the CAT-CAM sockets versus quadrilateral sockets. The shorter the femur and the greater the relative amount of soft tissue in which it can move, the more obvious the problems of the quadrilateral socket become. However, even with long and lean residual legs, patients still notice the difference in comfort and adduction associated with the CAT-CAM method. A common statement is "it feels more solid," "it feels like its under me again," or "my leg goes where I want it to go." Also, the short residual limbs simply have much more peripheral tissue containment in which to bear vertical and horizontal loading, since the CAT-CAM extends much higher and contains more tissue, especially gluteal.

Third, we have virtually eliminated use of hip joints even on very short sub-trochanteric above-knee patients. The adducted femur and the high lateral wall, snugly pressing into the intraillio-trochanteric region, help stabilize the M-L and tend to reduce the need for external support.

Fourth, to the question of sitting: will there be a lot of gapping anteriorly? Not if the socket is dimensionally correct. Bending forward at the hip is actually enhanced due to increased room anteriorly, and with the new flexible brim described next, the problem is completely eliminated.

Fifth, both the modified version of the Swedish Flexible design, with medial and lateral framing, and the new Total Flexible Brim (T.F.B.) mesh with CAT-CAM principles perfectly as both allow increased function of the A-P muscle groups (Figure 9). The CAT-CAM with T.F.B. is preferred because of its superior sitting comfort, adaptability, and dynamic comfort without sacrifice of A-P muscle freedom. The T.F.B., which allows the entire upper three-fourths of the posterior wall and the entire proximal portion of the socket to be flexible and allows a flexible anterior window, is actually opposite of the Swedish Flexible design, which has its greatest measure of flexibility concentrated in the mid-thigh. The T.F.B. is possible

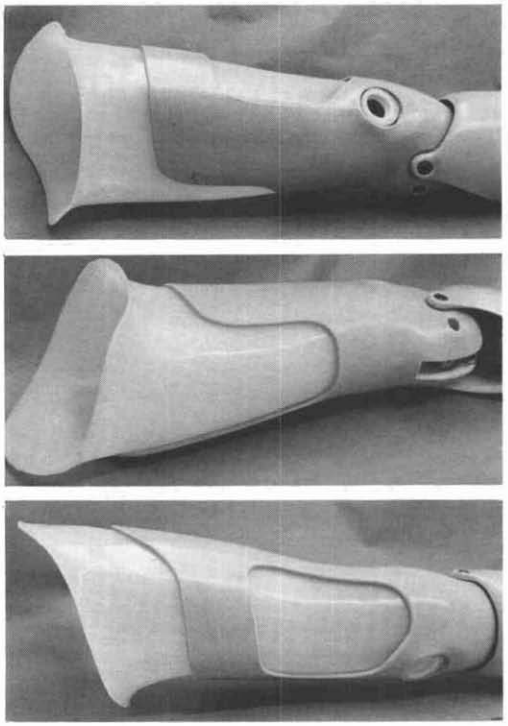

Figure 9. Three views of the Total Flexible Brim (T.F.B.) CAT-CAM.

because the ischial bone is no longer on top of the posterior or medial seat, but down in the socket, so it does not tend to collapse or push the flexible seat distally. Instead, the tuberosity forces out against the side of the socket as does the trochanter, adductor longus tendon, and peripheral tissues. This can be thought of as one trying to hold his body in place in a V-shaped vertical tunnel or shaft by pushing out on the walls of the tunnel with one's hands and feet. The residual leg pushes out in all directions at once, thus there is no collapse of the flexible posterior brim. For the first time in prosthetics, the proximal thigh is actually allowed to deform naturally during sitting and to change contour dynamically while ambulating. I feel this is important since a great deal of pain complaints are related to the proximal areas. This flexible brim has also allowed us to become much more aggressive and make a major change by extending the posterior and posterior-medial brims higher to capture the ramus and ischial tuberosity more effectively. It has also allowed us to actually slant the medial brim superiorly to better capture the ischium and ramus while relieving the pubis.

Sixth, bilateral above-knee patients gain additional benefit from the CAT-CAM design. Our bilateral patients who rejected their quadrilateral socket accept the CAT-CAM enthusiastically. They benefit from the extra space provided in the perineal area by the narrowed M-L (especially with male patients). Even the old round plug sockets gave more room in the perineal area (Figure 10). The shaded area in Figure 10 demonstrates the extra area available for the genitalia from plug sockets over the quadrilateral socket represented by the rectangles. The CAT-CAM, of course, allows even more room in this area due to its opposite shape and contour.

Seventh, the CAT-CAM has great advantages for the geriatric patient for several reasons. We have had our worst difficulties with quadrilateral socket on people with poor muscle tone. The shortcomings of the quadrilateral design become more obvious in the older population. The sharp angles of the adductor longus channel, the posterior medial corner, the medial brim, and the Scarpa's triangle of the quadrilateral socket were almost never really comfortable. With the CAT-CAM, these patients seem to have improved vascular flow; their residual limbs feel warmer after removing the prosthesis. This seems reasonable since the neurovascular bundle is not being choked off with a large bulge in the Scarpa's triangle. The

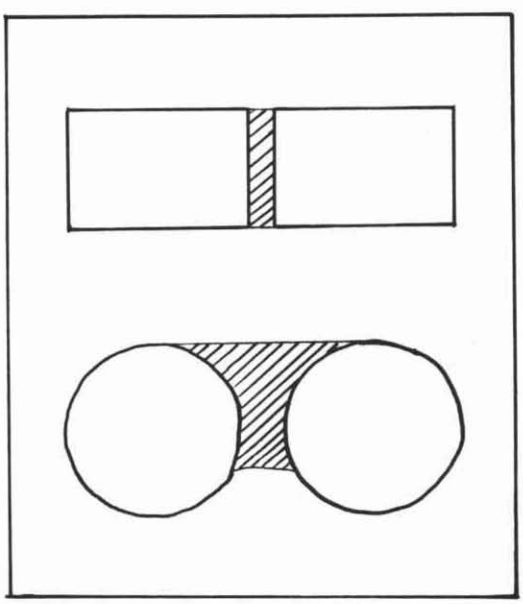

Figure 10. Graphical representation of the amount of room afforded in the perineum by a non-quadrilateral socket.

A-P is not being choked but opened up. We hope to conduct comparative temperature and later Doppler blood flow analysis of this phenomenon. For the extremely large geriatric patient population, this alone might be one of the single greatest benefits of research with CAT-CAM design. When the Total Flexible Brim is added, we have not only greater comfort, but further increase in circulation.

Eighth, we have noted that a large percentage of patients who were switched to CAT-CAM comment about energy savings. They do not seem nearly as tired after walking the same distance in the CAT-CAM as with their old prosthesis. This is probably first due to less lateral displacement of the center gravity. Second, patients do not have to fight to keep the femur from hitting painfully against the socket distally by tightening their musculature. Third, with more boney contact inside the socket and thus a more solid purchase, the prosthesis moves quickly without delay from false motion.

Ninth, we have found that by undercutting the greater trochanter, a much better purchase and counter force to the ramus and tuberosity can be generated with less M-L play and, I suspect, some vertical component of weight can be borne on the flare of the trochanter much like that of the medial tibial shelf in the below knee. Also, now that the femur is actually adducted, we are now probably picking up a vertical component of force on the lateral shaft of the femur.

Tenth and most important, after the 1981 seminar, we used a chart that related circumference of soft peripheral tissue to the desired medial lateral dimension of the socket. We found many fallacies with this method. The reason for this is that one cannot rely on circumference measurements to indicate the proper diameters between the ischial tuberosity and sub-trochanter, or the ramus and sub-trochanter. In our work, we found that it was absolutely necessary to obtain both of these measurements to obtain consistent results. A patient may be very fleshy and obese, but that in no way changes the anatomical dimension of the bony structures. The reverse is true with a thin patient. This was one of the most difficult stumbling blocks to obtaining truly good results. It seemed that when using this chart, the tuberosity was usually up on top of the medial superior shelf, which acted as an ischial seat, and this explained why the medial brims at the 1981 seminar were flat and $1\frac{1}{2}$" to 2" wide. In effect, the medial brim became an ischial seat. The sockets fabricated at the 1981 seminar still had the ischial tuberosity out of the socket proper and superior medial lateral diameters that were too narrow, resulting in M-L socket shift. True, the ischial tuberosity was no longer on the posterior shelf, but we had simply moved the tuberosity to the top of the medial shelf. The narrow M-L did provide better adduction of the femur, but not as good as when the ischial tuberosity and ramus are totally locked in the socket, providing a medial stop.

The reason for this was discovered with more research. Namely, that it is incorrect to rely on what a patient measures in circumference at the perineal or ischial level, and to expect to extrapolate the medial-lateral dimension of the socket. I had two years of severe problems in this area until we dropped the circumference chart and adopted methods to determine exact measurements through xerography, x-rays, and anatomical measurements. Only then was I able to obtain consistent results, symmetrical adduction of the femur, and stabilization of the proximal socket to prevent lateral socket shift.

Eleventh, through the course of our research, we have defined three ischial tuberosity-ramus types. We call these different configurations: alpha, beta, and gamma types (Figure 11). These classifications are valuable since they can

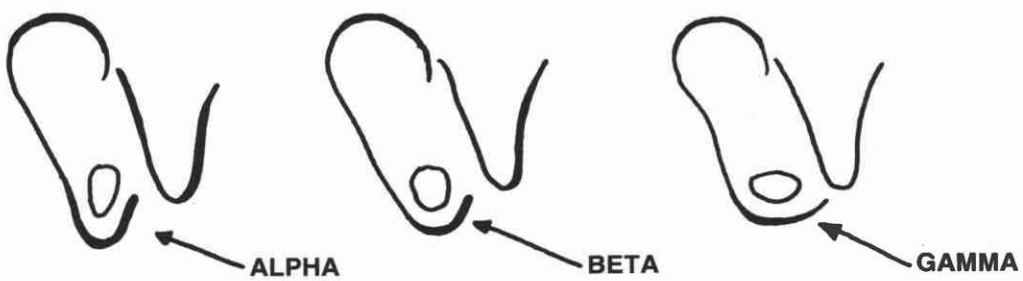

Figure 11. The well defined high slope of the alpha type usually results in improved femoral adduction and M-L control. At the other extreme is the gamma type which is more difficult to grasp properly with the socket.

be used to predict to what extent we will be able to control femoral adduction comfortably. The more purchase one can obtain by locking against the medial border of the ischial-ramus, the less the pressure that comes to bear on the soft medial proximal tissues, and the less the M-L shift of the socket.

The alpha type is the most desirable, since it has a medial side which slants up at a sharp angle, making it more appropriate for good M-L purchase, and also making it easier to slip into the socket. The beta type has more sloping sides, making purchase somewhat more difficult.

The gamma is the poorest type for purchase. We tend to have some pressure problems in the medial proximal area with the gamma types due to M-L socket shift. It is difficult to get this wide bone inside the socket proper. This necessitates widening the medial lateral dimensions of the socket so the wide gamma tuberosity will slip into the socket. With the gamma types, we usually have to settle for a less adducted femur than the patient exhibits on the contralateral side.

Another very important point that finally emerged as research continued was that, not only ischial tuberosity, but medial inferior ramus containment was very important to stabilize the socket from lateral shift. The reason for this is that, while the ischial tuberosity is more posterior, and thus helps prevent anterior shift of the socket at heel strike, the ramus is a greater asset when it comes to prevention of M-L shift of the socket and is in a much better anatomical and mechanical position to provide a true medially directed force to the socket, since it is more diametrically opposite the trochanter and sub-trochanteric regions than is the ischial tuberosity.

We have had some problems in the beginning with CAT-CAM due to inexperience. However, these have fallen below the one percent range. I find this one percent figure extremely interesting since most patients, especially older people, tend to reject new designs. We found almost none of this phenomenon, however, in switching from quadrilateral to CAT-CAM. We did experience problems due to low back pain in two very old patients. This problem is probably due to the fact that the quadrilateral sockets worn for years and associated with an abducted femur, allowed the lumbar spines to drift to one side. Apparently, fitting the CAT-CAM sockets suddenly pulled the lumbar spines in the opposite directions, inducing low pack pain.

During the early years, we sometimes had to fit many transparent check sockets to the same patient before we had successful outcomes. With increased experience and the formulation of rational guidelines and more exacting anatomical measurements, this necessity has been greatly reduced. However, one should expect to spend a great deal more time fitting CAT-CAM design sockets due to the intimate bony contouring.

A comprehensive CAT-CAM program should include use of comparative x-rays, which aid in modification and establishment of the angle of correction, as well as transparent diagnostic sockets, video gait analysis, and biofeedback as described in the next paragraph. We also recommend that previous quadrilateral patients undergo an intensive program of abductor strengthening with a prosthetically knowledgeable physical therapist, who will also later teach them not to laterally trunk bend from habit. The full benefit of the CAT-CAM socket is not achieved if the patient has been using a quadrilateral socket long enough to weaken his gluteus medius and abductor mechanism. If the femur tends to be in abduction (Figure 12), the gluteus medius is slack and not under normal tension, causing it to have a poor mechanical advantage and makes this muscle effectively weak.

We have developed a CAT-CAM program to strengthen the gluteus medius muscle through the use of myoelectric biofeedback during gait training. Pressure sensitive electrodes are mounted to the patient over the gluteus medius, and the biofeedback unit emits an audible signal proportional to the electrical activity generated by the muscle when it fires. Using this method, the patient can actually listen to the muscles fire and begin to force himself to use

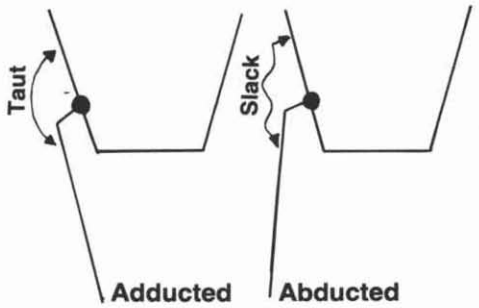

Figure 12. The gluteus medius is not effective when the femur is in abduction.

the abductors more. The stronger this abductor mechanism becomes and the more training the patient receives, the less the classical A.K. "lateral trunk lean" during stance phase is observed. This is an important phase of the program and a very effective way to not only strengthen the gluteus medius, but to do so dynamically while the patient is ambulating. We also explain to the patients the reason why they must trunk lean laterally in a quadrilateral socket and use a video system to provide visual feedback to enable them to see themselves walk. This works very well since people seem to react better to watching themselves walk incorrectly and correcting it voluntarily, than to have a practitioner telling them what they are doing wrong. With former quadrilateral patients, do not expect this lean to go away completely because the habit is so well entrenched; however, it can be greatly reduced if not eliminated.

FUTURE PLANS

In late 1985 or early 1986, we will introduce the SCAT-CAM, or Skeletal CAT-CAM, which is a highly bone and muscle contoured design. We have been working on this design for three years and it looks considerably different than CAT-CAM (Figure 13). We feel this approach is the next logical step with the evolution of CAT-CAM and are very pleased with the results. SCAT-CAM is actually a third generation CAT-CAM exhibiting, among other refinements, a highly relieved lateral wall with Oklahoma City channel (O.K.C.), which is actually a trough for the entire femoral shaft along with full length of the lateral wall (Figure 14). I feel this is a major advance, since it attempts to capture the femur in the A-P direction and to prevent A-P and transverse pseudo movement.

The O.K.C. fossa is provided in a SCAT-CAM to place the ischial tuberosity in a hollowed out relief as opposed to the angular shelf of the second generation CAT-CAM. This fossa enhances the locking effect A-P and M-L. A transparent diagnostic socket is very helpful to properly locate this fossa placement. Also, the medial superior wall has undergone drastic changes to allow relief for the pubis, but still quickly slant superiorally posterior of the pubis to trap even more of the inferior ramus of the ischium and tuberosity. This gives a much improved medial superior locking counter force than a horizontal medial brim. It takes on the shape of a letter "V." With the SCAT-CAM, the pubis can be relieved in the vortex of the "V," while the medial border of all but the inferior apex of the ramus and all of the ischial tuberosity are caught in the arms of the "V."

The use of direct anatomical measurements instead of the circumference chart has resulted in a drastic change in general contour where the superior medial-lateral dimension is wider to catch the bony areas, then quickly reduces in M-L dimension and becomes very narrow distal to the sub-trochanteric area, resulting in superior adduction control of the femur. Another important change was with the radius of the superior medial brim. We have changed from a 90° to a gentle upward sloping brim, which prevents the ramus and tuberosity from sliding or shifting out of the socket. With the SCAT-CAM, even more vertical loads are possible on the ischium than with quads sockets since the

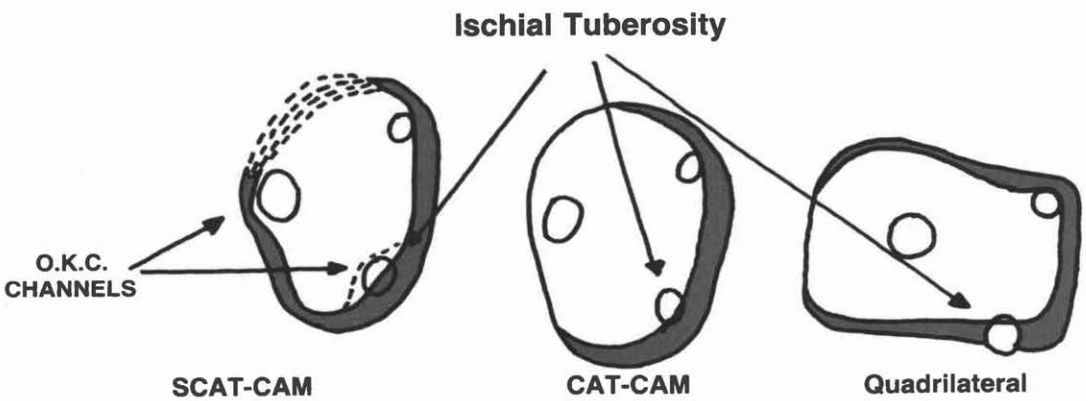

Figure 13. Evolution in shape from the quadrilateral socket (right) to the SCAT-CAM socket (left).

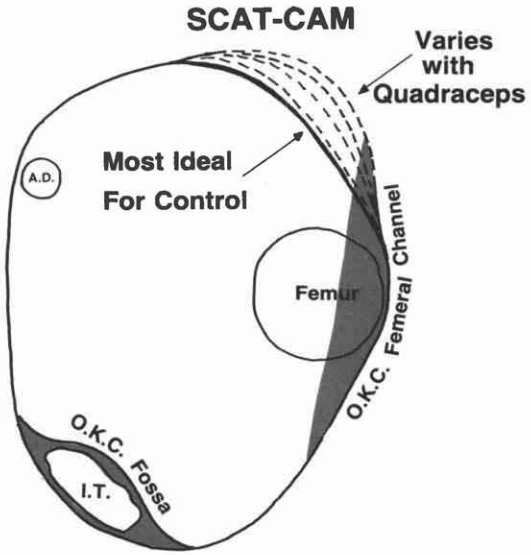

Figure 14. Cross-sectional view of the SCAT-CAM socket.

forces can be wrapped around this complex and curved ischial-ramus bone, which in essence can now be used for vertical posterior and medial loading.

We are planning a research program which we hope will contain the following studies:

Quantitative

1. X-ray with comparative study of femur adduction-abduction angles.
2. Digitally timed video comparison of gait A-P and lateral analysis.
3. Myoelectric measurements of major muscle groups, especially the abductors.
4. Dynamic oxygen consumption rates to monitor energy expenditure.
5. Relative Doppler blood flow in distal residual leg.
6. Temperature of skin in both sockets after controlled time factor.
7. Data on acceptance rates.
8. Atrophy data or hypertrophy comparisons.
9. Determination of the weight bearing mechanism.

Qualitative

1. Video comparisons.
2. Patient comments.

CONCLUSION

Even though the CAT-CAM and SCAT-CAM are diametrically opposite to the quadrilateral in design and precept, I believe these new principles will eventually be widely accepted and deeply penetrate the prosthetic field. I encourage practitioners to insist on weight bearing x-rays as part of a comprehensive prosthetic program, which lend credibility to our premise by exposing internal problems which result in external manifestations. My sincere hope is that the prosthetic community will not take this article to be controversial, but as a statement of what we have discovered and felt compelled to share.

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ACKNOWLEDGMENTS

The main source of strength in perpetuating my interest in CAT-CAM has come from the support of my father, Lester J. Sabolich, C.P.O., Thomas Guth, C.P., Mike Wilson, C.P.O., and Dr. Ernest Burgess. These people have supported this project from early on and deserve much credit.

I would also like to credit Ivan Long, C.P. who defined his alignment principles in 1975 and thus started us on the right track. Enough credit cannot be given this man!

Also I thank my wife Lee, who has not complained about many lonely evenings during this research project.

I thank the entire staff of Sabolich Prosthetics Orthotic Center. Without these people, none of this research could have been achieved. Only they understand the grit of many failures and garbled plastic in the trash.

I thank all of the prosthetists who have worked with us and tried this method. Their feedback has been invaluable.

Last, special credit goes to Chuck Childs, C.P.O., who could see the profound effect of this method and was in hot pursuit of it when he was taken from us.

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Lead Article

Flexible Socket Systems

by David J. Jendrzejczyk, C.P.

Over the past two years there has been impetus towards the use of the flexible socket interface in above knee prosthetics. For our purposes here, it is widely accepted that the flexible socket is of multiple benefit to the patient. We will concentrate on discussing the different systems available.

The history of flexible sockets dates back a number of years. The article by Charles Pritham, C.P.O., et. al. "Experience with the Scandinavian Flexible Socket"[10] provides a concise summary of this train of development.

At the present time, there are numerous flexible socket systems being used in the United States and throughout the world. These sockets differ in design in two major areas: flexible socket interface and the outer hard socket. The flexible socket is currently being used with three types of support mechanisms:

1. Total hard socket as the support
2. Hard socket with strategic fenestrations
3. True frame design

The prosthesis discussed by R. Volkert in the article, "Frame type Socket for Lower Limb Prosthesis"[12] is constructed with a frame outer socket and an elastic stocking interface. This system can accommodate stump volume changes, therefore, it appears to be most useful with early amputees.

The TC Couple Socket[6] above-knee prosthesis used a polyethylene flexible interface and an external polypropylene socket. There are no fenestrations in the outer socket, so it doesn't have some of the benefits of sensory feedback as a fenestrated outer socket would. The advantage of this system is its light weight polypropylene outer socket.

Work done at the Institute of Rehabilitation Medicine, New York University Medical Center, is detailed in "Flexible Prosthetic Socket Technique."[8] Two systems are described in the article, both have a hard outer socket with windows cut out in strategic locations (Figure 1). The interface is either of thermo-formed polyethylene or of silicone elastomer lamination.

Currently, in the United States, the external

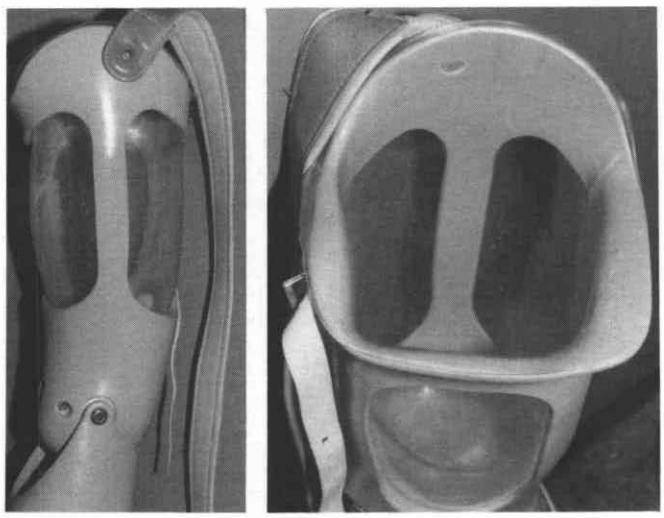

Figure 1. Prosthesis incorporating a flexible Polyethylene socket in a support with fenestrations in selected areas as fitted at the Rusk Institute of Rehabilitation Medicine (Photo courtesy RIRM).

frame with the thermoplastic interface seems to be the most commonly used. There are three major fabrication techniques for the frame system described. They are the IPOS System (Figure 2),[1,2,13] the ISNY (Figure 3),[14] and the SFS System (Figure 4)[7] (Fillauer Technique).[10]†

The intention of this article is to describe the differences and similarities of the above three systems.

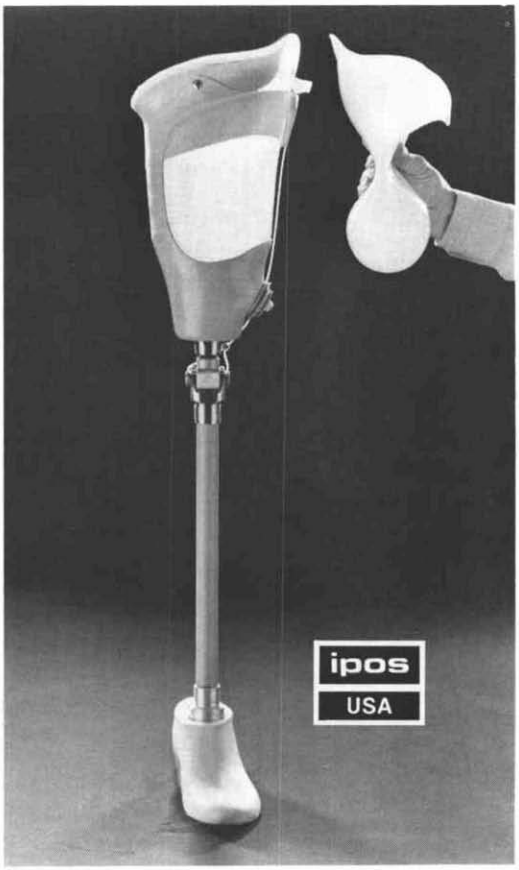

Figure 2. Flexible AK socket as fabricated by IPOS (Photo courtesy IPOS).

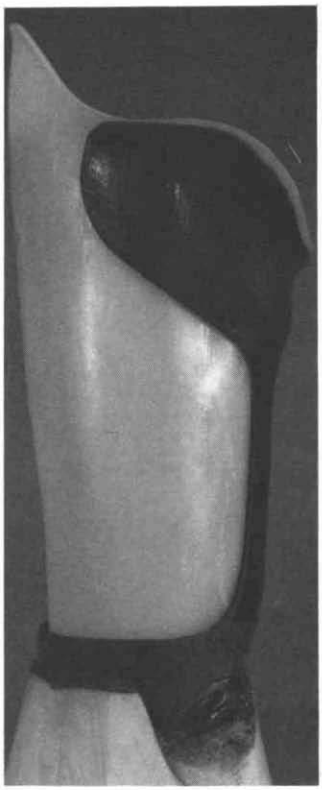

Figure 3. Icelandic Swedish New York (ISNY) flexible socket (Photo courtesy NYU).

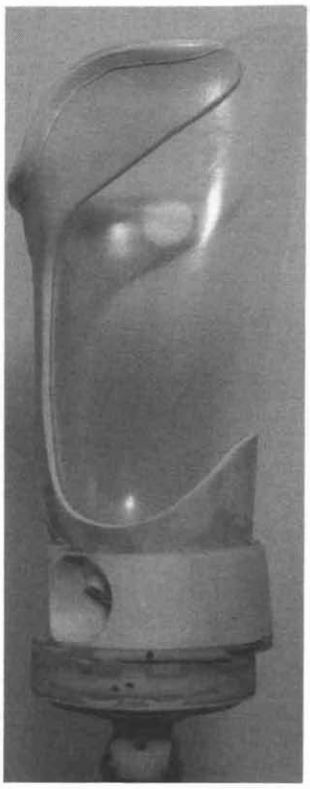

Figure 4. Scandinavian Flexible Socket (SFS) (Photo courtesy Durr-Fillauer Medical, Inc.).

† Further reference to the SFS system will be as it is fabricated by Durr Fillauer Medical, Inc.

SOCKET INTERFACE

All three systems use a thermoplastic material for their inner socket.

IPOS uses ipolen,[2] which is a specially formulated polyethylene and which reportedly provides a uniform socket thickness and has little shrinkage. The resulting socket is translucent.

The ISNY system prefers polyethylene which has a tendency to shrink. NYU reports that the shrinkage is not a problem. This socket is also translucent.

The SFS system recommends Surlyn®, but polyethylene can be used. Surlyn® is a thermoformable plastic which shrinks little and provides a transparent socket.

The thermo-forming method for the interface is basically the same for all three systems. The only difference is that IPOS recommends that you preheat the vacuum forming frame, and they prefer a dry cast. If a wet cast is used, they recommend that an IPOS sheath be pulled over the cast before the thermo-forming. The SFS system recommends a warm, wet mold for Surlyn®. ISNY states no preference.

FRAME (Structural Element)

The most variation occurs in the fabrication of the frame. Materials and lay-up have a wide range of variation (Table 1).

IPOS laminates on the positive model with the flexible socket in place. Carbonacryl, which has been specially formulated to use with carbon fibers (13-1), is laminated over the appropriate layers of nylon stockinette, carbonglass stockinette, fiberglass matting, and fiberglass stockinette. Total lay-up is seven layers for the average size patient of 120 to 180 pounds.

The ISNY system laminates on the positive model with the flexible socket in place. Their recommendation is for 100 percent rigid polyester, acrylics if desired. A polyester lamination is done over the appropriate layers of nylon stockinette, fiberglass stockinette, and 1″ and 2″ unidirectional carbon tape. The total layup is 26 layers in both directions. In addition, they recommend adding dacron felt "to insure sufficient thickness in strategic areas."[14]

SFS laminates their frame over the positive

Frame Lay-up Comparison

SFS	*ISNY*	*IPOS*
1 Nylon stockinette	1 Nylon stockinette	1 Stretch nylon stockinette
2 3/16″ round Polyethylene rod medial wall	1 −1oz. Dacron distal end	1 Carbonglass stockinette
1 Nylon stockinette	1 Nylon stockinette	2 Fiberglass matting (on medial strut and anterior posterior phalange)
2 Fiberglass stockinette	4 −2″ Carbon—(Medial Struct.)	1 Carbonglass stockinette
1 −6″ Nylon folded lengthwise on anterior, medial and posterior of proximal brim	1 −1″ Carbon—(Proximal Frame)	1 Fiberglass/nylon stockinette
1 Fiberglass—Carbonroll* medial wall proximal to distal	12 Fiberglass	1 Stretch nylon stockinette
1 Fiberglass—roll proximal brim	4 −2″ Carbon	
1 Fiberglass—Carbon roll* medial wall proximal to distal	1 −1″ Carbon	
1 Fiberglass—Carbon roll*—Proximal brim	1 Nylon Stockinette	
2 Fiberglass stockinette	*Add Dacron felt and smooth transition and insure sufficient thickness in strategic area.*	*For the average size patient, 120 to 180 lbs., the lay-up remains constant.*
2 Nylon		
Acrylic resin with 10 percent thinner.	*100 percent Rigid polyester acrylic if desired.*	*Carbonacryl Resin*

* Roll = 6 Fiberglass and 31″ carbon tape.

Table I.

model, which has been built up with varying layers of stockinette used as a filler in place of the flexible socket. An acrylic lamination is done over the appropriate layers of nylon stockinette, fiberglass stockinette, and 1" unidirectional carbon tape. Total lay-up at the proximal brim is 25 layers, and 26 layers at the medial brim.

In the ISNY and SFS systems care must be taken in the lay-up of the medial/proximal brim where the materials overlay to avoid excessive thickness.

FRAME DIMENSIONS

There are some variations in the final trimlines of the frame. The medial strut on the SFS and ISNY are approximately $2^1/_2$" and $2^3/_4$" wide. The medial strut on the IPOS frame extends around the anterior and posterior medial edge by one centimeter.

The proximal trimlines on the SFS, anteriorly and posteriorly, are $^2/_3$ the medial/lateral width. The proximal trimlines of the ISNY extend to the anterior and posterior lateral socket corners. The proximal trimlines of the IPOS extend around the anterior and posterior lateral corner by 2 centimeters.

In the SFS and IPOS systems, the distal trimline cups around the lateral distal femur. The ISNY does not. All systems tell you to take care to have an adequate radius on connecting edges between the medial strut and the proximal and distal trimlines.

COMMENTS AND CONCLUSIONS

The afore-mentioned indicated that there are many questions still unanswered. The varying lay-up design makes for varying flexibility and weight difference in the frames. At Newington, we question why the severe differences in build-up exist and as a result are undertaking a research project with some students at the Engineering Department at the University of Hartford. As a senior research project, they are planning an evaluation of the mechanics and structure of the three strut designs as well as the flexible socket material.

It should be noted that if there are severe undercuts on the positive model, removal of the finished strut from the model can cause stress cracks in the frame.

Problems have been noted by Newington and others of the flexible socket breaking after delivery to the patient. Care must be taken in fabrication of the socket that all flares are built into the positive mold. This will help reduce the stress in the molding process. Another recommendation to remove the stress from the finished flexible socket is an annealing process. We have yet to evaluate its effectiveness.

In conclusion, there has been some confusion as to the different systems. Our purpose here has been to clarify the systems and their differences. As with any new system, questions and confusion are to be expected.

It is still a subjective evaluation. As long as the patient benefits, use the system (or combination of systems) with which you are the most comfortable.

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Technical Article

Flex-Frame Sockets in Upper Extremity Prosthetics

by Donald L. Fornuff, C.P.

The development of various new plastic materials has brought about a rapid change in the design and fabrication of lower extremity prosthetic sockets. We can now expect most of these revolutionary developments to overflow into other areas of prosthetics and orthotics. The most natural area next to be influenced is upper limb prosthetics.

We at Rusk Institute of Rehabilitation Medicine have been trying various socket frame configurations with all levels of upper limb amputees, from wrist disarticulations to above elbows, including the humeral neck amputation.

The following is a brief "technical note" describing the technique we use for fabricating the flex-frame socket for the upper limb prosthesis and a sampling of various socket designs.

BELOW ELBOW SOCKET

When the below elbow socket model has been modified and smoothed, a flexible socket is made by vacuum molding, using Surlyn or Ethalux polypropylene (Figure 1). A thin socket is then laminated in the conventional fashion over the flexible socket (Figure 2). This socket will act as a frame for the flexible socket and will allow for the secure attachment of the forearm extension and wrist unit. Upon completion of the thin laminated socket, the P.V.A.

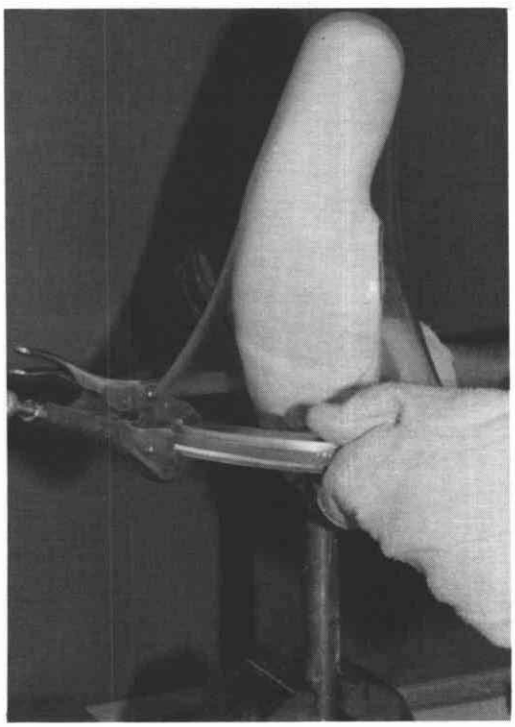

Figure 1. A flexible socket is made by vacuum molding, using Surlyn(R) or Ethalux polypropylene.

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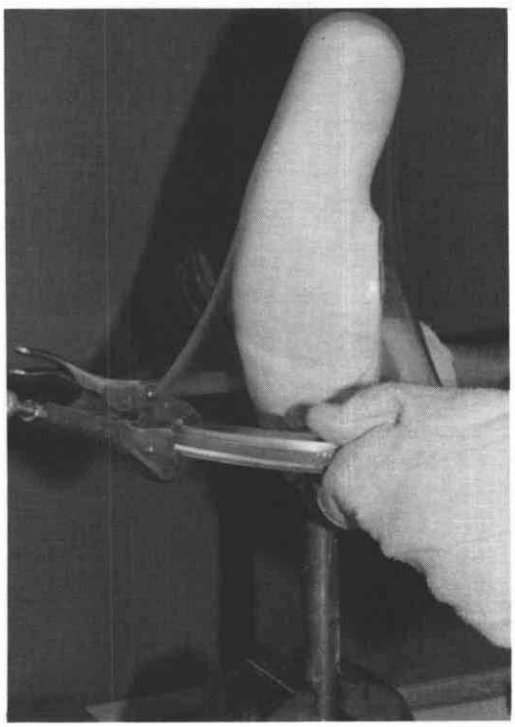

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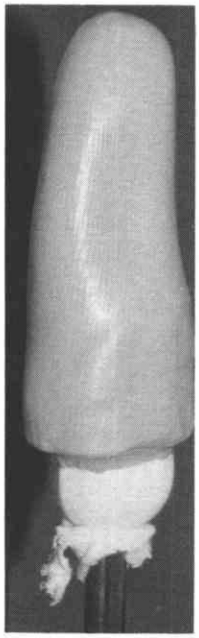
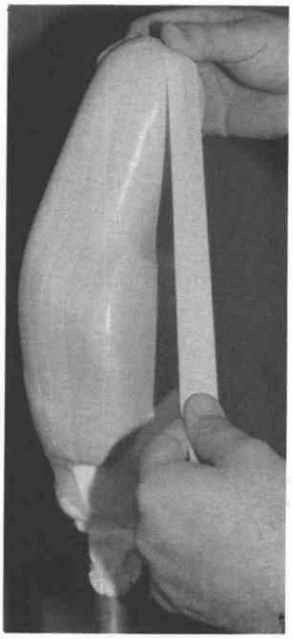


Figure 2.



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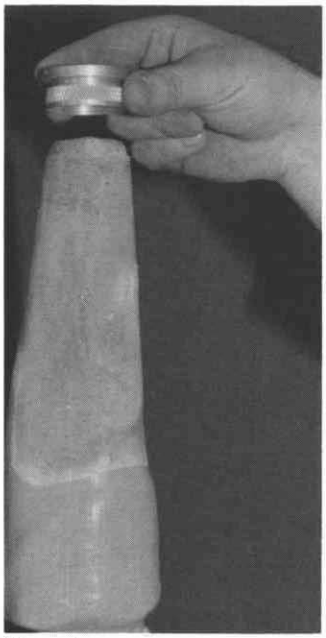


Figure 4.

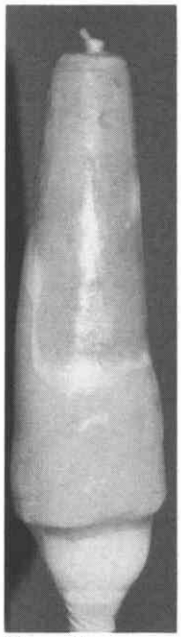


Figure 5.

sleeve is removed. The socket is then covered, using strips of 1″ masking tape (Figure 3).

The forearm extension form, or mold, holding the wrist unit is mounted to the below elbow socket in the correct alignment, position, and length (Figure 4). The wrist unit is taped over to prevent foam from clogging various screw holes. A hole is cut in the forearm extension piece just proximal to the wrist unit. Foam is poured into this hole to form the forearm extension piece. Additional foam may be required to ensure proper shaping of the forearm section. When shaping is completed, the wrist unit is heated slightly and removed. Vaseline® is applied to the remaining foam and socket, and a P.V.A. sleeve is pulled on and tied at both ends (Figure 5). The wrist unit is replaced over the P.V.A. sleeve, held in place by the layers of material to be used in the second lamination. The material is tied off in the usual manner.

When the forearm has been laminated, it should be completely removed from the below elbow socket and foam extension (Figure 6). This removal is relatively easy because of the P.V.A. sleeve applied over the shaped foam forearm section. After the laminated forearm is removed, the foamed forearm section and tape are completely removed from the laminated socket.

The laminated and vacuum molded flexible sockets are removed from the model (the model

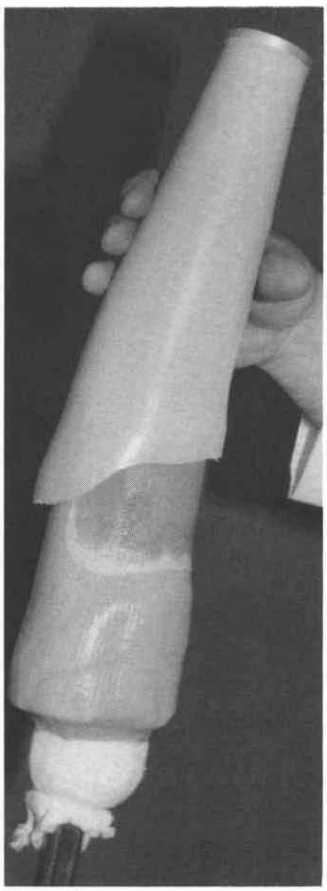
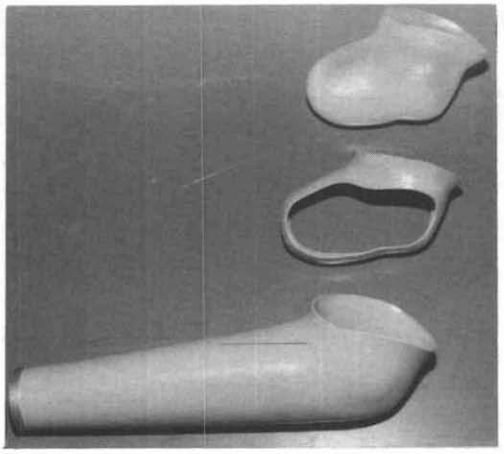


Figure 6.



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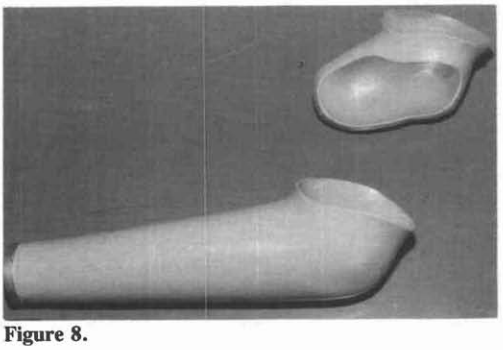

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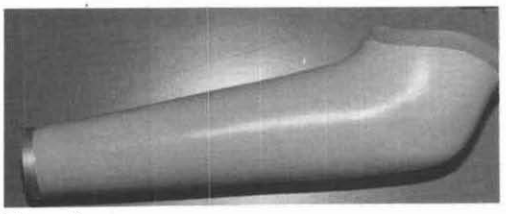

Figure 9.

must be broken many times) and the laminated socket frame is cut to its desired shape to allow maximum flexibility of the flexible socket (Figures 7 and 8).

The frame socket is placed into the forearm section and trim lines are established. Both sections are then sealed together. The flexible socket is placed in the frame socket and the trim line is established: 1/8" to 1/4" above the edge of the laminated frame socket to minimize the stiffness gradient and to allow a gradual transition from the flexible socket to the rigid frame (Figure 9). Socket designs are many and quite variable (Figures 10 and 11).

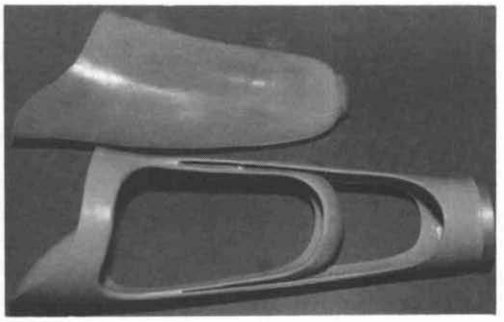

Figure 10.

Figure 11.

ABOVE ELBOW SOCKET

All previous steps used in the below elbow prosthesis apply to the above elbow prosthesis until removal of the laminated humeral section with the attached elbow turntable. When the humeral section is removed from the foamed humeral extension, it is set aside (Figure 12), while the laminated above elbow socket is cut out to allow maximum flexibility of the flexible socket. The laminated humeral extension holding the turntable is then re-attached to the

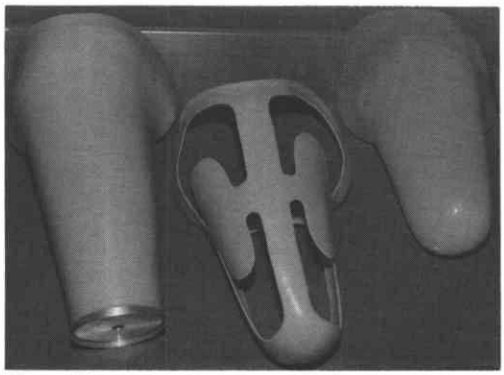

Figure 12.

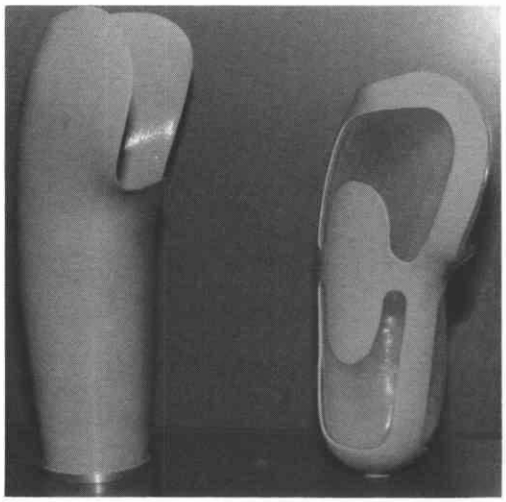

Figure 13.

flex-frame socket with a rigid plastic resin (Figure 13). Easy removal of the flexible socket will allow for easy access to the elbow friction and attachment nut at the elbow turntable.

Again, configurations of both below and above elbow flex-frame sockets are many in design, but must provide attachment areas for harnessing and base plates for proper transition of the cable control system.

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ACKNOWLEDGMENTS

The author wishes to acknowledge Mr. Steve Szabo's technical assistance.

Technical Article

New Concepts in Post-Operative Scoliosis Management

by Robert D. Fitch, M.D.
Carrie Louise Beets, C.O.

As improved surgical techniques and stronger spinal instrumentation are developed, the need for external stabilization post-operatively and the design of post-operative orthotics have also evolved. The purpose of this article is to review the many recent advances in the surgical technique and spinal instrumentation, and the early results of a new management protocol (both surgical and orthotic) in the treatment of selected spinal deformities.

EVOLUTION OF SPINAL STABILIZATION

The goal in the surgical treatment of scoliosis is to correct the deformity and maintain correction until fusion of the spine occurs. It is the surgical technique of fusion that provides long term spinal stability. Until the fusion mass matures, we must rely on stability provided through surgical instrumentation (internal support) and casts or orthoses (external support). If the spine is not stabilized sufficiently internally and externally, then a non-union of the spine will occur similar to that which occurs with inadequate immobilization of long bone fractures. Once a non-union develops, the deformity may gradually recur.

Prior to the advent of the Harrington rod, correction of the spinal deformity was obtained through complicated casting techniques. Risser described the turnbuckle in 1927[6] (Figure 1). Later he developed the localizer cast.[5] A cast technique similar to this was perfected by Dr. Cotrel of France[1] (Figures 2 and 3). These casting techniques allowed correction of the deformity in the cast. The spine was then operated upon in the corrected position through the cast and the patient was maintained in a cast post-operatively for a period of nine to 12 months. With this form of treatment, there was a high incidence of failure, primarily due to the development of cast complications, or pseudoarthroses.[4] Many surgeons advocated routine exploration of the fusion mass six months post-operatively to identify any areas of non-union.

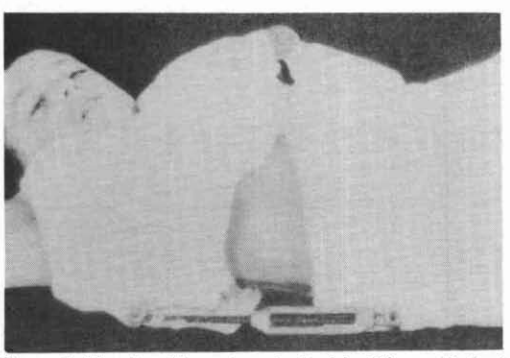


Figure 1. Turnbuckle cast as devised by Risser. Patient had to remain in bed for six months. (Photo reproduced with permission from *Scoliosis* by J.I.P. James, Williams & Wilkins Publishers, 1967.)

In 1960, Paul Harrington reported on the use of a stainless steel distraction rod for the correction and stabilization of spinal deformities.[2] The Harrington device has since become the mainstay of surgical treatment for scoliosis. It has shown to be of great benefit in experienced hands and has shortened hospitalization time, avoided the need for preoperative correction with casting, permitted early mobilization of

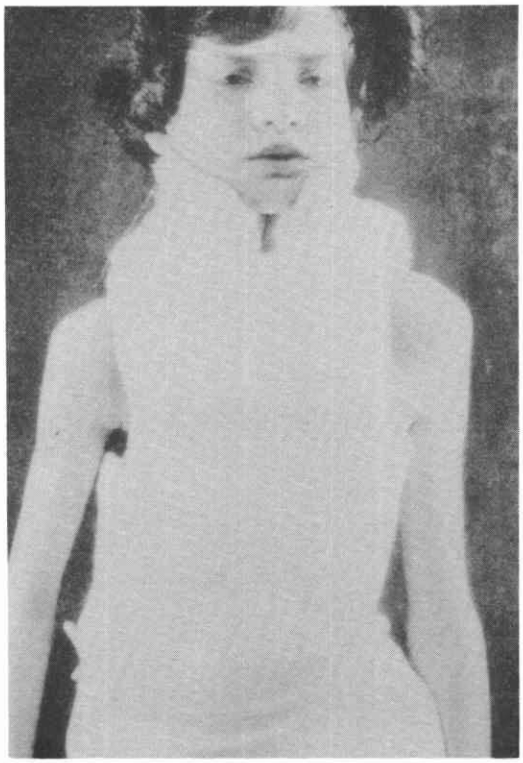


Figure 2. Localizer cast which extends up over the occiput and mandible. (Photo reproduced with permission from *Scoliosis*, ibid.)

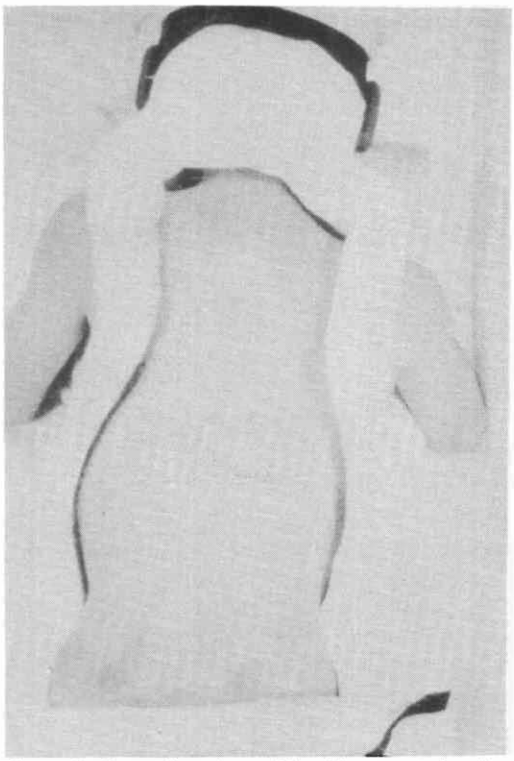


Figure 3. Posterior view of localizer cast showing window through which surgery was performed. (Photo reproduced with permission from *Scoliosis*, ibid.)

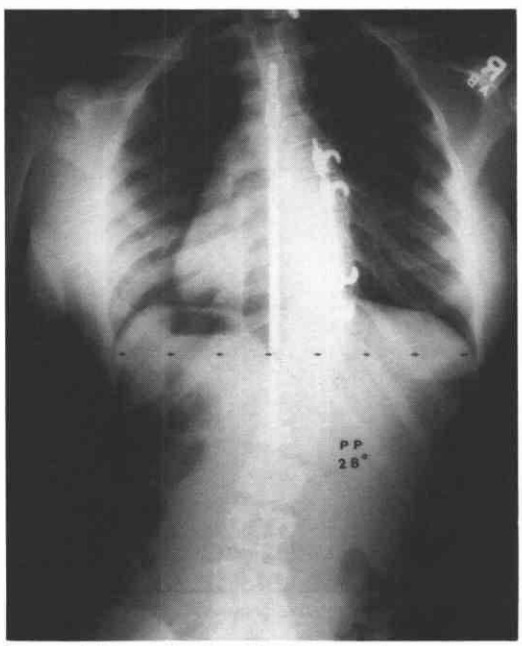


Figure 4. X-ray showing Harrington rod system.

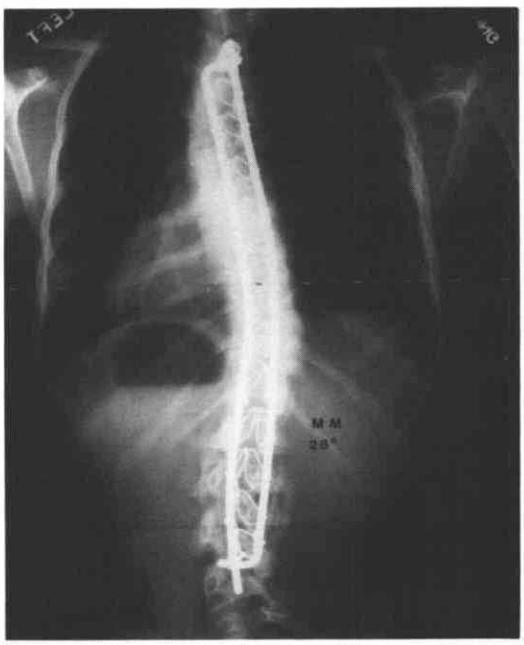


Figure 5. X-ray showing Luque rod instrumentation.

the patient in a well-fitted cast or orthosis, and has markedly decreased the pseudoarthrosis rate following fusion. What it has not accomplished, however, is the ability to provide sufficient internal stabilization to allow the abandonment of external support either by cast or orthosis.

There are many instances in which external immobilization is undesirable. These include patients with insensitive skin, spasticity, or respiratory compromise. During the early 1970's, Edwardo Luque, M.D. from Mexico City was faced with many complex spinal deformities similar to those just mentioned. This led him to develop a new form of spinal instrumentation called segmental spinal instrumentation.[3] Unlike the Harrington rod, which uses distraction forces and is fixed to the spine at the top and bottom so that all the forces are concentrated at the bone-hook interface superiorly and inferiorly, segmental instrumentation provides corrective forces in a transverse manner at each spinal segment and, therefore, the distribution of forces is spread out over the whole length of the instrumentation. This has been shown to be much stronger biomechanically than the Harrington system and is extremely stable[7] (Figures 4 and 5).

Segmental spinal instrumentation has become the preferred method of treatment of complex spinal deformities, especially those associated with neuromuscular conditions such as muscular dystrophy, myelodysplasia and cerebral palsy. However, it has not replaced the Harrington rod for the management of idiopathic scoliosis. This is primarily because of the added neurologic risk that is involved when performing segmental spinal instrumentation. Wires must be passed sublaminarly within the spinal canal at every level to perform this technique. The potential for neurologic complications is related to invasion of the spinal canal with these wires and the potential for vascular compromise to the cord by correction of the deformity, which leads to elongation of the spinal canal and vascular stretch.

It must be kept in mind that segmental spinal instrumentation does not take the place of a meticulous fusion, and if fusion does not occur, then instrumentation failure in inevitable. In general, patients who have been treated with segmental spinal instrumentation are not placed in any cast or orthosis post-operatively. This is based on the assumption that the Luque instrumentation is so strong that no external support is needed. However, recently some surgeons have questioned the requirement for external support even with Luque instrumentation. Although the early instrumentation failures have been solved with segmental spine instrumentation, some surgeons have found increased loss of correction over the first few months in patients not treated with orthoses, compared to those who have been treated with orthoses post-operatively. Also, the question of late pseudoarthroses must yet be resolved; and if there is a significant incidence of pseudoarthroses with Luque instrumentation, would post-operative orthotic support decrease this incidence?

Because of the added neurologic risk, we have opted not to use segmental instrumentation in dealing with most idiopathic spinal deformities. Rather, we continue to use the Harrington rod with some recent modifications. The modified Harrington rod provides enough internal stability to allow us to use a post-operative orthosis that is comfortable, convenient, and cosmetic. Added stability to the Harrington system has been achieved by a simple modification of the Harrington hooks. This was devised by Dr. Bobechko of Toronto. The new hook has a cam placed inside a slot which allows two hooks, rather than one hook, to be utilized at the upper level. Since most of the early instrumentation failures with Harrington rods have been with the cut-out of the upper hook, two hooks allow the forces to be distributed over a larger surface area, and when the technique is properly performed, corrects that problem. At the bottom end, a specially designed hook with a longer shoe is used to prevent dislodgement of the hook in this area, which can occur when the patient flexes forward.

With the degree of stability provided by this method, post-operative cast immobilization is unnecessary. In addition, currently available orthoses such as the Greenville spinal orthosis, the SOS modular orthosis, or the Milwaukee brace also provide more external support than we feel is necessary. This has led us to adopt the use of a posterior plastic shell with corset front and shoulder straps.

CURRENT MANAGEMENT PROTOCOL

This post-operative orthosis is used in two situations: (1) in the patient with idiopathic scoliosis who has undergone Harrington rod instrumentation with modified hooks as described above, and (2) in patients with more complex

spinal deformities who have had segmental instrumentation and are at risk for loss of correction or late pseudoarthrosis.

Our post-operative regimen consists of taking a mold at the time of surgery. The patient is then mobilized quickly beginning on the first post-operative day. The patient is allowed to stand at the bedside twice a day until the orthosis is ready and applied, usually on the third post-operative day. At that point, the patient is allowed to begin ambulation and sit with the orthosis on. Following discharge, the patient is allowed to doff the orthosis at night and once a day for showering. The orthosis is worn for four months post-operatively.

ORTHOSIS DESIGN

The posterior shell orthosis used at Duke University Medical Center is based on an orthosis design that was originally used at the Texas Scottish Rite Hospital for Crippled Children in Dallas, Texas. At the Scottish Rite Hospital a Surlyn® posterior shell, with a special order Camp corset front riveted to the shell, is used. It is cast and delivered post-operatively, or sometimes on an outpatient basis.

At Duke, the design was modified by the addition of shoulder straps for provision of an anti-rotatory movement reminder. The shoulder straps and the corset front are removable for easy laundering. The Duke protocol is for its use as an immediate post-operative orthotic device.

CASTING

The Department of Prosthetics and Orthotics at Duke University Medical Center has the advantage of being located on site. This permits close coordination with the physician and his operating room schedule. The dates for which an orthotist is needed in the operating room are known in advance, as well as the time and estimated length of surgery. The surgeon notifies the orthotist as the surgical team prepares to close the case. The orthotist arrives in the operating room while the case is being closed. Adequate time is available to set up splints and water, inspect operative x-rays, and confirm the length of the instrumentation (helpful in determining proximal trimline of orthosis).

Following closure of the surgical site, a small temporary sterile dressing is placed over the suture line for protection. The orthotist places a split piece of cotton stockingette over the patient's back and buttocks. Using an indelible pencil, the axillary and proximal trimlines are marked, C-7 is marked for reference, the waist and the gluteal fold and a horizontal line across the top of the gluteal fold are also marked (Figure 6). Six inch wide plaster splints, three layers thick, are applied lengthwise starting with the center back and overlapping towards both sides. Attention is paid to apply the plaster splints as far anteriorly on the patient as possible to make sure the cast impression has been taken to midline or just beyond. If a patient appears large busted or overweight, the sides of the impression can be compressed while the plaster is setting up (Figure 7). This will afford a truer M-L measurement for the patient when standing and sitting. The cast impression is removed (Figure 8) and the post-operative bandages are applied.

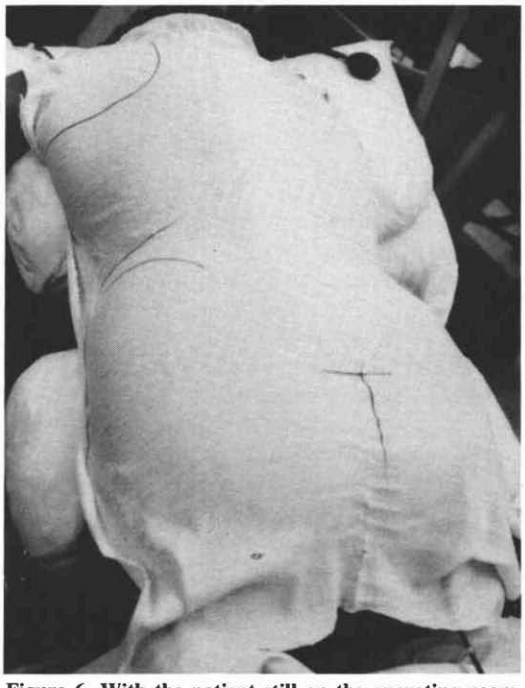


Figure 6. With the patient still on the operating room table, a split piece of stockinette is placed over the patient's back and landmarks and trimlines are marked.

FABRICATION

Any number of thermoplastics can be used to fabricate this orthosis, however, we have found Surlyn® to be sufficiently rigid and cos-

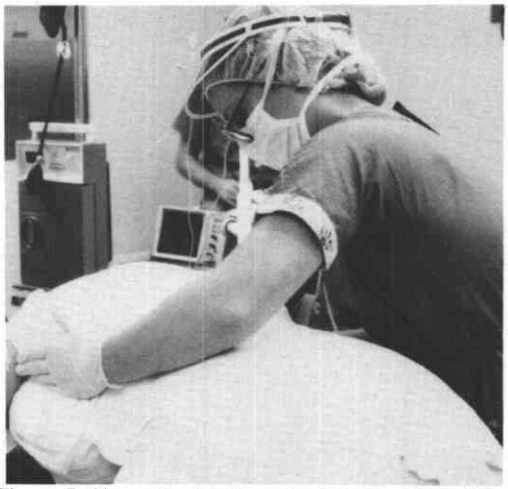


Figure 7. If a patient is large busted, the sides of the cast impression can be compressed while the plaster is setting, allowing a truer M-L dimension for when the patient will be sitting and standing.

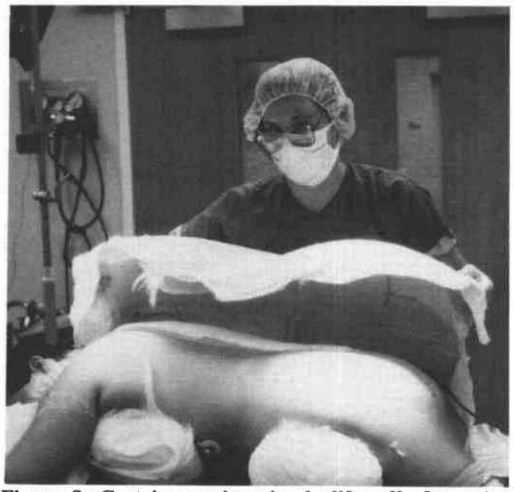


Figure 8. Cast impression simply lifts off. Operating room nurses replace temporary bandage, protecting the suture site with a regular post-op dressing.

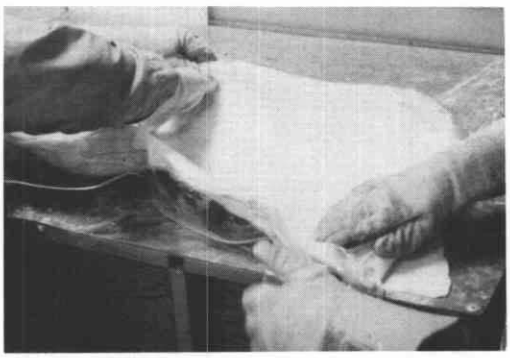


Figure 9. Surlyn®, heated just until pliable, is pressed into the contours of the cast impression.

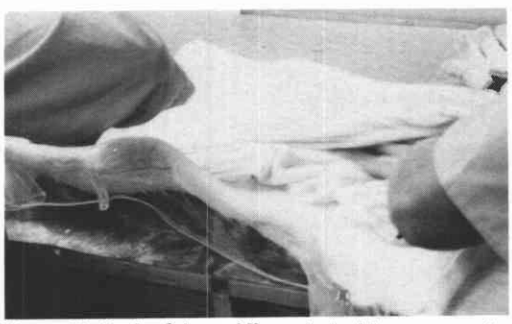


Figure 10. Surlyn® is rapidly cooled with a wet towel.

metic. The advantage of fabricating with Surlyn® is that the standard practice of pouring, stripping, and modifying a positive model can be completely eliminated.

In the fabrication lab, the cast impression is allowed to dry 30 minutes to an hour. The stockinette is then powdered. The impression is placed into an adjustable support to prevent any M-L spreading during the plastic molding. A piece of $^{3}/_{16}$″ thick Suryln®, large enough to cover the inside of the impression, is placed in the oven and allowed to heat just until it is pliable (about five minutes). The heated plastic is placed in the impression and pressed into the contours of the cast impression (Figure 9). The plastic is then rapidly cooled by a wet towel or air (Figure 10). When completely cooled, the plastic shell is lifted off the cast impression and the stockinette is stripped, exposing trimlines and reference marks made at the time of casting. The plastic shell is set back on top of the cast impression and the trimlines are transferred to the shell (Figure 11). The shell is trimmed and the edges finished (Figures 12 and 13).

The posterior shell is ready for the attachment of the corset front and shoulder straps. We use a standard corset front available from Truform in either a 9″, 10″, or 12″ abdominal length, depending on the patient's stature. Holes corresponding to the corset eyelets are drilled in the lateral edges of the posterior shell

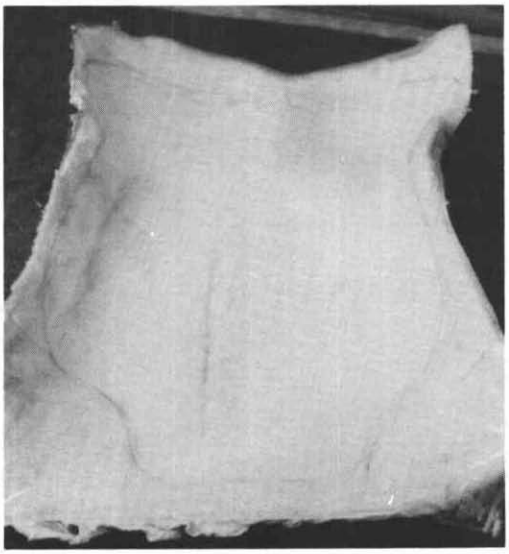
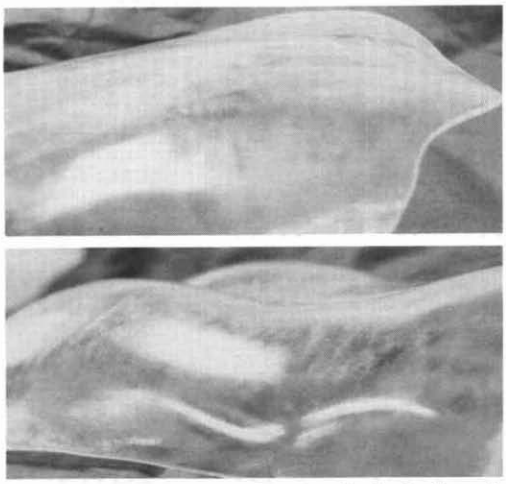


Figure 11. Trimlines are transferred from the cast impression to the Surlyn® shell.



Figures 12 and 13. Drape forming the Surlyn® to the cast impression without pouring a positive mold gives excellent contour detail to the resulting posterior shell.

and the corset front is laced onto the posterior shell (Figure 14).

The shoulder straps, which are also removable for laundering, are attached to the posterior shell via Velcro® on the ends which double back on themselves after slipping through loops permanently riveted to the posterior shell. The shoulder straps are attached to the shell just proximal to the interscapular level. They cross the shoulders and attach laterally several inches distal to the axillae via a standard corset style hook. Placement of the lateral hooks midway between the axillae and the waistline prevents binding in the axillae when the straps are tightened. Total fabrication time from casting to initial fit is approximately four hours.

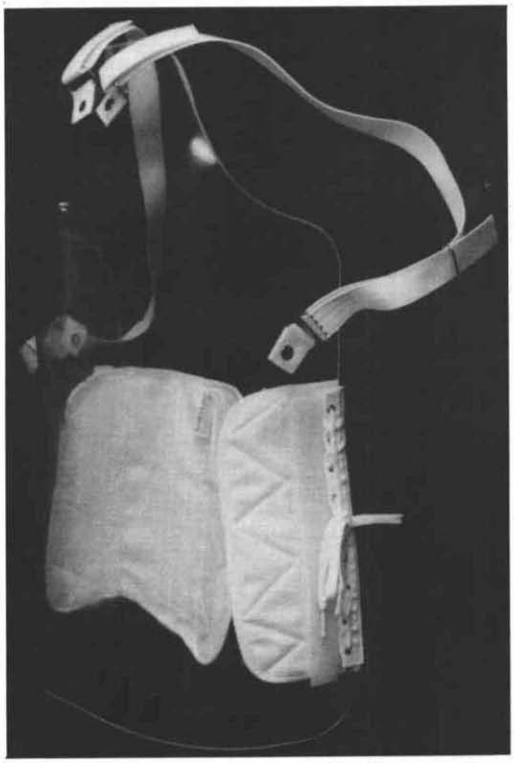


Figure 14. Finished posterior shell with corset front laced in place and shoulder straps also removable for laundering.

FITTING

Though the fabrication of the posterior shell orthosis is fast enough to permit fitting the same day as the cast impression is taken, the orthosis is usually delivered on the third post-operative day. This is done to allow post-operative illeus with accompanying abdominal distention to resolve. If the orthosis is fit too soon, the corset front invariably needs to be altered or the size of the front changed altogether. By the third day, the patient is alert and tolerant of being log-rolled, and the majority of abdominal distention has subsided. The posterior shell is tried for initial fit in bed and the patient is measured

for the corset front with the shell in place. The accuracy of the trimlines is noted and the shell is marked if any adjustments are needed.

After the corset front is attached, the orthosis is delivered to the patient, along with two pieces of stockinette to serve as in-hospital t-shirts and a written information/instruction sheet which covers care of the orthosis and basic "do's and don'ts."

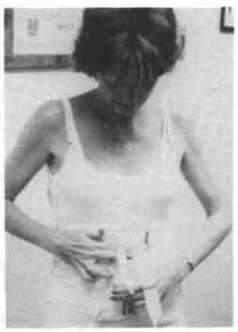
When providing this orthosis for community physicians at nearby hospitals, rather than trying to coordinate with their operating room schedule since travel time is involved, we cast the patient several days post-operatively. The patient is log-rolled in bed to a prone position and the plaster impression is taken the same way as in the operating room. If thick bandages are still over the patient's surgical area, the impression will be slightly deeper than the final product. Trimlines must be adjusted accordingly. The community hospital patient is measured for the corset front at the same time as casting since he can be log-rolled back to a supine position for measuring. The M-L measurement for the corset front is taken midline to midline. The shell is then delivered in 24–48 hours. By either method, the patient is up and walking in the orthosis at four days post-operative and is usually discharged at 6–7 days post-operative.

SUMMARY

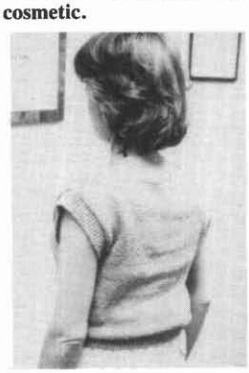
As of this writing, the protocol described above had been utilized in 44 patients over a period of 18 months. Diagnoses include adolescent idiopathic scoliosis, myelodysplasia, adult scoliosis, and adult spinal tumor. There has been one occurrence of instrumentation failure in a patient with adolescent scoliosis who had dislodgement of the upper hooks as a result of improper hook placement at the time of surgery.

We feel that with the increased internal support provided by the Bobechko hooks in the Harrington rod instrumentation that the modified bracing provided by the posterior shell (versus Milwaukee or Greenville orthosis) has provided satisfactory restriction of gross motions which might endanger the success of surgery. Forward bending and twisting are restricted and the shoulder straps add an upper torso anti-rotatory reminder for the patient. We have had no problems with lack of compliance in brace wearing, even though both the shoulder straps and the corset front are removable.

The orthosis has been well received by the patients. It is cooler and more comfortable than many of its counterparts. It is also cosmetically acceptable and is easily donned and doffed. Hygienic maintenance requires minimal time and effort. Finally, it has been well received by both adolescent and adult patients (Figures 15, 16, 17, and 18).



Figures 15 and 16. The orthosis is easily donned by the patient.



Figures 17 and 18. Posterior shell orthosis is very cosmetic.

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Technical Article

Dual Function Orthotic Ankle Joint

by Gustav Rubin, M.D., FACS
Malcolm Dixon, M.A., R.P.T.
Eugenio Lamberty, C.O.

This is a brief report of a simple mechanism which permits locking and unlocking of an orthotic ankle joint. It allows an individual who requires a locked ankle for ambulation to unlock the ankle, permitting plantar flexion of the foot for pedal control while driving a car.

We have found this to be a useful device for patients who have painful arthritic ankles which interfere with ambulation, but who find the discomfort tolerable when they are seated and the limb is unweighted. In such instances, an immobile ankle interferes with the smooth operation of the pedal while contributing little to the relief of pain when sitting.

The following cases illustrate the manner in which this problem was solved with two different types of AFO.

L.S. was 57 years of age when first seen by the VAPC Clinic Team in 1978. He had sustained a fracture of the right femur in WWII, which had healed in 20° of internal rotation of the distal fragment and with subsequent posttraumatic arthritis of the knee. A concomitant sciatic nerve injury indicated the need for a drop foot orthosis and the patient was provided with a light-weight shoe clasp orthosis.[1,2] Because of the internal rotation deformity, the patient was pushing off from the lateral aspect of the foot, and he developed callosities beneath the fifth metatarsal base. Subtalar, ankle, and mid-tarsal motion were painful. The shoe clasp orthosis did not adequately control the flexible equinovarus of the foot; a double bar orthosis with varus correction T-strap and spring loaded ankle was prescribed. The spring loading was permitted because the patient indicated that a solid ankle would interfere with the operation of the gas pedal of his car. The spring loaded ankle did not sufficiently relieve the pain and on October 10, 1984, the VAPC Clinic Team prescribed an AFO with an ankle joint which could be locked for ambulation and unlocked

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AUTHORS

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Technical Article

Dual Function Orthotic Ankle Joint

by Gustav Rubin, M.D., FACS
Malcolm Dixon, M.A., R.P.T.
Eugenio Lamberty, C.O.

This is a brief report of a simple mechanism which permits locking and unlocking of an orthotic ankle joint. It allows an individual who requires a locked ankle for ambulation to unlock the ankle, permitting plantar flexion of the foot for pedal control while driving a car.

We have found this to be a useful device for patients who have painful arthritic ankles which interfere with ambulation, but who find the discomfort tolerable when they are seated and the limb is unweighted. In such instances, an immobile ankle interferes with the smooth operation of the pedal while contributing little to the relief of pain when sitting.

The following cases illustrate the manner in which this problem was solved with two different types of AFO.

L.S. was 57 years of age when first seen by the VAPC Clinic Team in 1978. He had sustained a fracture of the right femur in WWII, which had healed in 20° of internal rotation of the distal fragment and with subsequent posttraumatic arthritis of the knee. A concomitant sciatic nerve injury indicated the need for a drop foot orthosis and the patient was provided with a light-weight shoe clasp orthosis.[1,2] Because of the internal rotation deformity, the patient was pushing off from the lateral aspect of the foot, and he developed callosities beneath the fifth metatarsal base. Subtalar, ankle, and mid-tarsal motion were painful. The shoe clasp orthosis did not adequately control the flexible equinovarus of the foot; a double bar orthosis with varus correction T-strap and spring loaded ankle was prescribed. The spring loading was permitted because the patient indicated that a solid ankle would interfere with the operation of the gas pedal of his car. The spring loaded ankle did not sufficiently relieve the pain and on October 10, 1984, the VAPC Clinic Team prescribed an AFO with an ankle joint which could be locked for ambulation and unlocked

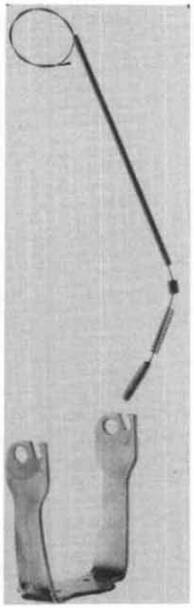

Figure 1. The stirrup has been slotted to receive the pin, the threaded screw drilled to permit passage of the cable and the pin welded to the cable. Note also the spring and the cable housing.

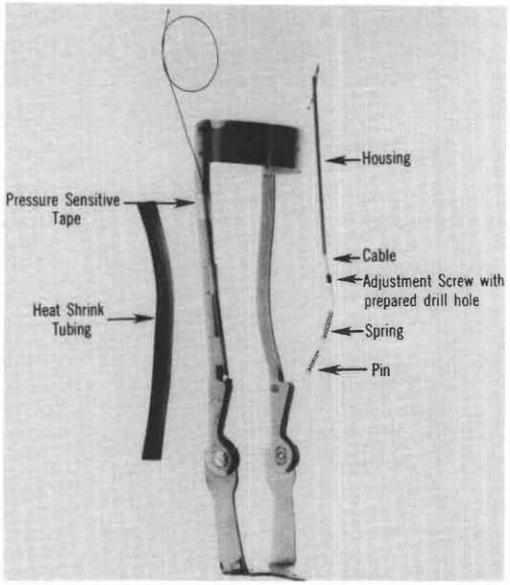

Figure 2. The basic components of the dual function ankle.

for driving. This functioned well and accomplished the purpose for which it was designed. The shoe incorporated a rocker bar and long steel spring.

FABRICATION

1. A 1/4" wide by 3/8" deep slot was prepared in each stirrup upright with a 1/4" drill. The tubular area in the distal upright (for the adjustment screw and Klenzak spring) was used to guide the drill (Figure 1).
2. A drill hole was made vertically through the center of the adjustment screw with a size 40 drill and a conventional upper extremity control cable was passed through this hole (Figures 1 and 2).
3. One end of the cable was welded to a 1/4" wide steel pin, 1" long (Figures 1 and 2).
4. The above components were assembled as shown in Figure 2. Each cable was passed through a conventional upper extremity cable housing, which was then strapped to each upright of the AFO, using pressure sensitive tape (Figure 2). Finally, the housing was covered with heat shrink tubing (Figures 1, 2 and 3).
5. A plastic "handle" was fabricated for attachment to the proximal ends of the cable and adjusted to lock, under spring tension, to a pin fixed to the middle of the calf band (Figures 3 and 4). When hooked over the retention pin, the locking rod was released from the stirrup slot allowing ankle motion. When the handle was disengaged, the spring became effective, locking the ankle.

A similar approach was also used for a PTB orthosis (Figures 5 and 6). The basic fabrication technique was the same, although the pathological problem required a PTB Orthosis rather than an AFO.

A.T. was initially seen by the VAPC Clinic Team in 1973 when he was 49 years of age. As a result of multiple injuries sustained in 1967, several surgical procedures had been carried out: an arthrotomy of the left knee, followed by an osteotomy of the tibia to correct valgus, and, in 1970, a triple arthrodesis of the right foot. Non-union of the right talo-navicular joint and medio-lateral ankle stress pain developed. Special shoes incorporating a support for the long arch on the right were ordered, as well as a right AFO with free motion ankle. A KAFO was prescribed for the left side, with free mo-

Figure 3. The AFO in the locked mode.

Figure 4. The unlocked AFO.

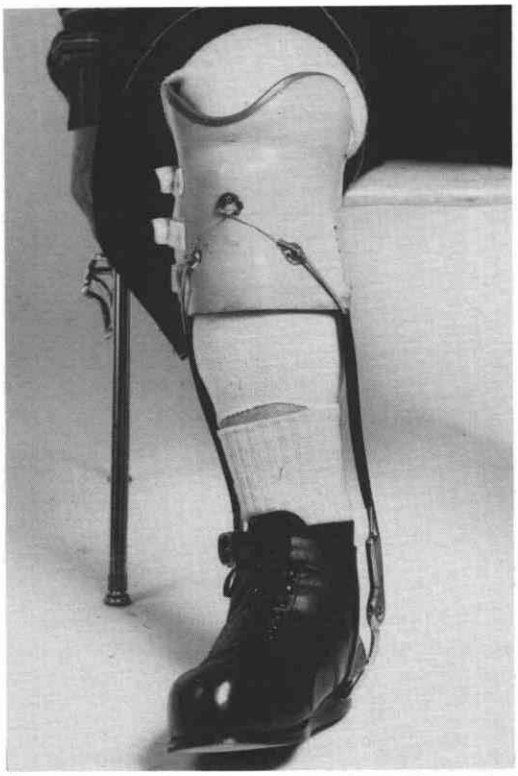

Figure 5. PTB Orthosis with anterior cuff retention button.

Figure 6. Lateral view of PTB.

tion ankle, because of persistent pain in the left knee with progressively increasing varus deformity and secondary ankle pain due to malalignment.

In January, 1977, a rocker bar was prescribed for the right shoe in an attempt to diminish A.P. ankle stress in view of moderate limitation of anatomical ankle motion.

In July, 1978, the patient returned and reported that his right ankle pain had increased with progression of osteoarthritis and a PTB[2,3] orthosis was ordered. When this was shown to the patient, he indicated a reluctance to try it because limited ankle motion or the absence of ankle motion would interfere with his driving and he did not wish to consider hand controls.

The Clinic Team decided to prescribe an ankle joint which the patient would be able to unlock for driving and relock for walking. This was to be designed as a tongue-in-groove, manually controlled lock similar to that previously described.

In this instance, since the retention button was on the anterior cuff and readily visualized, a less obtrusive metal device was fabricated to hook over the retention button.

SUMMARY

A modified ankle joint has been described which permits the user to lock the ankle for ambulation and unlock it for specific sedentary functions.

REFERENCES

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AUTHORS

Gustav Rubin, M.D., Malcolm Dixon, M.A., R.P.T., and Eugene Lamberty, C.O. are all members of the Special Clinic Team at Veterans Administration Prosthetic Center (VAPC), 252 Seventh Avenue, New York, NY 10001.

Results of Questionnaire—Contractures and Related Conditions

Contractures apparently are not a major preoccupation. There were eight responses to the questionnaire. Six of these said that contractures and related deformities are a significant factor affecting their abilities to meet their patients' needs. Conversely, six said that treatment of such conditions did not constitute a significant portion of their practice.

In response to question number 3, "Which condition is the major factor affecting such patients?," the respondents replied:

a. Post trauma immobilization
b. Related deformities, TKA line, ROM, Sitting (respondent is apparently a prosthetist in light of his answer to #5)
c. Elbow contracture secondary to CVA
e. Fixed deformities
f. Ankle contractures secondary to CVA

The orthoses or other devices most commonly used were:

a. Adjustable limited ROM joints, 3 points of pressure
b. Infants and small children, lively adults; Limited success with all types tried
c. Surgical intervention
d. Several types of custom designs: Have tried to use prefab orthoses, but have not had great success because cuff pressure areas were not large enough to lower P.S.I. and make the dynamic stretch tolerable.
e. KAFO
f. Adjustable type locks for contracted knees
g. AFO-Lively Splint
h. AFO's—plastic, jointed metal, and spring

Additional comments were:

a. Much of the local medical (orthopedic) community seems to be too aggressive and impatient in reduction of contractures.
b. Contractures are also a prosthetic problem.

Questionnaire—
New Concepts in AK Sockets

1. Are you satisfied with your quadrilateral socket?
   Yes ___ No ___

2. Do you think there is room for change in the method of fitting AK's?
   Yes ___ No ___

3. Do you think the closely related techniques described by Messrs. Sabolich and Long are the correct approach?
   Yes ___ No ___ Maybe ___

4. Do you have personal experience with these techniques?
   Yes ___ No ___

5. Have these experiences been positive or negative?
   Positive ___ Negative ___

6. How many such sockets have you fit?
   0–5 ___ 30–35 ___
   5–10 ___ 35–40 ___
   10–15 ___ 40–45 ___
   15–20 ___ more than 45 ___
   25–30 ___

7. How many flexible wall AK sockets have you fit?
   0–5 ___ 30–35 ___
   5–10 ___ 35–40 ___
   10–15 ___ 40–45 ___
   15–20 ___ more than 45 ___
   25–30 ___

8. Do you consider flexible sockets an advantage for the patient?
   Yes ___ No ___ Selected Patients ___

9. Comments: _____

Send all completed questionnaires to: Charles H. Pritham, C.P.O., % Durr-Fillauer Medical, Inc., Orthopedic Division, 2710 Amnicola Highway, Chattanooga, Tennessee 37406.

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Calendar

1985

October 31–November 1, The 1985 National Sports Prosthetics/Orthotics Symposium, Bayview Holiday Inn, Santa Monica, California. Contact: Tim Staats, CP, UCLA POEP, Room 2246, Rehabilitation Center, 1000 Veteran Avenue, Los Angeles, California 90024; tel. 213-825-6341.

November 2, Midwest Chapter of the Academy Fall Continuing Education Seminar.

November 2–3, Lower Extremity Prosthetics Update, Holy Cross Hospital, Fort Lauderdale, Florida. Contact: Esther S. Durbano, Program Coordinator, Physical Medicine and Rehabilitation Services, Holy Cross Hospital, 4725 N. Federal Highway, P.O. Box 23460, Fort Lauderdale, Florida 33307; tel. 305-771-8000.

November 8–9, A Lower Limb Prosthetic Symposium: Clinical Frontiers, Featuring Ivan Long, CP; Dale Berry, CP(C); John Michael, CPO. Sponsored by Duke University Medical Center, Department of Prosthetics and Orthotics. Contact: John Michael, CPO, Director, Dept. of Prosthetics and Orthotics, Box 3885, DUMC, Durham, North Carolina 27710.

November 13–15, Hosmer Electric Components Seminar/Workshop in Dallas. Contact: Catherine Wooten, Hosmer Corp., 561 Division St., Campbell, California 95008, Telephone (408) 379-5151.

November 15–16, American Academy of Orthotists and Prosthetists Continuing Education Conference 5-85, "Powered Limb Prosthetics," Downtown Holiday Inn, Atlanta, Georgia.

November 15–17, Medithon '85, multidisciplinary seminar devoted to running injuries, Hotel Intercontinental, San Diego, California. Contact: Medithon '85, P.O. Box 89, Jackson, Michigan 49204.

November 18–19, Second European Conference on Research in Rehabilitation, Dusseldorf, Federal Republic of Germany. Contact: Conference-Secretariat Prof. K. A. Jochheim, Rehabilitationszentrum der Universitat zu Koln, Linderburger Allee 44, D-5000 Koln 41, Federal Republic of Germany; Tel. 02 21-4 78 50 12.

December 3–6, "Credentialing Revisited: Practical Approaches to Familiar Problems," Nat'l. Comm. for Health Certifying Agencies, 9th Annual Meeting, Marriott Marquis Hotel, New York, New York.

December 6–8, "The Geriatric Foot: A Multi-Disciplinary Approach," Dept. of Family Practice, Div. of Podiatry, Univ. of Texas Health Science Center at San Antonio. Contact: Med. School Continuing Ed. Services, UTHSCSA, 7703 Floyd Curl Drive, San Antonio, Texas 78284; tel. 512-691-6295.

1986

January 27–February 2, Academy Annual Meeting and Scientific Seminar, MGM Grand, Las Vegas, Nevada. Contact: Academy National Headquarters: (703) 836-7118.

February 20–25, American Academy of Orthopedic Surgeons Annual Meeting, New Orleans, Louisiana.

March 2–5, 3rd Israel-Scandinavian Rehabilitation Seminar, "ISRASCAN: Work for Disabled Adults," Eilat, Israel. Contact: Israel Rehabilitation Society, 18 David Elazar Street, Tel Aviv 61901, Israel.

March 14–15, American Academy of Orthotists and Prosthetists Continuing Education Conference 1-86, "Spinal and Seating Orthotics," Birmingham, Alabama.

April 8–11, Pacific Rim Conference, Intercontinental Hotel, Maui, Hawaii.

April 9–12, Ambulatory Surgery in 1986—What's Happening Now. Freestanding Ambulatory Surgery Association, Boston Marriott Copley Place, Boston, Massachusetts. Contact: 703-836-8808.

April 12, Midwest Chapter of the Academy Spring Continuing Education Seminar/Social Event.

May 16–17, American Academy of Orthotists and Prosthetists Continuing Education Conference 2-86, "Lower Limb Prosthetics," Kansas City, Missouri.

May 28–30, S. M. Dinsdale International Conference on Rehabilitation, "Towards the 21st Century," hosted by the Royal Ottawa Regional Rehabilitation Centre, 505 Smyth Road, Ottawa, Ontario K1H 8M2. Contact: Education Dept. tel. 613-737-7350, ext. 602.

June 19–22, AOPA Region VI and Academy Midwest Chapter Combined Annual Meeting, Lakelawn Lodge, Delavan, Wisconsin.

July 18–19, American Academy of Orthotists and Prosthetists Continuing Education Conference 3-86, "Disarticulation Prosthetics," Milwaukee, Wisconsin.

September 19–20, American Academy of Orthotists and Prosthetists Continuing Education Conference 4-86, "Powered Limb Prosthetics," Albany, New York.

October 24–25, American Academy of Orthotists and Prosthetists Continuing Education Conference 5-86, "Spina Bifida," Cincinatti, Ohio.

1987

February 15–22, Academy Annual Meeting and Scientific Symposium, Hyatt Regency Tampa, Tampa, Florida. Contact: Academy National Headquarters, 703-836-7118.

PAMPHLET COMPETITION

The Academy has long recognized the need for the development and publication of patient guidelines in the form of small pamphlets or booklets suitable as handouts by the practitioners to patients after they have received their prosthetic or orthotic devices. The Academy, therefore, last year initiated a contest for the development of such material.

These booklets should inform the patients in a simple and clear manner about the do's and don'ts of proper maintenance of their prosthetic/orthotic device; also, the maintenance of proper fit and personal hygiene. They should also tell the patients what to do in case of tissue breakdown, discomfort caused by incorrect use of the device or problems caused by shrinkage or swelling of the affected extremity. The pamphlets should also cover donning and doffing of the device and proper treatment of the extremity when the device is not in use. Each pamphlet should stress the need for frequent follow-ups by the certified prosthetist/orthotist and return visits to the prescribing physician.

The written text should be accompanied by suitable illustrations or photographs enhancing a particular procedure or description. Proper nomenclature should be used in all instances and should be elaborated on at the end of the text in the form of a glossary.

PAMPHLET CATEGORY

Contestants participating in the contest for the patient guidelines can choose from one of the following categories:

1) Above knee prosthetics
2) Below knee prosthetics
3) Upper extremity prosthetics (including myoelectric)
4) Lower extremity orthotics
5) Spinal orthotics

ELIGIBILITY

The contest is open to the following persons:

1) Students presently engaged in or matriculating in a qualified P&O program, but not yet certified in the discipline about which they choose to write.

2) Practitioners who are Board eligible but not yet certified in the discipline about which they choose to write.

In compiling the material, the contestants can seek the assistance and guidance of other practitioners, members of the medical or paramedical field, as well as resort to helpful suggestions from the patients themselves.

The Special Awards Committee will determine two winners if the submitted material is suitable for printing. These winners will be announced at the Academy's next annual meeting in January, 1986 in Las Vegas, and each will be awarded a grant in the amount of $1,000.00 toward completion of his or her prosthetic/orthotic education. Each winner will have to relinquish his or her copywrite to the Academy and the material would be subject to revision or addition as the Academy deems appropriate.

DEADLINE

The completed material for the booklet must be received at the Academy National Office by **December 15, 1985.** Please send entries to the following address:

Mr. Norman McKonly, Academy Liaison
American Academy of Orthotists and Prosthetists
717 Pendleton Street
Alexandria, VA 22314

We hope that all who are eligible will participate. Your efforts will be appreciated not only by your peers, but foremost by the handicapped people we serve.

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Tony Marschall, CO

Richrd R. LaTorre
CO, Chairman
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Committee Members:
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Gunter Gehl, CP
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C.P.O. MANUSCRIPT GUIDELINES

1. Manuscripts must be typewritten, double-spaced with wide margins.
2. Indicate bibliographical references by means of Arabic numerals in parentheses (6).
3. Write out numbers less than ten.
4. Bibliography should follow the correct forms as shown below.
   a. Book
      Murphy, Eugene F., Ph.D., "Lower-Extremity Component," *Orthopedic Appliances Atlas,* Vol. 2, J.W. Edwards, 1960, pp. 217–224.
   b. Journal Article
      Panton, Hugh J., B.S., C.P.O., "Considerations for Joints and Corset," *Newsletter . . . Amputee Clinics,* 8:3: June, 1975, pp. 1–3, 6–7.
   c. Lecture or Verbal Presentation
      1. Holmgren, Gunnar, "The PTB Suction Prosthesis" from the written material of a lecture delivered at the third of the "Strathclyde Bioengineering Seminars," 8–11 August, 1978.
      2. Wagner, F.W., Jr.: "Classification and treatment for diabetic foot lesions"; Instructional Course, American Academy of Orthopedic Surgeons, New Orleans, Louisiana, February, 1976.
   d. Personal Communication
      Irons, George, C.P.O., Personal communication, June 1977. Presently, Director of Research, United States Mfg., Glendale, California. Formerly, Research Prosthetist, Patient Engineering Service, Rancho Los Amigos Hospital, Downey, California.

   Arrange all references alphabetically.
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9. Mail the original manuscript with accompanying photographs/illustrations and one xerox to:

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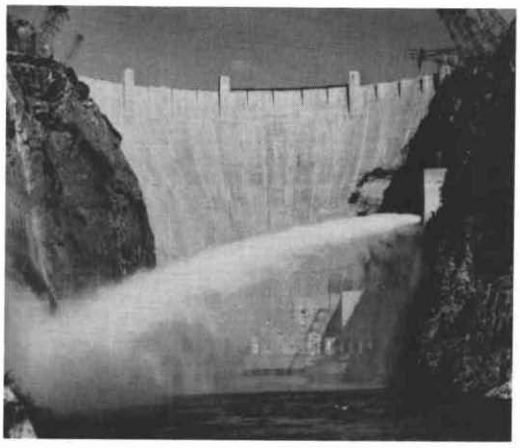

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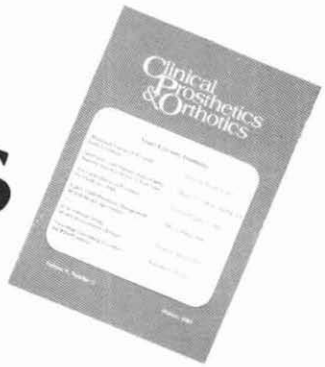

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