Clinical Prosthetics & Orthotics

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Volume 11, Number 1 **Winter, 1987**

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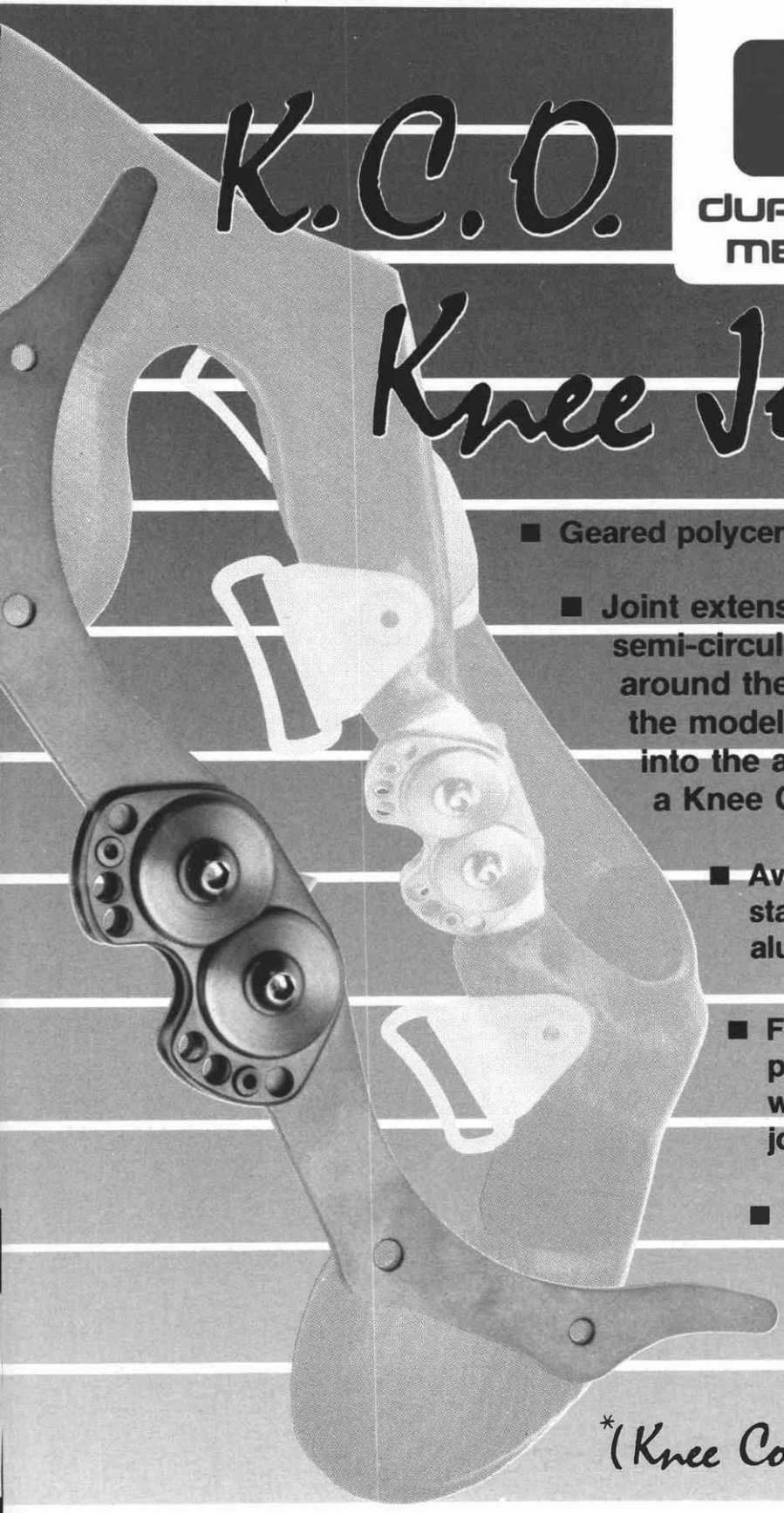

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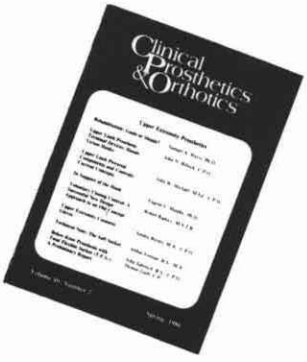

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AUTHOR INFORMATION

Clinical Prosthetics & Orthotics

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 the 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 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 Office for production and printing.

The chosen topics for *Clinical Prosthetics and Orthotics,* Volume 11, Number 2 and Volume 11, Number 3, and deadlines for submission are as follows:

Volume 11, Number 2	"Orthotic Management of Paraplegia" Deadline: February 1, 1987	
Volume 11, Number 3	"Sports Prosthetics"	Deadline: May 1, 1987

Please remember that although these are the chosen topics for these particular issues, we gladly welcome submissions on other topics. Please feel free to contact the National Office if you have any questions on whether your article would be appropriate for *C.P.O.*

If you have an article that has been previously published in another scientific journal and think it may be appropriate for *C.P.O.,* please let us know.

Submit articles to: Charles Pritham, CPO, Editor, c/o Durr-Fillauer Medical, Inc., Orthopedic Division, P.O. Box 5189, Chattanooga, Tennessee 37406.

Questions should be submitted to: Christopher R. Colligan, Managing Editor, Academy National Office, 717 Pendleton Street, Alexandria, Virginia 22314; or call (703) 836-7118.

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   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.

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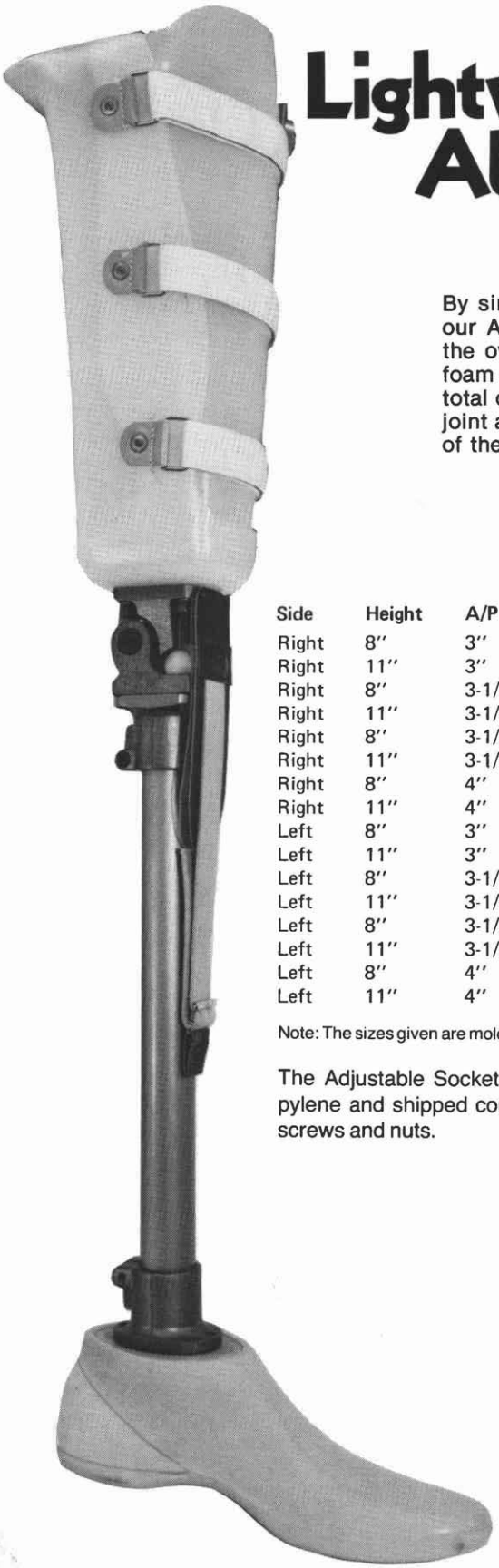

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Letters to the Editor

Dear Editor,

I am pleased to follow up on Dr. Gustav Rubin's article in *Clinical Prosthetics and Orthotics* (Fall, 1986), regarding Mr. Harold Forster, a quadruple amputee. I have been providing the prosthetic care in this case since his return to Ohio in 1981.

Harold Forster is a uniquely motivated individual who currently lives independently in his own home and is a full time prosthetic wearer. He uses the support of a walker or cane only on rough terrain. He performs all light housekeeping chores and prepares his own meals. He pursues his interest in art via watercolor and oil paints.

His current lower limb prostheses were provided in 1986 and consist of bilateral endoskeletal BK prostheses with soft anterior panel frame sockets and energy storing feet.

He sends his best wishes and tremendous appreciation to Dr. Rubin and staff for their assistance, guidance, and support in his rehabilitation.

Sincerely,
Daniel L. Shamp, C.P.O.
Vice-President
Shamp Prosthetic Orthotic Center
Norton, Ohio

Dear Editor,

I wish to comment on the article, "Rehabilitation: Goals or Shoals?" by Samuel A. Weiss, Ph.D. (*Clinical Prosthetics and Orthotics,* Volume 10, Number 2, p. 55). Dr. Weiss is, of course, absolutely correct. His only error is that he does not go far enough in my opinion.

Basically the issue is that we must treat people and not stumps. We must know the individual who has the amputation in order to help him help us to decide on what, if any, prosthesis he needs.

Those of us who know Reverend Harry Wilke know that this bilateral upper amelic is completely independent with no arms and no prostheses. He has never used prostheses and never should.

In my experience, as apparently in Dr. Weiss', there are no unmotivated patients. What we call unmotivated is merely that the patient's goals are different from the goals of the therapeutic team. Every person has motivations. It is the job of those of us who try to help him to ascertain his motivations and goals and work with the patient to meet them to the best of his and our ability.

Our error is to assume that our goals and motivations are those of our patients.

We should inform our patients of what is available and the advantages and disadvantages of each and allow our patients to decide which "breakfast cereal" they wish to purchase at a particular time. As Dr. Weiss points out, over time some will return and request a different prosthesis when they find that they have a need for different function. It is important to note that cosmesis is a very valuable function for most individuals while it may not be grasping or manipulation, it is nonetheless an important function and should be so regarded, rather than denigrated.

Sincerely yours,
Lawrence W. Friedmann, M.D., Chairman
Department of Physical Medicine &
Rehabilitation
Nassau County Medical Center
2201 Hempstead Turnpike
East Meadow, New York 11554

Clinical Prosthetics and Orthotics, Vol. 11, No. 1, pp. 1–4

Preparatory Prosthetics

by Bruce P. McClellan, C.P.O.
Donald R. Cummings, C.P.

The use of preparatory prostheses has for some time been a widely accepted methodology for the immediate or early management of the amputated limb. Burgess, et al., first introduced and popularized the immediate postoperative fitting procedure back in the late 60's.[3] Since that time, the use of early weight bearing prostheses has become the norm in fitting centers around the country and indeed in other parts of the world.

This paper will deal primarily with preparatory prostheses as they relate to the below-knee amputee. The rationale for such devices will be emphasized in a generalized fashion, as opposed to presenting a different array of commercially available systems or components.

The word "preparatory" denotes that these prostheses are used to prepare the amputated limb for definitive fitting with a prosthesis. Within this context, the scope of prostheses which may be considered preparatory in nature ranges from immediate postoperative fitting to the laminated socket with pylon and SACH foot. In between these two ends of the spectrum are such devices as the pneumatic air cast and Wu early fitting prosthesis. All of these devices have the major purpose of either controlling postoperative swelling or promoting the inevitable atrophy of muscles which were transected during surgery.

SHORT TERM VERSUS LONG TERM DEVICES

The differences between prostheses used for immediate or very early fitting and those used for long term are worth noting. We will clarify the terms "temporary" and "intermediate" to distinguish between the two types of devices. The term "temporary" will be used to describe those prostheses which are intended for relatively short usage; they are applied soon after amputation, and usually are applied directly to the patient using plaster or a plaster substitute. "Intermediate" describes those prostheses which are intended for relatively long-term use; they are generally applied following the use of a temporary prosthesis and are fabricated from plastic over a positive model instead of being formed directly over the patient.

TEMPORARY PROSTHESES

A temporary prosthesis is primarily used to control postoperative edema and is often the initial step in the residual limb maturation process. But the temporary prosthesis has many additional functions, one of which is early mobilization of the patient. This is especially critical to the physiological well-being of elderly patients. The less time the generally debilitated patient is confined to a bed or a wheelchair, the better the chances for overall recovery and successful long-term prosthetic use.[1] Indeed, the early mobilization of any patient can shorten the hospital stay and, therefore, save the patient and the insurance company the costs of increased hospitalization.

Another benefit of the temporary prosthesis is the psychological lift it can give the new amputee by reducing phantom pain and permitting early ambulation. Temporary fitting may also help offset some of the anxiety the patient experiences after an amputation.

TEMPORARY DESIGN CONCEPTS

A temporary prosthesis is essentially a rigid dressing with a foot and pylon attached (Figure 1). It is a total contact system, encapsulating the amputated limb, including the patella, and extending to the mid-thigh. The knee is main-

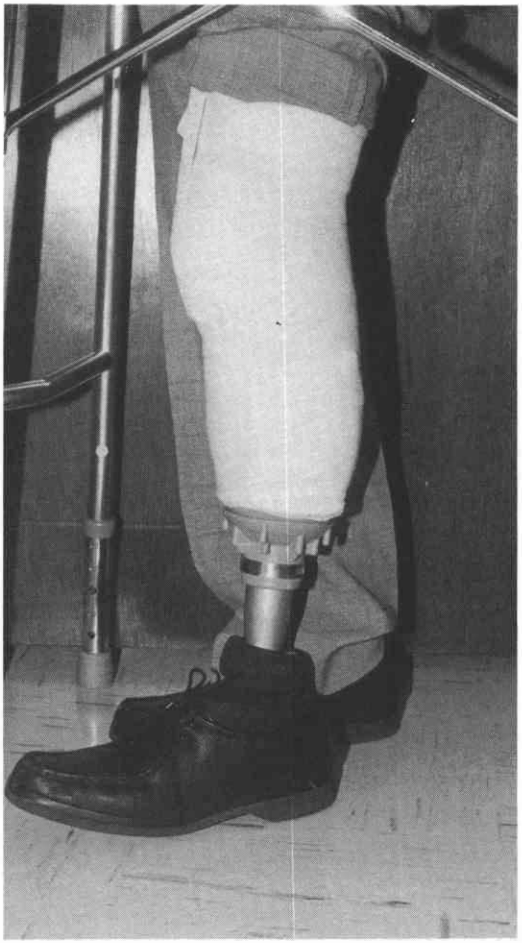

Figure 1. Temporary below-knee prosthesis.

tained in five to ten degrees of flexion. Suspension is by total contact, with some purchase over the adductor tubercle of the femur, and by a waist belt incorporated into the cast. Padding is provided for the distal end and bony prominences.

The standard mid-thigh height of the temporary prosthesis serves some definite purposes. This design assists in sharing weight bearing over a larger surface area, which reduces the load on the amputation site itself. The amputee can also ambulate with less risk of traumatizing the residual limb.

Encapsulating the knee also helps prevent knee flexion contractures, which are a very real threat to successful rehabilitation. In spite of the well-documented benefits of early fitting, all too often patients are sent home in an Ace® wrap to languish in a wheelchair for a period of weeks until their "stump toughens up enough" to be fitted with a prosthesis. This is the scenario that results in the elderly patient appearing for prosthetic fitting with hip and knee flexion contractures and an edematous residual limb.

Although the knee is fully encapsulated in the traditional temporary prosthesis, knee contractures are rare; partially because the cast is usually changed at weekly or biweekly intervals over the period of use. To enhance knee motion, the patient should be encouraged to flex and extend the knee through its range of motion at the time of each cast change. Intermittent weight bearing in the prosthesis also prevents a knee contracture, much as it does in the case of a long leg weight bearing case used in fracture management.

The non-removable nature of the temporary prosthesis has the advantage of continuous control of the tissues. When left to the patient to control via an Ace® wrap or shrinker, the limb is often wrapped intermittently or not at all. Rigid dressings have proven in most cases to be far superior to elastic wrappings in reducing the limb's soft tissue volume, especially in conjunction with controlled weight bearing.[4]

The inclusion of a waist belt, or billet, is essential in maintaining suspension in this type of system. As the residual limb shrinks, the prosthesis will piston on the limb if not supported by this auxillary suspension.

The pylon system is equally important with respect to the success of the temporary prosthesis. Although the patient walks with a stiff knee, appropriate alignment is essential for single limb stance stability.

INTERMEDIATE PROSTHESES

The primary role of the intermediate prosthesis is to act as a preparatory device to reduce the limb to a definitive fitting status. It is generally fit when the postoperative swelling and distal edema have been reduced to a point where the bulbous end can be introduced into a socket. This prosthesis acts as the interim step between the temporary and definitive, thus the term "intermediate." The intermediate differs significantly from a temporary in that it is re-

movable and allows free flexion of the knee. Residual limb shrinkage is accommodated by prosthetic socks as opposed to cast changes. Aside from the obvious advantages of full range of motion and free access to the residual limb, the intermediate prosthesis allows the patient to learn appropriate sock ply management prior to being fitted with a permanent prosthesis.

The length of time a patient wears his intermediate prosthesis varies from person to person. Body type, cause of amputation, level of activity, and other considerations all play a part in how rapidly a residual limb will mature to a definitive fitting status. The duration of use can be anywhere from two months to six months, or longer. A general guideline which may be used to determine whether a limb has "plateaued" with regard to shrinkage is when weight bearing and wearing time have stabilized, and the patient has gone approximately three weeks without adding any additional plys of socks.

INTERMEDIATE DESIGN CONCEPTS

The design of the intermediate socket is generally consistent with the standard PTB or TSB configuration (Figure 2). A soft liner may or may not be incorporated in the system. In either case, it is appropriate to fit the socket to the patient with as few ply of socks as possible. A one ply or even a nylon sheath fit is preferable in light of the fact that shrinkage, and thus the need for additional plys, is inevitable. As with the temporary, dynamic alignment plays an important role. This importance is now magnified by the fact that the patient is ambulating in essentially the same manner as he will in his definitive prosthesis. Again, it is recommended that the patient be fit with some sort of waist belt suspension to minimize relative motion between the socket and limb as shrinkage continues.

GAIT TRAINING

At the time of fitting of the intermediate prosthesis, gait training becomes most significant. This is one of the great advantages of preparatory prostheses: the patient can be monitored and guided by a physical therapist in regard to an appropriate gait pattern while a prosthetist can periodically make alignment modifications as the patient becomes a more proficient ambulator. This advantage is lost, of course, in some of the commercially available systems, which do not allow for fairly precise alignment adjustability.

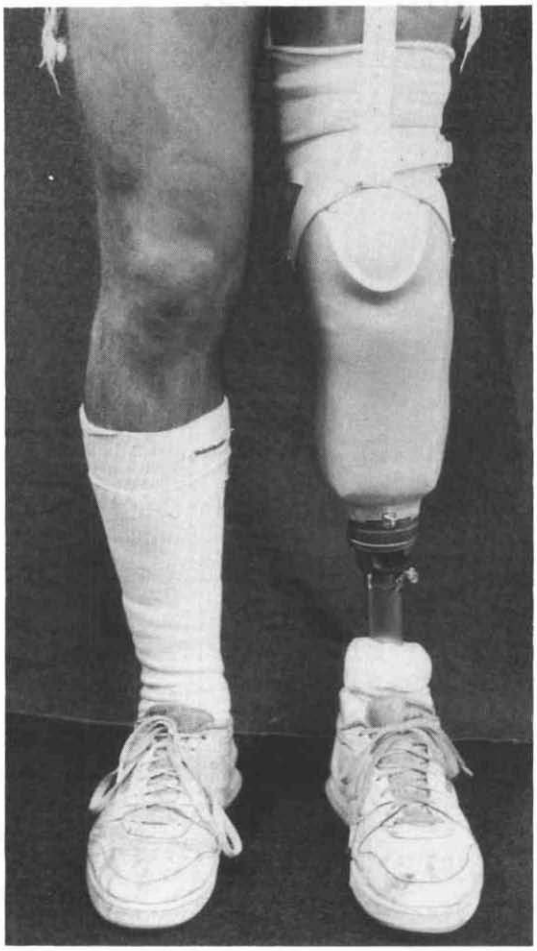

Figure 2. Intermediate below-knee prosthesis.

THE FORGOTTEN LIMB

One of the least considered aspects of the benefits of preparatory fitting is the contralateral leg. Not only does the preparatory device make it easier for the amputee to maintain his balance, it also allows him to share his weight

partially on the prosthesis instead of totally on his remaining limb. In the case of the diabetic or peripheral vascular disease patient, this can be critical, as the remaining leg is usually at risk as well. Any additional trauma, such as prolonged single limb body support or hopping, should be avoided. Preparatory prostheses make this weight sharing possible, and thus prevents overuse or trauma to the remaining leg and foot.

It is clear that the role of preparatory prostheses and the management of the new amputee is a necessary and essential component in reaching the fullest rehabilitation potential of the patient.[5] The encroachment of non-traditional providers into the prosthetic arena, especially with regard to early fittings, poses a real threat to the realization of these patients' full potentials. It is critical that the prosthetist understand and appreciate the important role of preparatory prostheses in the total regimen of medical and prosthetic care. Success with preparatory fittings depends upon competent management by all members of the rehabilitation team. Temporary and intermediate systems must be applied and managed competently by the prosthetist. Weight bearing, gait training, and residual limb atrophy must be monitored carefully.

The term "preparatory" implies that such systems are designed to achieve specific desirable objectives. In this case, the objectives are the maturation of the residual limb and optimum patient readiness for definitive fitting. Comprehensive patient management with preparatory systems produces many advantages, including the provision of maximum early function, improved evaluation of the patient's long-term needs, and reduction of rehabilitation time and expense.[2]

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AUTHORS

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Clinical Prosthetics and Orthotics, Vol. 11, No. 1, pp. 5–10

The Stat Limb: A Prosthesis for Immediate Postoperative Fitting of AK and BK Amputations

by Joseph C.M. Sheehan, M.D.
Michael J. Quigley, C.P.O.

INTRODUCTION

Postoperative care of amputation wounds varies significantly ranging from simple daily dressings to rigid immobilization. These variations make it difficult for the occasional surgeon to judge the virtues of each method from available literature. A basic prefabricated plastic supportive structure is described here to simplify the use of an immediate postoperative prosthesis (Figure 1).

Although immediate post surgical fittings (IPSF) were in common use 20 years ago, they are used only in isolated areas today. The reasons for the decline of IPSF were both educational and logistical. Most amputations today are done by general and vascular surgeons who are not trained in IPSF principles or rehabilitation, and who do not have a working relationship with a prosthetist. Secondly, to use the conventional IPSF technique as taught by Weiss and Burgess, a prosthetist needs to be available at surgery with a number of special socks, attachment plates, tubes, padding materials and the associated tools needed to apply the prosthesis. Scheduling the prosthetist caused logistical problems, so physicians began to simply apply a rigid dressing in surgery and call the prosthetist in a week or so later to apply a shrinker. A preparatory prosthesis is not usually prescribed until three to four weeks post-surgery.

ADVANTAGES OF EARLY MOBILIZATION

The postoperative disease problems of the amputee are typical of any long term illness en-

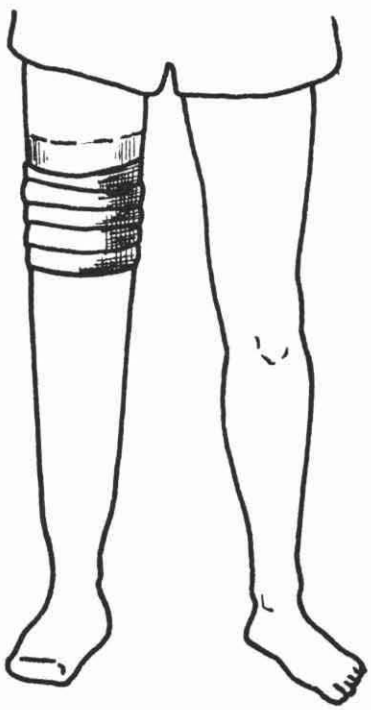


Figure 1. The Stat Limb is a prefabricated high density polyethylene shell that can be applied in less than ten minutes in the operating room.

countered in medical practice. Thinking solely of the amputated limb is a grave mistake, not only for the mental health of the patient, but also for the surgical wound itself.

Early mobilization after surgery is a necessity in preventing bowel, bladder and cardiopulmonary complications. The post-amputated patient is usually a high risk patient. Often, severe diabetes with restricted cardiopulmonary reserve is a common associated medical problem. Small pulmonary emboli cause major cardiac changes, and bladder/bowel stasis of recumbency may lead to recurrent septicemias. Each day of postoperative immobilization adds a significant risk to ultimate survival. First or second day mobilization into the standing position is a necessity to reduce basilar atelectasis, reduce the residual urine volume in the bladder, and allow feces to move into the rectum for evacuation.

Even without the psychological and balance effect of a second limb, the process of getting a weak postoperative patient to stand on the unaffected leg alone is next to impossible. However, a rigid locked knee above a "weightless" prosthesis gives the patient more stability than when they had a painful necrotic leg before surgery. It is possible to mobilize a patient within 24 hours post-surgically or to at least have the patient stand and transfer to a commode or wheelchair using a limb, even though they have been bedridden entirely for many weeks preoperatively. Minimal ambulation in therapy from the second day onwards is important. The wound risk involved with minimal weight bearing and the brief stance phase on the amputated leg is outweighed by all the general advantages to the patient for ultimate survival.

The Stat Limb was designed to allow even the surgeon doing an occasional amputation to apply an immediate postoperative prosthesis himself following surgery. The Stat Limb comes in one size that fits both right and left legs, eliminating the requirement for inventory. The patient receives all the advantages of a rigid dressing, with the added advantages of early weight bearing. The psychological boost given to a patient who wakes up following surgery with two feet under the covers cannot be easily measured, but is definitely a positive factor. In addition, the medical team working with the patient (physician, nurse, therapist, etc.) automatically become rehabilitation oriented. The patient is no longer laying in bed week after week waiting for his new leg. Early ambulation is safe and is encouraged as early as one day postoperatively. The lack of knee flexion in the prosthesis poses no particular problem to the patient during walking, and the extremely light prosthesis allows the patient to move the leg around easily in the sitting and supine positions.

Patients who have worn the Stat Limb make the transfer to a preparatory prosthesis very easily; they already know how to walk and are not afraid to place weight on the residual limb.

APPLICATION PROCEDURE

The major advantages of the Stat Limb immediate postoperative fitting are as follows:

1. a rigid dressing,
2. the knee fixed in hyperextension,
3. rapid application of the prosthesis while the patient is under anesthesia,
4. light weight due to the structural strength at the periphery of the prosthesis, and
5. modification of the limb as rehabilitation continues.

Rigid Dressing

The application of a rigid protective dressing is important to the survival of a poorly perfused limb. By surrounding the limb in a soft, heat-insulated environment, free of shearing forces, the limb is maintained at near 37 degrees centigrade, which is optimal for almost all physiological functions of wound healing, tissue resistance, and arteriolar dilation, and gives the surgery its best chance of success. Daily opening of the wound by tearing off adherent, coagulated dressings is not only painful, but rarely indicated unless for observation of unexplained pyrexias or blood loss.

The dressing is nothing other than a gauze dressing over the wound site, to allow for any drainage which might occur, followed by multiple layers of cotton, giving a total of about two centimeters of thickness of cotton from groin to the distal end. A thin layer of fiberglass casting material is then applied to provide a rigid outer layer, preventing knee flexion and maintaining the residual limb shape, and protecting the wound (Figures 2 and 3). If plaster

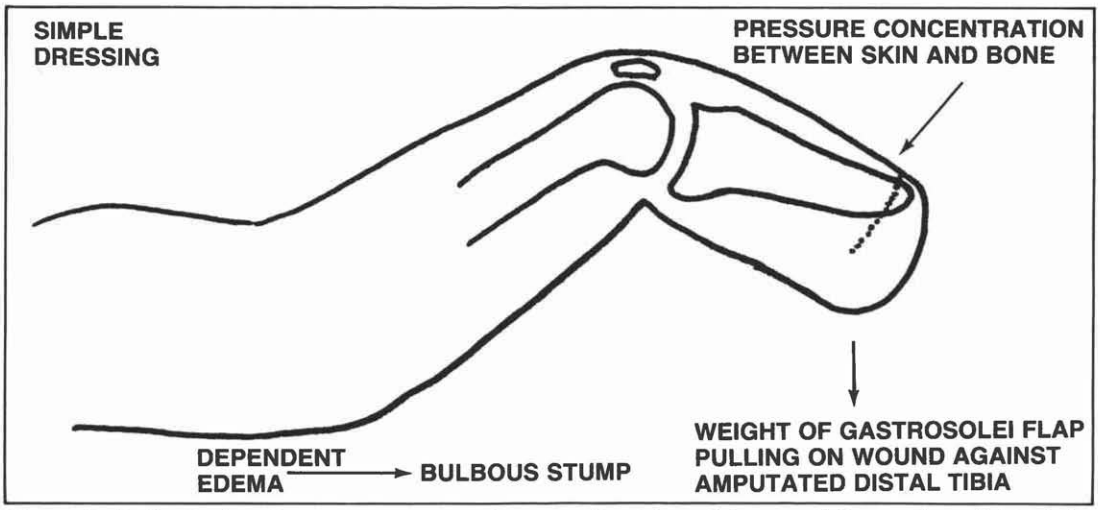


Figure 2. A simple dressing creates pressure between the skin and bone and forces the weight of the gastrosolei flap to pull on the wound against the amputated distal tibia.

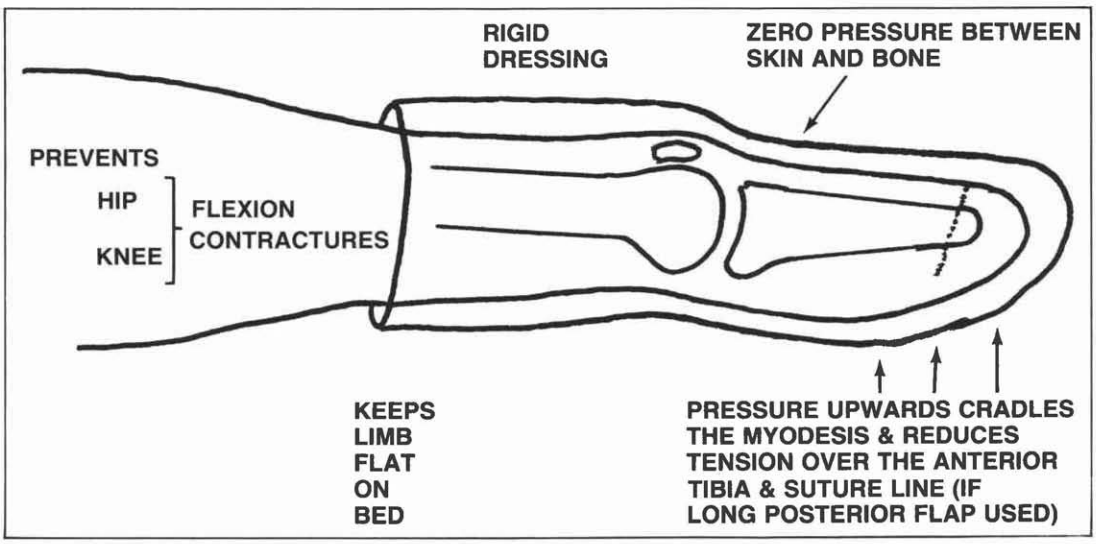


Figure 3. The rigid dressing maintains the knee in extension.

is used for the rigid dressing, it must be allowed to dry 24 hours before the Stat Limb is applied. At no stage is compression ever applied in the application of the rigid dressing. The speed of limb application is important in the critically ill, and with prior experience of one or two applications, it should be successfully applied in less than eight minutes (Figure 4).

Stat Limb Application

Following the application of the rigid dressing, the Stat Limb is applied. The Stat Limb is designed to fit both left and right legs and can be cut to fit around the rigid dressing in nearly all cases.

The desired length of the Stat Limb is approximated by either measuring the sound side,

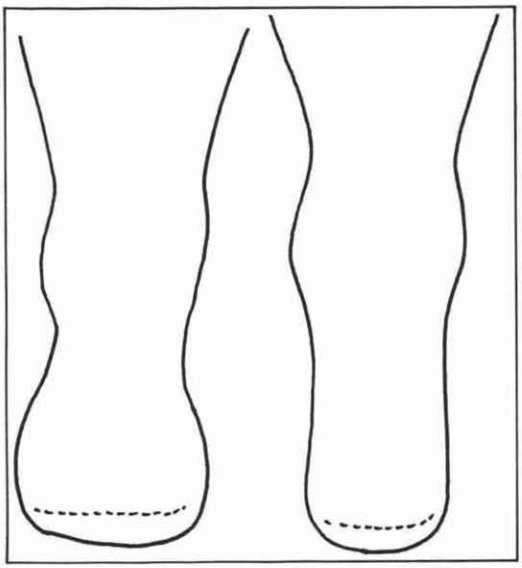


Figure 4. Left, a bulbous residual limb after compression wrap. Right, a cylindrical residual limb after rigid dressing.

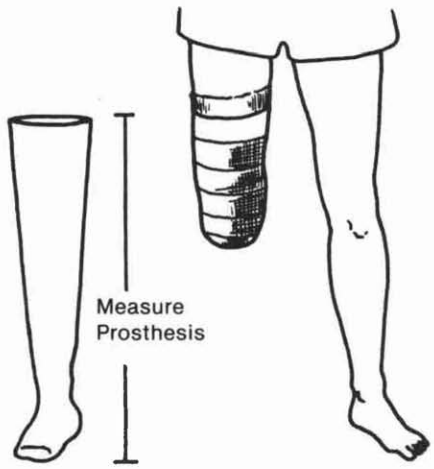


Figure 5. The rigid dressing consists of a gauze bandage over the wound, about two centimeters thickness of cast padding, and two layers of fiberglass casting tape to mid-thigh. The Stat Limb should be one centimeter shorter than the sound side, and the knee cast in extension.

or by laying the Stat Limb next to the patient and marking the section to be cut off. The top edge of the Stat Limb should be trimmed a few inches short of the top of the rigid dressing (Figure 5).

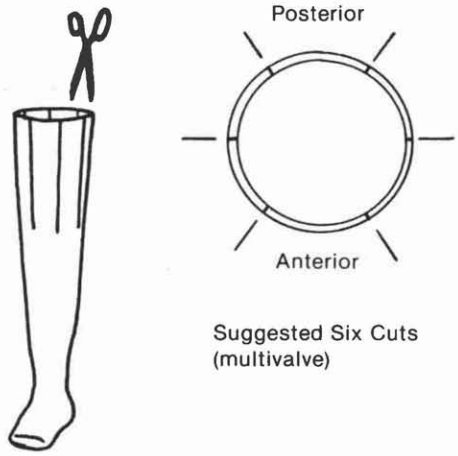


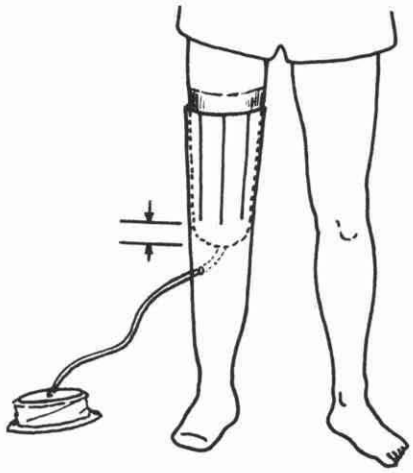
Figure 6. A scissors or cast saw is used to cut off excess length and multivalve the Stat Limb. Six longitudinal cuts are recommended. The cuts may have to extend past the end of the rigid dressing if a bulbous end is present.

Six vertical cuts are then made in the Stat Limb to allow it to form around the rigid dressing (Figure 6). Alignment is approximated while wrapping the Stat Limb onto the rigid dressing. The Stat Limb should be about a half inch shorter than the sound limb to allow toe clearance with an extended knee (Figure 7). Toe out, foot in-set and out-set, and the anterior-posterior positioning of the foot should be held in a normal position as the casting material sets (Figure 8).

Knee in Extension

Keeping the knee in extension, or locking it in about two degrees of hyperextension, makes the knee stable at the tibiofemoral joint. Subsequently, the quadriceps, hamstrings, and gastrocnemius are reflexly relaxed. Pain and associated spasms are reduced. The reduction of spasm of the gastrocnemius reduces the stress placed upon the distal myodesis and, indirectly, on the wound itself.

With the knee in extension, the distal residual limb can be molded to prevent posterior migration of the long posterior flap. In extension, limb application is easier and it is easier to judge valgus, varus, rotation, and length of the limb. Application under anesthesia is justifiable because the patient is relaxed and this



Multivalve the prosthesis to about 5cm (2 inches) above the distal end.

Figure 7. For most applications, the vertical cuts can stop two centimeters from the distal end of the rigid dressing, and the proximal edge of the Stat Limb should be a few centimeters distal to the rigid dressings upper edge. A drain hole can be punctured through the Stat Limb, allowing removal in 24–48 hours.

avoids fighting with a flexed knee joint four days later.

Lightweight Due to Exoskeletal Construction

Using the mechanical principles of the square area of inertia, the prosthetic material and the intended forces acting through the prosthesis are distributed to the periphery. This allows the use of a minimum amount of material while gaining the maximum strength to the prosthesis. A semi-pliable thermoplastic of high density polyethylene is used to give toughness to the prosthesis, to reduce the chance of any brittle failures, and to allow for cold forming of the prosthesis around the rigid dressing.

MODIFICATION AS REHABILITATION CONTINUES

As the patient's healing improves and rehabilitation continues, the thigh length rigid dress-

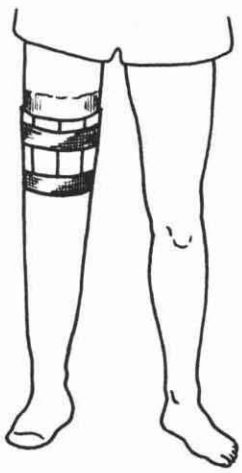


Figure 8. A double layer of fiberglass material is used to fasten the Stat Limb to the rigid dressing. All of the vertical slits should be covered. For heavy duty users, reinforce the ankle area with casting material as well. Normal toe-out and foot positioning should be maintained while the casting material sets.

ing is changed for a padded P.T.B. socket, also made of fiberglass cast material and attached to the limb. Depending on the strength of the quadriceps and hamstrings, the suspension is either a supracondylar strap or a simple single axis hinge from a knee orthosis; this usually occurs at the end of the second week. At the end of the seventh week, the residual limb is usually mature enough for a standard P.T.B. prosthesis. In a similar manner, the prefabricated limb can be used with less complexity for an above-knee prosthesis.

A non slip sole material should always be worn when a patient is using the Stat Limb, as the plastic foot section is very slippery. A hospital slipper can be used as can elastoplast adhesive tape.

On some occasions, buckling of the plastic at the ankle has occurred. This is usually a sign that the patient has become either very active or is wearing the prosthesis for a longer time than for which it was designed. Reinforce the ankle and foot with fiberglass tape during the original application process if it is felt that the patient will be a heavy user.

The same Stat Limb module can be used for cast changes. However, it is important to cut off the cast carefully to prevent damage to the Stat Limb. It is not recommended to reuse the

Stat Limb on other patients since it is designed for limited use.

The earlier a prosthesis is applied, the more successful and pain free is the final fitting. The problems encountered in the use of any system have to be recognized, but it is difficult to scientifically explain why a minimally weighted limb can impede wound healing. If the prosthesis is not applied to the patient for a few days, we note the rate of progress is retarded. This is detrimental to the functional recovery of wound healing and the entire patient.

CASE HISTORY

Although over 1,000 Stat Limbs have been used to date, one case history will be presented to illustrate the benefits of the Stat Limb in a community hospital setting.

Patient A.B. is an 80 year old woman who had a right below-knee amputation, secondary to diabetic gangrene, two years ago. She was fit with a Stat Limb immediately and began weight bearing in physical therapy two days later. A cast change was made 12 days postoperatively when the stitches were removed. The Stat Limb was reapplied and the patient was discharged home with a walker and wheelchair. Two weeks later, a second cast change was made and measurements were also taken for a preparatory prosthesis. The following week, the Stat Limb was removed and the patient was fitted with her prosthesis. She walked six full lengths of the parallel bars without hesitation.

One year later, the same patient lost her left leg below the knee and was immediately fit with a Stat Limb. Within two weeks she was home with a walker using a definitive right below-knee prosthesis and her Stat Limb. Without the availability of the Stat Limb in this case, this patient would have been wheelchair bound for weeks, the time needed for physical therapy would be lengthened, and many activities of daily living would have required assistance.

SUMMARY

With the decline in use of immediate post-surgical fitting of prostheses, most amputees do not walk for several weeks post-surgically. The Stat Limb is designed for easy application by even the occasional surgeon and allows weight bearing within days following surgery.

The Stat Limb does not provide the answer to every amputation. Each patient is entirely different from another in any series, and many other factors must be taken into account, including the initial pathology, age, cooperation of the patient, availability of nursing and physical therapy care, and other associated problems.

The Stat Limb does remove most of the logistical and educational problems that are associated with IPSF, and should allow many new amputees to benefit from early weight bearing and walking.

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Clinical Prosthetics and Orthotics, Vol. 11, No. 1, pp. 11–19

A Variable Volume Socket for Below-knee Prostheses

by A. Bennett Wilson, Jr.
C. Michael Schuch, C.P.O.
Robert O. Nitschke, C.P.O.

The benefits concerning control of edema by fitting the lower limb amputee as soon as the stitches are removed are well documented,[2,5,6] yet for a number of reasons, mostly economic, the majority of new amputees are not treated in this manner. As a result, most patients present for their first prosthesis with an edematous residual limb that can be expected to shrink even when it has been wrapped properly with an elastic bandage or with a shrinker sock. Proper management of these patients has usually required the fabrication of several provisional sockets in successively smaller sizes until the soft tissues have reached a point where no further reduction is to be expected. Besides the expense involved in this procedure, a truly proper fit occurs only for a very short period after each new provisional socket is provided, a condition which is bound to have an effect on the activity of the newly fitted patient. Thus, a socket that can be adjusted to accommodate the gradual change in residual limb volume is desirable.

HISTORY

Attempts to provide adjustable socket volume are found more commonly at the above-knee level.[1,4] The Irons, et al.[4] socket design has evolved to become available as a non-custom fitted, prefabricated socket system, manufactured and distributed by Orthomedics[9] and United States Manufacturing Company.[11] To quote Mooney,[7] a co-author of the paper by Irons, et al.,[4] "For the above-knee stump, the design constraints are simpler in that the residual limb usually presents no significant bony contours and adequate soft tissue covers all bony elements. On this basis, the fabrication of a lightweight above knee prosthesis with an adjustable socket is a relatively simple problem." Referring again to the Irons, et al.[4] study, Dr. Mooney[7] states that, "a significantly higher percentage of amputees became functional users due to the availability of the adjustable above-knee prosthesis than would have been expected by previous experience if they had waited for the maturation time to be considered for a conventional socket. The average time to fitting with a conventional socket in the past was about six months. In this group, using earlier fit of adjustable sockets, which were also lightweight, a higher percentage of patients became functional users."

The only volume adjustable below-knee socket system reported on to date is by Mooney, et al.[7] from the University of Texas at Dallas, who report early gratifying results with use of this system. However, it is an off-the-shelf item, which inherently presents fitting problems. As opposed to the above-knee limb, the below-knee limb requires more exacting contours of fit due to prominent bony contours, and relatively less soft tissue. In addition, the below-knee amputee often presents with adherent scar tissue in the suture areas. For these reasons, most will agree that a custom fit is mandatory at the below-knee level.

An interesting fact can be noted in all of the designs cited: ease of volume adjustments were concentrated in the proximal aspect of the socket as opposed to the distal aspect, where the greatest reduction in volume occurs.

GOALS AND DESIGN CRITERIA

After reviewing existing designs in which the volume of the socket can be adjusted, and considering the use of materials and techniques now available, a set of criteria was established for a custom fitted variable volume below-knee socket as follows: 1) the socket would be custom fitted to the individual patient; 2) existing prosthetic molding, modification, and fabrication techniques would be used as appropriate; 3) the volume would be controlled equally or selectively between proximal and distal parts of the residual limb; 4) normal prosthetic cosmesis would be possible and practical; and 5) the finished prosthesis would be light, but durable.

The original, primary purpose of the project was to design a socket for use as a preparatory prosthesis, and thus avoid the need for several socket changes before stabilization occurs. However, it appears that the design that has resulted may also be very appropriate for use over extended periods where fluctuation in limb volume is difficult to control, or where the

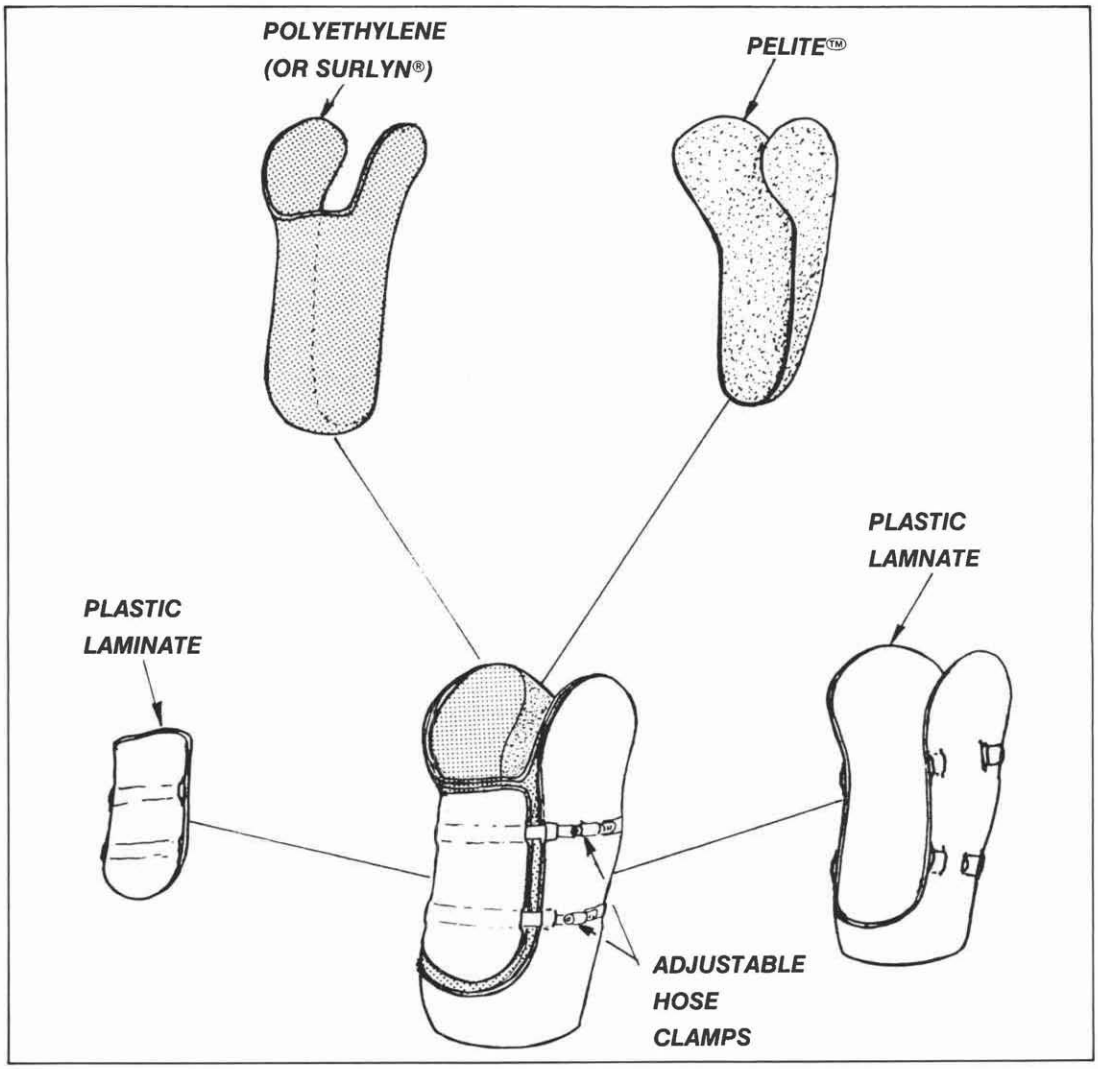


Figure 1. Exploded schematic view of the variable volume socket showing major components.

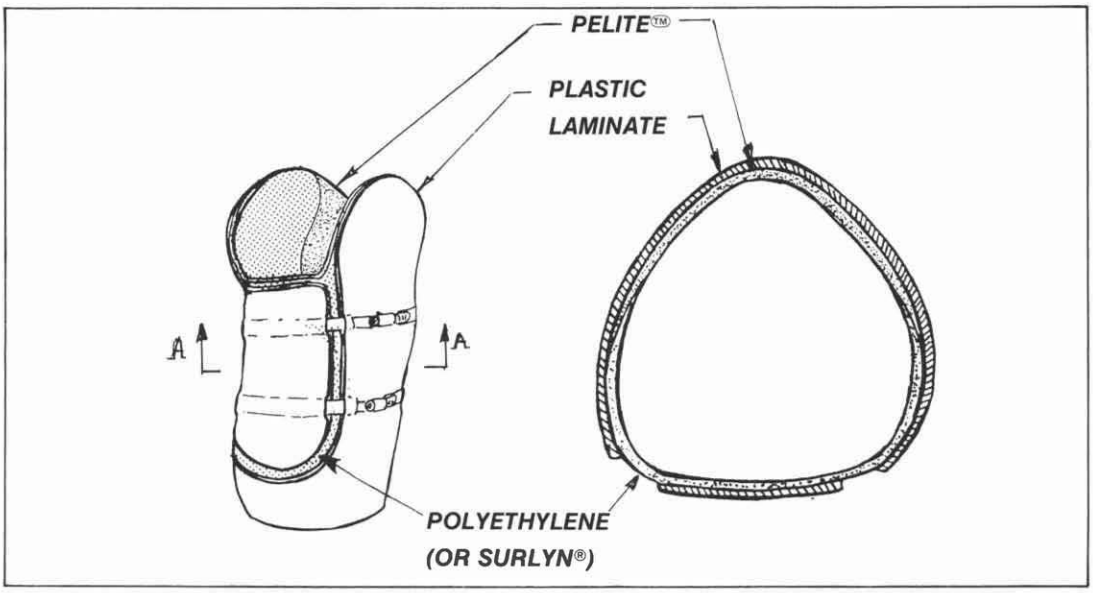


Figure 2. Schematic showing relationship of the major components of the variable volume socket.

shear stresses normally encountered with present day socket designs present a problem.

Because of the two-piece design (Figures 1 and 2), it is possible to don and doff the prosthesis without subjecting the skin of the residual limb to shearing forces, and thus should be considered when it is desirable to avoid shear on the limb. Additionally, the two-piece construction should add a measure of suspension if this element is considered in the individual design.

We are confident that the concept is valid and useful. What follows here is, we hope, sufficient information for an experienced prosthetist to try the concept. The materials and dimensions given are those that have been found to work in our still limited experience, but are by no means considered to be the best.

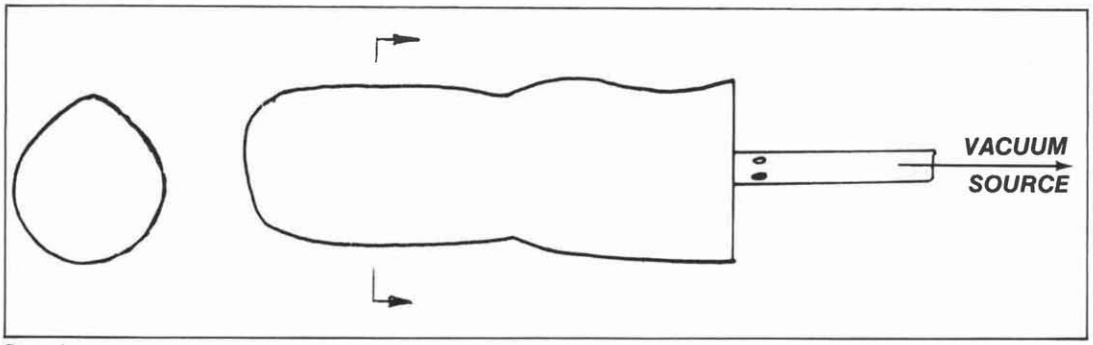
Our original method for controlling volume, by use of two conventional hose clamps, is described here, because we have yet to locate a commercially available adjustment buckle that is suitable. We made some progress in designing a buckle especially for this purpose, but have not pursued the idea since the hose clamps can be made to work satisfactorily. However, there is probably a place for a more convenient method of controlling the circumferential dimensions.

CASTING AND MODIFYING THE POSITIVE MODEL

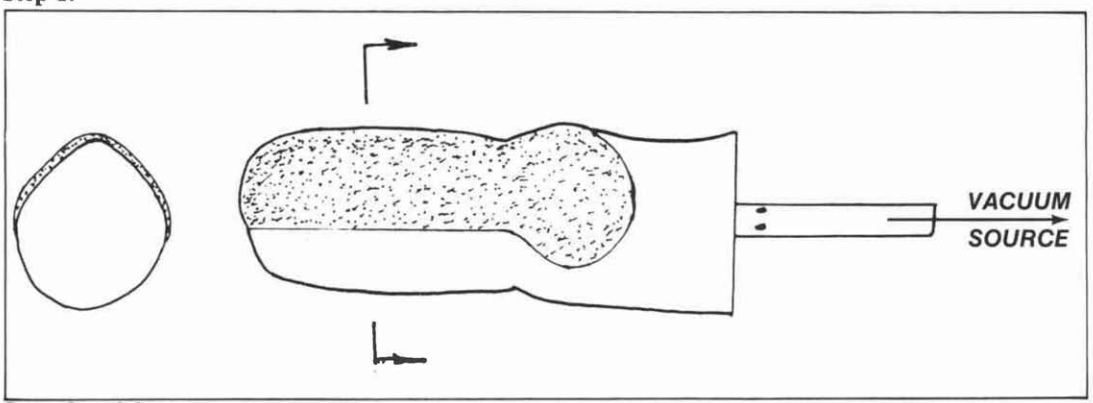
As stated in the design criteria, this socket system is intended to make use of existing prosthetic molding, modification, and fabrication techniques. We recommend use of the casting procedure described by Fillauer[3] in which an impression of the anterior portion of the limb is made first, using plaster splints to capture the bony definition before enclosing the remainder of the residual limb with plaster. Model modification should be carried out in normal function. We also recommend the use of a transparent diagnostic socket and algination procedure as described by Schuch and Lucy,[8] before proceeding with pouring the final positive model and fabrication of the socket.

Fabrication of the Socket

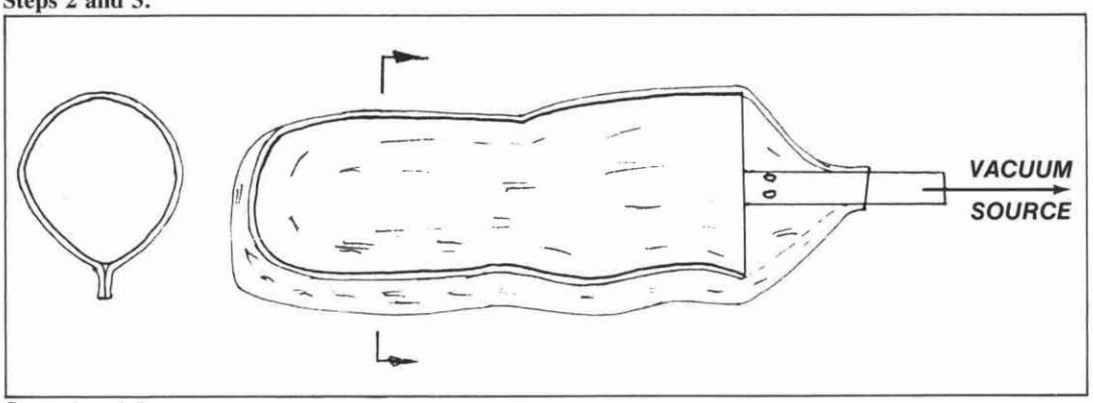
1) Place the positive model in a vise horizontally with the anterior section facing up.
2) Over the positive model, form a Pelite™ liner for the anterior half of the socket. After heating a proper size sheet of Pelite™, a piece of latex rubber can be used to form the Pelite™ around the cast model.



Step 1.

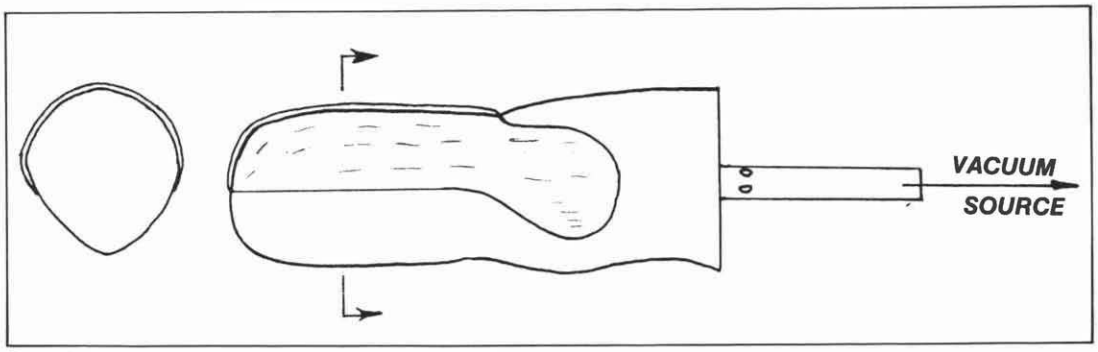


Steps 2 and 3.



Steps 4 and 5.

3) Trim the Pelite™ liner so that it extends posteriorly slightly past the midline, dividing the anterior-posterior halves of the model. Skive all edges that will be inside the socket. Remove the Pelite™ liner from the cast in preparation for the next step.
4) Rotate the model in the vise 180° so that the posterior surface is up.
5) Using conventional drape molding techniques, vacuum form a piece of ⅛ inch polyethylene (or Surlyn®) around the model, posterior side up so the seam is on the anterior side.
6) Trim the polyethylene to form a posterior socket shell that extends anteriorly just past the midline and ''underlaps'' the Pelite™ anterior liner by about ⅜–½ inch. Again, skive all edges that will be inside the socket.

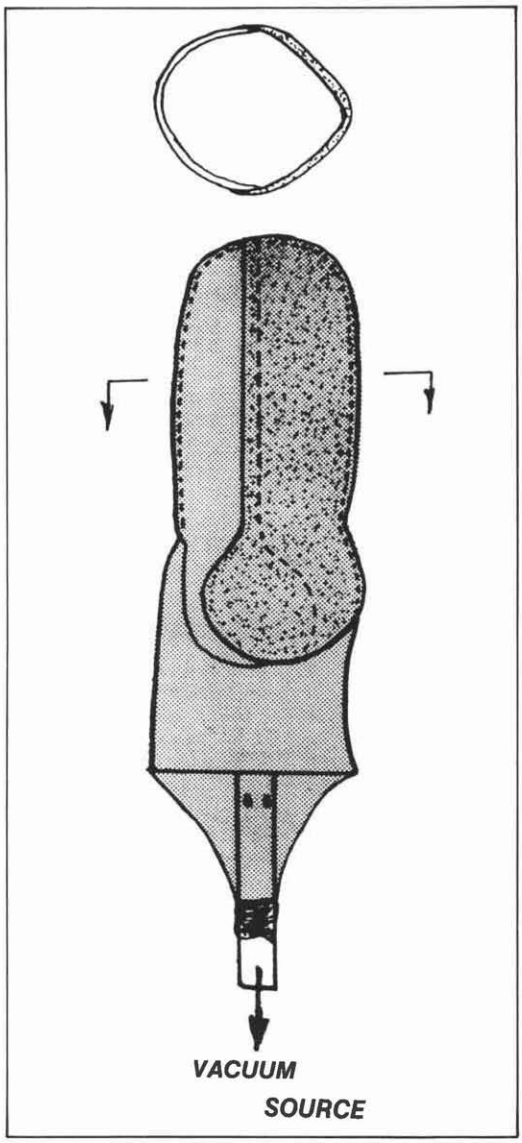


Step 6.

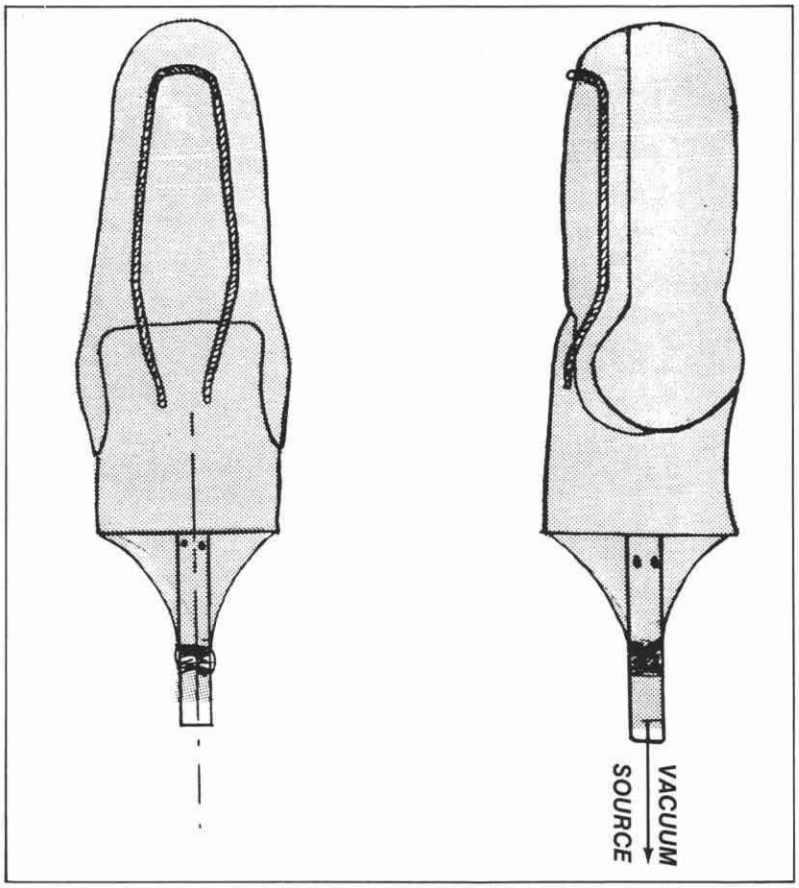
7) With the Pelite™ anterior liner and the polyethylene posterior shell in place on the model, pull a thin sheath of nylon over both to hold them in place.
8) On the posterior aspect of the model, glue a ¼ inch diameter rope to form the cutout for the posterior volume control panel. Prepare for lamination in the usual manner. For use as a temporary design prosthesis, we use Otto Bock[10] modular endoskeletal components and laminate the 4R42 component (socket adaptor with pyramid and lamination anchor) directly into the socket.
9) Before beginning the lamination procedure, cut two polyethylene strips 1/16 inch thick by 9/16 inch wide by the circumference, plus ½ inch of the cast model at the levels shown.

The strips are placed in the lamination layup and are removed after the lamination sets up to form channels for the volume control straps. Layup for the lamination is as follows:

1 layer of ½ oz. dacron felt
1 nylon stockinette
the 4R42 component (if used)
I.P.O.S.[12] glass matting over the lamination anchors of the 4R42 component and over the medial, lateral, and posterior aspects of the layup
1 nylon stockinette; the two polyethylene strips cut earlier are placed at the appropriate levels;
1 nylon stockinette
2 nyglass stockinettes; laminate with 80:20 mixtures of acrylic resin



Step 7.

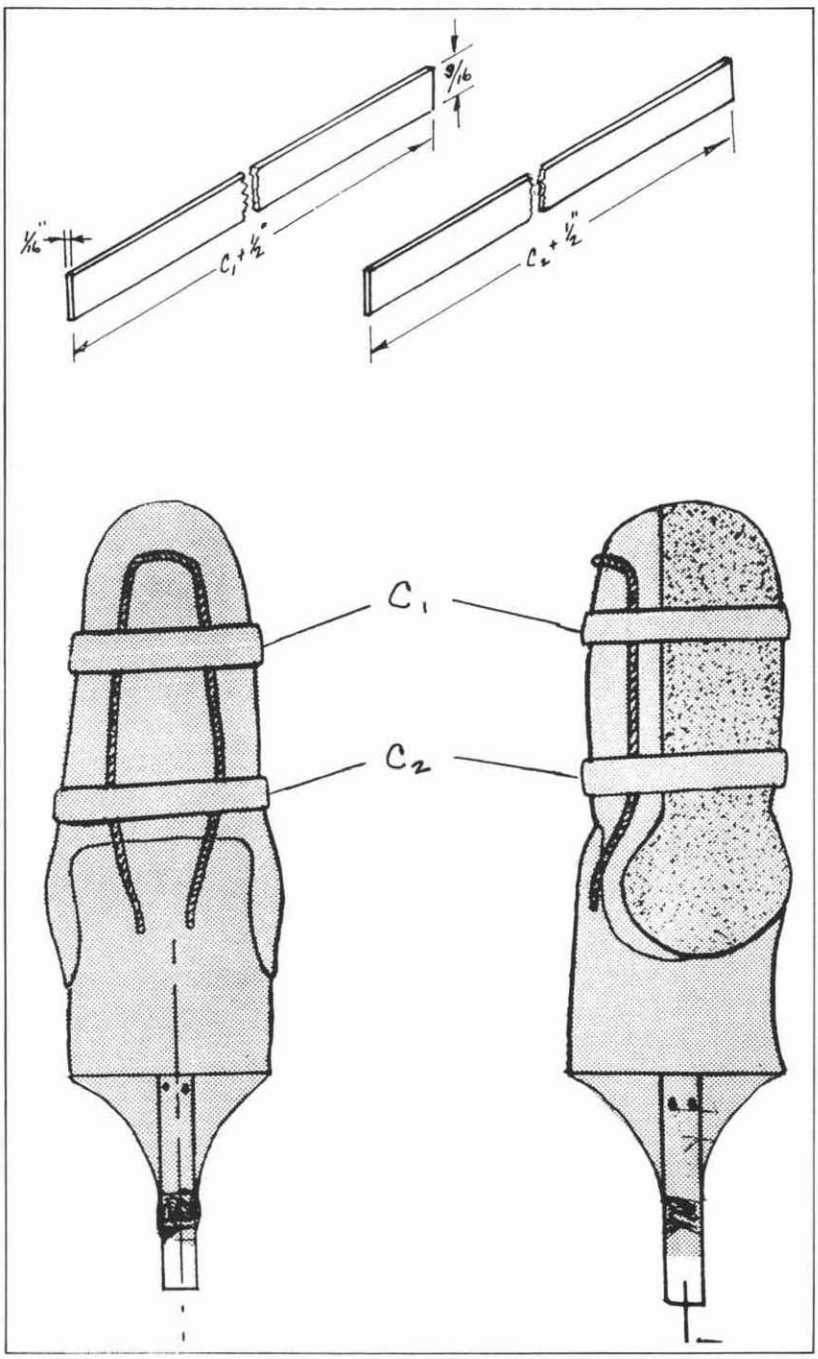


Step 8.

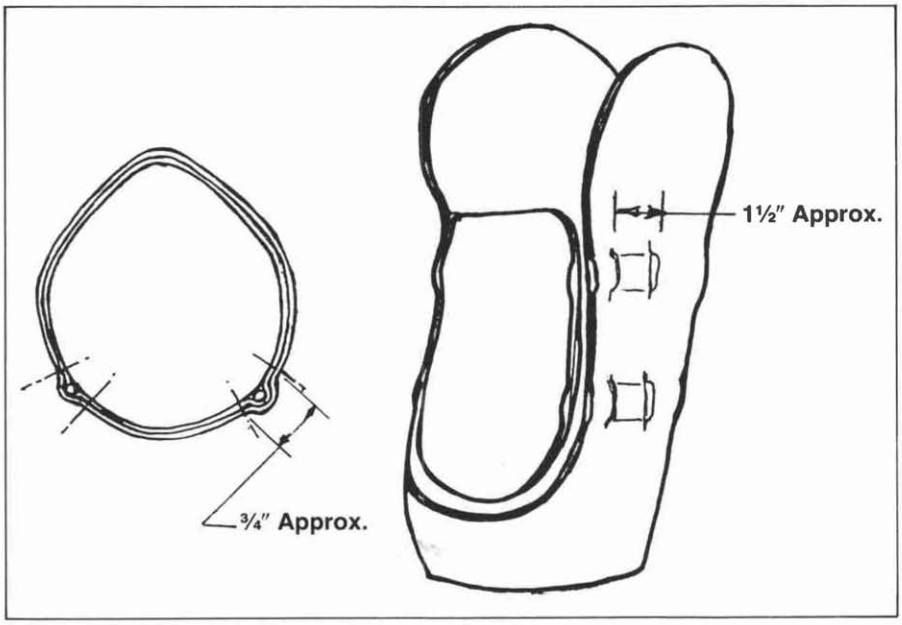
10) When the laminate has set and cured, cut out the window over the rope and trim as shown.
11) Using a pair of needle nose pliers, pull out the two polyethylene strips imbedded in the lamination. This leaves a clean, hidden track for guiding the pull of the control straps.
12) Cut out an area about 1½ inches along each control strap track in the anterior-lateral area of the socket, to allow for exposure of the adjustable part of the control strap.
13) Make up control straps of ½ inch dacron tape and two to three inches of the hose clamps.
14) Put the socket system back on the cast model for determination of the initial volume setting. Insert the dacron straps through the tracks and speedy rivet the hose clamp section so that the hex head of the clamp is exposed in the slots cut in step 12 above (Figure 3).
15) Attach the pylon and foot and align in the conventional way (Figure 4).

CLINICAL EXPERIENCE

To date, seven variable volume below-knee sockets have been fitted on six carefully chosen amputees. Five of these patients were new amputees and the variable volume socket prosthesis was their first prosthesis. One of these five had an extremely edematous limb due to a recent infection, and required two successive variable volume sockets before being fitted with a definitive conventional P.T.B. prosthesis. The remaining patient was a young amputee, three years post-amputation, who was having difficulty maintaining consistency in limb volume. The variable volume socket



Step 9.



Steps 10, 11, and 12.

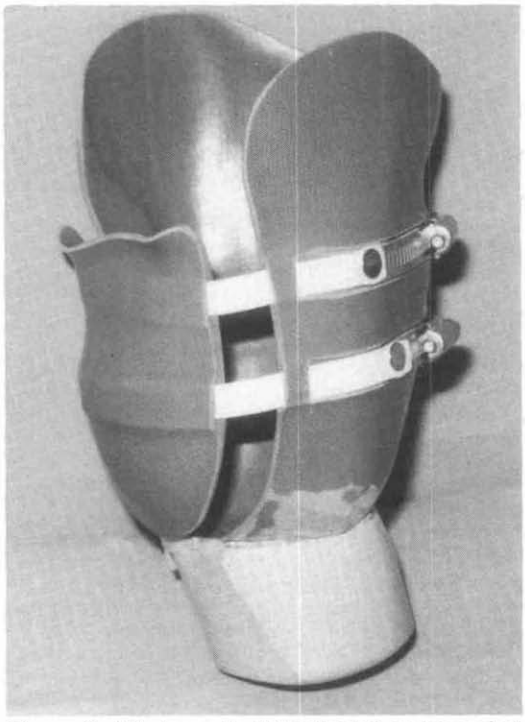


Figure 3. Photograph of laminated outer socket prior to mounting on adjustable leg. A foam block is shown here but this practice has been superceded by use of the Otto Bock 4R42 component which is laminated into the distal end of the outer socket.

proved to be very useful in managing this patient.

Evaluation was basically simple and subjective. The clinic team discussed and recorded any problems that arose with the socket design and documented that atrophy was accommodated by the variable volume socket. In all cases, maintenance of socket fit was made possible by decreasing socket volume as atrophy of the residue limb took place. At no point was comfort compromised by a reduction of socket volume.

In addition to the patients fitted at the University of Virginia; trial fittings were made by Mr. Nitschke in the courses of development at Leimkuehler, Inc. in Cleveland, Ohio, American Orthotic and Prosthetic Laboratory, Inc. of Columbus, Ohio, and Rochester Orthopedic Laboratories, Inc. in Rochester, NY where we were given much help and encouragement. In addition, Karl Fillauer, CPO of Fillauer Orthopedic, Inc. in Knoxville, Tennessee has fit two patients and Robert Gooch, CP and John Michael, CPO of Duke University have fit one patient, all of whom are currently being followed.

SUMMARY AND CONCLUSION

Rationale, design criteria, and fabrication techniques for an adjustable volume below-knee socket have been discussed and described. Successful fittings with the system have been noted. It is felt that this system can meet a need by providing new amputees with a durable, cosmetic, and reasonably long lasting preparatory prosthesis that accommodates the familiar problem of residual limb volume shrinkage.

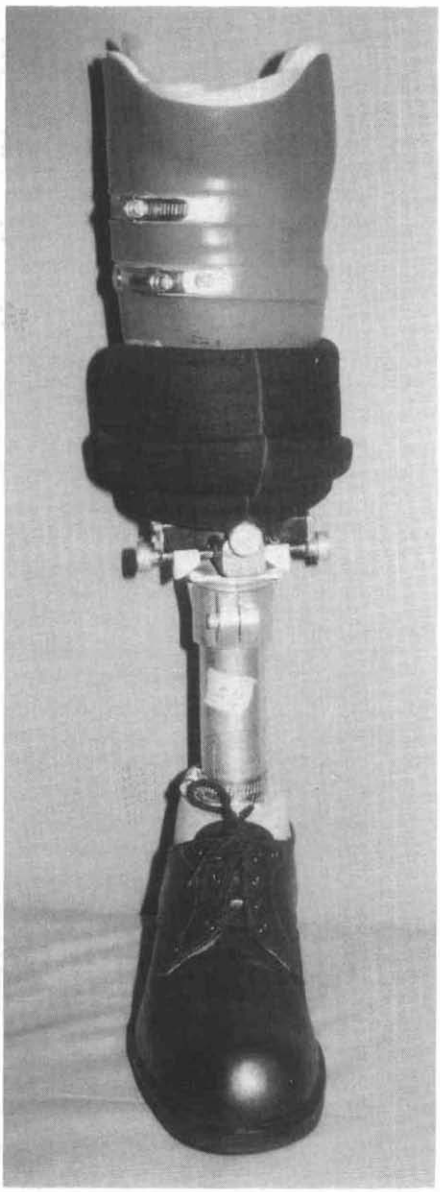


Figure 4. Variable volume socket mounted on an adjustable leg.

ACKNOWLEDGMENTS

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[10] Otto Bock Orthopedic Industry, Inc., 4130 Highway 55, Minneapolis, Minnesota 55422.

[11] United States Manufacturing Company, 180 North San Gabriel Blvd., Pasadena, California 91107.

[12] I.P.O.S., U.S.A., 155 Portage Road, Lewiston, New York 14092.

Clinical Prosthetics and Orthotics, Vol. 11, No. 1, pp. 20–32

The Design and Testing of a Gradient Pressure Sock for Control of Edema

by Martha Field, M.S.
Joseph Zettl, C.P.

INTRODUCTION

Since the fit of a prosthesis on a residual limb influences skin condition, gait, comfort, and even whether or not the prosthesis will be worn, the stability of the limb size is critical. Even in a whole leg, prolonged standing without the 'pumping' action of the leg muscles leaves a poorly supported column of blood within the veins. "The amputated limb has virtually no muscle contraction to aid venous return."[21] External pressure, when well applied, does facilitate venous return, reduces hemostasis, and provides comfort. Pressure must be sufficient to offset the increased hydrostatic pressure of trauma, standing, or straining and yet not interfere with arterial flow.[2] Poorly applied pressure may be injurious. Various investigators have charted the wide range of pressures obtained by elastic wrap and have cautioned against the harmful effects that could result from this edema control method.[13,21] Isherwood states that "elastic wrap bandaging is unreliable and dangerous in terms of pressure and pressure distribution,"[10] because pressure can become so great from too tight a wrap that a tourniquet effect results.

The use of tubular elastic bandaging results in more predictable and less pressure fluctuation, and requires considerably less skill in application. Especially for below-knee edema problems, Compressogrip† and similar products, including the Puddifoot method,[15] have proven to be effective, inexpensive, easy to apply, and well liked.

However, as early as 1961, Beninson recognized that, "Pressure gradient dressings can, in some instances, be used following surgery to hasten healing prior to application of the supports."[1] In 1971, Mooney, et al., stated that their study revealed postoperative residual limb care using plaster shell or plaster with pylon resulted in more successful prosthetic fittings than those using soft dressings.[14] In 1975, Isherwood defined the requirements of a good dressing by stating that "as intracapillary pressure varies with dependency, the ideal bandage should provide a graded pressure which is maximum at the most dependent distal point, decreasing proximally."[15]

Shaping the residual limb is also recognized as a function of a shrinker sock. Available shrinker socks generally lack the shaping capacity, particularly at the distal end. Our objective, therefore, was to make a shrinker sock which would shape the distal end, have gradient pressure, and be accepted by wearers. This sock would not only accomplish the task of reducing post-amputation edema, but would also control fluids which might recur as the result of illness, injury, or any number of conditions. When any edema is uncontrolled, the tendency is not to wear the prosthesis.

In defining the size and shape of the residual limb, two studies were helpful. In the July, 1983 *Journal of the American Geriatrics Society*, Dr. Clark, et al., described ideal limb characteristics including length below knee (6–8 inches) and above knee (8–10 inches) and shape (cylindrical).[4] A Swedish study actually measured 58 below-knee amputations. They found that 66 percent of the residual limbs were conical, 28 percent cylindrical, one percent bulbous, and five percent were other. The length in the supine position from the knee joint, i.e. the anterior rim of the medial condyle

† Available from Knit-Rite, Inc.

to the most distal part of the soft tissues at the end of the residual limb, was six inches (8 to 20 cm.).[16] No average measurement has been found in the literature for above-knee residual limbs. This lack of information about residual limb measurements may result from the fact that, in spite of what researchers have said, wrapping has been the most universal method of residual limb reduction. It may be that prosthetists feel no two limbs are identical and each needs to be treated individually. Nevertheless, with cooperation and knowledge, general parameters can be established for socks which will exert the desired graded pressure over a limited measurement range so that standard sizes of socks can be readily available.

Although the benefits of using pressure as a prophylactic aid to reduce edema after amputation, or whenever edema develops in a mature stump, have been recognized for centuries, no precise definition of the amount of pressure to be used has been created. Part of the reason is that each researcher has used a different instrument for measurement, and although each instrument can be calibrated to a manometer, certain features of each instrument result in uncomparable readings.[3,7,8,11,12,17–21] Much of the research on using pressure to alleviate pain and ulcers in cases of deep venous insufficiency supports much higher mmHg readings than those indicated by the fairly limited research on wrapping and tubular elastic bandaging pressures.

Our request for information on instruments being used to obtain the pressures printed on packaging of various companies making pressure garments only revealed the use of the Kompritest II (Figure 1). We secured that instrument and found it gave readings 15–20 mmHg higher than the CTC 250 we had been using (Figure 2). We pursued this with Midwest Research Institute[‡] and received the following explanation:

> Both devices accurately measure pressure imposed upon their respecting sensing elements.

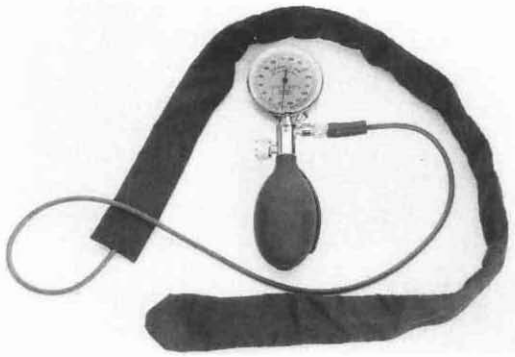

Figure 1. Kompritest II for measurement of pressure values of elastic stockings.

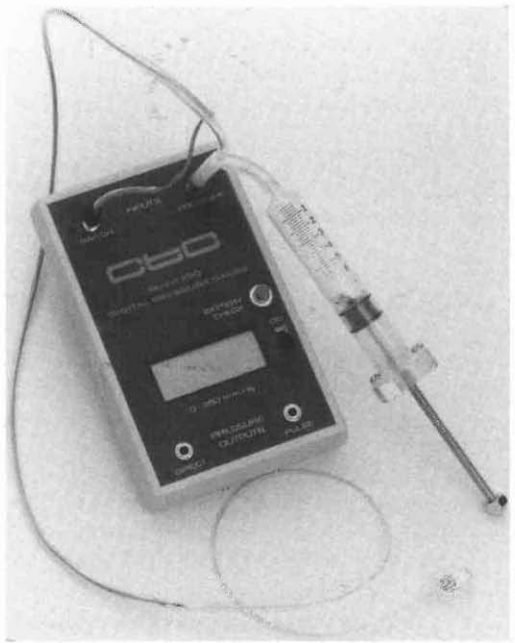

Figure 2. CTC 250 Digital Pressure Gauge.

When placed under an elastic fabric, the devices produce different readings because the Kompritest II (K-II) device distends the elastic fibers surrounding the bulge of its inflated bladder and thus produces a local increase in pressure over the measurement site. This local pressure increase observed using the K-II accounts for the difference between values produced by the two devices, and suggests that the CTC device is the more accurate of the two for measuring the pressures exerted by elastic fabric.[5]

[‡] Midwest Research Institute is a professional not-for-profit corporation doing contract research for business, industry, government, individuals and groups.

Although some instruments have misrepresented pressures on the high side and some researchers have advocated unusually low pressures,[9] a 1985 study by Hendricks and Swallow used stockings "designed to exert graded compression from 24 mmHg pressure at the ankle to 16 mmHg pressure at the calf." They admit that "the optimal amount of compression at the ankle and calf necessary to heal and prevent statis leg ulcers is not known at this time." Their explanation of the value of external compression therapy is that "it compresses the superficial veins and prevents extravasation of fluid into the subcutaneous tissues . . .," thus reducing "swelling of the leg as measured by total leg volume and by lower extremity circumference measurements."[6] The study by Varghese, et al., obtained similar results with similar pressure readings using the CTC instrument. To date, capillary and anteriolar blood pressure have not been related for the purpose of establishing pressure values that would reduce edema; nor has the difference between new or mature residual limbs been studied. Different pressure readings have been observed over bony areas versus fleshy areas.[22]

PROCEDURES

Since our aim was to develop a sock which would be fashioned to give greater pressure distally, less pressure proximally, and have a rounded toe to shape the distal end, the flat, V-bed type machine was employed. Figure 3 is a close up of the carriage and the needle bed where needles are picked up or dropped according to machine programming so that widenings or narrowings (fashionings) can be made. All standard prosthetic socks are full-fashion knit in this way, with gradual widenings up both sides of the sock. To give even greater rounding, a new widening for the toe was programmed. On circular machines, as used for most currently available shrinkers, widening can only be achieved by loosening

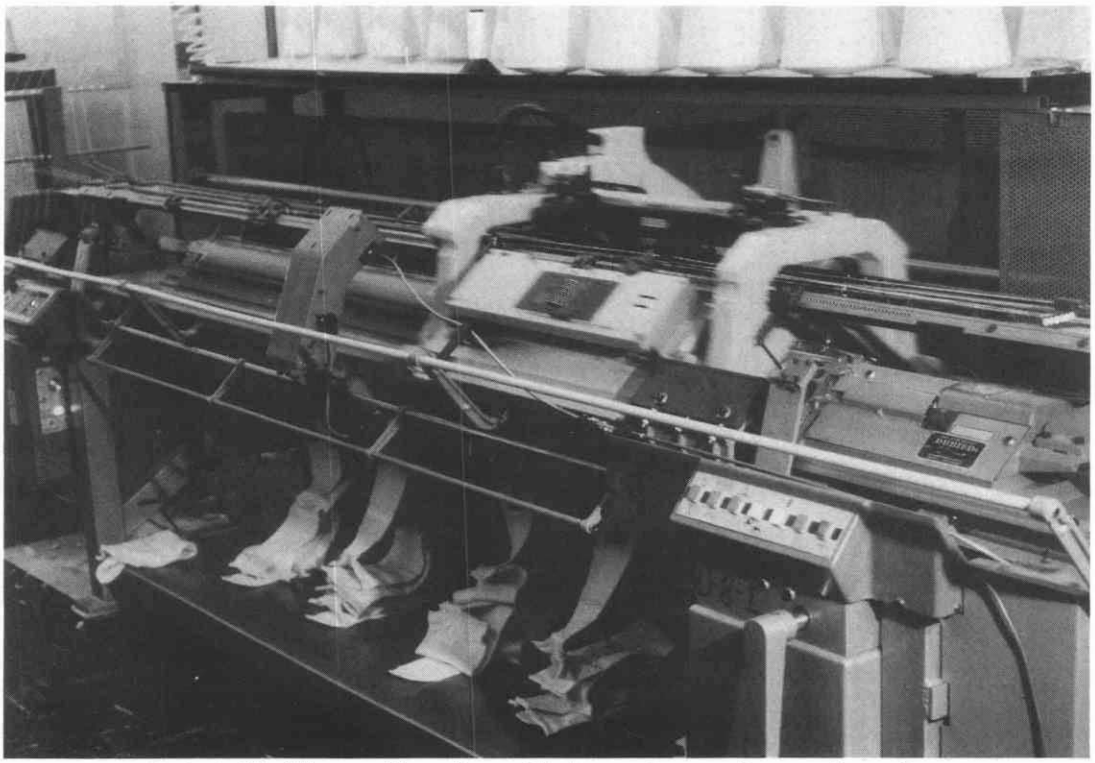

Figure 3. Needle bed of knitting machine where widenings and narrowings can be made.

EXPERIMENTAL SIZE RANGE Regular Taper Shrinker					
		Flat Width		Fits Circumferences	
Size	Length (inches)	Top (inches)	Toe (inches)	Top (inches)	Toe (inches)
Narrow	10″ 12″ 14″	5″	3″	13″–14″	9″–11″
Medium	10″ 12″ 14″	6″	4″	15″–17″	12″–14″
Wide	10″ 12″ 14″	7″	5″	18″–20″	15″–17″

Table 1.

the knitting tension. Knitting a rounded toe on a circular machine is not possible.

The yarn to be used for this sock needed firmness in its stretch so that the desired pressures could be obtained. Softness, strength, and washability were also considered important. A corespun yarn was selected, with Lycra spandex being the core and Avril rayon being the covering.

Attempts were made to obtain postoperative edemic residual limb measurements from various facilities. Not enough measurements were obtained to make any generalizations. Therefore, our knowledge was combined with that of the Knit-Rite production manager to formulate an experimental size range (Table 1).

Specifications were made for the knitting machines so that the desired pressures would be obtained when tested over a steel cylinder (Figure 4) at the Fits Circumference measurements. Heavy pressure was defined at the top of the effective range, i.e. 25–30 mmHg for the distal pressure and 15–20 mmHg for the proximal pressure. The recognition that some patients could not tolerate heavy pressure, and that some researchers suggested less pressure for nighttime wear, led to the development of a sock having distal pressure in the 15–20 mmHg range and proximal pressure in the 10–15 mmHg range. Socks were identified with color stitching at the top: green for heavy pressure and gray for medium pressure. The increase in pressure caused by the increased stretch over the range was measured to be no greater than the allowed variance. Shrinker socks were sent to many prosthetists who indicated that they would use them and return evaluation forms.

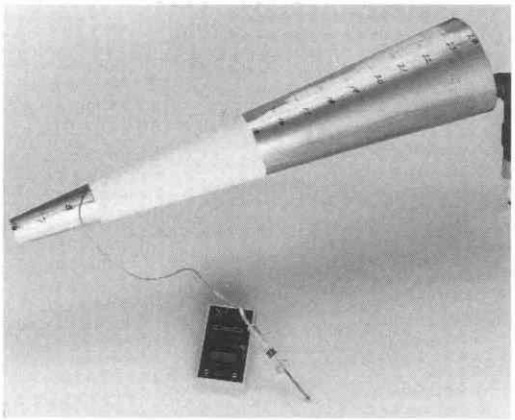

Figure 4. Testing cylinder with pressure sensing device in position.

RESULTS

Forty-five evaluations were returned representing 43 patients. All but three of these evaluations were for below-knee amputees (Table 2). Of the 42 below-knee evaluations, 17 had

ACTUAL BK CIRCUMFERENCE MEASUREMENTS Measurements from distal end			
1″	3–4″	6–8″	Top
8		11	13⅛
8¼	7	9⅝	12
8½	11⅜		14½
8½	12½	15½	14½
8¾	10½		
9	7½	9½	10
9¼	10	10¾	
9½	10	12	
9½	11¾		14½
9¾	12	12	
9⅞	12½		15
10⅜	12½	13 KC	
10½	11⅜	14	14½
10½	10¼	12¼	13
10⅞	11¼		
10⅞	11		
11	12¼	14¼	13¾
11⅛	11¾	14⅝	14½
11½	13	14¼	16½
11½	13	14¼	16½
11½	12	13¾	12½
11½	13	14¼	14½
12	14	15½	15½
12⅛	13¼	15	15¾
12¼	13¾	16	17
12½	15½	17½	15
12½	13½	15	17½
12½	12⅞	14½	14¾
12½	12¾	14¼	
12¾	13	15	
13	13⅜	16½	16¾
13	15	16¼	15½
13½	13¾	15¾	16½
13½	13½	15½	17½
13⅝	13¾	13¼	13¾
14½	16⅞	18½	20¼
14¾	16¾	17	17¼
15⅞	16½	18⅝	19¾
16	15		16

Table 2.

toe measurements ranging in circumference from eight inches to 11 inches; 18 had toe measurements ranging from 11⅛ inches to 13⅝ inches; four had toe measurements ranging from 14½ inches to 16 inches; and three did not give measurements (Table 3).

The significance of grouping the measurements in this way was so they would correspond with the size range we had developed for testing purposes. A smaller toe circumference measurement was encountered than had been anticipated, but the actual toe sizing ranges could be compared with the experimental toe sizing ranges in the narrow, medium, and wide. Top measurements were ranged as they corresponded with toe measurements in each size (Table 3). Note, the actual tester range of top circumference measurements was both larger and smaller than the experimental sizing range for the narrow and the regular, but was only smaller for the wide (Tables 1 and 3).

Pressure measurements were again taken which defined ranges of each size as reported for the wearers. Figure 5 shows pressure measurements of heavy shrinker socks at circumferences one inch from the distal end. These pressures should relate to pressures exerted on those fitted with the narrow, the medium, and the wide as indicated by the rectangles. Our KU study indicated laboratory pressure measurements over steel cylinders are approximately ten percent higher than pressure measured on patients, or control volunteers making these pressures in agreement with our criteria, if the larger circumference in each specified Fits Circumference range is the cut off point; therefore, if 11 inches is the larger suggested circumference, 11⅛ circumference inches would be fit with the next size unless greater pressure is desired.

Figure 6 shows pressure measurements of heavy shrinker socks at circumferences six to eight inches from the distal end. These pressures should relate to pressures exerted on those fitted with the narrow, the medium, and the wide as defined by the rectangles. These pressures are less than the distal end pressures. However, particularly in the narrow size, some readings were at the 20 to 25 mmHg level. Since some wearers' residual limbs were exceeding the suggested range in top circumference measurement and were obtaining greater proximal pressure than might be desired, patterns were made using the measurements given for each limb. These were grouped by shape. As a result of comparing these shapes and listening to comments from several facilities, a double tapered shrinker was developed. Comparison to the regular taper is shown in Figure 7

RANGED BELOW-KNEE CIRCUMFERENCE MEASUREMENTS (inches)		
Toe 1″ from Distal End (as close as possible)	3–4″ from Distal End	**Top** 8″ from Distal End
8 – 11	7 – 12½	9⅝ – 14⅝
11⅛ – 13⅝	12¾ – 15	11¾ – 17½
14½ – 16	15 – 16⅞	17 – 18⅝

Table 3.

where the dotted lines represent the regular tapered sock and the three toe lengths represent the 10, 12, and 14 inch sock lengths.

When knitted, the regular taper and double taper can be compared as in Figure 8. The toe is the first consideration for fit using the Fits Circumference range as the guide. Then, if the top circumference exceeds the recommended limit of the regular range, a double taper should be ordered or at least considered.

Figure 9 shows pressure measurements of medium pressure shrinker socks at circumferences one inch from the distal end. These pressures should relate to pressures exerted on those fitted with the narow, the medium, and the wide as indicated by the rectangles. These pressures met our criteria for a sock with medium pressure of 15 to 20 mmHg. Figure 10 shows pressure measurements of medium pressure shrinker socks at circumferences six inches to eight inches from the distal end. These pressures should relate to pressures exerted on those fitted with the narrow, the medium, and the wide as defined by the rectangles. These pressures were lower than our criteria when circumferences were less than our sizing guide. This was not considered to be a problem unless a lack of pressure caused slippage. Where circumferences were more than our sizing guide, the pressures of the narrow exceeded our criteria as did those of the heavy shrinker sock. As for the heavy shrinker sock, when the top circumference exceeds the Fits Circumference recommendation, the double taper is recommended to get the advantages of gradient pressure.

Evaluation forms revealed that both green top, heavy compression socks, and gray top, medium compression socks, were used for day and night wear. Four testers used two socks: heavy compression for daytime wear and medium compression for nighttime wear. Seventy percent of the testers wearing the heavy compression felt the tops stayed up adequately; 65 percent of the testers wearing the medium compression socks felt the tops stayed up adequately. Night-time was the most difficult time. To one tester who complained in detail about the roll down, we sent him a shrinker with a turned down zigzagged stitched top. He liked this top, but it was not pursued for fear the doubled top would cause greater pressure proximally. Some trials indicated the shrinker should come up proximally past the patella and that if it comes a little higher, it is less likely to roll.

All but one of the testers using the heavy compression felt that the shrinker was improving the shape, decreasing the edema, and/or maintaining the limb. One tester, who felt the heavy pressure was not adequate, used both heavy and medium socks at the same time and still felt the need for greater pressure. The prosthetist noted this was a young man with a high pain level and a drive to get back on his legs. Sixty-four percent of the testers using the medium compression felt the shrinker was maintaining the limb's size and shape. Thirty-five percent of the respondents felt the pressure of the medium compression sock was not sufficient. Most of the amputees using the experimental shrinker socks were new patients who lost a leg because of vascular disease, usually diabetes. Any undue pressure over the residual limb serves as an excuse to take the shrinker off; therefore, medium pressure may help to start the process of controlling edema so that heavy pressure will eventually be tolerated as needed. Some of the shrinkers were worn over Ace® bandaging and some comments were made about using Ace® bandaging some of the time.

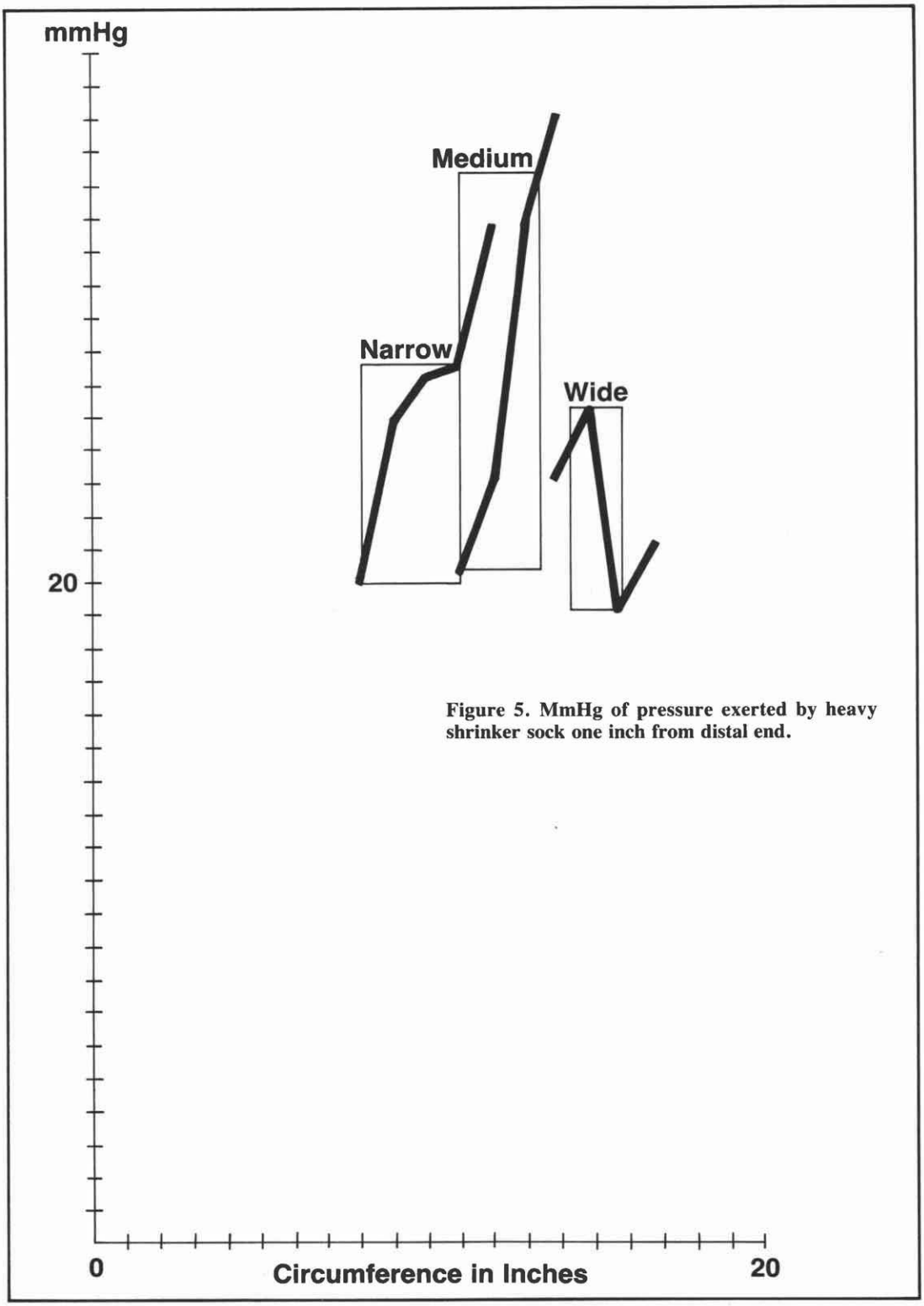

Figure 5. MmHg of pressure exerted by heavy shrinker sock one inch from distal end.

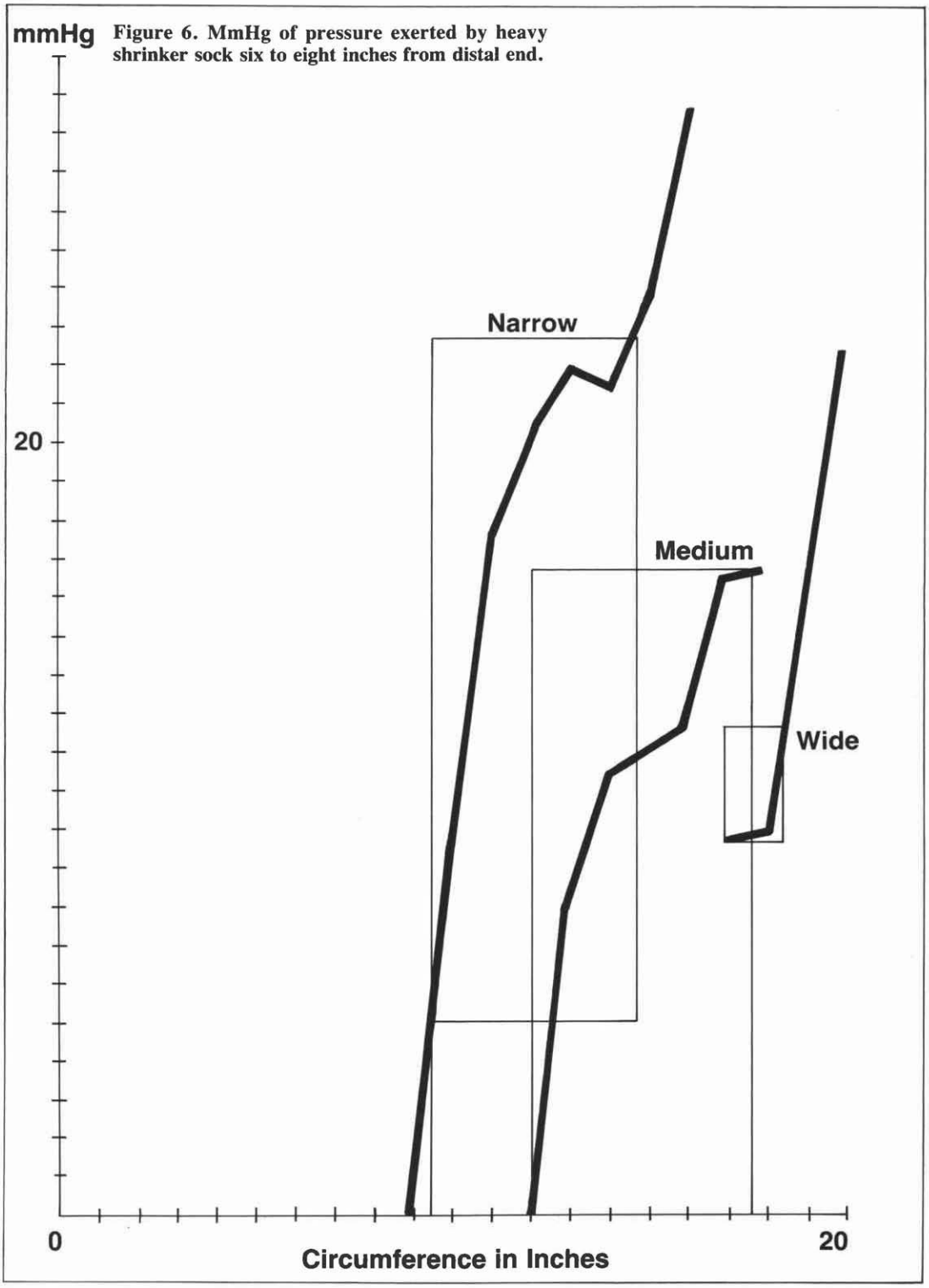

Figure 6. MmHg of pressure exerted by heavy shrinker sock six to eight inches from distal end.

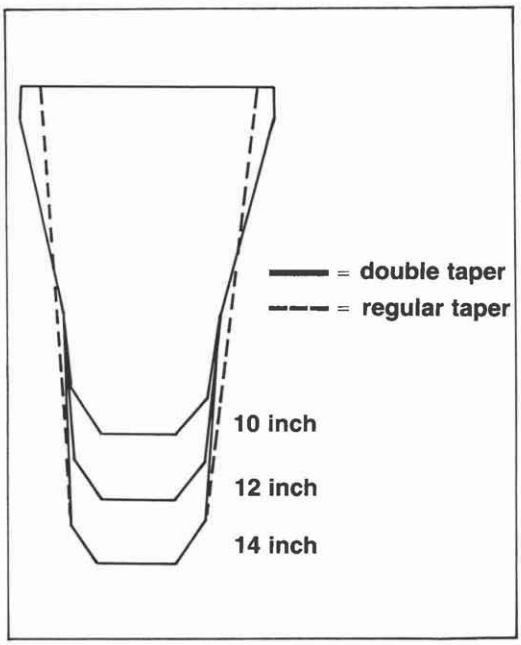

Figure 7 (left). Scale of regular and double taper.

Prosthetists' comments revealed that the experimental shrinkers were effective in shaping the distal end, hugging the anatomy, and giving good overall suspension. The distal end support was positive as long as the patients applied the shrinker firmly. Some residual limbs are very bulbous initially following surgery. This depends on the patient's physique, the surgical technique use, and the amount of edema. Previous experience indicates a bulbous residual limb will, in time (six to 12 weeks post-surgery), become slowly cylindrical, and a cylindrical amputation will become cone-shaped.

Thirty percent of the wearers said they had not washed their shrinker sock which may have meant that they were wearing it continuously. Five percent did not answer the question. Of the 65 percent who did wash their shrinker, none mentioned any washing problems.

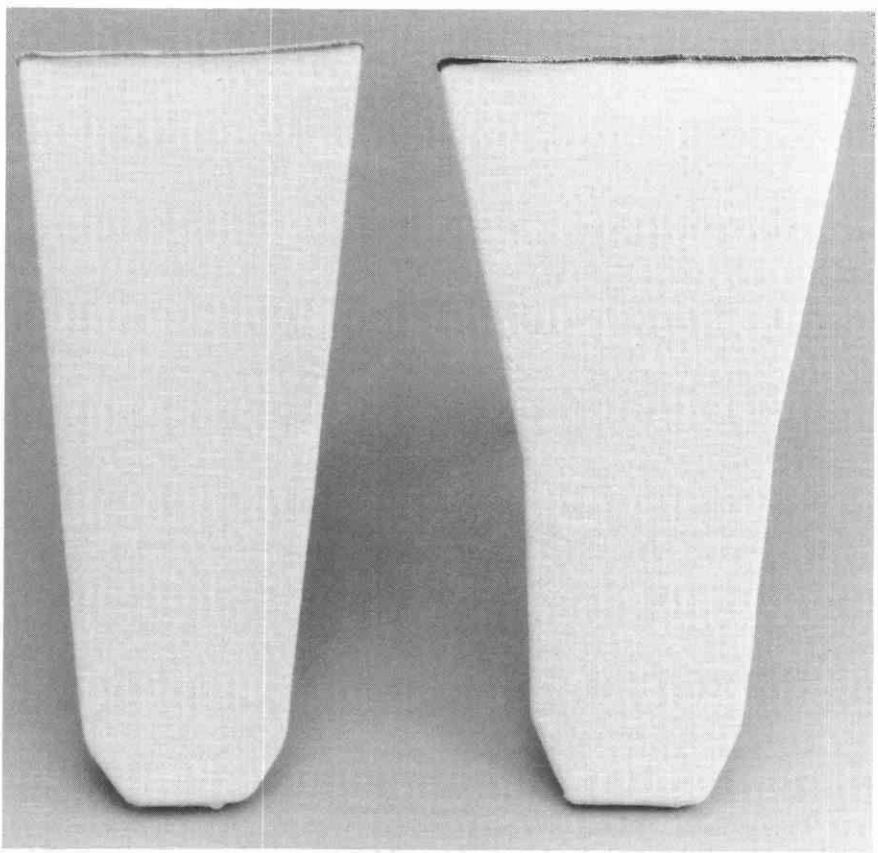

Figure 8. Comparison of regular and double taper shrinker sock (14 inch length).

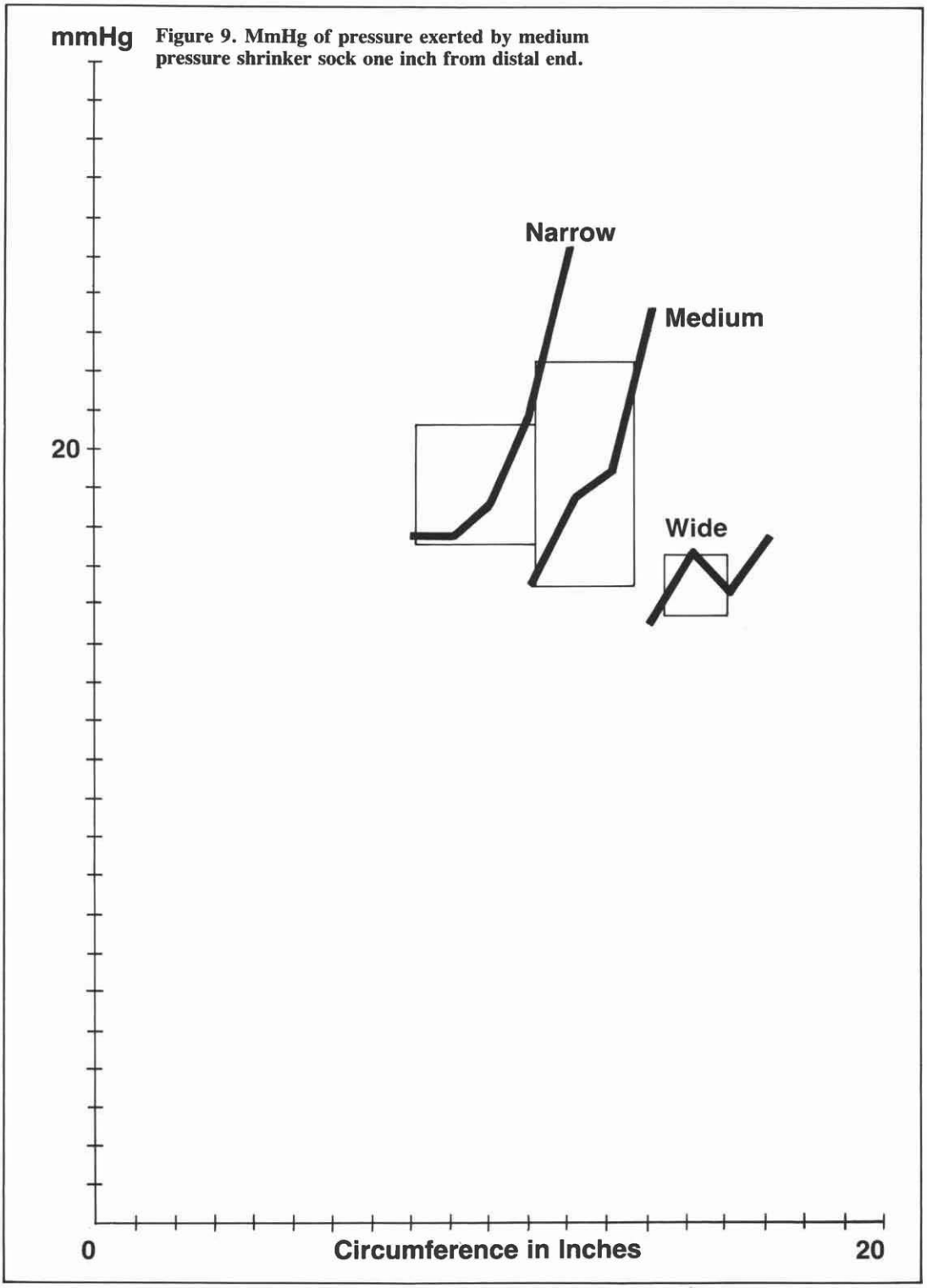

Figure 9. MmHg of pressure exerted by medium pressure shrinker sock one inch from distal end.

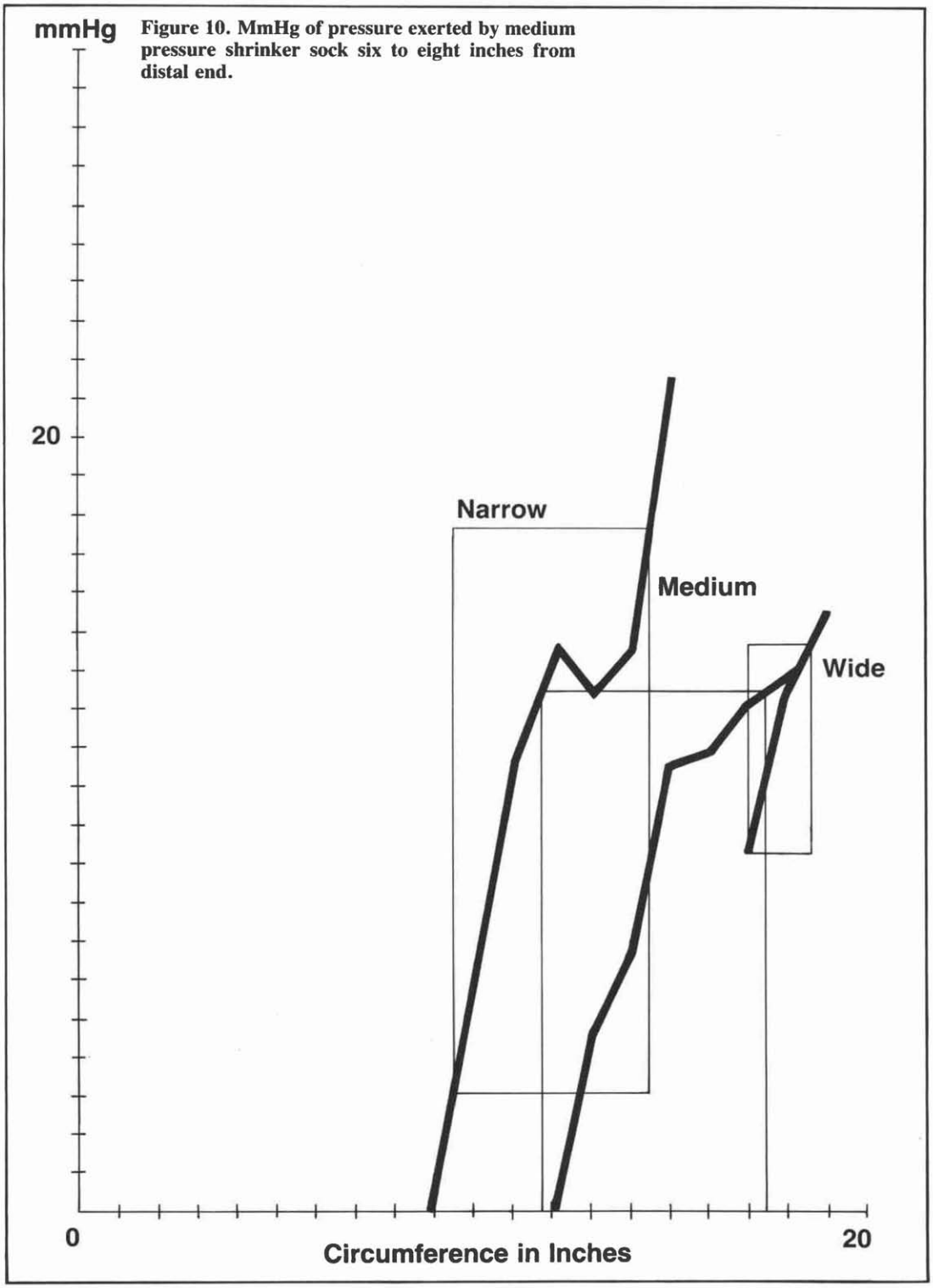

Figure 10. MmHg of pressure exerted by medium pressure shrinker sock six to eight inches from distal end.

In answer to the question, "Is the sock easy to apply", 100 percent of the testers said, "Yes." One said, "Very." In answer to the question, "Is the sock comfortable?," all but one tester replied positively. This one tester was having some orientation problems. Other comments were "Feels good," "Feels great, except at first when a little tender."

CONCLUSIONS

Evaluation forms for a new below-knee shrinker sock revealed it was comfortable, easy to put on, stayed up on most but not all wearers, gave desired shrinking and shaping in the heavy compression, and some shaping and residual limb maintenance for 65 percent of the medium compression wearers. When pressure was greater and the sock was fitted longer, proximally past the patella, roll down was less of a concern. Analysis of residual limb measurements and pressure measurements determined that both the heavy and the medium compression shrinker socks did exert greater pressure distally than proximally, and that wider circumferences than those recommended at six or more inches from the distal end could be accommodated by the double tapered sock.

This study did not offer the opportunity to study above-knee shrinkers, but they are being custom made in order to gain knowledge of fit and support. The same fabric used in the below-knee shrinkers can be cut and sewn to make above-knee socks. To meet the needs of shrinking stumps, below-knee shrinkers can be altered with a sewing machine stitch if the sock is not to be used for walking. If the sock is to be used for weight bearing, it can be returned to be altered with a flat seam according to specified markings, or a smaller size can be fitted.

ACKNOWLEDGMENTS

We are especially indebted to the prosthetists from the various facilities who did most of the reporting for the testers. Without their help, this report would not have been possible. We also wish to thank William B. Smith, CO, President, and Larry Pierce, Production Manager, of Knit-Rite, Inc.. Without their product, knitting knowledge, and encouragement, no sock would ever have been made.

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Clinical Prosthetics and Orthotics, Vol. 11, No. 1, pp. 33–44

Removable Rigid Dressing for Below-knee Amputees

by Yeongchi Wu, M.D.
Harold Krick, C.P.

BACKGROUND

According to the National Center For Health Statistics, there were 274,000 patients with amputations of major limbs in 1971 in the United States. This number rose to 358,000 in 1977. Kay in 1975 reported 53.8 percent of the 6,000 reviewed new patients had had amputations at the below-knee level.[3] If the percentage and the number of amputees remained unchanged, there would be at least 200,000 below-knee amputees in this country at any given time. It is possible that this number could have been doubled in the past ten years. The most recent information regarding amputation available to the authors was the Vital and Health Statistics published by the U.S. Department of Health and Human Services in April, 1986. A review of 192,000 medical records from the 407 hospitals that participated in the 1984 National Hospital Discharge Survey showed an estimated 32,000 below-knee amputations alone. Therefore, improvement in the management of below-knee amputees will certainly benefit a significant number of patients.

At the V.A. Lakeside Medical Center (VALMC) and Rehabilitation Institute of Chicago (R.I.C.), members of Northwestern University-McGraw Medical Center, Chicago, three techniques have been developed for treatment of below-knee amputees. These include the Removal Rigid Dressing (R.R.D.), Scotchcast™ preparatory prosthesis, and the "one-step socket lamination definitive prosthesis." These approaches have been invaluable in the management of below-knee amputees.

This paper describes the Removal Rigid Dressing for postoperative management of the below-knee amputee. Clinical experiences since 1977 have shown the benefits of the R.R.D. to be the following:

1. Rapid residual limb shrinkage
2. Prevention of edema
3. Possibility of frequent residual limb observations
4. Soft tissue immobilization to facilitate wound healing
5. Elimination of skin breakdown commonly seen in elastic bandaging
6. Simplicity of donning and doffing
7. Development of tolerance to weight bearing
8. Prevention of residual limb trauma
9. Reduction of wound pain

With nine years clinical experience at this university medical center and dissemination through the Northwestern University Prosthetic School, it appears to us that this technique has its merits in the postoperative and pre-prosthetic management of the below-knee amputee.

In a study done in 1977, the average hospital stay for amputees at VALMC was reduced by 90 days after the development of the R.R.D.[6] This was achieved primarily by complete elimination of skin breakdown seen previously from elastic bandaging and by speeding stump shrinkage with the R.R.D.[7]

In the 1970s, at the VALMC in Chicago, there were many problems in postoperative below-knee residual limb care. For many years, the below-knee amputees were managed with a soft dressing or thigh high cast, i.e. Immediate Post-Surgical Fitting (IPSF) without pylon, followed by elastic bandaging, as many hospitals did at that time. The technique was done by the therapists, nurses, and patients, following the procedure learned directly or indirectly from

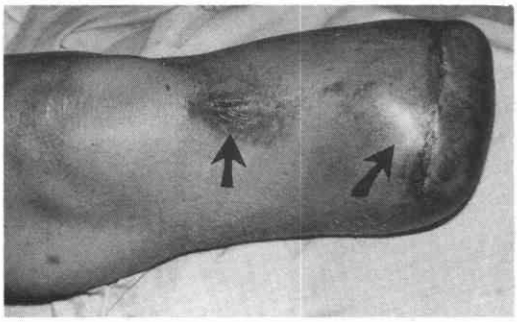


Figure 1. A typical pressure sore over the tibial tubercle and distal edema from conventional elastic bandaging.

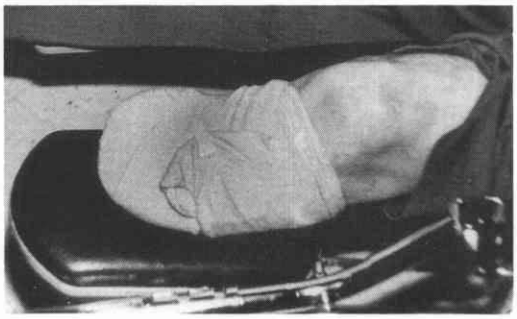


Figure 2. A conventional elastic bandage is an unreliable technique in a patient's hand.

the Northwestern University Prosthetic/Orthotic School. There was no special team or particular therapists assigned to amputee care. Inevitably, many techniques differing from the original were used by different individuals. For a long time, the staff was puzzled by the very high frequency of skin breakdown and distal edema (Figure 1). At times, it was a surprise at the V.A. Prosthetic Clinic when a patient presented who was free of any residual limb complications.

It was apparent that inconsistent limb care techniques by the staff and the patient himself was a contributing factor (Figure 2). Many thoughts came to mind and many attempts were made to remedy this problem, such as using a protective covering made of thermoplastic or a donut shaped sponge over the tibial tubercle to prevent skin breakdown. Nothing was promising until one afternoon in early 1977 when the idea of the R.R.D. came to light.

This happened after seeing a 90 year old man develop a tibial pressure sore on his well healed limb only three hours following the change from a thigh high plaster cast to an elastic bandage. We decided that the elastic bandage was guilty and should never be used for below-knee amputees again, and the thigh high cast could be modified to continue the excellent results. We analyzed the principles behind the thigh high plaster cast and incorporated them into the R.R.D. system.

The design was completed on the same day and the same principles have been kept until this date without any further modifications. This system is a below-knee plaster cast suspended by a stockinette to a supracondylar suspension cuff (Figure 7). Underneath the below-knee plaster cast, sport tube socks are added to provide continuous controlled compression.

WHY DOES R.R.D. WORK?

No matter how successful this method has been, we certainly were inspired by the important pioneer work by Dr. Weiss in Poland, and later by Dr. Burgess[1,2] in this country. A few of the principles that made the R.R.D. an effective procedure were originally utilized in the IPSF system:

1. Use of a non-expandable dressing prevents the development of edema following amputation.
2. Use of supracondylar suspension keeps the cast in place.
3. Rigid dressing is effective in immobilization of soft tissue, which is essential for wound healing and pain control as well as trauma prevention.
4. Controlled compression of the residual limb avoids skin breakdown and facilitates shrinkage.

FABRICATING THE R.R.D.

The R.R.D. consists of four components: a) tube socks, b) below knee plaster cast, c) suspension stockinette, and d) supracondylar cuff (Figure 3).

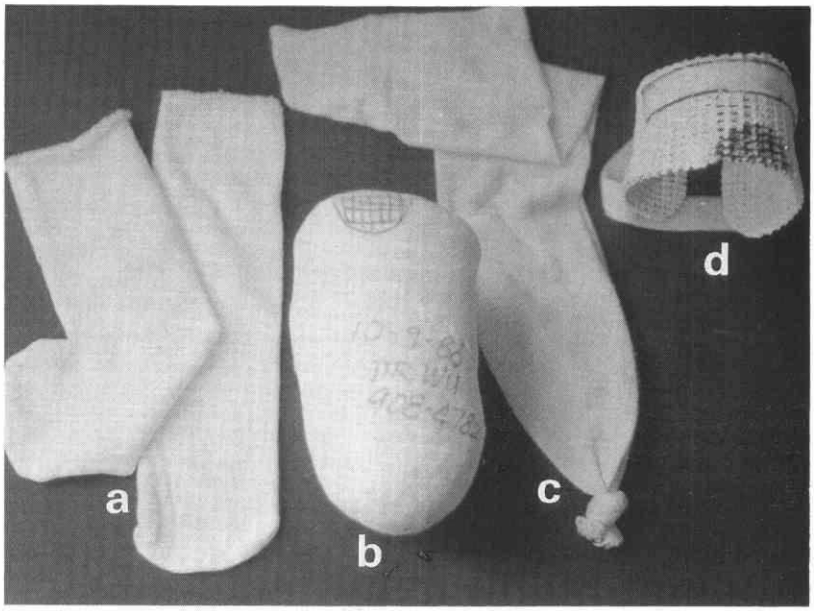


Figure 3. Components of the Removable Rigid Dressing: a) athletic tube socks with the elastic band removed, b) below-the-knee cast, c) suspension stockinette, and d) thermoplastic supracondylar suspension cuff.

Tube Socks

The idea of using tube socks arose because of the difficulty in obtaining wool socks from the V.A. supply center in early 1977 and the necessity of hand care of wool socks. By replacing the elastic bandaging with R.R.D., we noted that below-knee residual limbs changed from their previous conical shapes to cylindrical contours. The measurements of properly fitted wool socks for our patients differed from those supplied by the V.A. supply center. For a while there was a shortage of socks for our patients. This led to the need for alternatives. One day, we tried a large size tube sock on sale at the V.A. canteen store.

To this date, we still use tube socks routinely at the V.A. hospital and R.I.C. They can be changed daily by the patient and are machine washable. They also provide excellent sock marks on the skin for determining the degree of pressure over the residual limb. They are cheaper and available at most department stores (Figure 3A). We simply cut off the elastic tops and use them as nice fitting #2 size, 2 ply socks.

Tube socks are cut in long and short lengths. Short tube socks are effective for localized compression with a bulbous limb so that progressively diminishing shrinkage can be achieved from the distal to proximal area.

For the large residual limb, when the tube socks may not be long or wide enough, Soft-socks (Knit-Rite, Inc.) can be used.

Plaster Cast

The cast for a R.R.D. (Figure 3B) is shorter than that of the IPSF. It extends only up to the knee level for easy removal. The casting procedure also differs slightly for pressure relief. In the IPSF, felt paddings are used to bridge the bony areas. In the R.R.D., cotton paddings, six layers at the center and tapered to the margins, are used as "spacers" over the bony prominences of the tibial tubercle, tibial crest, fibular head and any pressure sensitive areas. Once the cast is made, the spacers are discarded. An empty space between the cast and the skin is formed to provide a controlled pressure relief (Figure 4).

The trim line of the plaster cast is up to mid-patellar level anteriorly and lower posteriorly to allow knee flexion. It is wider proximally in order to ensure easy removal and reapplication of the cast. This is especially true with a bulbous limb where the concave side needs additional padding to avoid a cast that is too tight at the top (Figure 5). In case of a narrow proximal opening, a longitudinal cut on the back of the cast can be used to widen the proximal part and allow reapplication (Figure 6).

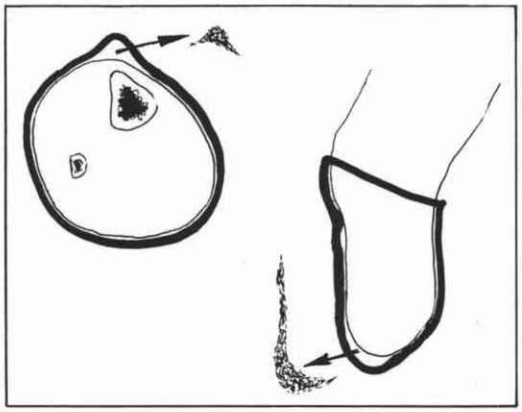


Figure 4. Cotton paddings are used as spacer for pressure relief.

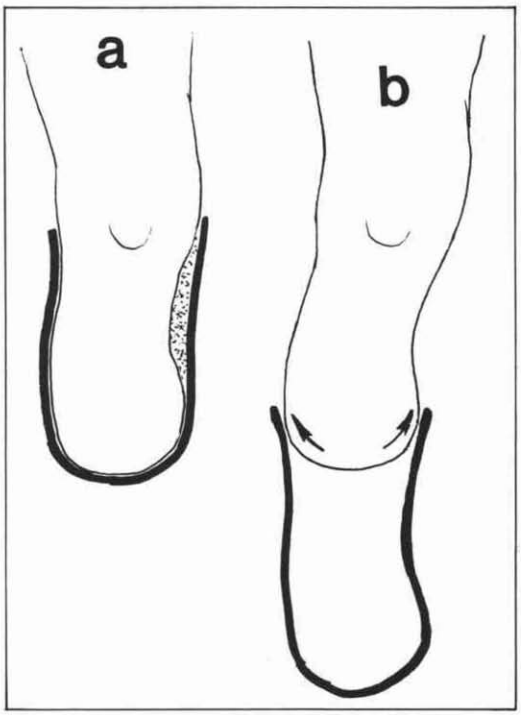


Figure 5. Adequate medial padding is needed to assure a wider proximal opening for easier cast re-application (a). A narrow opening makes cast reapplication impossible (b).

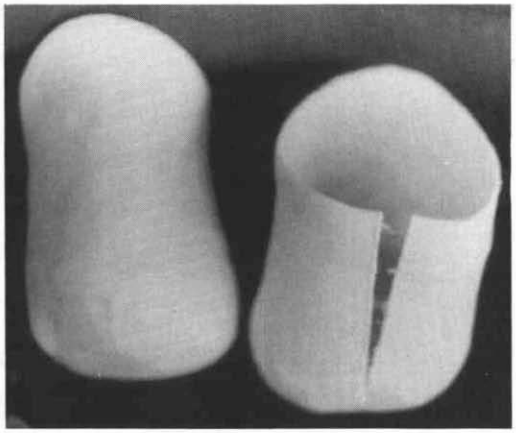


Figure 6. If cast opening is too narrow, a longitudinal cut on the back of cast allows widening of the cast proximally while still maintaining distal compression.

Suspension Stockinette

The suspension stockinette, made of 4-inch casting stockinette with one end tied, secures the cast to the suspension cuff (Figure 3C).

Supracondylar Suspension Cuff

The suspension cuff is made of thermoplastic material. It has a Velcro® closure to keep the cuff in place and a strip of Velcro® hook along the upper edge to secure the suspension stockinette (Figure 3D). For the obese patient who has very limited purchase over the femoral condyles because of tissue bulk, a fork strap with a waist belt can be used.

APPLICATION OF THE REMOVABLE RIGID DRESSING

After the surgical wound is properly dressed, the proper number of tube socks are applied layer by layer to avoid possible wrinkles. Then the plaster cast is applied and followed by the suspension stockinette and the supracondylar cuff (Figure 7). To make the application easier, a semi-circular mark is made on the cast and another on the supracondylar cuff so that the patient can match both marks to form a circle over the patella.

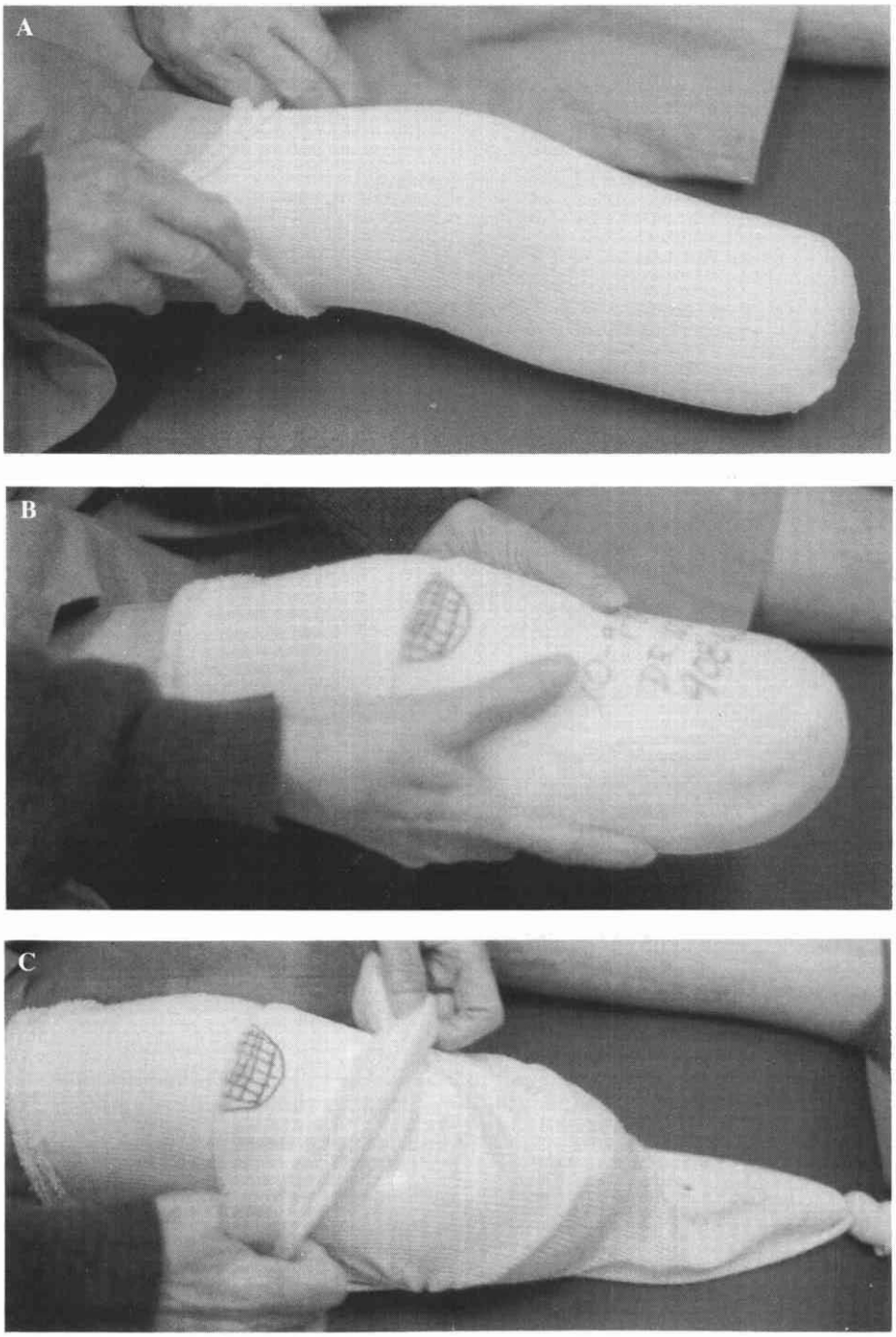
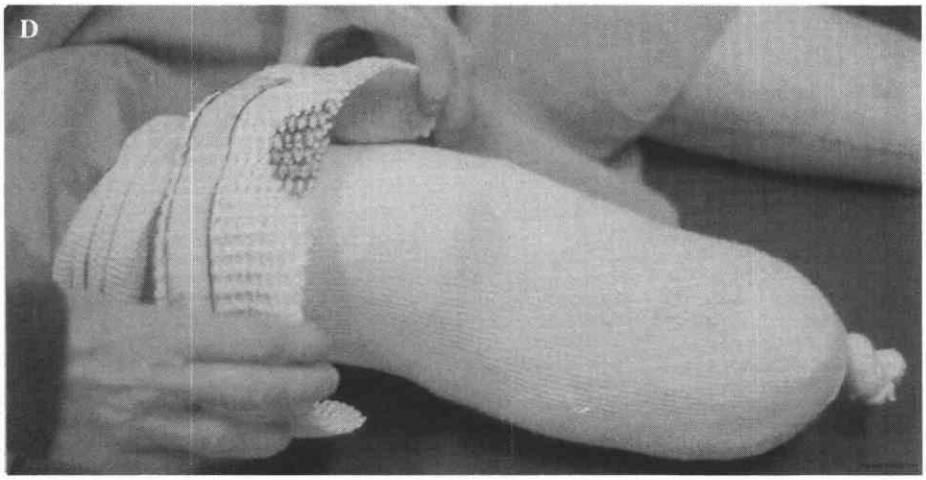


Figure 7d, e, and f (right). Application of the Removable Rigid Dressing: d) the supracondylar cuff, e) pull the stockinette, and f) fold the suspension stockinette to make sure the cast is secured over the supracondylar cuff.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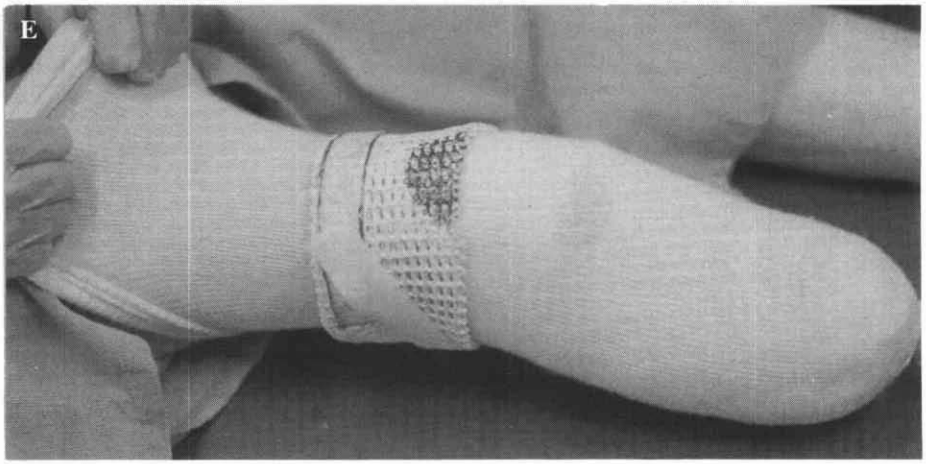
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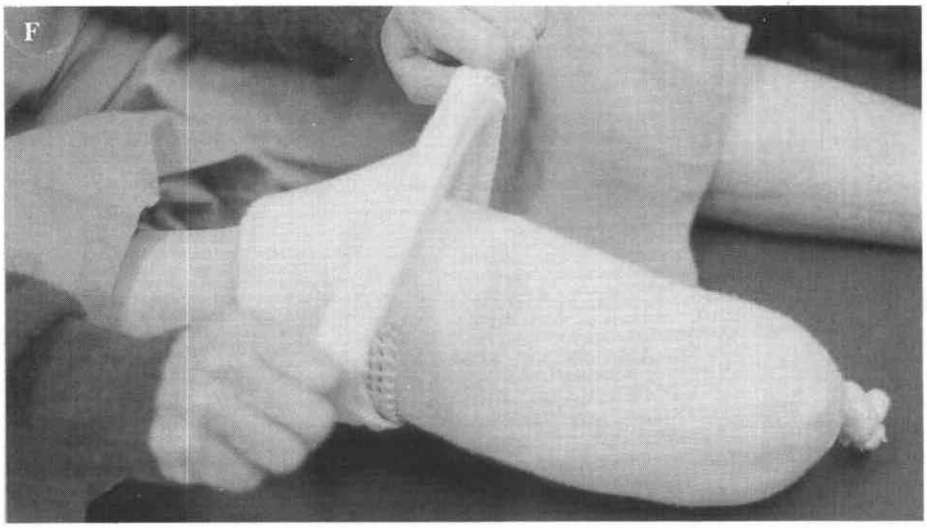
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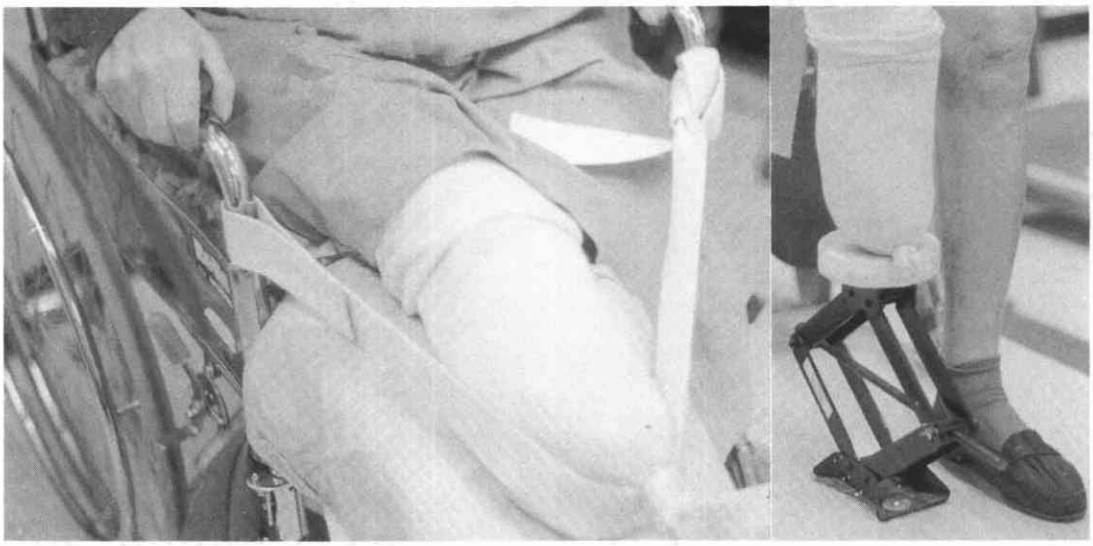


Figure 8. A strap is attached to the arm rests for the patient to exert partial weight bearing exercise while in the wheelchair (left). A car jack mounted onto plywood becomes an inexpensive adjustable stool for weight bearing and balance exercise (right).

The patient is then instructed in how to apply the R.R.D. A strap with Velcro® closure on one end is attached to the armrest of the wheelchair for static weight bearing exercise (Figure 8). The R.R.D. is worn continuously except for periodic observation to the residual limb and hygiene procedures, or when the prosthesis is being worn.

WHEN TO APPLY THE R.R.D.

The R.R.D. can be applied at the completion of surgery or when the first thigh-high rigid dressing is removed for wound inspection. It can be used whenever there is a need for limb shrinkage in any new or old amputee.

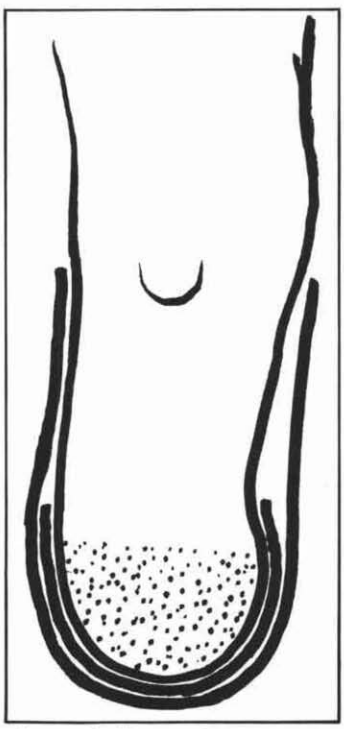


Figure 9. Short tube socks provide localized compression in bulbous stump.

ADDING SOCKS

When possible, additional socks are applied to maintain a comfortable snug fit and to facilitate progressive shrinkage. Sometimes short socks distally are preferred to provide localized distal compression without building up the thickness proximally (Figure 9).

WEIGHT BEARING EXERCISE

It is not possible to say how many days after amputation one can start weight bearing. In general, initiation of weight bearing exercise is determined by the state of wound healing, usually seven to 14 days after surgery. Immediate postoperative weight bearing is likely to cause mechanical shearing from movement and delay wound healing during the first two weeks after amputation, as reported by Mooney.[4] However, steady pressure without mechanical shearing on the residual limb using a wheelchair strap can be very beneficial (Figure 8). We have found this can be used even within the first week after surgery. While in the wheelchair, the patient is encouraged to push frequently with the R.R.D. against resistance of the strap.

Because it is removable, one can decide the time to start body weight bearing exercise based on the wound condition. The R.R.D. allows observation of the limb after each graded weight bearing exercise. By doing so, one can plan both the amount and duration of the next weight exercise.

For unilateral amputees, the weight bearing exercise can be done by standing on a padded car jack (Figure 8).

For bilateral amputees, the tilt-table is used for weight bearing. The degree of weight stress is controlled by the inclination of the tilt table and the duration of standing. This proceeds progressively to the upright position and is followed by ambulation with walking heels attached to the casts (Figure 10). Walking with

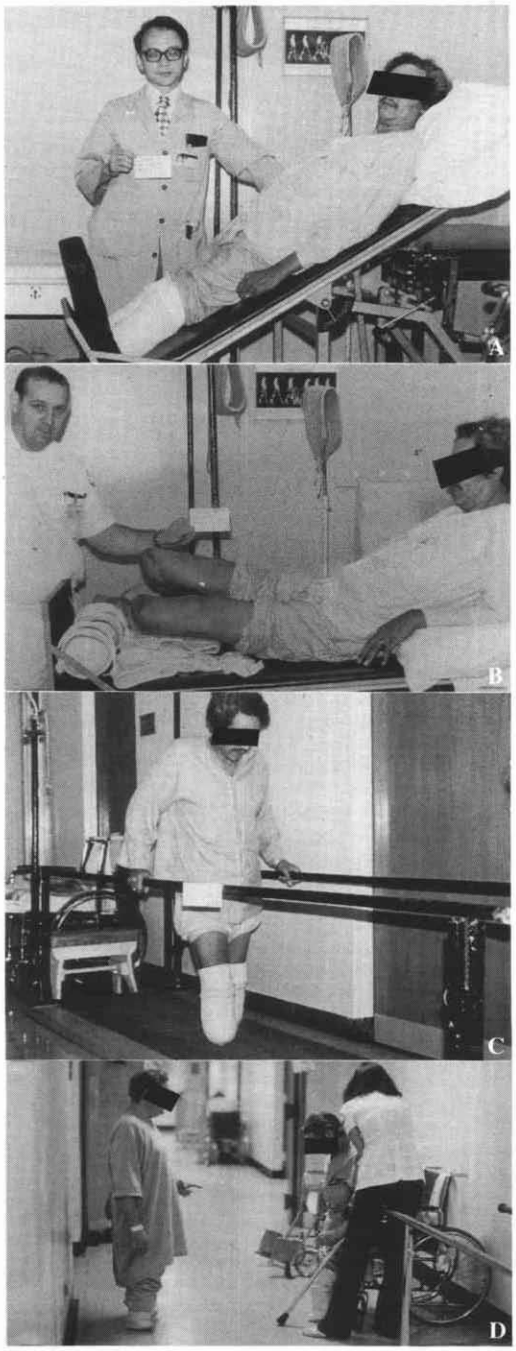


Figure 10. A) For bilateral amputees, weight bearing exercise is done on the tilt table. B) The stump is examined to modify the amount of weight bearing, i.e. the degree of inclination and duration of weight bearing. C) Weight bearing continues to the upright position in the parallel bars, and D) eventually to ambulation with walking heels attached to the casts or with a preparatory prosthetic fitting.

Rigid Dressings helps bilateral amputees develop balance and sometimes is preferred by the obese and cardiac patients at home (Figure 10). Walking with the R.R.D. also assists the evaluation of questionable candidates for prosthetic fitting. Ambulatory use of the R.R.D. produces simulation of prosthetic stress, allowing the amputee to quickly adapt to the actual prosthesis, an impossible step when using the conventional elastic bandaging method.

MAKING A NEW CAST

The below-knee cast is changed whenever the residual limb has shrunk to the point at which too many tube socks are being used, usually about 10–14 ply of socks. The total number of casts needed depends on the speed of progressive shrinkage. Frequently three or four casts are required before the patient is ready to be fitted for a preparatory prosthesis.

R.R.D. COMPARED TO IPSF

Both the R.R.D. and the thigh high rigid dressing provide immobilization of soft tissue, prevention of trauma, and prevention of edema. However, being removable, the R.R.D. allows frequent limb observation without a need for cast-cutting and cast-reapplication as needed in a thigh high rigid dressing. More importantly, it permits frequent addition of tube socks for fast shrinkage.

Because space is provided between bony prominences and the plaster, adding tube socks will produce compression force to soft tissues, but will not cause pressure sores (Figure 4). If there is excessive pressure over an area, the cast can be softened from outside with a hammer, then pushed from inside for relief.

Being removable, the R.R.D. has been very useful in monitoring the limb's response to weight bearing exercise. This facilitates progressive weight bearing within the safe tolerance range. Both undesirable skin breakdown from excessive weight bearing activity and hesitation in application of early graded weight bearing stress are minimized.

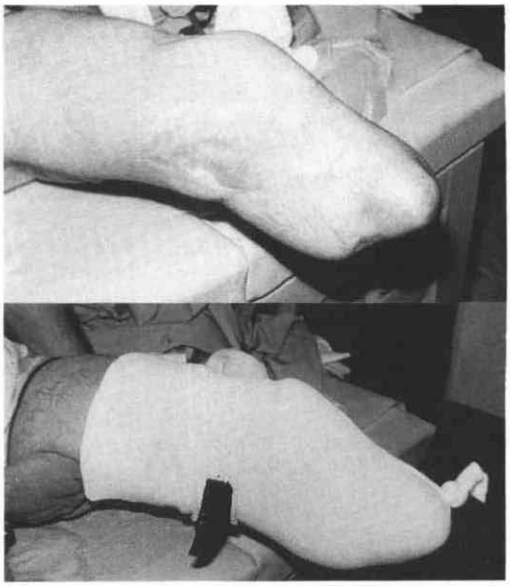


Figure 11. A stump with bony prominence and scars cannot tolerate the elastic bandage, but has no difficulty with Removable Rigid Dressing.

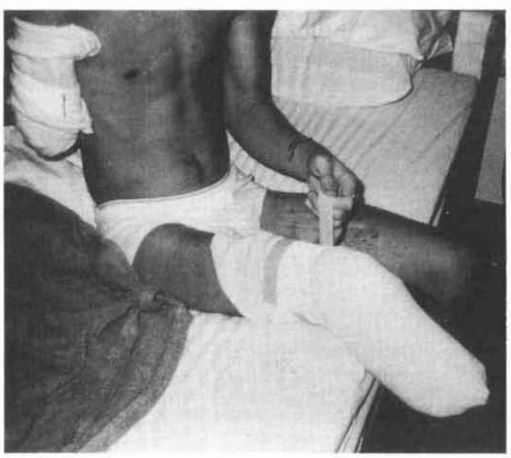


Figure 12. A one handed patient, either due to hemiplegia or upper limb amputation, can use the system easily.

R.R.D. COMPARED TO THE SHRINKER

The residual limb shrinker is an effective method for shrinkage, except for the danger of excessive pressure over bony areas or thin grafted skin. It does not protect the limb from unexpected falling, nor does it allow weight

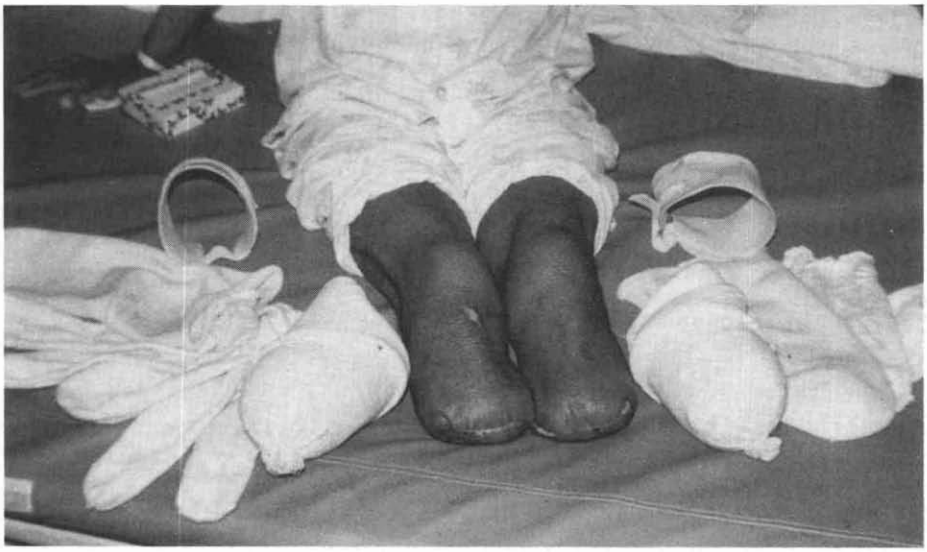


Figure 13. One of the first patients achieved 15-ply shrinkage in 7 days and spontaneous healing of the right pretibial sore caused by an elastic bandage.

bearing exercise. The compression force can be adjusted by sewing the shrinker periodically rather than by adding socks as with the R.R.D.

R.R.D. COMPARED TO THE ELASTIC BANDAGE

The elastic bandage is not only difficult to apply for the staff and the elderly below-knee amputees,[5] but also is so unreliable that it frequently causes skin breakdown and distal edema (Figures 1 and 2). It cannot protect the limb from trauma due to accidental falling. With the R.R.D., it is much easier for the patient to don and doff as well as adjust the compression, accommodate progressive shrinkage,[5] and perform weight bearing exercise.

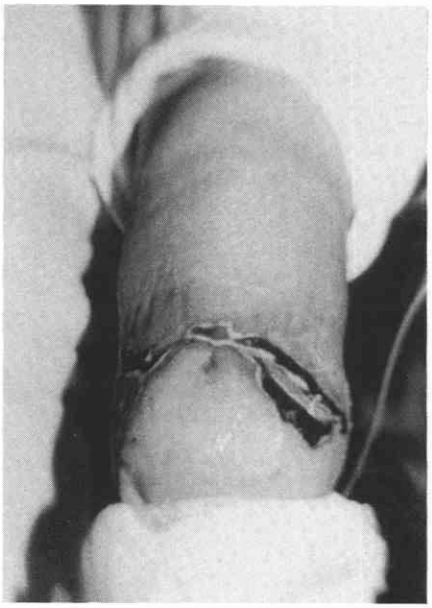
Since the adoption of the R.R.D. at this medical center, the problems of skin breakdown and distal edema, commonly seen in the past from elastic bandaging, have been completely eliminated (Figure 13).

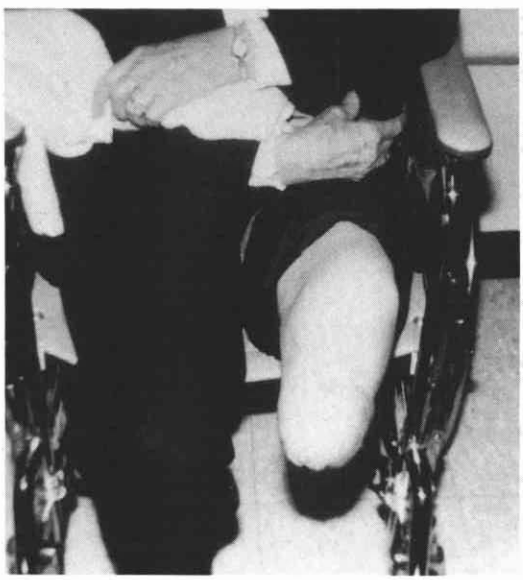
R.R.D. FOR DELAYED WOUND HEALING

Delayed wound healing is not a contraindication for using the R.R.D. or a preparatory prosthesis. The R.R.D. is a useful means to facilitate wound healing, because the system reduces edema and tissue tension. The size of the open wound can be reduced and the edges of the wound can be brought closer together. With frequent debridement of the necrotic tissue and adding socks for shrinkage, often a big open wound can be healed without surgery (Figure 14).

SCOTCHCAST™ PREPARATORY PROSTHESIS

When the patient is able to tolerate full weight bearing in the R.R.D. and the residual limb is no longer bulbous, a Scotchcast™ preparatory prosthesis can be fit for early gait training and further shrinkage.[8] The advantages of the Scotchcast™ preparatory prosthesis are its moderately light weight, comfortable fitting, rare need for realignment, and reduction of fabricating time. This is achieved by, 1) direct formation of the socket on the residual limb with special pressure relief techniques, 2) use of a wool sock lining as the soft interface, and 3) precise semi-dynamic alignment of the prosthesis. Since the Scotchcast™ prosthesis can be





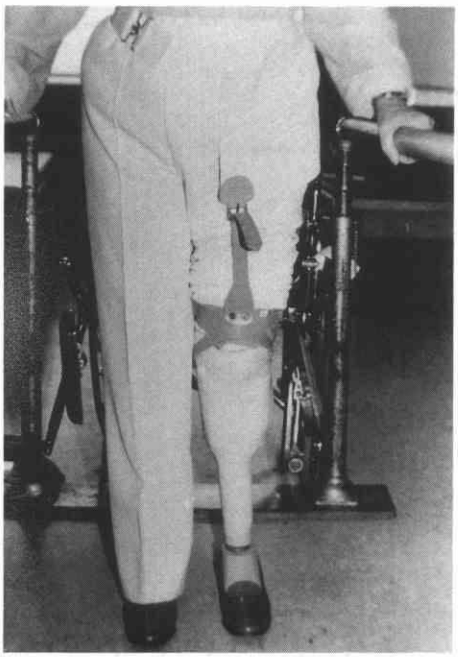


Figure 14. Removable Rigid Dressing facilitated shrinkage of the limb (upper left) and the open wound. By frequent debridement and prosthetic fitting (upper right), the wound completely healed without skin graft (lower left).

fabricated within 1½ hours during the patient's initial visit, the delivery of this prosthetic service is very efficient and cost effective.

CONCLUSION

The Removable Rigid Dressing has proved to be a very reliable means of preprosthetic management of the below knee amputee at this institution and others for the past nine years. It has proven to shorten the time from amputation to the initial preparatory prosthesis; is shown to be equal to or superior to all other means of preprosthetic stump management; features easy application; simple donning and doffing by the patient; progressive stump shrinkage by adding socks under the cast; gives protection through its rigidity for the not yet healed stump; ease in wound inspection; and allows early weight or pressure bearing to be started, thus conditioning the soft tissues for the first prosthesis. The R.R.D. has no contraindications other than application to a residual limb with a deep wound infection that requires surgical intervention.

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Transparent Preparatory Prostheses for Upper Limb Amputations

by Terry J. Supan, C.P.O.

The use of preparatory prostheses for lower extremity amputations has been widely published and publicized throughout the United States. Although techniques may differ from thermoplastic, laminated, or synthetic casting material for the socket, the concept of early fitting with a prosthesis to reduce the volume of the residual limb are fairly well adhered to. However, little has been publicized about preparatory fitting for arm amputations.

Since 1982, the Southern Illinois University School of Medicine has extensively used preparatory prostheses within the 30 day post-amputation time period. Techniques have changed gradually over the last four years, but a fairly constant, successful technique has evolved at the present time. Although myoelectric prostheses with their ease of therapy training have been the componentry of choice, the prosthesis design can also use conventional componentry.

The technique has also allowed us to utilize different componentry on an experimental basis to best determine the optimum componentry for the individual amputee. Prostheses have been used on all levels of amputation from wrist disarticulation through forequarter amputation (Figures 1–6). Since 1984, all prosthetic interfaces have been fabricated out of transparent material. Materials have either been Surlyn® or Durr-Plex. The transparent materials were chosen to improve monitoring of the residual limb during volume change. Surlyn® is used for below and above fitting sockets, while Durr-Plex is used for shoulder disarticulation and forequarter frames. With each of these systems, the prosthesis can be altered through heat forming as the patient's volume changes.

Standard electric prosthetic componentry has been used in all cases. However, minor modifications to the prosthesis/componentry interface have been necessary. Componentry which utilizes separate stainless steel electrodes from the amplifiers (Motion Control, VANU, and UNB) have been modified to use the stainless steel electrode developed for the Motion Control systems. Prostheses which utilize one piece electrode amplifiers (Otto Bock, Liberty Mutual) are primarily held in place utilizing Velcro® compression straps (Figures 7 and 8).

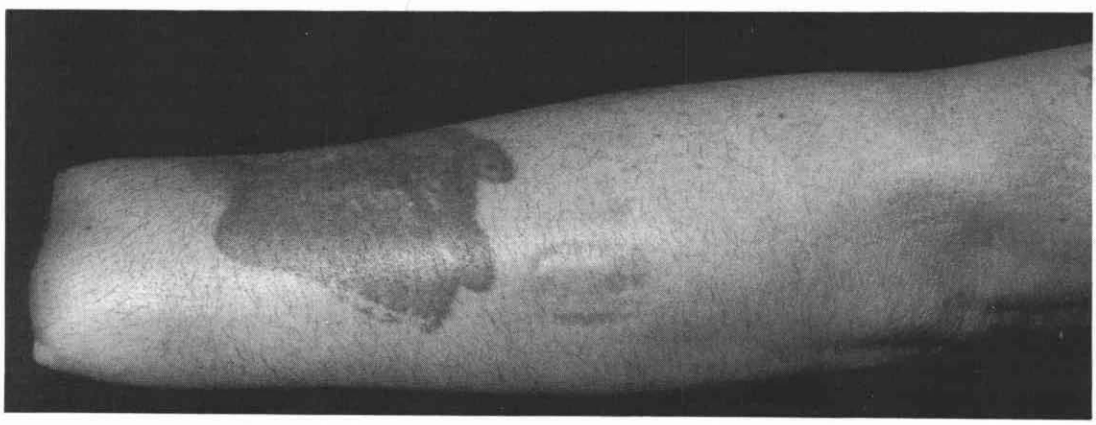


Figure 1. Left wrist disarticulation amputation secondary to trauma.

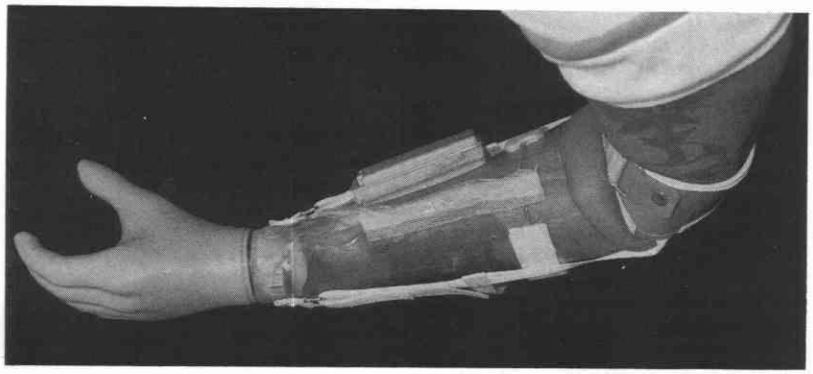
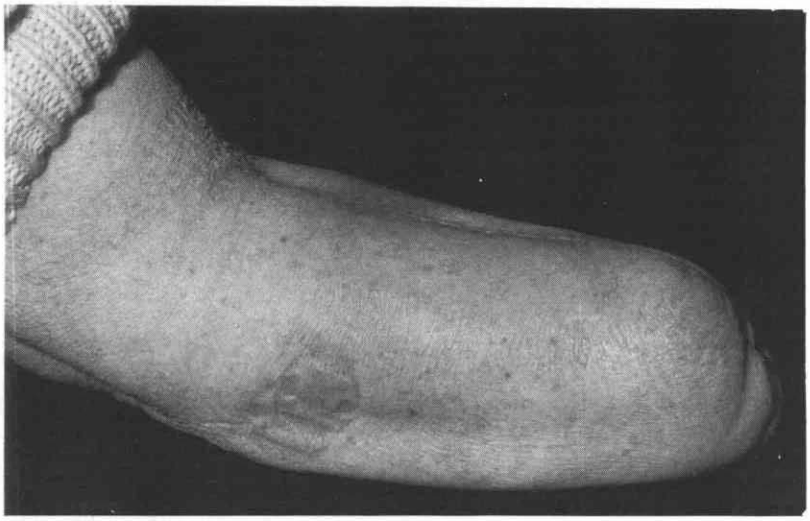


Figure 2. Left wrist disarticulation myoelectric prosthesis with supracondylar cuff to maximize supination and pronation.

Figure 3. Right mid-shaft below-elbow amputation, secondary to trauma and reattachment failure.



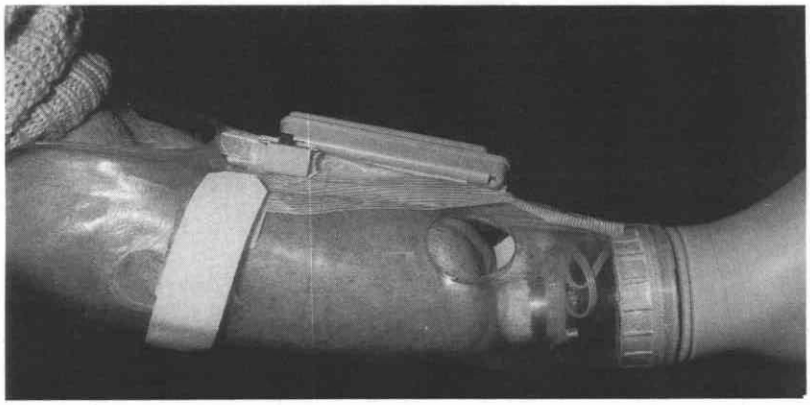


Figure 4. Right below-elbow prosthesis with supracondylar suspension and electric wrist rotator. Note that electronic controls, Otto Bock #, are mounted parallel to the electric rotator.

All loose wires are held in place with either strapping tape or duct tape. Manufacturers' recommendations concerning shielding of wires and electrodes are also followed.

An amputee's decrease in limb volume is monitored monthly until the volume has stabilized. If revisions of scar tissue, skin grafts, etc., are necessary, it is recommended that they be done during this time period as well. Modifications to the prosthesis must be made to maintain good electrode contact as well as suspension. Sockets may be split and Velcro® compression straps added if necessary. Electrodes may be replaced or locations adjusted if

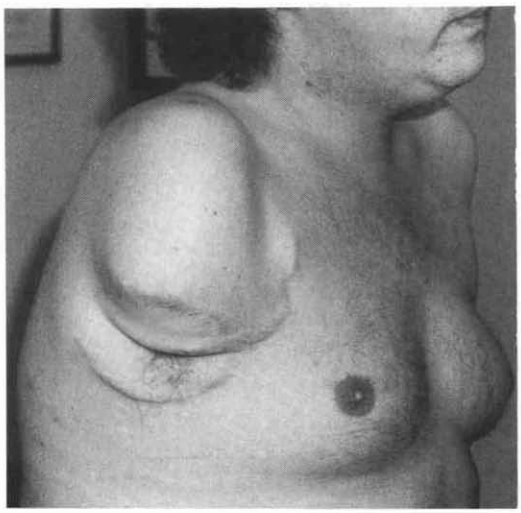


Figure 5. Right humeral neck above-elbow amputation secondary to trauma.

Figure 7. Close-up view of electrode site in Surlyn® wrist disarticulation prosthesis. The area of the Otto Bock electrode extension tabs have been modified in the socket with a Dremmel tool to prevent rotation of electrode on skin.

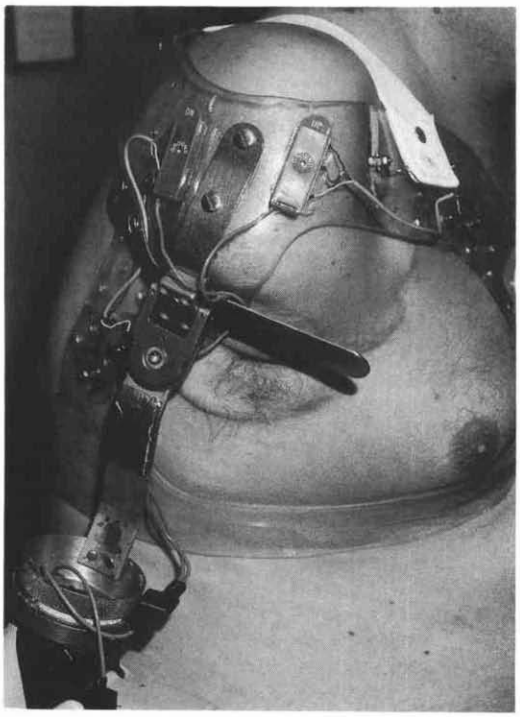


Figure 6. Shoulder disarticulation frame type prosthesis fitted to short above-elbow amputation.

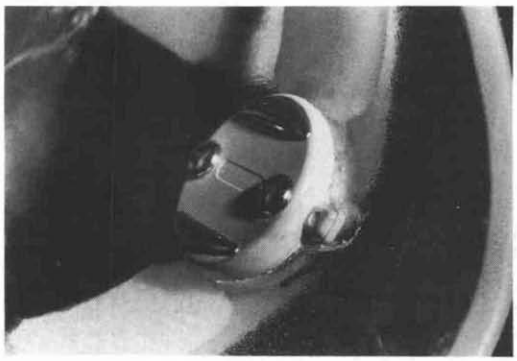


Figure 8. Otto Bock electrode mounted into preparatory prosthesis. Velcro® maintains the electrode from passing completely through the socket.

necessary (Figure 9). Although this is easily done with the Motion Control stainless steel electrodes by simply drilling another hole, it also can be accomplished with the Otto Bock or Liberty Mutual electrodes. If a hole saw is used to drill out the new location for the electrode, the cut-out material can be utilized to repair the previous location in the preparatory prosthesis.

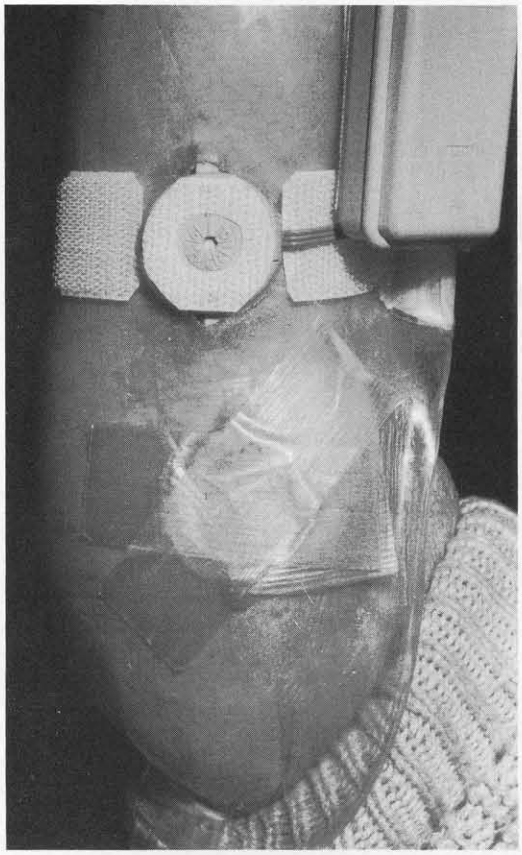


Figure 9. Close up view of preparatory below-elbow prosthesis. Hook Velcro® adhesive backing is used to suspend the electrode in the prosthesis. Previous incorrect electrode site is repaired with cut-out from new electrode site. Battery pack is held in place with adhesive backed Velcro® as well.

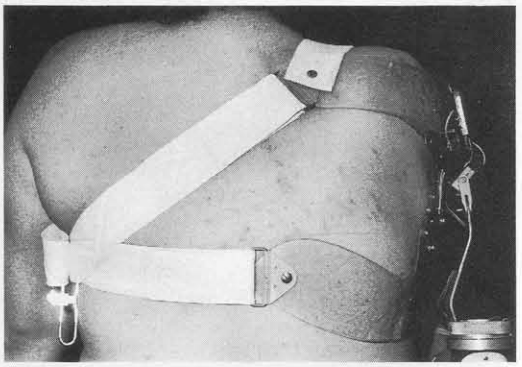


Figure 10. Posterior view of preparatory shoulder disarticulation prosthesis. Elastic strap superior to the shoulder improves comfort. Split of posterior frame into sections allows sitting comfort without electrode displacement.

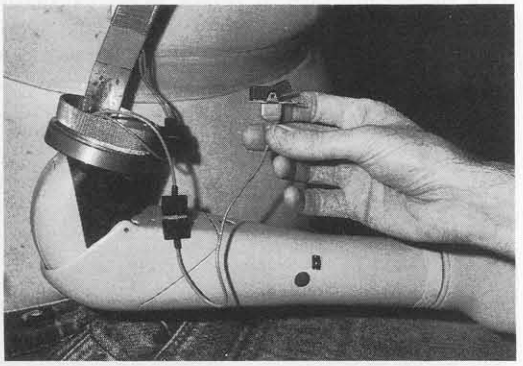


Figure 11. Lateral view of shoulder disarticulation prosthesis. Auxiliary switch is used to alternate EMG control between electric wrist rotation, hand opening, and closing.

Since 1982, 25 upper extremity amputees have been fit with this system. It has allowed us to closely monitor the development of the maturation process of the residual limb. Adjustments to the prosthesis have been made with minimal fabrication time. Total replacement of the preparatory prosthesis was only necessary in two cases. All other cases could be accommodated by modifying existing prostheses. All but one patient (forequarter amputation) went on to fitting and delivery of their permanent prosthesis. The results of these patients' permanent prostheses are consistent with the findings of Malone, et al.[1]

AUTHOR

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[1] Malone, J.M., M.D., et al., "Immediate, Early, and Late Postsurgical Management of Upper-Limb Amputation," *Veterans Administration Journal of Rehabilitation*, Volume 21, No. 1, May, 1984, pp. 33–42.

Clinical Prosthetics and Orthotics, Vol. 11, No. 1, pp. 49–54

Modular Seat-Shells and Standardized Manufacture of Individually Shaped Seats for the Severely Disabled—The Tubingen Experience

by George Neff
Klaus Fischer

Over the years, proper seating for the severely disabled has been neglected. Often, an approximate position of the patient in commercially available "grandfather-chair" seats, upholstered with cushions, seemed to be sufficient for the needs of these individuals. Custom shaped seats manufactured in the usual manner to taking a plaster cast, and molding the seat-shell of plastic material on this plaster model, after rectification, have proven to be helpful at least for limited periods, especially for growing children. However, often, during the time of plaster taking, an unfavorable position of a child, especially in cerebral palsy children, could be achieved, causing a permanently defective position for the child in such a seat. Moreover the entire process was time consuming, requiring the presence and active participation of an experienced and, therefore, expensive orthotic specialist. Also, the presence of the patient for a long period was necessary in comparison to our present procedure.

In 1978, we started a program for the improved manufacture of seats, using prefabricated seat shells and standardized patterns for the manufacture of individually shaped and adjusted seats for patients with seating problems, due mainly to neuromuscular diseases like cerebral palsy, muscle dystrophy, multiple sclerosis, and so on.

The idea was to improve the seating comfort of our patients and to increase the adjustability

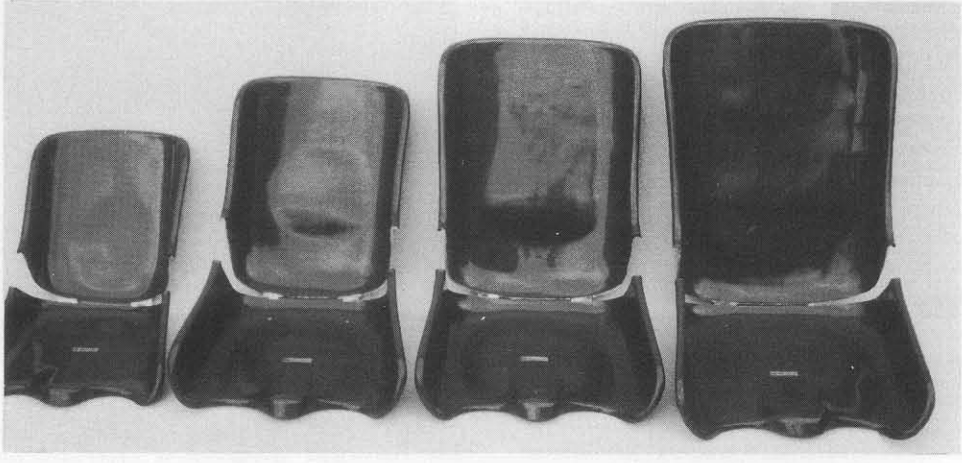

Figure 1. Four of six sizes of the modular seatshell. Two hinges connect the back and seat sections.

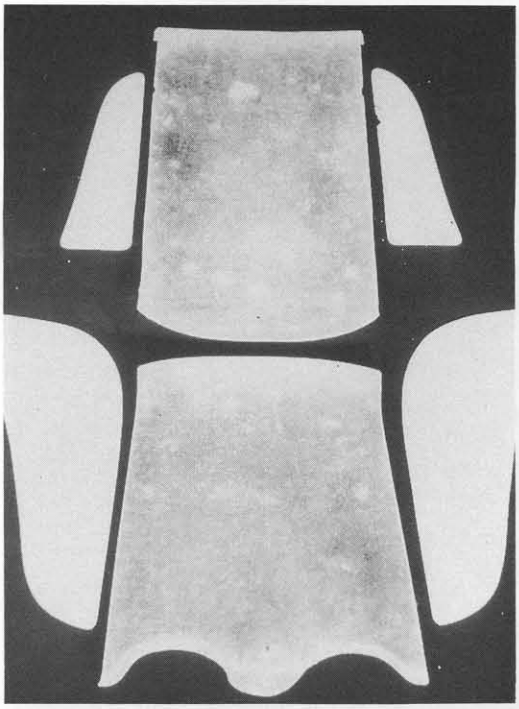

Figure 2. Seat, back, two upper side, and two lower side inner sections to be mounted in the seatshell.

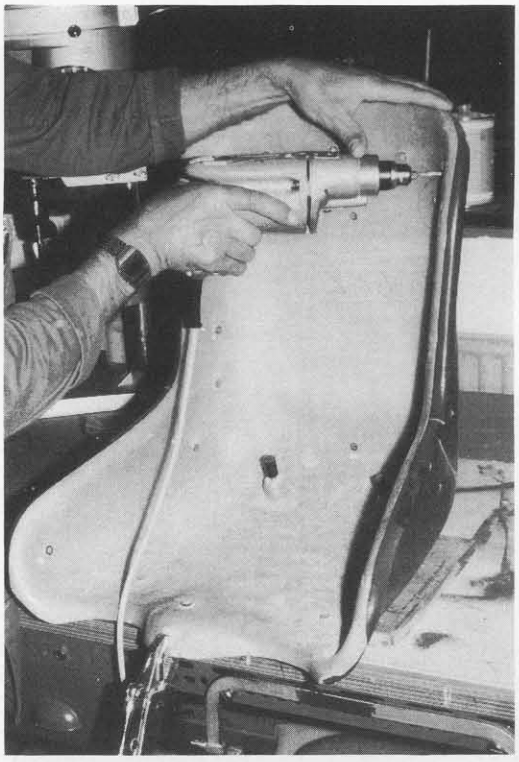

Figure 3. Use of the permanent pattern, or die, for drilling of screw holes, in a standardized array, in the seatshell for mounting of the inner sections.

for growth and clothing. At the same time we wanted to reduce the amount of work necessary, especially for the orthotist.

Presently, there are six different sizes of prefabricated seat shells made from glassfiber-reinforced polyester resin. These are divided in the seat and the back section and are connected with strong hinges integrated into the laminated resin (Figure 1). For each size of these seat shells, standardized inserts of polyethylene are necessary to form a second innershell. The inner shells consist of one seat, one back, two upper and lower lateral parts (Figure 2). The parts of the innershell are fixed to the outer seat-shell with screws. The holes are drilled with the use of a permanent pattern or die (Figure 3). This allows for the quick exchange of one or the other part of the seat. They can also be removed for easy cleaning, reshaping, or for the addition of spacers between the inner and outer wall for proper fit with respect to clothing and climate (Figure 4). Foot-rests,

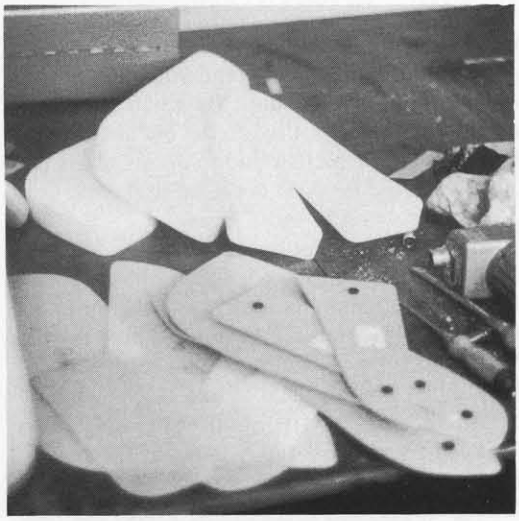

Figure 4. In the foreground, spacers for insertion between seatshell and inner shell to allow for seasonal variation in clothing. In the background can be seen foam rubber pieces to be glued to the inner shell.

Figure 5. Foam rubber pieces have been glued in place and ground to proper contour and fit.

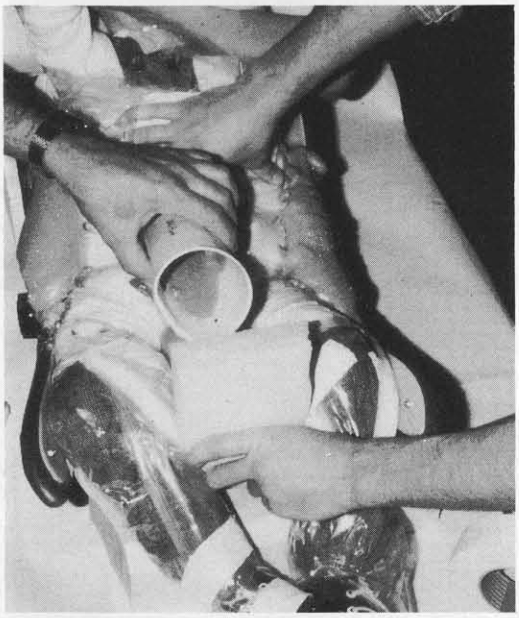

Figure 6. The child is held in place while the void between him and the seat is filled with polyurethane foam. Child is protected against exposure to foam with a layer of plastic film and against thermal burns with a layer of foam rubber. This also allows for the layer of foam rubber to be subsequently added for comfort.

headsupports, handles, quick-exchange boards are also prefabricated in standardized sizes and on stock in the workshop. By this means, the orthotist gains more time to devote attention to the needs of the patient and to optimize his position, because he does not need to devote time to the production of these items.

Prior to the initiation of this fitting procedure, the responsible physician, physiotherapist, occupational therapist, and the orthotist have to decide what they want and how the patient is to be best positioned with respect to his daily living and physical abilities.

The individual fitting of the module is achieved by optimal positioning of the patient in a seat shell of appropriate size and by positioning roughly cut foam rubber pieces between the patient's body and the sidewalls, seat, and back of the seat shell.

After having made a rough alignment of the foam rubber pieces, they are glued to the inner parts of the seat. Then they are removed entirely and ground down to the proper shape until each of the six pieces fit properly (Figure 5).

Another solution is used for children with extensive spasticity. After selection of the proper size seat shell and inner-liner, the child is covered completely, including legs, arms and head, with layer of foam rubber and isolated by a piece of plastic foil or film. This is to prevent polyurethane foam from coming into direct contact with the patient's clothing or skin and to prevent burns. The patient is then positioned as well as possible in the modular seat shell. This is preferably done by the therapist or the mother of the child so as to prevent spasticity as much as possible and to optimize the posture of the child.

If necessary, a foam rubber wedge is placed between the knees to create slight abduction of the legs. Then, the free space between the body and the seatshell module is filled with polyurethane foam (Figure 6). After the foam hardens,

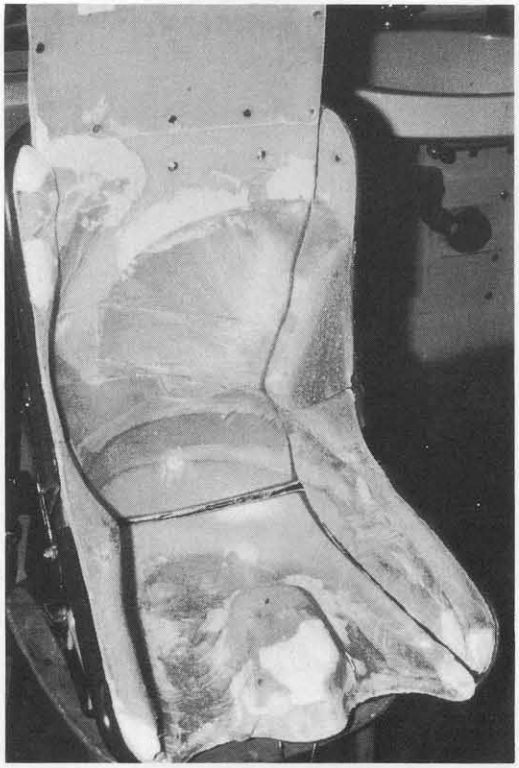

Figure 7. Seat following completion of the foaming procedure.

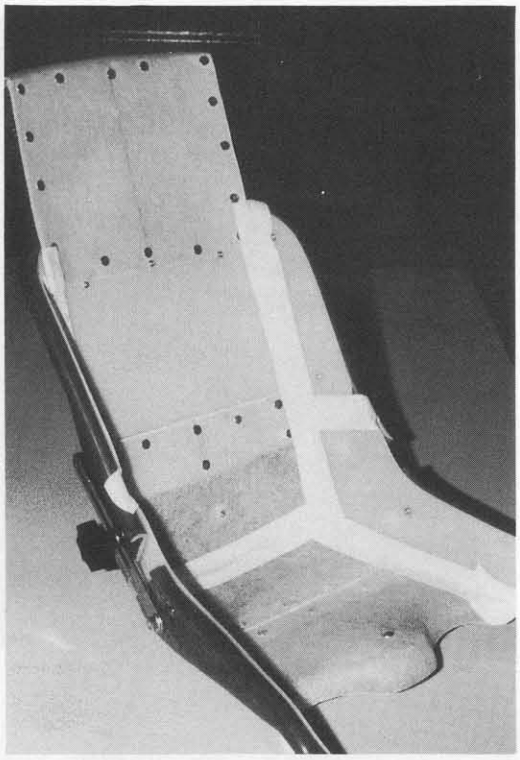

Figure 8. Section of polyethylene added to the top of the innershell to serve as the foundation upon which an integrated headrest will be built.

the child is removed from the seat and the foam is cut along the borderlines of the six parts of the insert, including the lengthened backpart for a headsupport if its use is necessary (Figure 7).

Each piece of foam is then ground to the proper fit and covered with a layer of foam rubber to prevent pressure sores and for sitting comfort.

The same procedure is carried out for those seats for which polyurethane foam was not used. By adding more foam rubber and grinding the six different parts to proper fit, an individually optimized shape of the interior of the modular seat shell is achieved.

A headrest may be made from a separate piece of polyethylene padded with foam rubber and shaped to properly fit the individual patient. It is fixed with adjustable metal bars on the backside of the seatshell. Another solution is the so-called integrated headsupport which is not removable, in contrast to the above-mentioned type. It is made from a sheet of polyethylene as an elongation of the polyester innerlayer of the back (Figure 8) on which foam rubber is glued and shaped to size. An additional pillow for the neck and head is easily removed and attached to the headrest by means of Velcro® fasteners.

In most cases, additional fixation of the patient is necessary to prevent him from falling out of the seat, e.g. during a sudden spastic convulsion. In moderate cases, safety belts adapted to the seat may be sufficient. If a more secure purchase is necessary, the lateral parts of the backrest are elongated at the level of the sternum and closed in around the front of the chest by an additional belt (Figure 9); or, an entire thoracic pad, made of a sheet of polyethylene, covered with foam rubber and ground to a snug fit, is fixed firmly to the seat by a hinge on one side and a clasp on the other to provide

Figure 9. Completed seat showing restraint system and anterior thoracic extension.

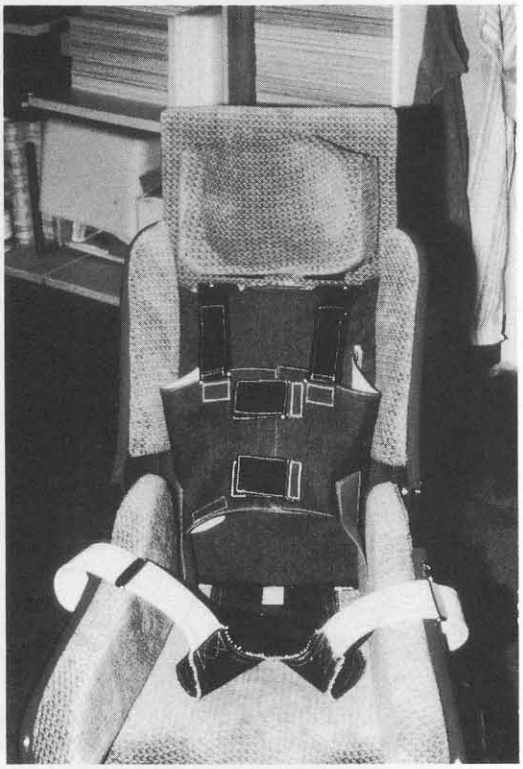

Figure 10. Completed seat showing apron and belt arrangement for restraint.

proper hold of the body. In severe cases, for example in athetoid spasticity, we use a kind of apron with a belt-system (Figure 10) to keep the pelvis and the trunk in proper position within the seat.

It is essential to provide enough free space for the bent knee joints. If necessary, the module and the seat part have to be cut out to allow for comfortable sitting. The abduction wedge must fit correctly too; otherwise it may increase spastic adduction patterns.

Due to the hinges between the seat and the backpart, and a stop on either side of the seat module, the patient can be leaned back in his seat, if desired.

In patients with limited movement in the hip joints, the seat part may be divided longitudinally. Then, each half can be adjusted independently to the individual position of either leg.

Additional armrests are used to prevent injuries to hands and arms if they are uncontrollable. For children and wheel-chair-bound adults a removable table may be added to the seat within the range of motion of both arms and the body, providing enough space for playing with toys, eating, paper work, and so on.

Finally, prefabricated footrests make sure that the entire body is in a proper and comfortable position. Our footrest is adjustable to height and inclination as dictated by the patients' needs.

The quick-exchange board system allows for easy removal of the entire seat from the wheel chair, normal chair, or the regular seat of a car. The wooden board of the seat is fixed with one or two special clasps and a "U" shaped metal stop to a second board which is screwed to the wheel chair or another chassis. This disconnecting device provides stable and safe fixation of the seat and the patient to the respective underlying surface.

If it seems preferable to first try the unfinished seat before finishing, the patient uses the seat at home for one or two weeks. After a final check and correction, the different parts of the

insert are removed once more and covered with a strong and long lasting colored nylon-velour. This gives the entire assembly a lively appearance, quite different from the ordinary "medical" wheelchair design.

Since we started this seating program, approximately 500 patients have been fit with this device. Each was provided with an individually shaped seat by using modular seat shells and pre-fabricated componentry to the largest extent possible. Only a few severely handicapped individuals had to be fit in the conventional manner by taking an individual plaster of Paris cast to create a mold for a seat. Thus, we recommend the use of prefabricated modular seat shells and componentry for satisfying the seating needs of the physically disabled.

From the Editor: This article was received too late for inclusion in the Fall, 1986 issue devoted to seating and thus is presented in this issue. The authors' effort in submitting it is greatly appreciated.

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Clinical Prosthetics and Orthotics, Vol. 11, No. 1, pp. 55–62

Motion Analysis of SACH vs. Flex-Foot™ in Moderately Active Below-knee Amputees

by Judy Wagner, L.P.T.
Susan Sienko, B.Sc.
Terry Supan, C.P.O.
Daryl Barth, C.P.O.

INTRODUCTION

Energy storing prosthetic feet have demonstrated clinical advantages for active below-knee amputees. However, indications for use of energy storage systems have not been established for less active, low velocity ambulators. The intent of this research was to determine if the general below-knee amputee population would benefit biomechanically from an energy storage prosthetic foot system.

A group of moderately active individuals, who could be referred to as non-vigorous ambulators, participated in the study. A physical exam (to rule out musculoskeletal causes of gait deviation) was followed by motion analysis. SACH and Flex Foot™ were analyzed. Statistically significant improvements were found in two important areas.

CASE STUDIES

Six male below-knee amputees between the ages of 23 and 56 participated in the study. The gait of three subjects was studied with both SACH foot and Flex-Foot™ prostheses. Direct SACH/Flex-Foot™ comparisons were made from this group (n = 3). Three additional subjects were analyzed with the Flex-Foot™ (n = 6). They enabled the investigators to determine the consistency of trends.

All subjects were asked to walk at their own comfortable pace, therefore, the results represent the biomechanics of walking. They do not reflect the action of the Flex-Foot™ during intense activities or vigorous ambulation.

RESULTS

Linear Gait Parameters

There were no differences found in velocity (walking speed) and cadence (number of steps per minute) between the Flex-Foot™ and SACH foot trials. Both variables were below normal values. This finding is true for a broad population of below-knee amputees as evidenced by other researchers.[9] It indicates that our population is representative of low intensity ambulators.

Two periods of single limb stance exist within a gait cycle. (One period is on the prosthetic side; the other is on the sound limb side.) One hundred percent of a gait cycle is from heel contact to ipsilateral heel contact. The percentage of single limb stance spent on the prosthesis did not vary when the Flex-Foot™ or SACH foot prostheses were worn. Likewise, the percent of the gait cycle spent on the sound limb did not vary between the Flex-Foot™ and SACH trials. However, single limb stance time was more symmetrical between the prosthetic and sound limbs when the Flex-Foot™ was worn.

Double limb stance is a period of weight transfer when both feet are on the ground. The total percent of time spent in double limb stance did not change between Flex-Foot™ and SACH trials.

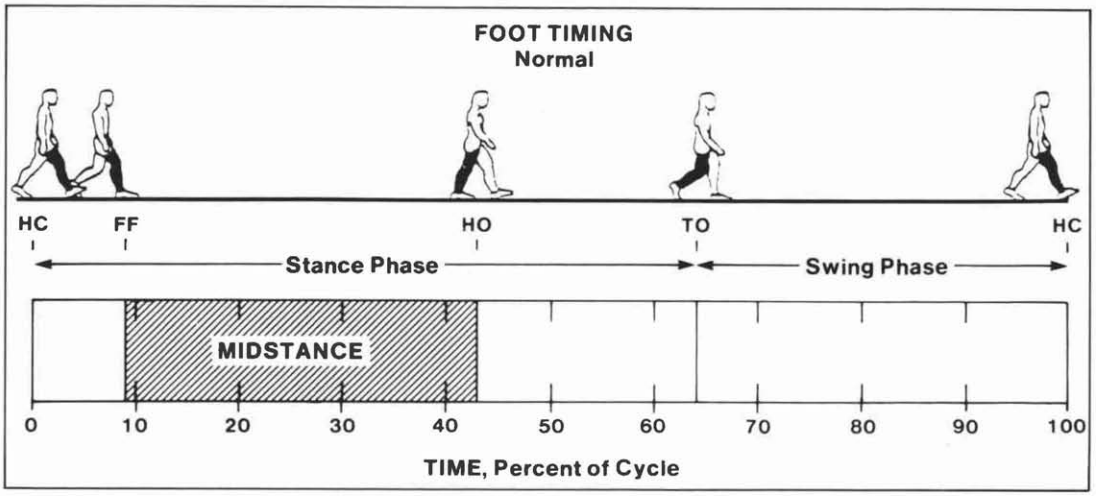

Figure 1. Normal foot timing. The periods of stance represented as a percent of the gait cycle: heel contact (HC), foot flat (FF), heel off (HO), and toe off (TO).[1,2,17]

Linear gait parameters did not change (between the Flex-Foot™ and SACH foot) for moderately active persons. The similarities found demonstrate the adaptability of the human body to the loss of a limb regardless of the type of prosthetic device. However, other variables such as joint rotations, foot timing, and force largely reflect the design and materials of the prosthesis.

Foot Timing and Joint Rotations

Stance has been delineated by the periods of heel contact (HC), foot flat (FF), midstance (MS), heel off (HO), and toe off (TO). This sequence of events shall be referred to as foot timing. It is measured as a percentage of the gait cycle (Figure 1).

The results of joint rotations (ankle range of motion) will be reviewed concurrently. Even though neither the Flex-Foot™ nor SACH foot contains an ankle joint, the gait analysis cameras can perceive their action as ankle dorsiflexion and plantarflexion. Because the computer software does not specify a neutral position, "relative" motion is analyzed. For these two variables (foot timing and joint rotation), the periods of early and late stance will be evaluated separately.

In normal gait, the ankle is in a neutral position when the heel strikes the floor. The ankle then plantarflexes 12 to 15 degrees[6] in order for the foot to become flat on the ground. Thus, foot flat occurs at nine percent of the gait cycle[1,2] as a result of 12 to 15 degrees of relative motion in early stance.

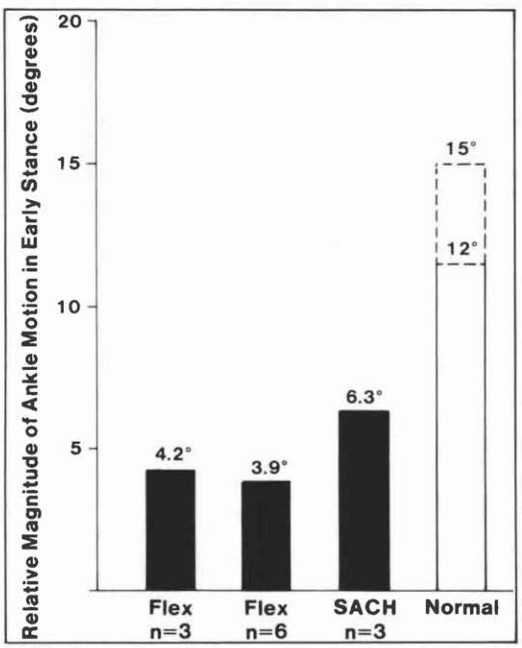

Figure 2. Relative magnitude of ankle motion in early stance.[6]

Compression of the SACH heel simulates ankle plantarflexion in early stance. However, this provides considerably less than normal

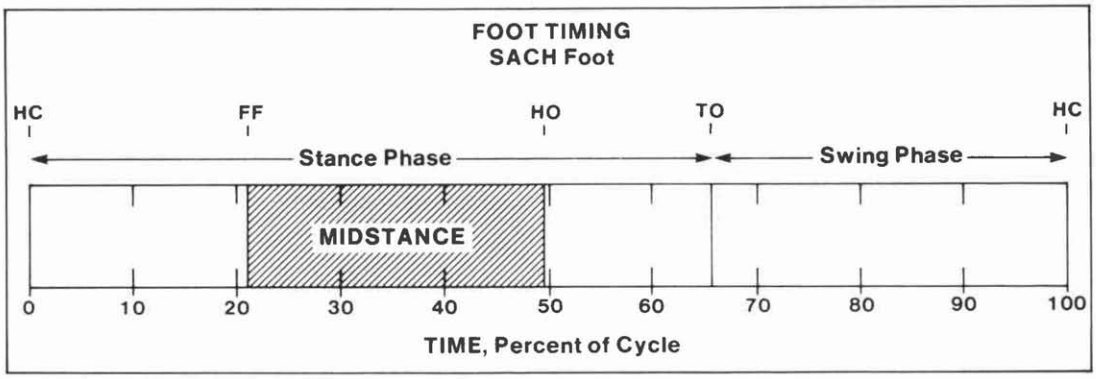

Figure 3: Foot timing: mean of the SACH trials.

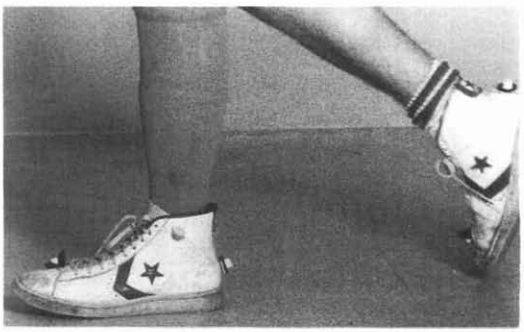

Figure 4a. Ankle motion at foot flat: *Flex-Foot.*™

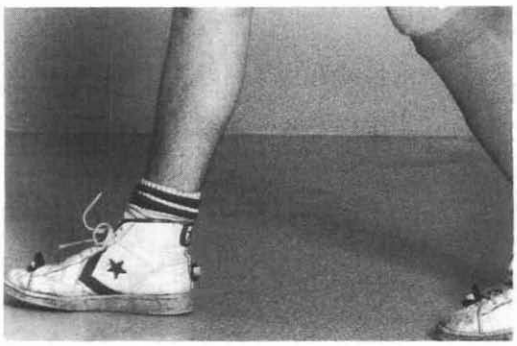

Figure 4b. Ankle motion at foot flat: sound limb

motion (Figure 2). As a result, the foot cannot become flat on the ground until much later in the gait cycle (21 percent) when the body weight is shifted farther forward (Figure 3).

Dynamic compression of the Flex-Foot™ heel pylon (''heel deflection'') is another attempt to mimic ankle plantarflexion in early stance. Likewise, it results in less than normal motion (Figure 2). This finding was demonstrated even when the population was increased to six. A comparison of the Flex-Foot™ prosthesis to the sound limb is illustrated in Figure 4. Note the limited ''ankle range of motion'' of the prosthetic limb at foot flat. Lack of plantarflexion, likewise, delays the timing of foot flat (Figure 5), but to a lesser degree than with the SACH foot.

During the early stance phase of non-vigorous walking, joint rotations and foot timing did not significantly differ (between the Flex-Foot™ and SACH foot). Both deviate from normal values.

After the period of foot flat in normal gait, the leg rolls over the planted foot until it reaches a peak dorsiflexion of eight to ten degrees.[6] Shortly thereafter, the heel rises from the ground (HO). Immediately following, the ankle plantarflexes to a position of 18 to 23 degrees of plantarflexion[6]; a total of 30 degrees of relative motion usually occurs during this latter part of stance.

Peak dorsiflexion occurs on the SACH foot as the forefoot bends over the keel (followed by a return to the starting position). This resulted in only 11 degrees of relative motion, which is considerably less than normal (Figure 6).

The Flex-Foot™ provides a significantly more normal substitute of ankle motion in late stance. Dynamic compression of the anterior pylon (''toe deflection'') and a plantarflexion rebound afforded 20 degrees of motion (Figure 6). Greater excursion potentially enables the amputee to lean farther forward and take more symmetrical steps. Figure 7 illustrates the similarities between the sound limb and Flex-Foot™ at the time of heel off.

Likewise, foot timing was positively affected in late stance. The period of toe off occurred

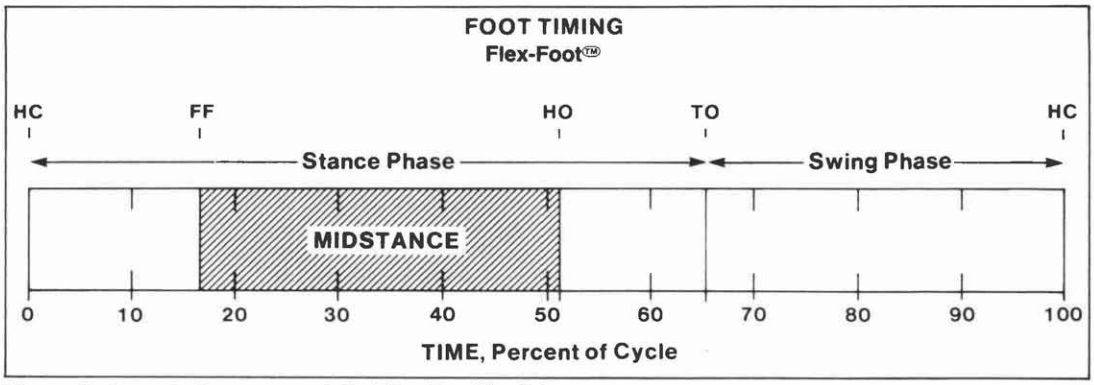

Figure 5. Foot timing: mean of the Flex-Foot™ trials.

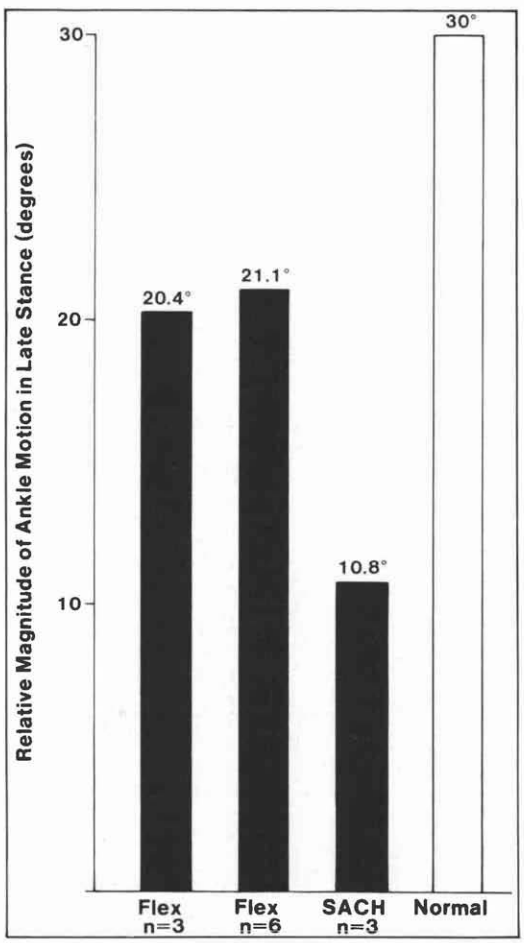

Figure 6. Relative magnitude of ankle motion in late stance.[6]

Figure 7a. Ankle motion of heel off: *Flex-Foot.*™

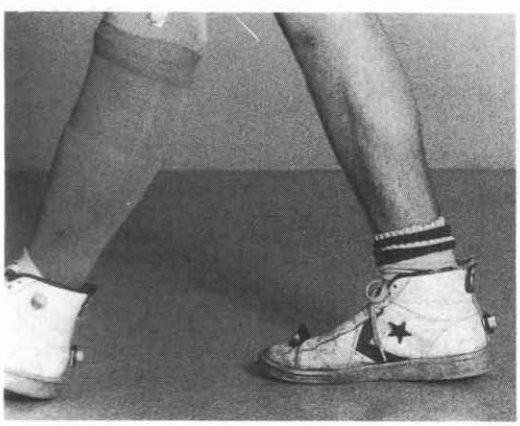

Figure 7b. Ankle motion of heel off: sound limb.

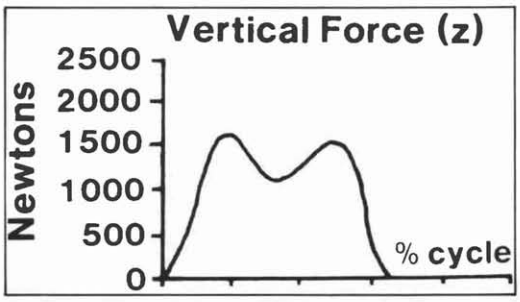

Figure 8. Sample representation of vertical force data.

more symmetrically between the sound and amputated limbs when the Flex-Foot™ was worn.

Therefore, even "average" walkers benefit from the ankle motion which the Flex-Foot™ provides in the late stance phase of gait.

Force

"Vertical force is the floor reaction force in the vertical direction as measured by the force plate."[10] The magnitude of vertical force is typically measured in newtons. The value has been normalized to body mass (ie. newtons/kg) to enable comparison among subjects. Vertical force is graphically represented by two peaks separated by a valley (Figure 8). The first peak occurs as a result of the initial impact of the foot on the ground. In the past, the second peak has been thought to represent a push-off by the ankle plantarflexors (posterior calf muscles).

Many of the energy storing feet claim to provide a push-off similar in nature to the action of the ankle plantarflexor muscles. It seems reasonable, then, to investigate this claim by looking at the second peak of vertical force.

Before doing so, current theories regarding the precise function of the ankle plantarflexor muscles should be reviewed. Cavagna continues to support the idea that muscle action generates a forceful push-off.[3] Although Mann does not support a "push-off," he claims that the "plantarflexors control the forward propulsive momentum, making it possible for the body to move farther from its base of support."[5] Sutherland recognizes that there is a "knee-ankle-stability linkage, suggesting that the ankle plantarflexors decelerate the tibia as it rotates in a forward direction over the talus, controlling a selective rapid extension of the

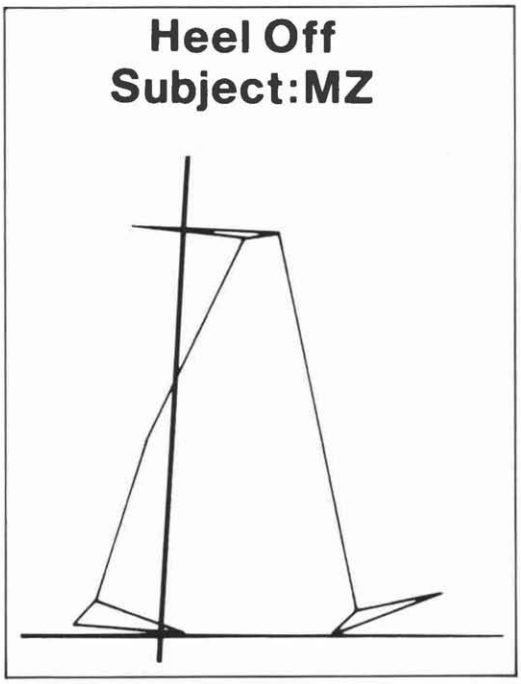

Figure 9a. Subject MZ: lateral stick figure representation with superimposed floor reaction force vector.*

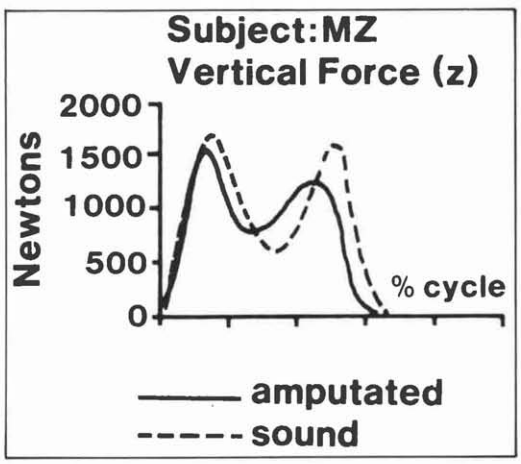

Figure 9b. Subject MZ: vertical force comparison of sound and amputated limbs.

*Hip joint marker placement on the ASIS rather than true joint center makes the knee appear more extended than what anatomically occurs.

knee.''[12] Perry reviewed Cunningham's study (1950) which found force plate records for below-knee amputees with SACH feet to be similar to the data of normal muscled persons.[4] She then theorized that ''the late floor reaction peak is the result of leverage by body alignment, rather than an active downward thrust.''[7]

The results of this study support Perry's contentions. The magnitude of the second peak of vertical force (normalized to body mass) was the same for the SACH foot as it was for the corresponding sound limb. Assuming that the SACH foot is not an energy storage system, it can be concluded that the similarity was due to ''leverage by body alignment''[7] (which for amputees is influenced by prosthetic alignment).

When the Flex-Foot™ population was three, the magnitude of the late floor reaction force was greater for the prosthesis than for the sound limb. This should not be interpreted as a superhuman ''push-off.'' In fact, when the population was increased to six, the force generated by the Flex-Foot™ was less than that of the sound foot. This discrepancy made it necessary to investigate the cause.

A trend was found, suggesting that when a knee extension moment existed at heel off, the late stance peak (of vertical force) of the Flex-Foot™ was less than that of the sound limb (Figure 9). Those subjects who had a knee flexion moment at heel off generated forces which closely resembled the sound limb (Figure 10). The Flex-Foot™ responds with optimal vertical force in late stance when a knee flexion moment is created through prosthetic alignment.

Thus far, it has been determined that muscular action in the late stance of normal walking is not actually a ''push-off.'' The data and literature suggest that the second peak of vertical force is primarily a product of alignment. Therefore, some other means of investigating the supposed energy storage and release of new prosthetic feet must be determined.

Simon studied subjects without posterior calf muscle activity and found ways in which they compensate. Because the plantarflexors were not available to provide a restraining force as the tibia rotated forward over the foot, his subjects spent less time in single limb stance (on the involved limb) and experienced premature opposite heel contact.[8] Neither of these occurrences were found in this study.

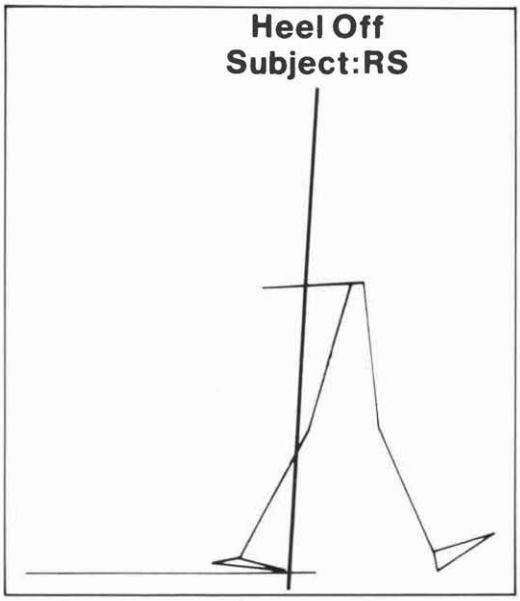

Figure 10a. Subject RS: lateral stick figure representation with superimposed floor reaction force vector.*

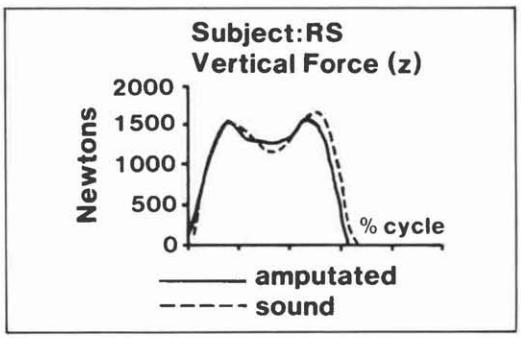

Figure 10b. Subject RS: vertical force comparison of sound and amputated limbs.

As a secondary means of compensation, Simon's subjects experienced excessive impact at opposite heel strike (HC on the sound limb).[8] This occurred because of an inadequate restraining force by the involved extremity.

In this study, the magnitude of vertical force at impact (i.e. the first peak, also normalized to

*Hip joint marker placement on the ASIS rather than true joint center makes the knee appear more extended than what anatomically occurs.

body mass) was the same when the Flex-Foot™ and SACH foot struck the ground. This finding is consistent with the fact that the sound limb provides a similar restraining action regardless of which prosthetic device is worn on the amputated limb.

However, the sound limb struck the floor with significantly greater force during the SACH trials (as compared to the Flex-Foot™ trials). Because SACH foot does not provide a controlled restraint, the corresponding sound extremity must hit the floor with an excessive amount of force. Such compensation was unnecessary during the Flex-Foot™ trials. Apparently, the restraining action which the Flex-Foot™ creates is a considerably better simulation of the function of the true ankle plantarflexor muscles.

After review of the data and current literature, the role of the calf muscles appears to be a restraining action rather than a "push-off" during normal gait. The Flex-Foot™ more effectively simulated the action of the calf muscles than the SACH foot in non-vigorous walking.

SUMMARY

Non-vigorous walking was studied to determine if the general below-knee amputee population would biomechanically benefit from energy storing feet during walking. We found that linear gait parameters did not significantly differ between the Flex-Foot™ and SACH foot. However, symmetry did improve with the Flex-Foot™. Ankle joint rotation in early stance was considerably less than normal with both types of artificial limbs. However, the Flex-Foot™ allowed significantly greater range of motion during late stance. Although foot timing was minimally improved with the Flex-Foot™, the period of foot flat was delayed with both types of prostheses. Energy storage and release is apparent through an investigation of vertical forces. Forces which normally result from muscle activity must be mechanically created by the prosthesis. Force data suggests that the controlled restraining action of the Flex-Foot™ is a significantly better representation of the function of the posterior calf muscles.

CONCLUSION

Moderately active below-knee amputees experience biomechanical benefits from an energy storage prosthetic foot system. Thus, indications for use of such systems should not be limited to athletes and vigorous ambulators. The Flex-Foot™ should also be considered for less active individuals. Biomechanical responsiveness should be considered along with other factors such as cost, fitting time, and cosmesis when selecting a prosthetic foot.

ACKNOWLEDGMENTS

The authors would like to thank Steven Verhulst from the Statistics and Measurements Department and William Andrea of the Biomedical Communications Department at SIU.

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Clinical Prosthetics and Orthotics, Vol. 11, No. 1, pp. 63–66

The following article is of relevance to the current interest in advanced education for prosthetists/orthotists. The concept as put forth in the article is similar to the concept of the Academy College Fund. In brief, the authors advance the idea that prosthetists/orthotists receive an advanced degree in the areas of education, research or administration to prepare them for academic and research roles.

The general objective of the Academy College Fund is to provide advanced, graduate training for prosthetists/orthotists, leading to a doctorate in the field of prosthetics and/or orthotics. The graduate of the Academy College of Prosthetics and Orthotics, after serving in a residency program, will be able to prescribe prostheses and/or orthoses for patients in consultation with the referring physician or surgeon. The goals and purposes, while not mutually exclusive, are fundamentally different.

What do you think? The readers are invited to voice their opinions in letters to the editor. (The above description of the two programs is the editor's interpretation).

The Editor

A Model for Graduate Education in Orthotics and Prosthetics

by Caroline C. Nielsen, Ph.D.
Ronald F. Altman, C.P.O.
Patricia Gillespie, M.P.H.
Priscilla D. Douglas, Ph.D.

INTRODUCTION

The Education Accreditation Commission (EAC) of the American Board for Certification in Orthotics and Prosthetics (ABC) has recognized the need for specialized and advanced education in the field of orthotics and prosthetics.[1] To address this need, the School of Allied Health Professions at the University of Connecticut, in collaboration with the Department of Orthotics and Prosthetics at Newington Children's Hospital, has developed a program leading to the Master of Science in Allied Health. The program is designed to address both the increasing complexity of technological developments in the field of rehabilitation and the need to extend the education and training of the orthotist/prosthetist in comprehensive areas of comtemporary practice including education, research, and management. As the orthotics and prosthetics field has progressed from the traditional cottage industry to the contemporary role of a legitimate allied health profession, trained individuals possessing the education and research skills necessary to participate in clinical or academic environments are being sought with increased frequency. No mechanism currently exists that prepares these individuals for leadership positions.

In the special edition of the journal of the American Orthotic and Prosthetic Association[2], *Orthotics and Prosthetics*, devoted solely to educational issues and programs, the basic responsibilities of the professional practitioner and technician in orthotics and prosthetics, as required by the American Board for Certification, were fully delineated. One of the major ABC objectives is "to contribute to the progress and growth of the profession through research and development activities, contributing knowledge to the profession, exercising leadership, and recruiting and training new entrants into the field."[3] However, current university based educational programs in the United

States do not offer advanced training in orthotics and prosthetics which integrates the education, research, and administrative aspects of the profession. As a result, administrative and faculty positions are now occupied by persons with years of experience or through international recruitment.[4]

This is the first program in the nation to address the recent policy statement of the Educational Accreditation Commission of the American Board for Certification in Orthotics and Prosthetics, recommending that:

> "Universities with the appropriate capability develop master level degrees in these disciplines. Such majors as research, education and clinical administration are recommended. The development of such advanced degree programs will increase the capability of the field of orthotics and prosthetics to rehabilitate the orthopedically handicapped."[5]

The Graduate Program of the School of Allied Health Professions was selected because the goals of this program are congruent with the needs of the orthotics/prosthetics profession. The program has been in existence since 1979, and was accredited by the Board of Higher Education in 1982.

THE PROGRAM

The program is designed for those individuals who have a Bachelor of Science degree from an ABC accredited practitioner program in orthotics and prosthetics and have completed a one year residency program in orthotics and prosthetics, or have a Bachelor of Science in a related field, have received a long-term certificate in orthotics and prosthetics from an ABC accredited program, and have a minimum of one year experience in orthotics and prosthetics. All candidates must be eligible for or have passed the ABC Practitioner Certification Examination.

Collaboration between the Newington Children's Hospital and the School of Allied Health Professions at the University of Connecticut provides a structured training program based within a university graduate program.† Placement of the program within an academic community insures stability, provides for utilization of existing faculty and courses, and allows the orthotist/prosthetist to interact with other health care professionals in an academic environment.

Newington Children's Hospital has been a leader in orthotics and prosthetics practice for over 50 years. It is one of the largest accredited institutional practices in the United States specializing in orthotics and prosthetics and serves over 2,000 clients annually. In 1980, the first orthotics and prosthetics residency program was established at Newington Children's Hospital admitting two students a year with a Bachelor of Science in orthotics and prosthetics. Expansion of the existing residency program at Newington Children's Hospital and satellite facilities will provide a variety of didactic clinical experiences within a well developed teaching environment.

PROGRAM OBJECTIVES

The program is designed to facilitate the development of leaders in health care through an interdisciplinary approach. The curriculum goals are to provide the student with the opportunity to develop knowledge of the health care system and understanding of the future role of the orthotist/prosthetist as an integral part of the rehabilitation system. The Master of Science in Allied Health program, with emphasis in orthotics and prosthetics, has been designed to:

- prepare orthotists/prosthetists to fill roles as educators, applied researchers, and administrators;
- emphasize a multidisciplinary team approach to graduate education in the health professions;
- to acquaint the student with new facets of health care and maximize potential to work effectively and cooperatively as members of a health care team; and
- to build advanced skills in orthotics/prosthetics while providing an opportunity to select an elective area in education, applied research, or administration.

† The program has been developed with the assistance of the Pediatric Research and Training Center, University of Connecticut Health Center, under a grant from the National Institute for Handicapped Research.

CURRICULUM MODEL

The curriculum has been designed to utilize the resources of both institutions. The model[6] has three components: 1) a required core of courses providing the student with a foundation in the health care delivery system and leadership development; 2) a tract of electives which provides the student with competencies in research, education, or management; and 3) a professional tract which provides opportunities for exploring selected areas of orthotics and prosthetics. These three components are synthesized with integrative seminars and a practicum.

Core Courses

The core courses in the School of Allied Health Professions have been designed and developed with an interdisciplinary focus to reflect issues, knowledge, and skills relevant to all health professionals. The core component consists of nine credits of course work related to the system in which the health professional works and interacts, role identity and conflict, the prevailing forces of contemporary society, and basic concepts of research in health care.

The core courses also offer an opportunity for interaction with other health colleagues and increased understanding of the role and function of the total health care team. Core courses include: "Health Care Processes and Systems," "The Allied Health Professional in Contemporary Society," and "Research Methods in Allied Health."

Elective Tract

The elective area provides an opportunity to gain further experience in education, research, or administration. The elective component consists of nine to twelve credits of course work in one of these areas of professional interest.

The **Education Elective** addresses the need to prepare health practitioners for teaching roles in clinical and academic settings. Course work focuses on learning theories, educational evaluation, and new instructional methods and media techniques.

The **Research Elective** offers considerable flexibility in design and course selection to meet the professional needs of the student. A course in statistics and computer application is required. The student may select other courses related to a research topic. Independent studies are also available with individualized guidance on research projects.

The **Administrative Elective** provides the administrative knowledge and skills required for effective administration performance at the department and program levels.

In both the Education and Administrative Electives, students participate in a final seminar integrating and applying the learned concepts to their allied health specialties.

Professional Tract: Orthotics and Prosthetics

The technical discipline component of the advanced degree program is designed to expand the professional's knowledge base and technical competence. The professional tract consists of a three credit seminar, examining the psychosocial aspects of disability, and 12 credits of internship rotations at the Newington Children's Hospital and satellite affiliates.

Project and Practicum

The project and practicum are the culminating experiences in the graduate program, consisting of nine credits of practical and academic activities. These supervised experiences provide the opportunity to integrate the academic and clinical experiences of the graduate program.

The **Project** allows the student to utilize abilities gained in the program by developing and implementing a project relevant to his professional interests. The project provides tangible evidence of knowledge gained during graduate study. Examples of projects include curriculum guidelines, exercise guides for patients, instructive video tapes, and research studies.

The **Practicum** provides the opportunity for an orthotist/prosthetist to be an educator, researcher, or administrator in a supervised practicum experience with constant evaluation and feedback. In conjunction with the practicum, students also take part in a related seminar. The seminar provides an opportunity to discuss and analyze major issues relevant to contemporary health practices and trends, and to examine individual goals within an interdisciplinary set-

ting. The practicum and seminar consist of six credits. Both the project and the practicum are designed to develop problem solving skills and promote increased awareness of the applicability of research.

The program is designed to be a full-time two year program. However, the courses can accommodate students from other disciplines, as well as health care professionals, seeking continued development in orthotics and prosthetics. It is expected that this will improve the cost effectiveness of the program, as well as create a learning environment enhanced by the diversity of the student pool.

PROGRAM EVALUATION

Since this is the first advanced degree program in orthotics and prosthetics in the United States, evaluation procedures have been developed to assess both the short and long term outcomes of the program. The evaluation will be both formative and summative. Ongoing evaluations will monitor program implementation and achievement of objectives with the goal of bringing about any indicated modifications for the program's improvement. An evaluation conducted at the conclusion of the initial two year cycle will produce an accurate description of the program and a summary of its effects. Results of the evaluation will illustrate any problems in implementation, the successes of the program, and budget expenditures. The report will serve as a planning document for others who may wish to duplicate the program.

CONCLUSIONS

The Master of Science in Allied Health program with emphasis in orthotics and prosthetics has been developed to address the rapidly expanding need for professionally qualified orthotists and prosthetists with the advanced skills necessary to participate in education and research. Collaboration between the Newington Children's Hospital and the School of Allied Health Professions at the University of Connecticut permits utilization of an established orthotics/prosthetics clinical teaching facility and an academic program within a university graduate school.

The interdisciplinary format of this graduate program addresses the stated needs of the profession to extend the education and training of the orthotist/prosthetist in education, research, and management to reflect the comprehensive scope of contemporary orthotic and prosthetic practice.

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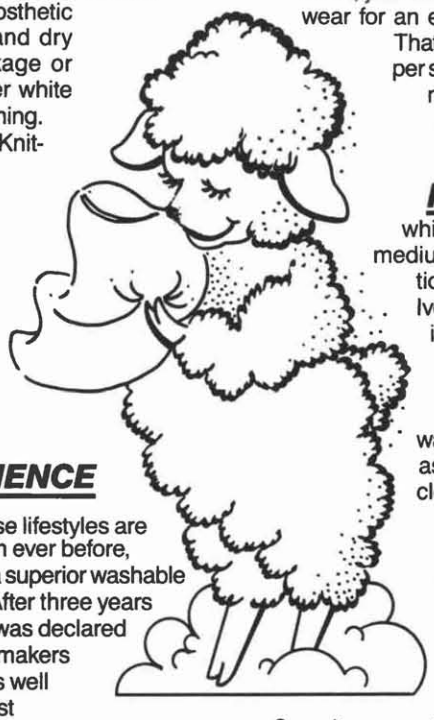

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