

A Variable Volume Socket for Below-knee Prostheses

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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 Orthomedics⁹ 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. Mooney⁷ 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

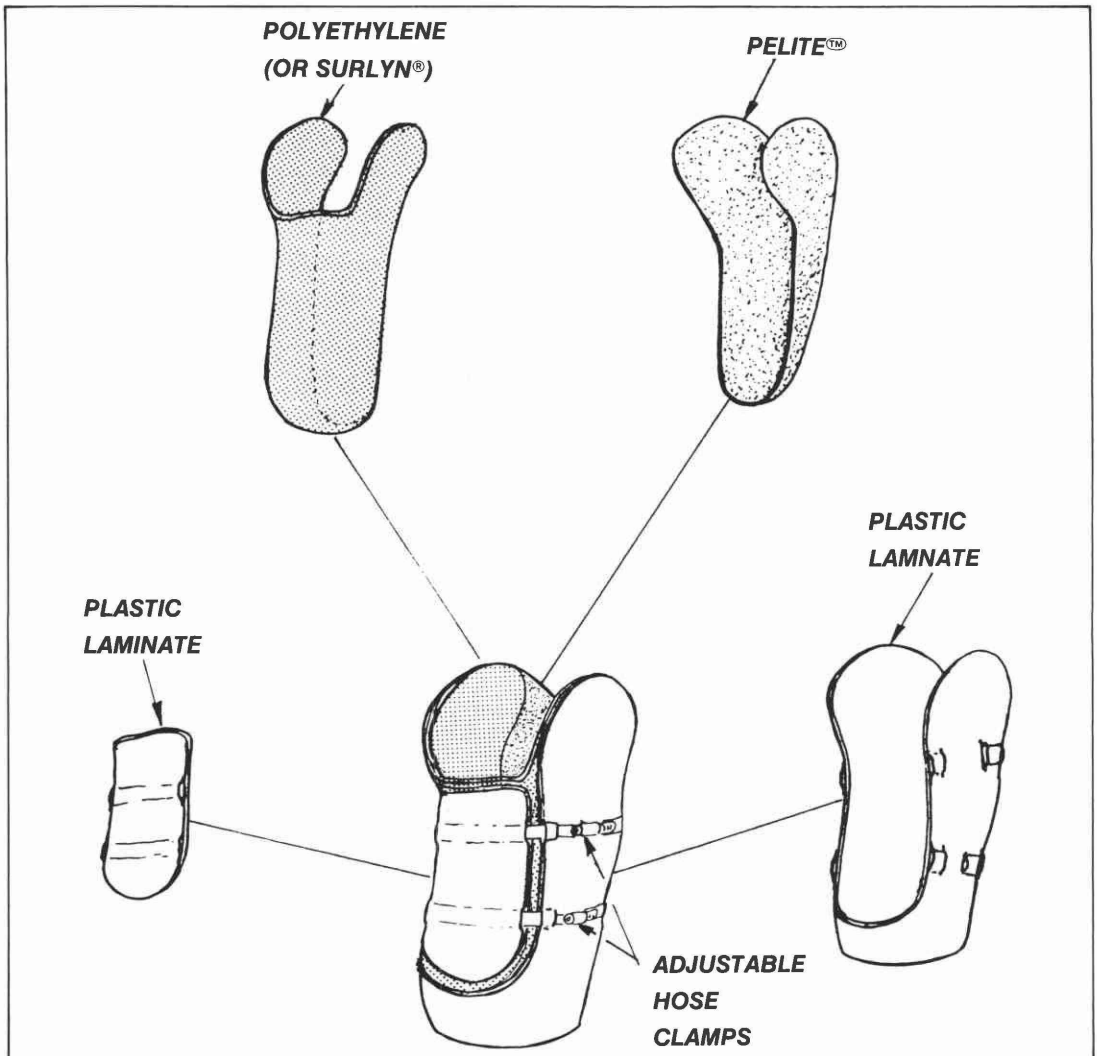


Figure 1. Exploded schematic view of the variable volume socket showing major components.

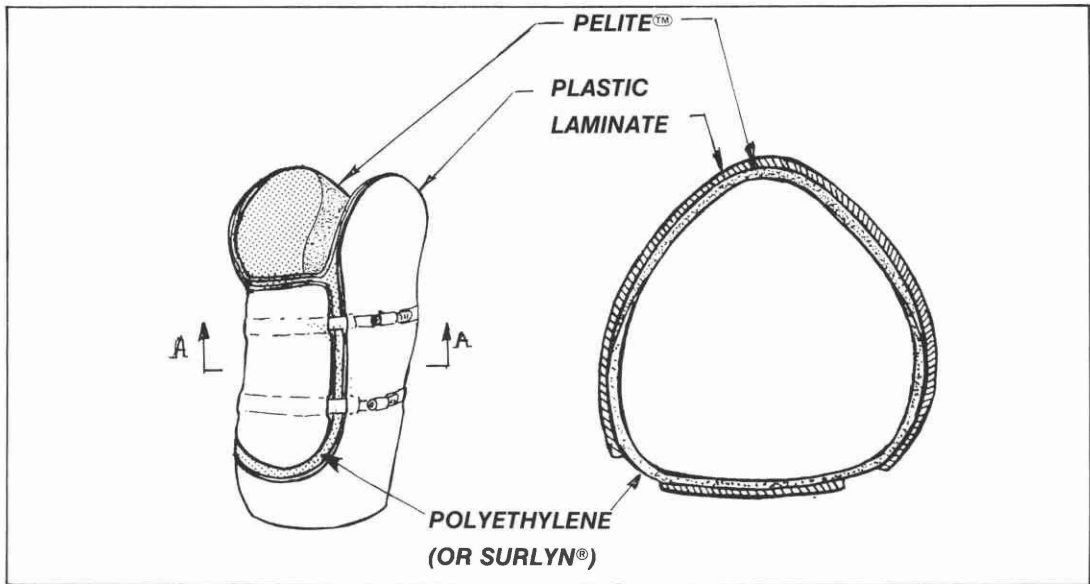


Figure 2. Schematic showing relationship of the major components of the variable volume socket.

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.

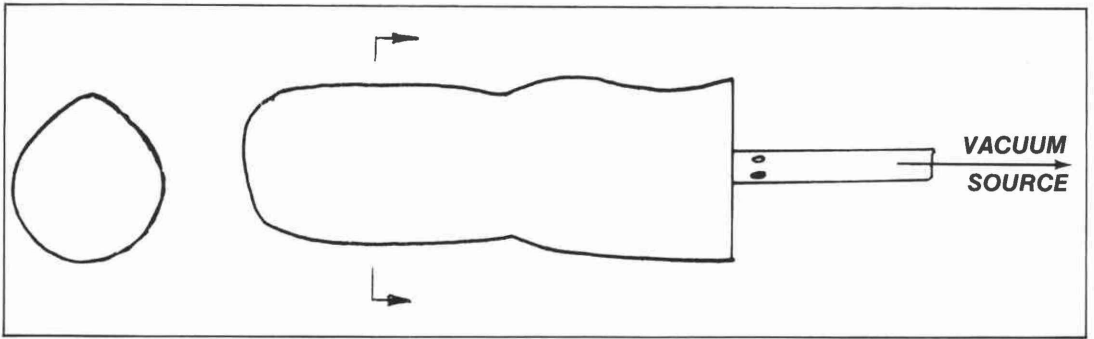
Our original method for controlling volume, by use of two conventional hose clamps, is described here, because we have yet to locate a commercially available adjustment buckle that is suitable. We made some progress in designing a buckle especially for this purpose, but have not pursued the idea since 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

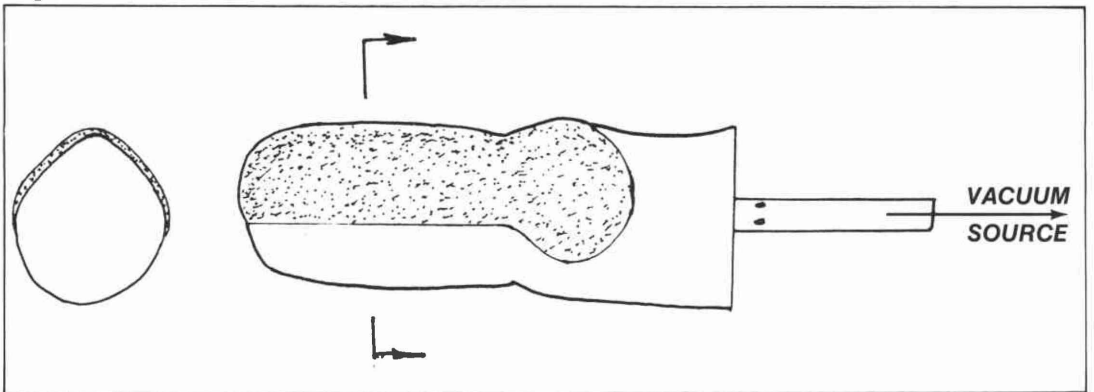
As stated in the design criteria, this socket system is intended to make use of existing prosthetic molding, modification, and fabrication techniques. We recommend use of the casting procedure described by Fillauer³ in which an impression of the anterior portion of the limb is made first, using plaster 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

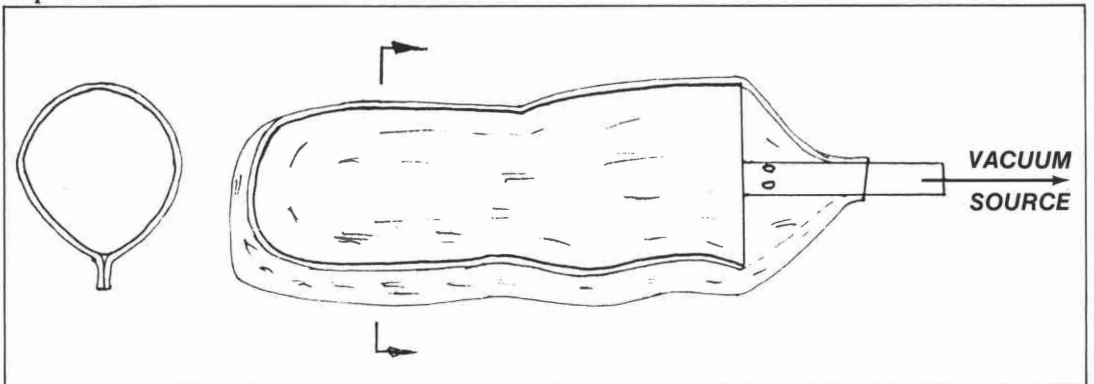
- 1) Place the positive model in a vise horizontally with the anterior section facing up.
- 2) Over the positive model, form a Pelite™ liner for the anterior half of the socket. After heating a proper size sheet of Pelite™, a piece of latex rubber can be used to form the Pelite™ around the cast model.



Step 1.



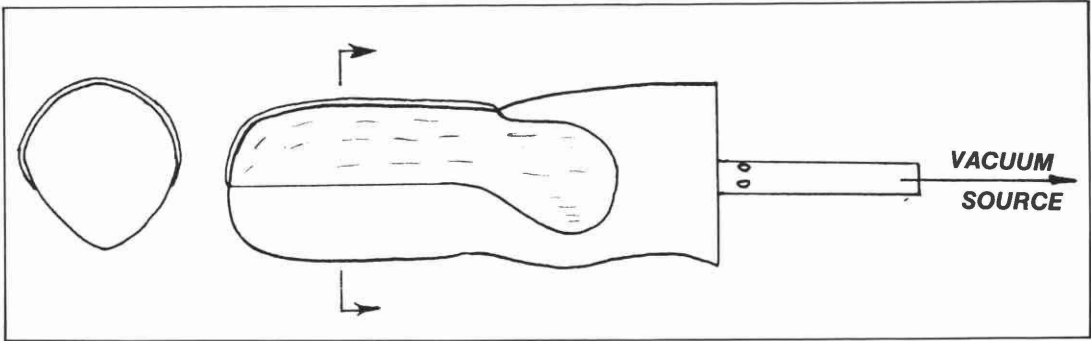
Steps 2 and 3.



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 1/8 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 3/8-1/2 inch. Again, skive all edges that will be inside the socket.

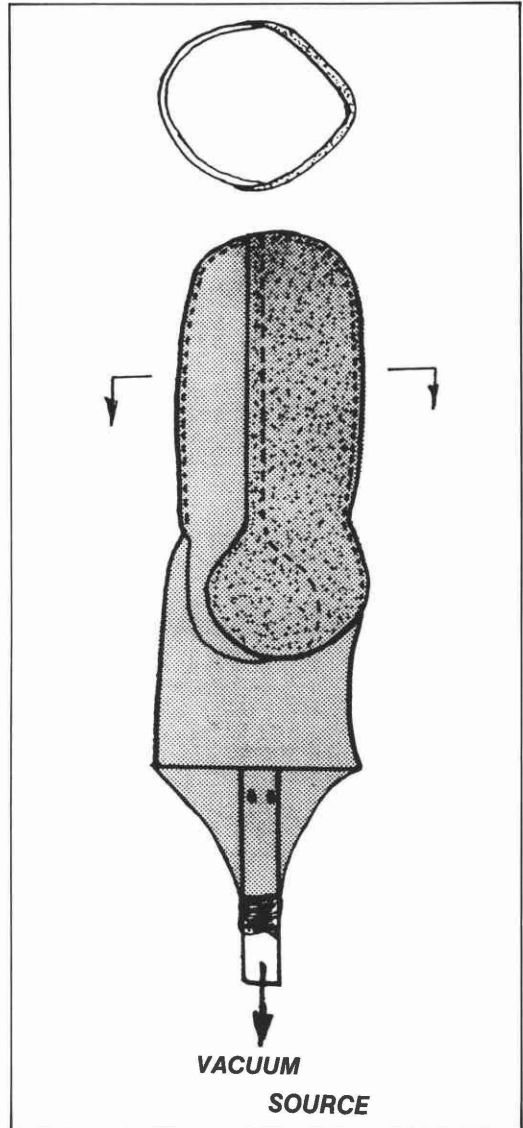


Step 6.

- 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 1/4 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 Bock¹⁰ 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 1/2 inch of the cast model at the levels shown.

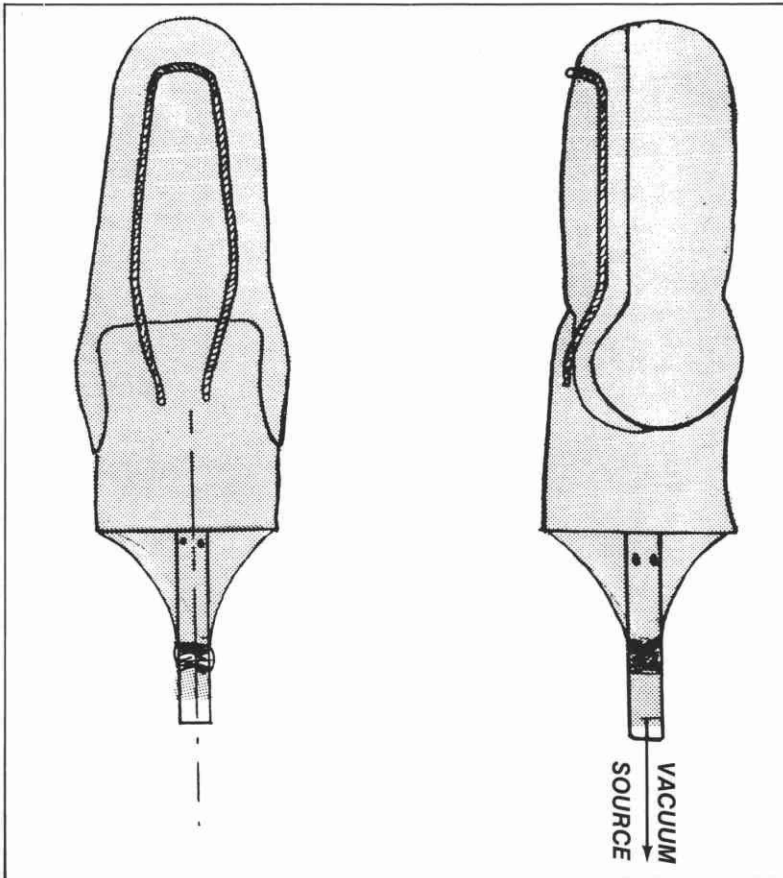
The strips are placed in the lamination layup and are removed after the lamination sets up to form channels for the volume control straps. Layup for the lamination is as follows:

- 1 layer of 1/2 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

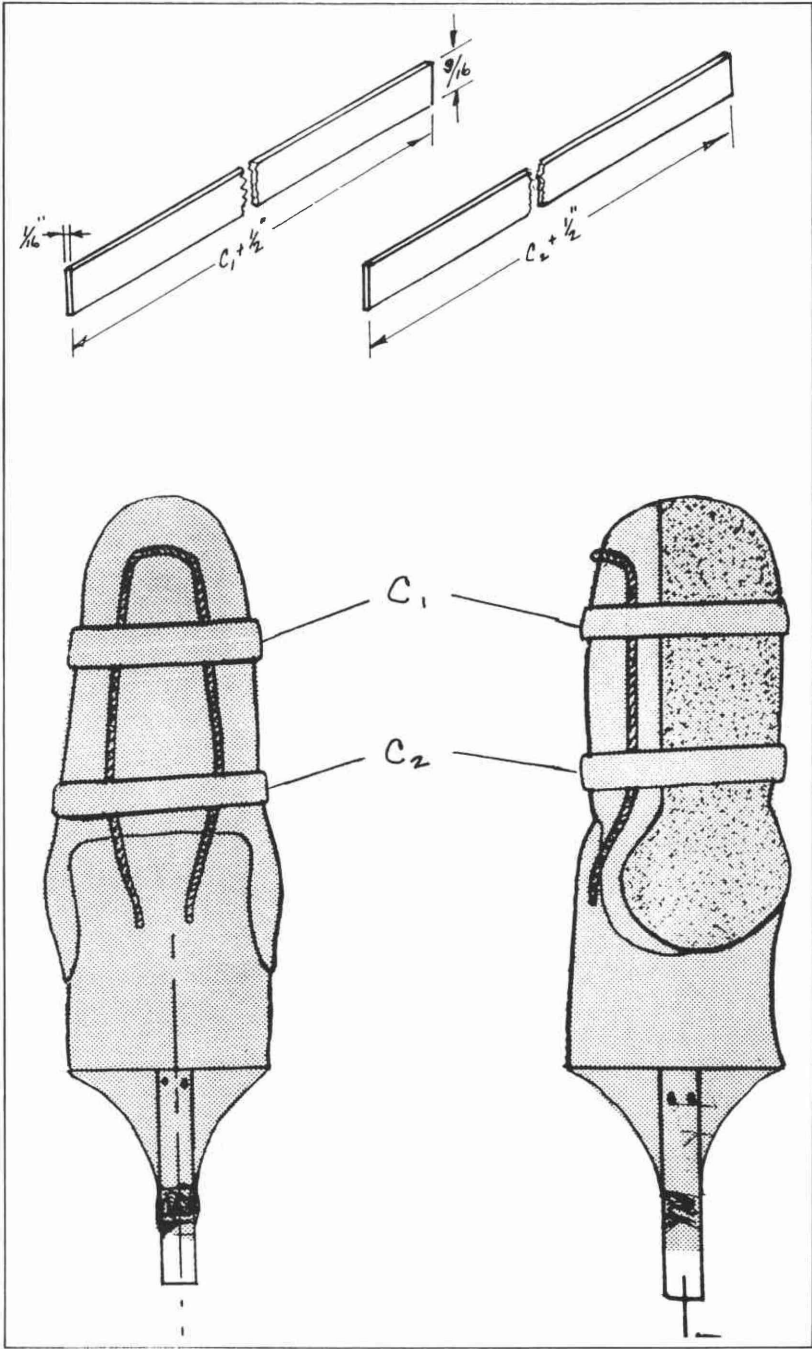
of the clamp is exposed in the slots cut in step 12 above (Figure 3).

- 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.

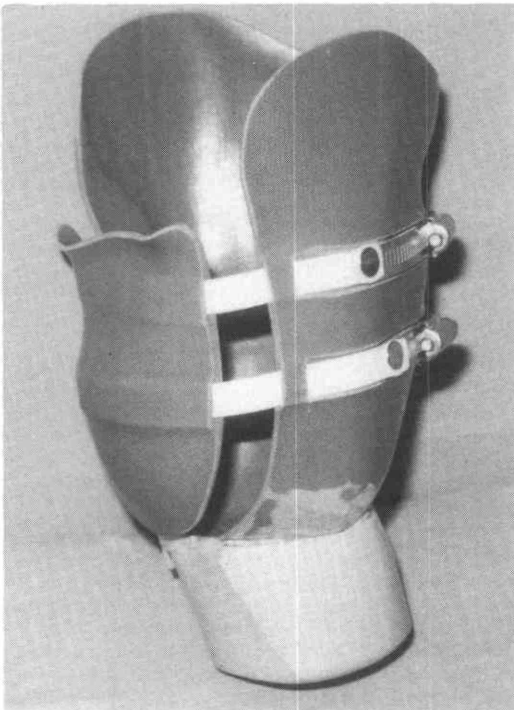
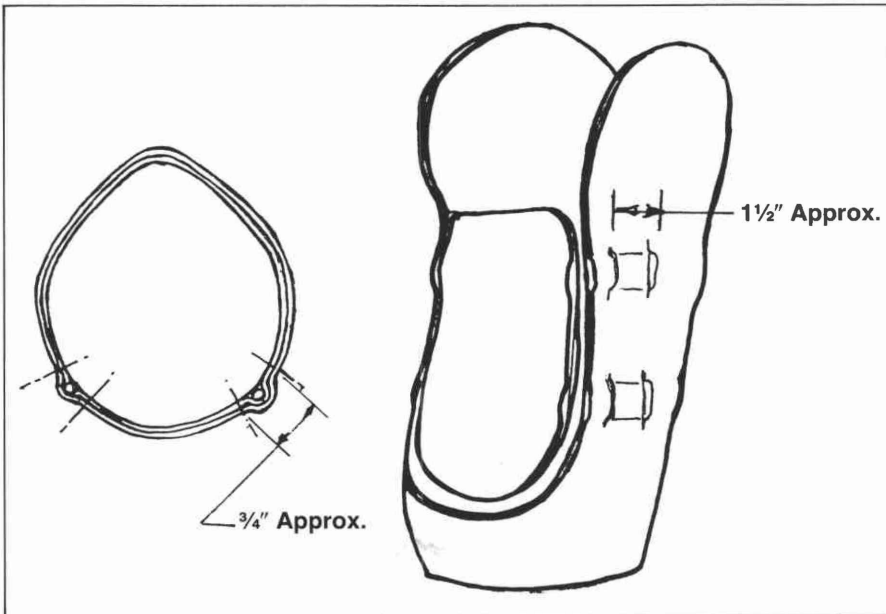


Figure 3. Photograph of laminated outer socket prior to mounting on adjustable leg. A foam block is shown here but this practice has been superseded by use of the Otto Bock 4R42 component which is laminated into the distal end of the outer socket.

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

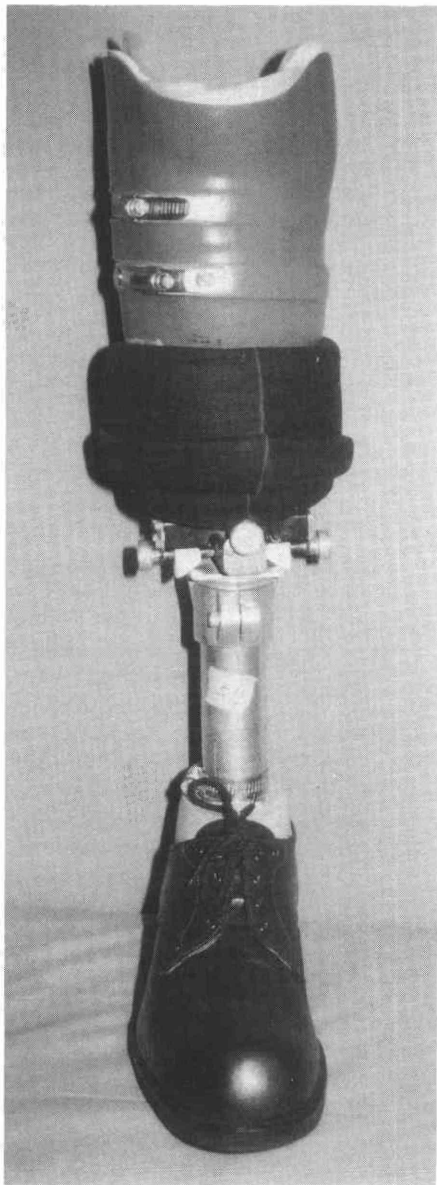


Figure 4. Variable volume socket mounted on an adjustable leg.

by providing new amputees with a durable, cosmetic, and reasonably long lasting preparatory prosthesis that accommodates the familiar problem of residual limb volume shrinkage.

ACKNOWLEDGMENTS

This work was made possible by support from the Veterans Administration Rehabilitation Research and Development Service. We are also grateful for the help and encouragement provided by Messrs. Jon Leimkuehler, CPO, Peter Ockenfels, CPO, Karl Fillauer, CPO, Carlton Fillauer, CPO, Robert Klebba, Robert Gooch, CP, John Michael, CPO, and Dr. Frank Clippinger.

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- ⁹ Orthomedics, Inc., 2950 East Imperial Highway, Brea, California 92621.
- 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.