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# The Use of Surlyn® and Polypropylene in Flexible Brim Socket Designs for Below-knee Prostheses

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The need for improved prosthetic socket designs to increase amputee comfort and function has long been recognized by prosthetists and other health care professionals involved in amputee rehabilitation. Reduction of the hardness and stiffness of wood and plastic laminate sockets has been addressed with various soft liners or inserts in an attempt to improve comfort and function. The subject is well covered in literature from Radcliffe's and Foort's initial description of leather and Kemblo® liners in 1961,[5] through Leon Bennett's work with gel liners in 1974,[1] to Tim Staats' description of multi-durometer liners in 1984.[6] Liners have no doubt been useful in below-knee prosthetics, but the proponents of soft liners seem to have overlooked the potentials offered by flexible brims.

At least two engineers active in prosthetics research have for some time raised questions concerning socket brim stiffness as a negative factor with respect to socket comfort. Dr. Eugene Murphy first considered this theme as early as 1957[3] when he proposed, "minimize the stiffness gradient between the rigid socket wall and the flexible skin, i.e., taper flexibility of the socket brim." As Dr. Murphy[3] later relates:

> "This theme was eventually published as the introduction to an extensive series of theoretical and experimental papers by Bennett. The series ended with limited clinical trials of sockets with flexible brims made of plastic laminates. These sockets appeared to be helpful for patients previously troubled by chronic or recurrent cysts, but the mechanical durability of the laminate was so poor that the sockets often lasted only six months."[4]

In the course of developing the ultralight weight below-knee prosthesis at Moss Rehabilitation Hospital,[8] A. Bennett Wilson, Jr. recognized the possibilities afforded by the use of thermoplastics to achieve flexible brims that would be sufficiently durable. During the past year, we have been funded by the Veterans Administration Rehabilitation Research and Development Service to carry this idea further.

After reviewing the theories set forth previously and considering the properties of new materials and techniques now available, a set of criteria for socket design was established:

1. Flexible brim
2. Tapering flexibility of the socket in the brim area
3. Flexibility options in other areas of the socket
4. Light weight, but durable
5. Thermoplastic and modular (i.e. no lamination, no epoxy, no glue, etc.)
6. Compatibility with existing modular component systems

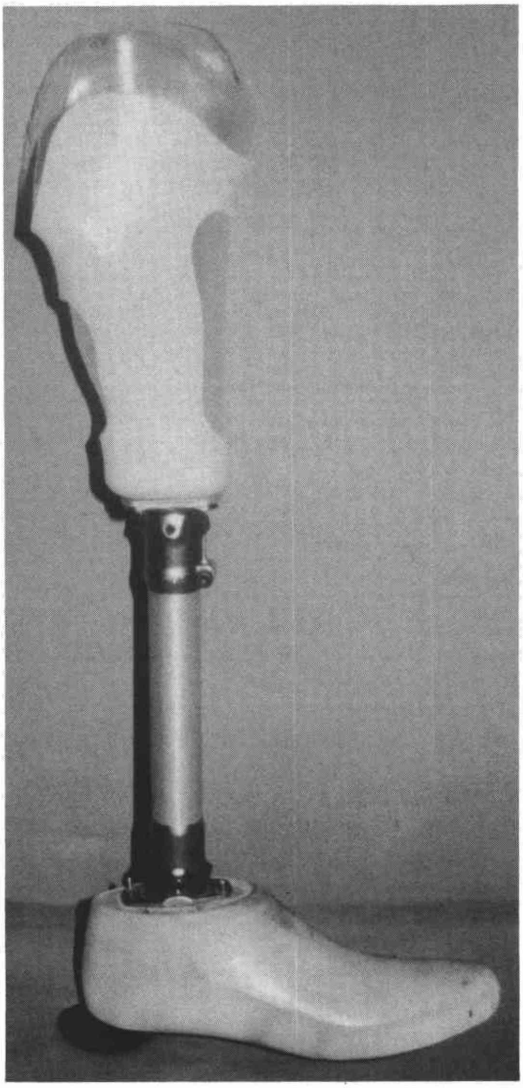

**Figure 1. Complete prosthesis, except for cosmesis and suspension, incorporating a socket with flexible brims.**

The resulting socket design (Figure 1) consists of the following components: (1) a Surlyn® inner socket or liner; (2) a polypropylene frame for socket support and attachment; (3) silastic foam soft end pad for establishing total contact; (4) United States Manufacturing Company[7] adaptor hardware† for attachment to Otto Bock[2] modular systems; and (5) neoprene sleeve suspension.

Fabrication of this socket system is as follows:

1. The cast is modified for a PTB-supracondylar socket design, and the distal end of the model is extended approximately one inch to allow for a silastic foam end pad and the modular adaptor (U.S. Mgf. Co.) for connection of the pylon to the socket (Figures 2 and 3).

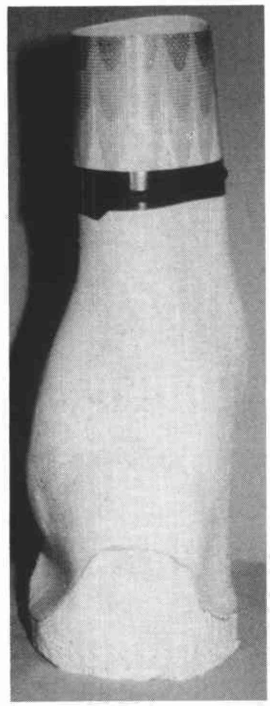

**Figure 2. The modified plaster model of the stump is extended to allow for location and alignment of the U.S.M.C. adaptor connector plate for the pylon.**

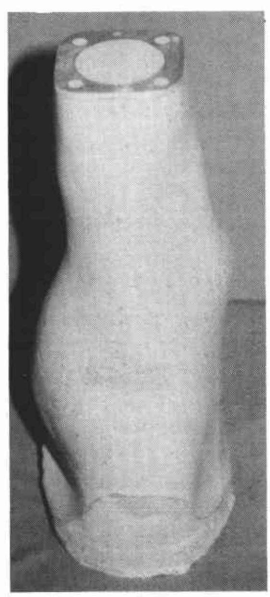

**Figure 3. The modified plaster model complete with adaptor, ready for vacuum-forming of the Surlyn® inner socket.**

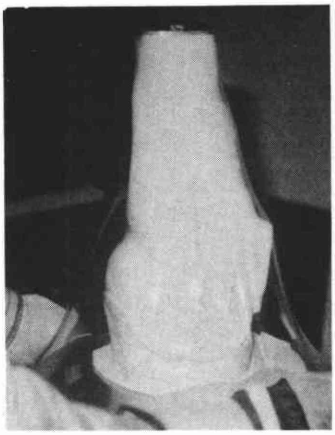

**Figure 4. Vacuum-forming the Surlyn® inner socket.**

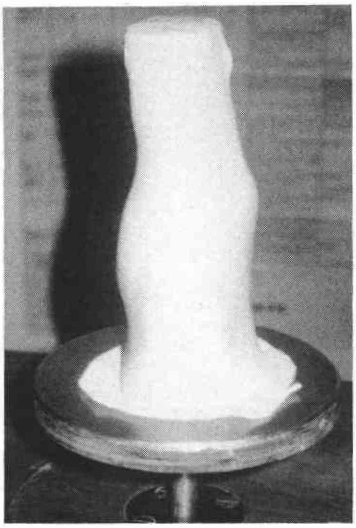

**Figure 5. Application of stockinette and nylon sock over Surlyn® inner socket to provide for separation of the polypropylene outer socket to be vacuum-formed over it.**

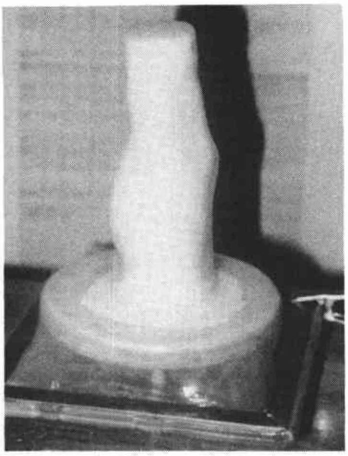

**Figure 6. The outer socket frame is vacuum-formed over the inner socket.**

2. An inner liner of Surlyn® is vacuum formed using either 12″ × 12″ × 3⁄16″ Surlyn® for light to regular duty sockets, or 12″ × 12″ × ¼″ Surlyn® for heavy duty sockets (Figure 4).
3. One layer of thick stockinette and a nylon stocking are applied over the vacuum-formed Surlyn® liner to facilitate separation of socket frame and liner (Figure 5).
4. The socket frame is vacuum formed of polypropylene directly over the inner socket. A piece 12″ × 12″ × ⅜″ is suitable for light duty while a piece ½″ thick is usually adequate for heavy duty (Figure 6).
5. After the final vacuum forming stage, the socket liner and socket frame are separated from each other and from the cast model (Figure 7).
6. The Surlyn® liner is trimmed for a PTB-SC design and the polypropylene frame is trimmed for a PTB socket design and is fenestrated over the tibial crest anteriorly and the gastrocnemius area posteriorly (Figure 8).
7. The Surlyn® liner is now inserted into the polypropylene frame (Figure 9).
8. The U.S. Manufacturing Co.[7] adaptor hardware is used to attach the socket to the Otto Bock[2] titanium modular endoskeletal components and an appropriate foot.
9. During initial fitting, the distal end pad is foamed in place while the patient stands to provide total contact.

The Otto Bock modular system has sufficient range of adjustment to suffice for alignment of prostheses for most geriatric patients. However, the use of the Berkeley BK alignment device might be desirable for some of the more active patients (Figure 10). A special adaptor plate is made of ⅛″ aluminum sheet so the Otto Bock 4R22 adaptor component can be used between the socket and the alignment device.

Cosmetic finishing may make use of any of several foam cover systems available, such as the round styrofoam cover available from the U.S. Manufacturing Company (Figure 11).

Below-knee patients fitted at the University of Virginia during the past two years, who voluntarily agree, are being refitted by their original prosthetist with the flexible brim thermoplastic system described here. Our initial conclusions are very positive. To date, eight flexible brim thermoplastic sockets have been fit on seven patients, with one patient having worn his for over one year. There have been six

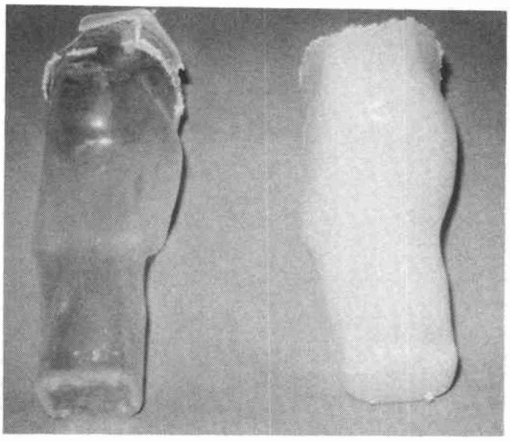

**Figure 7. The inner socket and socket frame before trimming.**

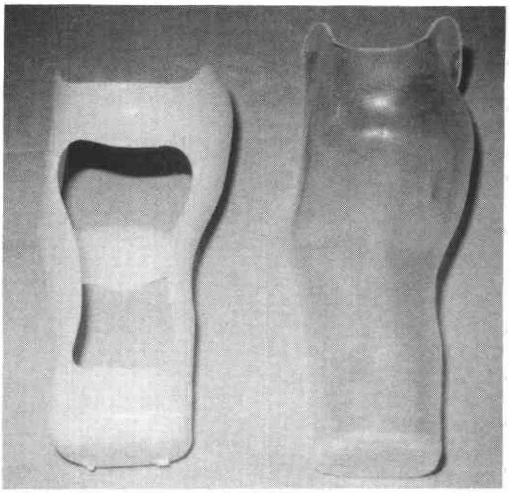

**Figure 8. The socket frame and inner socket after trimming.**

fittings since February, 1986. Only one socket failure has been noted, that of the Surlyn® inner flexible socket which split along the tibial crest on a patient weighing over 350 pounds. That particular socket lasted approximately four months. Though not indicated for use on someone of this weight, we were interested in determining its durability limits.

Subjective evaluation includes patient questionnaires and comments, comparing their existing prosthesis with the new flexible brim thermoplastic socket system. Patient reaction, thus far, indicates enhancement of patient comfort and awareness of reduced prosthesis weight, especially with our geriatric subjects. Although not originally designed for geriatrics, this patient population has specific needs that can be met by this socket design, such as socket flexibility, less confining brim, reduced proximal shear forces, and extreme light weight. When used with Otto Bock titanium modular components and a "Lite" SACH foot, this system weighs between one and a half and two pounds.

Current objective evaluation includes collecting heart rate and step count data in the patient's home environment, using a newly developed ambulatory physiological monitoring system. This includes physiological data with the patient's existing prosthesis in addition to that collected with the flexible brim thermoplastic socket system. This system of patient monitoring, or surveillance, electronically records heart beats (EKG), standing versus sitting posture, and step count, plotted against

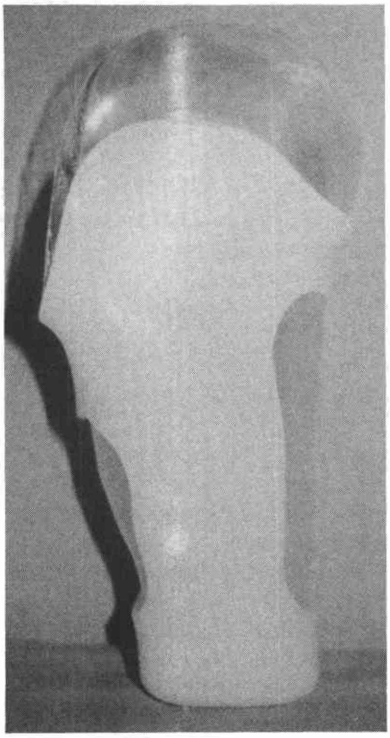

**Figure 9. The socket frame and inner socket assembled.**

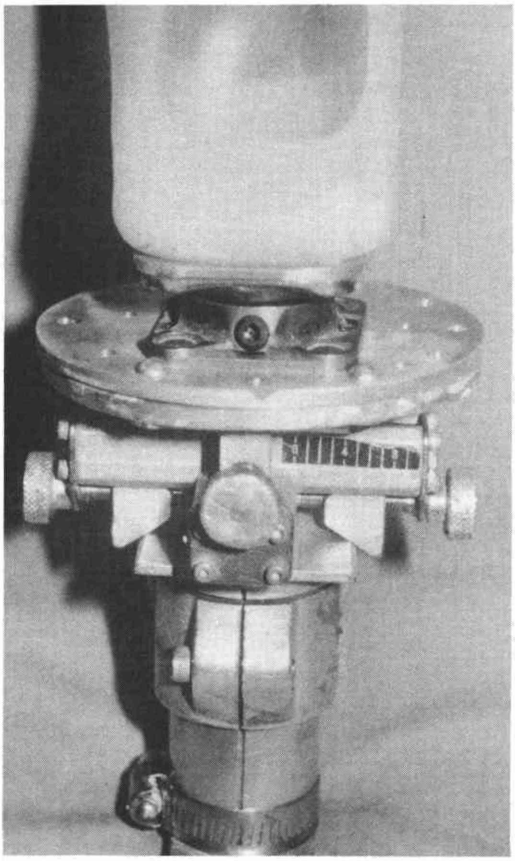

**Figure 10. View showing adaptor needed when the UCB adjustable below-knee "leg" is used for alignment trials.**

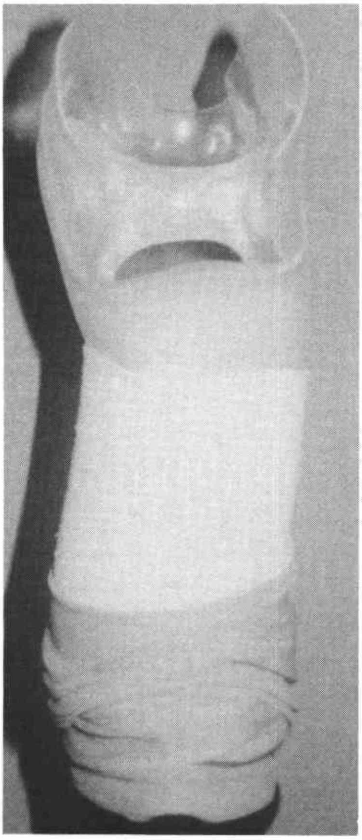

**Figure 11. The completed prosthesis with cosmetic stocking pulled down to show the carved styrofoam cover.**

time up to 24 hours. The goal is to document any changes in activity level and energy expenditure that occur with use of new prostheses, such as the flexible brim thermoplastic socket system presented in this paper.

In conclusion, a new socket design rationale and system utilizing existing thermoplastic materials has been presented. Patients fit with this system are currently being evaluated both subjectively and physiologically. Fittings and evaluations will continue until a significant number are completed and related data gathered. A follow up report will follow with final conclusions and statistical data presented.

† USMC Part Nos. 41014, 42012, 43026, and 29316

## REFERENCES


[1] Bennett, Leon, "Gel liner effects," *Bulletin of Prosthetic Research,* BPR 10:21; Spring, 1974, pp. 23–53.

[2] Otto Bock Orthopedic Industries, Inc., 4130 Highway 55, Minneapolis, MN 55422.

[3] Murphy, Eugene F., "Sockets, Linings, and Interfaces," *Clinical Prosthetics and Orthotics,* 8:3, Summer, 1984, pp. 4–10.

[4] Murphy, Eugene F., "Transferring Load to Flesh," *Bulletin of Prosthetic Research,* BPR 10:16; Fall, 1971, pp. 38–44.

[5] Radcliffe, C. W., and J. Foort, "The Patellar-Tendon-Bearing Below-knee Prosthesis," Biomechanics Laboratory, Dept. of Engineering, Univ. of Calif., Berkeley, and School of Medicine, Univ. of Calif., San Francisco, 1961.

[6] Staats, Timothy B., "Multiple Durometer Socket Liners for P.T.B. Prostheses," *Orthotics and Prosthetics,* 38:4, Winter, 1984, pp. 63–68.

[7] United States Manufacturing Co., 180 North San Gabriel Boulevard, Pasadena, Calif., 91107.

[8] Wilson, A. Bennett, Jr., "Ultralight Prostheses for Below-knee Amputees," *Orthotics and Prosthetics,* 30:1, March, 1976, pp. 43–48.

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