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Experience with the Scandinavian Flexible Socket

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INTRODUCTION

In October of 1982, we were visited by personnel from Een-Holmgren (Nils Thuring, Bo Klasson, and Robert Axelson) of Stockholm, Sweden. Among other matters that were discussed, they told us of the above knee prosthetic developments of Össur Kristinsson with the Scandinavian Flexible Socket and of their experience with the techniques involved (Figure 1). It was with heightened interest, therefore, that we listened to Mr. Kristinsson's presentation at the AOPA National Convention in Houston, Texas. This work has recently been published and need not be elaborated on here.[1] The personnel of Een-Holmgren have over the past few years employed the technique extensively in their clinical facilities in Stockholm and Uppsala. Their experience substantiates that of Mr. Kristinsson and has enabled them to develop specific criteria for the fabrication of sockets and support elements. Our own efforts have followed theirs closely.

Upon our return from Texas, it was decided that the Scandinavian Flexible Socket (SFS) definitely merited further attention. The cooperation of a patient was secured, and in November of 1982 work commenced on the first such socket fabricated by us.

Figure 1. Amputee wearing a prosthesis incorporating a Scandinavian Flexible Socket.

The completed prosthesis was delivered in December, 1982. The results of the first five patients fit with the SFS are summarized in Table 1. The one patient who rejected the socket did so despite his ability to walk with it comfortably and the evidence that it met his physical needs. Mentally, he simply could not accept the change from his conventional hard socket. The other patients have been unanimous in their acceptance and prefer it to their old sockets. Problems have been experienced with leakage between the vacuum formed socket and the valve seat. This has been eliminated by our adherence to the methods of Een-Holmgren and the use of the Hosmer Red Dot Value as described by them. Ironically, despite this problem, several of the suction socket wearers have experienced difficulty in doffing their prostheses with the valve removed due to the flexible walls of the socket clinging to their flesh.

The Hosmer Red Dot Valve has been used successfully for about a year now, but problems with cosmesis (due to its length) prompted a new design. The various suction valves available were surveyed as to length and available features. Ultimately it was decided that the USMC Green Dot Valve offered the best combination of features and to specifically adapt this valve to the needs of the SFS, a Delrin valve housing has been designed by Durr-Fillauer and is now available. The Hosmer Red Dot Valve housing is fabricated with a relatively narrow and shallow groove in the base. While this is satisfactory for laminated sockets, it was deemed necessary to cut a much deeper and wider groove in the new valve housing so as to assure a proper mechanical interlock between the socket and the valve housing. As a consequence of this decision, it was considered proper to drill a series of holes about the periphery to make sure that the Surlyn® is fully drawn into the groove. Preliminary results with this valve have been quite favorable.

This series of fittings, limited as it may be, has enabled us to substantiate for ourselves the experience of others and to familiarize ourselves with the fabrication methods involved. We would be remiss if

Patient	Date Measured	Date Delivered	Stump	Suspension	Age	Gender	Comments
E.N.	Sept. 1982	Dec. 1982	Left, Long, Average Size, Cylindrical	Suction	57	Male	Very Pleased
O.M.	Nov. 1982	Dec. 1982	Left, Long, Average Size, Cylindrica	Hip Joint and Pelvic Band	68	Male	Rejected
R.E.	Jan. 1983	March 1983	Right, Long Average Size, Cylindrical	Suction	30+	Male	Very Active
G.B.	March 1983	June, 1983	Right, Medium length, Average Size, Cylindrical	Silesian Band	76	Male	Very Pleased
J.F	Sept. 1983	Nov. 1983	Right, Medium length, Average Size, Cylindrica	Suction	32	Female	Very Pleased

Table 1. Patients fit as of December, 1983.

While other patients have been fitted these are the only ones on whom complete data and adequate length of follow-up are available for.

we were not to acknowledge the excellent cooperation we have received from the personnel of Een-Holmgren. Several letters have been promptly responded to and, in the spring of 1983, Bo Klasson spent another day with us in Chattanooga and compared notes. In August of 1983, Carlton Fillauer, CPO, in the company of Herman Hittenberger, CPO, and members of their families, visited Stockholm and Uppsala to observe firsthand the techniques employed. Ake Friestedt, a prosthetist employed by Een-Holmgren in Uppsala, spent several days with us in November of 1983 and commented fully on techniques we were employing. In addition, he told us of his experience with below knee suction sockets, expanding on his presentation at the AOPA National Assembly in Phoenix.[2]

It should also be mentioned, at least in passing, that the Prosthetics and Orthotics education program of New York University, under the leadership of Sidney Fishman, Ph.D., has devoted considerable time and effort to acquiring experience with the methods involved. They have called their development the Icelandic, Swedish, New York (I.S.N.Y.) socket. At the start of 1984 they started a series of short term courses on the subject. We have exchanged information with them, and for the cooperation we have received we are duly grateful.

FEATURES

The SFS is primarily indicated for patients with mature residual limbs and for whom substantial changes in limb volume are not anticipated. However, since the socket is separate from the supporting structure, minor changes in volume or contour can be accommodated by fabricating a new socket. Any discrepancy between the socket and weight bearing receptacle distally can be taken up with filler material. While the procedure can be used with any length residual limb, the benefits to be realized diminish as residual limb length decreases. This is because the surface area of the flexible socket not contained in the rigid frame is proportionately less for shorter sockets than for longer sockets. This tendency is accentuated by the need to extend the proximal brim in a full circumferential enclosure so as to allow for attachment of a Silesian band or hip joint. The need for such auxiliary means of suspension is of course greater for short residual limbs than for long residual limbs.

This should not be interpreted to mean that the SFS is contraindicated for patients who need such auxiliary means of suspension. The limiting factor is residual limb length, not age, inability to manage suction suspension, or inadequate hip musculature.

One attractive feature of the SFS is that in many respects it is very conventional. Casting and modifying techniques for the production of the positive model require no deviation from current practice. The weight bearing mechanism of the socket is unaffected and the manner by which the femur is stabilized in the socket is likewise unchanged. While suction suspension has been used primarily, hip joints and Silesian bandages can be used as well. In these latter two instances, the proximal portion is continuous and runs all the way around the brim.

Patient comments have been largely related to the flexibility of the socket. It seems that the socket walls adapt to changes in limb contour that occur because of muscular contractions during ambulation as well as during sitting. As a result, the socket feels less constricting than a rigid wall socket and more natural. Suction suspension is improved due to the clinging nature of the socket walls and the greater accommodation to active muscular contraction. It would seem, hypothetically at least, that these same factors lead to improved proprioception and feedback from the prosthesis. One amputee likened the sensation to the same as scratching your thigh through your pants leg. Patients are able to perceive chair and table edges through the flexible socket, thus gaining increased information about their environment, and security. The thin walls of the Surlyn® socket, and the maximum amount of surface exposed, lead to less heat build up in the socket and greater comfort.

BACKGROUND

The concept involved in the SFS is that a thin-walled socket is first vacuum-formed of Polyethylene or Surlyn®†. Around this socket an outer supporting structure is laminated of carbon fiber, fiberglass, and acrylic resin. This structure is then trimmed to the smallest possible size. This is made possible by the superior strength and rigidity afforded by the materials used.

In the 1950s, Johann Bach of Essen, Germany developed what may be considered an indirect ancestor of the SFS. He was specifically interested in developing a solution to the serious problems with distal edema that were then being experienced with rigid suction sockets. His objective was to train the amputee to walk using active muscular contraction in the remaining limb to reduce congestion in the residual limb. To facilitate this objective he believed it was necessary to have a socket with flexible walls. Mr. Bach eventually worked out a solution to this problem and patented his design. The patent was acquired by Fillauer Orthopedic in the period 1958–60 and Kingsley Manufacturing Company agreed to fabricate the sockets. In the United States the design was named the Flexi-Cage socket (Figure 2).

This design entailed a wood brim and distal end with a middle portion between them of numerous parallel strands of cord approximately 1/8" in diameter. The two end sections were connected by four aluminum struts that provided structural integrity. Sockets came right and left in about six sizes and with about three different degrees of taper of the flexible sections. The wood sections were considerably undersize and had to be fitted to the patient in the same manner as a conventional wood socket block.

The Flexi-Cage received a measure of acceptance and many patients were quite satisfied with their sockets. It passed from the scene in about five years, however. Aside from the fact that suction suspension was clearly impossible, it required a certain measure of skill and experience with the system to select the proper socket and to modify it satisfactorily. Finishing was troublesome and repairs, particularly if the ends of the strands were disturbed, were difficult, if not impossible.

Figure 2. Flexi-Cage Socket.

It would seem that one of the earliest mentions in the literature of this train of development proper occurred in 1968.[3] In an article by McCollough et. al., there appears a passing reference to a method of fabricating an above knee prosthesis with flexible socket and outer rigid socket receptacle. The technique was described in further detail the following year by William F. Sinclair, C.P.O.[4] The inner flexible socket was secured to the outer receptacle by a Velcro® strap laterally and the anterior wall of the receptacle was trimmed away lateral and distal of the Scarpus' triangle to permit muscle bulging. The objective of these design features was to provide a prosthesis better suited to the needs of

†Een-Holmgren originally used polyethylene, however, due to shrinkage of the polyethylene sockets, they resorted to the use of Surlyn.® Surlyn,® despite its greater expense, also has the advantages of greater clarity and easier modification. In his article, Össur Kristinsson comments explicitly on the problem of polyethylene shrinkage and the resulting looseness that develops between socket and frame.[1]

geriatric amputees. Specifically, it was intended that donning would be made easier by virtue of the fact that the amputee could, in a sitting position, don the socket separately and then connect the socket to the receptacle and prosthesis. In 1973, Mr. Sinclair reported in a CPRD workshop that amputees still experienced difficulties in donning their prosthesis.[5] He also reported that the inner socket was now being fabricated of silicone RTV elastomer. The technique failed to catch on, and it would seem that the primary reason for this was the fact that the benefits of the relatively small exposed areas did not warrant the increase in fabrication difficulty and time.

In this same period, the VAPC reported on similar work.[5,6] They employed a PVC polymer (Cordo) and Plastazote™ to fabricate inner sockets of variable flexibility and with a novel interlocking technique. The inner socket was fabricated with a round button protruding above its surface. The socket receptacle was laminated over the inner socket and the laminate covering the top of the button was then trimmed away. To withdraw the socket from the receptacle the button would be pushed inward, depressing the soft tissue of the patient's residual limb, and the socket pulled out of the receptacle. In use, the edges of the hole in the receptacle would lock around the button and hold the socket and receptacle firmly together.

The VAPC employed Cordo-Plastazote liners with above knee, below knee suction, and Symes prostheses. Fabricating such sockets or socket liners of Cordo was a very long, drawn-out, protracted process and involved a good deal of labor. The material was also very flammable and eventually became involved in questions of toxicity and carcinogenicity. Needless to say, use of Cordo and Plastizote liners did not find much favor.

The concept of a removable inner socket to facilitate donning has received further development in Japan by Koike, et al.[7] This work was undertaken at the Tokyo Metropolitan Rehabilitation Center and therefore, designs in this work have been dubbed TC1, TC2, etc.

The TC2 prosthesis embodies an inner socket of Surlyn® supported in a receptacle of polypropylene. A novel valve design using a sheet of latex and with the valve hole on the very distal end of the socket is employed, and a Velcro® strap secures the socket to the receptacle.

In May, 1983, one of the authors (CHP) undertook a commercial tour of Japan. On this tour, personnel of Keiai Company demonstrated the use of the TC concepts with the aid of prostheses and a videotape. Among other patients, the videotape showed one gentleman, a bilateral above knee amputee, who used one set of sockets interchangeably with full length articulated prostheses out of the home and stubbies about the house. It was also demonstrated how an amputee could achieve greater sitting comfort in a car over long distances by releasing the Velcro® strap and easing the prosthesis half off the socket. Work with the concept has been applied to other levels of amputation, most especially with below knee suction sockets. Interestingly enough, at the time of the visit, the concept of cutting windows in the socket receptacle was not being employed.

Writing in 1982, R. Volkert of the University of Mainz, Mainz, West Germany described his experiences with this latter concept.[8] His particular concern was to develop a technique which would more readily accommodate changes in volume in the patient's residual limb. To this end then, a rigid socket is laminated and windows, or fenestrations, are cut in it medially, posteriorly, and anteriorly. This leaves three supporting struts laterally, antero-medially, and postero-medially. A complete ischial-gluteal brim provides weight-bearing proximally and an elastic compression stocking, worn either inside or outside of the prosthesis (or both) is used to provide control of the soft tissue.

The lateral strut acts, not only as a structural element, but also to provide a reaction point for the distal femur. This latter point is described by Volkert as a femoral clasp and he ascribes the concept to Kuhn. Rudolph Poets, in 1974 seems to discuss the same principles, but he attributes the design to Burger.[9] What seems to be involved is that not only is the lateral wall adducted and flattened as in U.S. practice, but the distal lateral wall is modified in a "V" shape groove or clasp in the transverse plane, to grip the anterior and posterior portions of the distal femur as well as the lateral surface. The objective is to provide better control of the prosthesis.

This concept is dwelt upon in some length to point out the fact that new materials can not be adopted by chance but in accordance with accepted principles of prosthetic design. The SFS socket, as described by Össur Kristinsson and personnel of Een-Holmgren, also provides a resting or stabilizing point for the lateral distal femur.

To return to the work of R. Volkert, he extended the concept of the frame type socket he was employing with above knee amputees to the needs of hip disarticulation amputees as well. He stated that the experience of 23 patients (14 AK, 9HD) was overwhelmingly positive.

In this country, Peter Ockenfels, C.P.O., of Columbus, Ohio has gained experience with the techniques of Volkert and described them with the aid of a videotape.[10] Mr. Ockenfels' work substantiates that of Mr. Volkert. It would seem that the technique of Volkert with compressive dressing is best indicated for patients with immature residual limbs, while the SFS is best indicated for patients with mature, dimensionally stable residual limbs.

THEORETICAL IMPLICATIONS

A socket performs a variety of functions in a prosthesis. First and foremost, natually, it functions as a receptacle, controlling the volume of the residual limb and transmitting forces to and from the limb. In an abstract sense, that portion of the socket that performs this vital fitting element is the innerface of the socket. It is this function that people are attempting to describe when they use the word "interface" as a synonym for the word "socket." Everything peripheral of the innerface of a socket, that is, the wall, serves as a structural component. The wall provides adequate strength and rigidity to maintain the shape of the innerface. In doing so, it should be no thicker than absolutely necessary.

In an abstract or ideal sense, the innerface, or interface, can be imagined as an infinitely thin membrane encapsulating the residual limb. In order to respond to changes in limb contours or volume, the membrane is expanded or contracted. If a thermoplastic medium, such as Surlyn,® is used to construct a socket, this can be done in a literal sense.

If, however, the socket is fabricated of some medium such as wood, the interface can only be altered by adding pads or liners, or by grinding into the wall. In this latter instance, the interface is expanded outward. It is for this reason, therefore, that socket walls are quite frequently made thicker than absolutely necessary for structural integrity.

If we apply these theoretical concepts to the case of the SFS, we can see that the flexible socket is functioning as the interface and the carbon fiber structure is functioning as the structural element. Neither is capable of functioning alone, yet working together it is possible for the two to provide a measure of function and comfort greater than that which can be achieved by more conventional means. It is this point that marks the larger significance of a design such as the SFS.

Different materials with quite different properties working together in a synergistic fashion can be used to provide a socket more closely matched to the needs of an amputee. To mention but one possibility, the theoretical concepts of Eugene Murphy, Ph.D. and Leon Bennett[11, 12] can be used to design a socket brim that more effectively moderates the shear forces that occur in the soft tissues about the brim.

It is almost axiomatic that progress in prosthetics and orthotics does not occur due to the discovery of new concepts, but rather by the application of new technology to make possible old concepts, concepts oftentimes old enough to be forgotten by all but the oldest practitioner.

Ample precedent can be found in prosthetics for structures such as the SFS; namely, prostheses fabricated with steel frames and leather sockets. This form of construction was apparently quite prevalent in Germany prior to World War I, and above knee prostheses fashioned in this manner resemble nothing so much as Hessing style KAFO's. The use of steel frames and leather sockets was common in the U.S. up until World War II for upper extremity prostheses, Symes prostheses, and knee disarticulation prostheses. Indeed, vestiges of this form of construction can be found even today. More than one prosthetist can attest that amputees quite frequently prefer such "old fashioned" prostheses to new style laminated prostheses, due to the greater comfort afforded. The challenge to the field of prosthetics, therefore, is to apply the lessons learned with the SFS to other levels of amputation, and design modern analogues to some of these older designs. In addition, of course, new concepts need to be explored.

Colin McLaurin, et al. in describing their open-shoulder above elbow socket, talked of the functional elements as being a ring about the distal portion of the socket and the proximal brim.[13] This is analogous to the concepts discussed by Poets and Volkert in conjunction with the above knee socket, and as realized in designs such as the SFS. It would seem eminently logical, therefore, to extend the construction principles to the design of an above elbow socket, as well as other levels of amputation.

In 1971, Nigel D. Ring of Chailey, England, described a technique for fabricating from carbon fiber and polyester resin, a frame type socket for use with externally powered shoulder disarticulation prostheses.[14] While the report was of preliminary nature and described the early results of fitting one child, it did describe the results of comparing the carbon fiber/plastic structure to the metal structure it was intended to supplant. In these tests, the carbon fiber/plastic structure was considered superior in stiffness, ultimate strength, weight and ease of fabrication. In regard to this latter point, it is worth pointing out that the technique employed by Mr. Ring is essentially the "vacuum-bag" technique that is very much in vogue today among wooden boat builders.

FABRICATION

Preparation of the Positive Model

- Pour check socket or negative model with brim extended at least 4" above the normal medial trim line. Use a removable square mandrel and smooth the positive model. When the model is stood on the proximal surface, the model should not lean to one side or the other. This is necessary to prevent the formation of uncontrollable webs during the vacuum forming process.
- Drill 1/16" diameter holes in brim area for proper evacuation of air.
- Locate position of the S.F.S. valve* as usual and mark. It should be located anterior-medial and as far distal as possible so it won't interfere with removal of the socket from the weight bearing structure. This is especially critical to facilitate removal and insertion of the socket from the weight bearing structure in the case of residual limbs with small distal ends.
- Drill a hole 23/64" in diameter and 2 3/4" deep in the center of the marked position (Figure 3). Drill another 1/16" dia. hole from just inside the periphery of the valve housing into the central chamber.
- Drive the tube into the positive model (using the steel pin in the tube and a hammer) until it is 1/8" below the surface (Figure 4). This and the preceding step are to facilitate accurate reproduction of the valve position.
- Flatten the area around the tube to match the base of the S.F.S. valve

*Durr-Fillauer S.F.S. valve.

housing, extending the flat area 1/8″ beyond the edge of the housing.

- For vacuum forming of Surlyn,® the positive model should be very smooth, warm, and wet. If the positive model has set overnight, it will be cold to the touch. To insure adequate working time, we have been submerging such models in a bucket of hot water.

Vacuum Forming

- Oven is set at 325°-350° Farenheit.
- Select a sheet of 3/16″ or 1/4″ Surlyn.® When proximal circumference is 21″ or under, use a 12″ × 12″ sheet. Otherwise use a 16″ × 16″ sheet.
- Select appropriate sized platen and frame.
- Secure Surlyn® in the frame with spring loaded clamps and place in the oven. The frame should be held on a rack or support at least 10″ above the floor of the oven.
- Secure the S.F.S. valve housing on a valve mount (Cat. #807406). If a valve housing without the adhesive coating already applied is used, clean the outside of the valve housing with solvent and wrap it with double faced clear adhesive tape (D-F Cat. #807446). Use of the tape helps bond the Surlyn® to the valve housing and prevent leaks. Place the valve housing and mount in the oven. Adhesion and proper for-

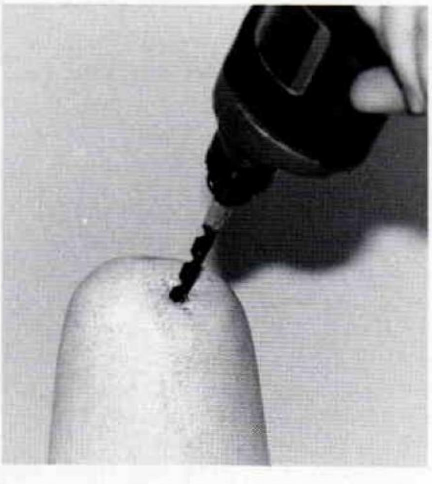


Figure 3. Drilling the hole in the positive model by which the valve housing will be secured for vacuum forming of the socket.

Figure 4. Driving the steel tube, or ferrule, into place.

mation of the Surlyn® about the valve housing are helped if the valve housing is heated in the oven while you wait for the Surlyn® to drape an appropriate distance.

- The positive model is positioned on the platen with a layer of dacron felt beneath it and extending slightly beyond the edge of the positive model. There should not be any gaps between the model and platen so as to avoid blowouts.
- The Surlyn® should be allowed to drape about $^1/_3$-$^1/_2$ the height of the model (about 10 min.). Care should be taken not to let it drape too much or considerable difficulty will be experienced.
- When the Surlyn® is about ready, remove the valve housing and stem from the oven and place on the positive model (Figure 5).

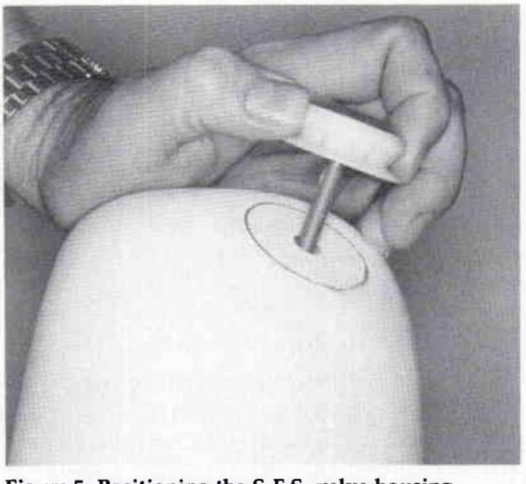


Figure 5. Positioning the S.F.S. valve housing.

- With the vacuum on, the control valve of the mobile vacuum unit (Cat. #807305) is set at the low pressure setting (2-3 In. Hg.).
- Remove the Surlyn® from the oven, center over the model, and draw down.
- The plastic is stretched down over model slowly so as to avoid webbing. Fundamentally, the plastic is allowed to descend almost under its own weight with very little assistance. The Surlyn® is sealed around the edge of the platen. As the plastic is drawn in and as webs start to form, the foot valve is closed and fingers are used to pat the webs out (Figure 6). Pressure on the foot valve is then released. Proceed in this manner until the Surlyn® is drawn in completely about the model without webs.
- Immediately open the high pressure line of the mobile vacuum unit.
- A string is used to draw the plastic tightly into the groove at the base of the valve housing. This step is useful in cases where delay in molding the Surlyn® may have led to excessive

Figure 6. Patting the webs out of the Surlyn as they form both proximally about the brim and distally about the valve housing.

cooling of the plastic in the area of the valve housing.

- After the initial cooling, cut the surplus Surlyn® from the face of the valve mount in the area of the central hole and from around the base of the model.
- Screw the shaft of the trimmer tool (Cat. #807396) into the valve mount and with the blade protruding about 1/4", carefully rotate the blade holder as you feed in the blade (Figure 7). Continue until the point makes uniform contact with the surface of the valve housing.

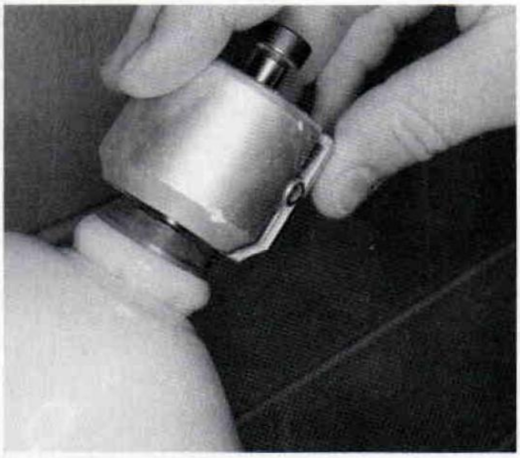


Figure 7. Trimming the excess Surlyn away from the end of the valve housing with the trimmer.

- Remove the trimmer and shaft.
- Remove and discard the ring of surplus Surlyn® and trim the sharp edge of the Surlyn® left standing around the valve opening (Figure 8).
- Remove the valve mount from the housing and model.
- Position the model on a work bench and stuff material into the central chamber to create back pressure for the next step.
- With the aid of a rubber stopper, blow compressed air into the valve housing and pull the socket off the model. It may be necessary to cut several vertical slits in the excess Surlyn® above the trim lines, particularly if the surfaces of the model proximal to the trim line slope inward.

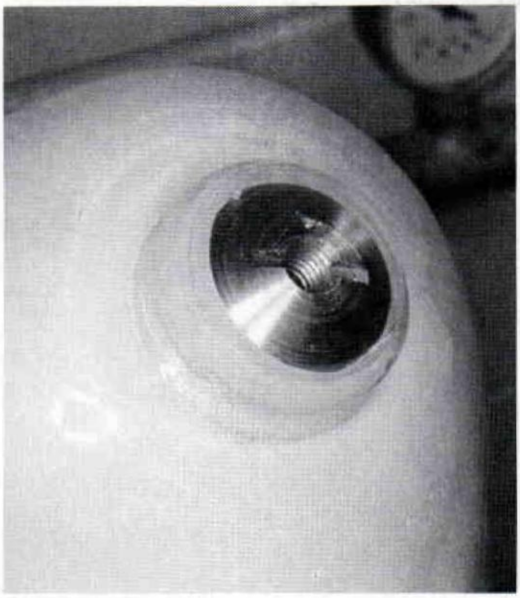


Figure 8. Excess Surlyn has been trimmed away and the edge smoothed.

- The socket is now ready to be cleaned and finished.

Preparation for Lamination

Previously, the outer structure was laminated directly over the socket. This involved rather elaborate steps to avoid cutting or marring the socket when removing the outer structure. The procedure described below is much easier and gives equally good results. It is contingent, however, on the fact that the valve position be exactly duplicated. To assure that the valve position is duplicated exactly, the tooling depicted in Figure 9 is used. Use of such tooling has the further advantage that additional sockets can be vacuum formed (if necessary for whatever reason) with the assurance that they will be compatible with the frame, if the socket model has been preserved.

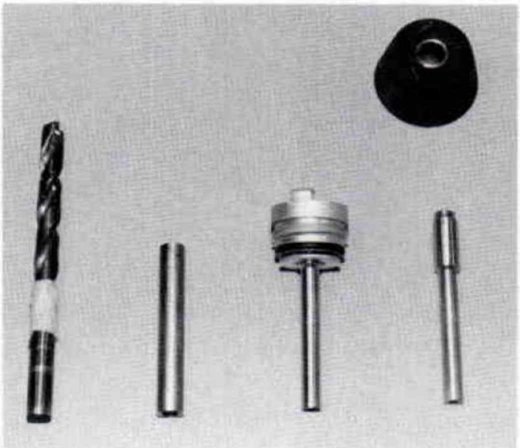


Figure 9. Tooling. Bottom row from left to right, 23/64" drill, steel tube or ferrule, modified valve body with pin for positioning valve housing, loose pin for positioning rubber laminating dummy (top row).

- Position the positive model on the mandrel.
- To allow for the thickness of the socket, stockinette is used as a spacer. Two short pieces (3 for ¼" Surlyn®) are used distally with the edges staggered. The distal ends should be sewn off smoothly.
- A rubber laminating dummy the same size as the exterior dimension of the valve housing is positioned on the model in the tube with the aid of a matching steel pin.
- Pull on one layer of stockinette (2 for ¼" material) over the entire model, with the distal end sewn off smoothly.
- Apply a PVA sleeve and cap the end for a smooth interior finish.
- Use double/faced adhesive tape to secure the three polyethylene laminating dummies** (to provide recesses for the velcoins in the laminated structure) in place (Figure 10). One is located on the medial wall below the brim and the other two are located laterally inside the trimlines of the proximal trim. Relatively flat spots should be selected and, if necessary, heat can be used to soften the dummies so that they will conform better. Polyethylene laminating dummies are not reuseable, as the lamination exotherm causes them to shrink as they attempt to regain their original shape.

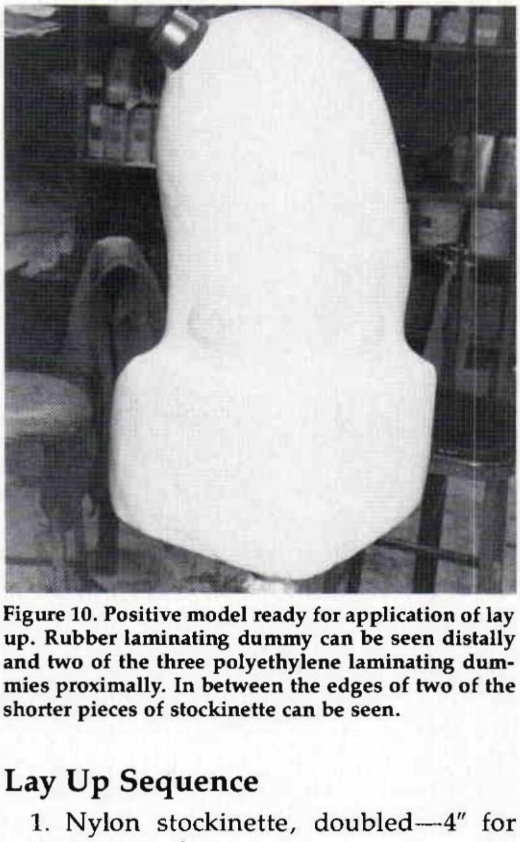


Figure 10. Positive model ready for application of lay up. Rubber laminating dummy can be seen distally and two of the three polyethylene laminating dummies proximally. In between the edges of two of the shorter pieces of stockinette can be seen.

Lay Up Sequence

1. Nylon stockinette, doubled—4" for average size.
2. Attach two pieces of plastic welding rod to the medial wall (Figure 11) spaced ¾" to 1" apart, between the two layers of nylon stockinette, to serve as corrugation strips. Secure in place with gauze.
3. Fiberglass stockinette, doubled—4" for average size.
4. One piece of 6" nylon stockinette folded lengthwise and placed at the medial brim and extending from the anterior lateral end (Figure 12). This

**A set of the laminating dummies, Velcro® fasteners, and ¼" #4 screws are available as Durr-Fillauer Catalog Number 807412.

††One inch unidirectional carbon fiber webbing is available as Durr-Fillauer Catalog Number 6381.

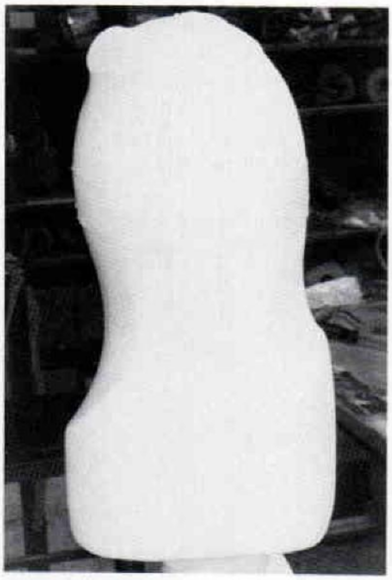
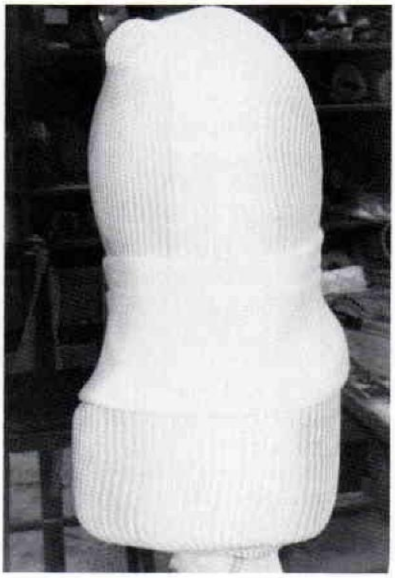


Figure 11. (left) Two pieces of polypropylene welding rod secured in place on the medial wall with one inch cotton gauze.

Figure 12. (right) Initial layers of nylon stockinette and fi-ber-glass stockinette have been applied to the model. In addition the folded layer of 6″ nylon stockinette has been applied at the medial brim.



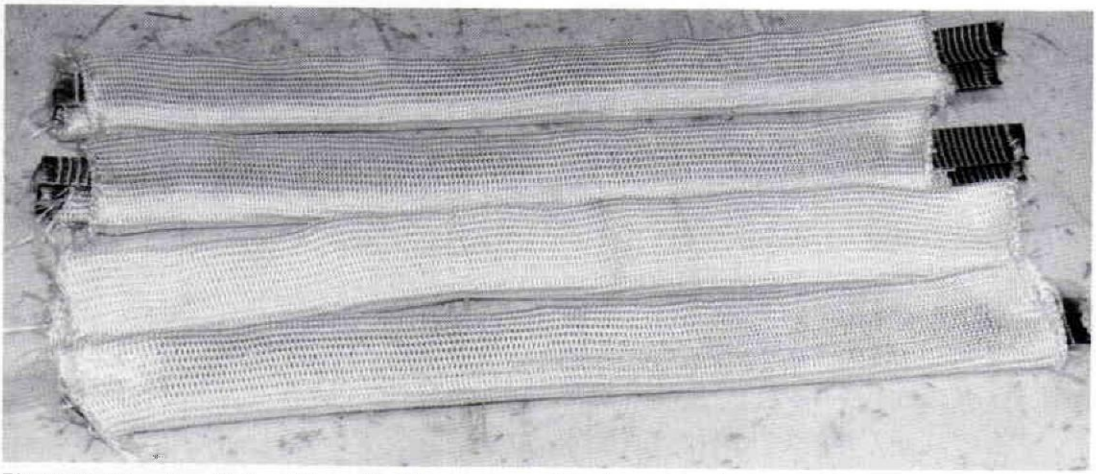


Figure 13. Fiberglass-Carbon fiber rolls. The top two and the bottom one have carbon fiber in them, the second from the bottom is fiberglass only.

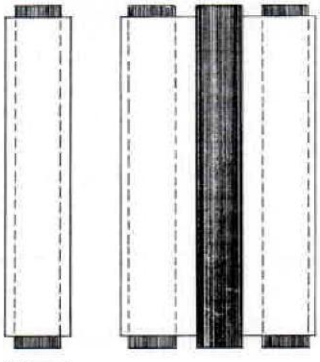


Figure 14. Method for securing the carbon fiber inside the fiberglass stockinette (two inside, one on top) and rolling the assemblage up.

provides extra material for cutting the radii in the anterior and posterior medial proximal corners.

5. Fiberglass-Carbon roll (Figures 13 and 14) from anterior to posterior lateral ends of the weight bearing structure as in the previous step above and horizontal. Tape is used laterally, outside the trimlines to secure the roll in place.
6. Fiberglass-Carbon roll on the medial wall and extending from the medial brim to distal lateral end of the socket. Distally, fan the ends of the rolls out. Again, tape is used to secure the distal end in place.
7. Fiberglass only roll positioned horizontally as in the fifth step above.
8. Fiberglass-Carbon roll vertical as in the sixth step (Figure 15).
9. Fiberglass Stockinette, doubled overall. If the lay up is so heavy that the fiberglass stockinette cannot be pulled down over the model in the conventional fashion, then an appropriate length is stretched into place medially and secured there with tape. This will provide the additional two layers of fiberglass needed for bulk and strength (Figure 16).
10. Nylon stockinette, double overall.
11. If a Silesian bandage or hip joint is to be used, the reinforcing material described in steps 5 and 7 should be extended all the way around the model. If necessary, additional material should be added distal of this section for the hip joint.
12. For large residual limbs, extra carbon fiber webbing should be added to the fiberglass roll in the seventh step. Additional material can, of course, be added if its use seems warranted.

Lamination and Removal from Model

1. Apply the outer PVA sleeve, punch hole in inner PVA sleeve for vacuum.
2. Laminate with acrylic resin using 10 percent thinner††† for better satura-

†††Durr-Fillauer Catalog Number 6380

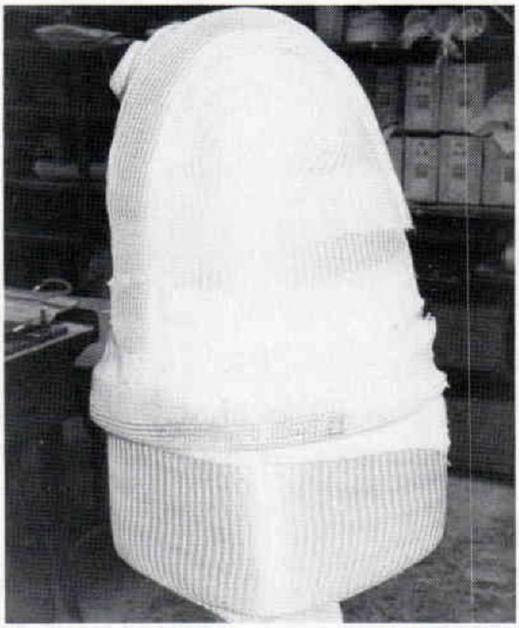


Figure 15. All of the fiberglass and fiberglass-carbon-fiber rolls secured in place with tape and gauze.

Figure 16. The final two layers of fiberglass stockinette secured in place medially. In this instance it proved impossible to stretch the fiberglass on as usual.

tion, 550cc for average size—650cc for a large model (Figure 17).

3. Once the lamination has cooled, trimlines are drawn and the excess lamination is trimmed off beyond the trimlines with a cast saw. Open up the area over the end of the rubber laminating dummy and remove the pin. The laminated weight bearing structure is then removed from the model (Figure 18).

Trimlines

Proximally, the trimline follows the conventional trimline (Figure 19). If a suction socket is to be fit, the trim lines are terminated at about the lateral two-thirds of the socket, approximately the deepest point of the rectus femoris channel anteriorly, and opposite it posteriorly. If a Silesian band or hip joint are to be used, the brim extends about the full circumference of the socket. The inferior edge of the posterior portion extends in an oblique line from the lateral juncture to where it meets the medial vertical strut in a smooth, even radius. At the ischial support point, the brim is about 2″ wide from the proximal to distal edge. The anterior extension is trimmed in a similar fashion. At a point opposite the ischial support point, the brim is about 3″ wide. The medial support strut is trimmed within the anterior-medial and postero-medial angles of the socket. At its mid-point, it will be about 2½″-2¾″ wide from anterior to posterior. It will be wider proximal and distal of the middle portion due to the need for relatively long radii.

Distally, the structure is trimmed at about the juncture of the vertical walls and the distal end of the socket anteriorly and posteriorly. Laterally the trim line should extend to a point about 2½″-3″ proximal of the distal end of the residual limb to insure pain-free stabilization of the femur in the socket. This distance may be greater, however, if there is an abnormal amount of redundant tissue distally. This portion can subsequently be trimmed lower if experience warrants. Trimlines can be adjusted during fitting if adequate material is left. If the Surlyn® socket has been trimmed over-

Figure 17. Lamination.

size, the proximal edge can be heated and rolled over the edge of the weight bearing structure for comfort. Pinching of the soft tissue between the Surlyn® socket and

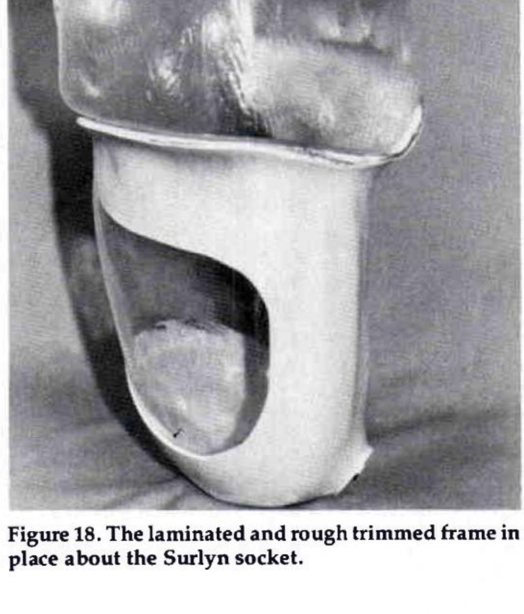


Figure 18. The laminated and rough trimmed frame in place about the Surlyn socket.

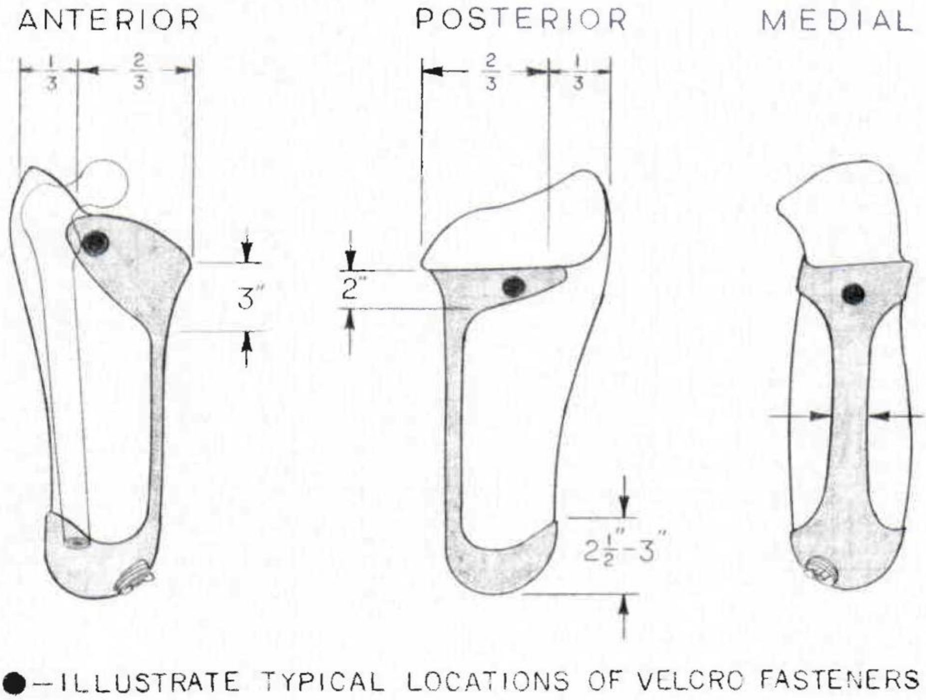


Figure 19. Guide for the establishment of trimlines. The figure 2½"-3" for the height of the lateral posterior trimline is intended as a guide only. The exact height is established by the length of the femur.

brim of the frame may occur if this is neglected.

The velcoins are secured in place with epoxy and the self-tapping screws. The Velcro® patches should not be secured to the socket now so as to allow for its removal from the frame during finishing. Alignment and fitting proceed in the normal fashion.

Finishing

Once final trim lines have been established, all edges, except the proximal one, should be beveled down to meet the Surlyn® socket, and to provide a smooth esthetic appearance after the final lamination (Figure 20). The inside of the frame is greased and it is secured on a pipe or mandrel with plaster or some other means. Finish lay up and PVA bag are applied as usual. The final lamination is done with

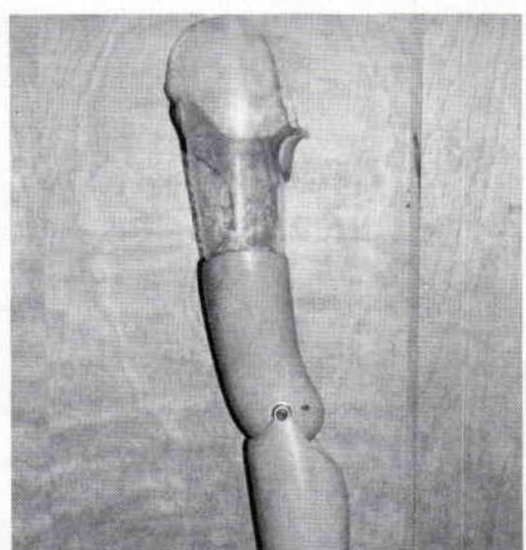


Figure 20. Finished prosthesis.

minimum vacuum, and the resin is applied only to the areas laying over the frame.

When hard, the final lamination is trimmed to the edge of the weight bearing structure and the thigh piece is otherwise finished in the usual fashion.

During final delivery, the Velcro® patches are applied to the socket when it is clear that the socket will not again need to be removed from the frame.

To do this, the Velcro® patches are applied to the velcoins and the protective backing removed. Long strips of this same backing material should then be applied to the adhesive of the Velcro® so that the strips extend beyond the trimlines. The socket is then secured in place and the strips of protective backing peeled loose from the Velcro.® Heat and pressure from the patient walking will cause the Velcro® to adhere firmly to the Surlyn.® The socket should, of course, be cleaned prior to insertion in the frame.

The use of Velcro® has thus far proven superior to the use of rivets for securing the socket to the frame. The rivets displayed a tendency to pull through the socket walls, particularly if the fit between the socket and frame distally was not solid. With Velcro,® it is of course possible with minimum effort to remove the socket from the frame for repairs or adjustments.

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