DIRECT FORMING OF BELOW-KNEE PTB SOCKETS WITH A THERMOPLASTIC MATERIAL

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This procedure of direct forming of below-knee PTB sockets with a thermoplastic material was first described by the VAPC staff in the March 1969 issue of "Orthotics and Prosthetics," the Journal of the American Orthotic and Prosthetic Association. Since that date, simplifications were developed in the technique, particularly in the elimination of the pressure apparatus, the use of which also proved not too advantageous for the fitting of newly amputated stumps. The updated version of the description detailed here still employs much of the original text with pertinent portions rewritten to accommodate the changes in the procedure.

The authors also wish to acknowledge the contributions of the entire VAPC staff in the development of this technique.

INTRODUCTION

Research and development groups especially in Toronto, Miami, and New York have recently been using thermoplastics which when softened can be applied on the body to form orthotic or prosthetic sockets. Sockets for both fracture braces and artificial limbs have been made with these materials.

Noted has been the particularly successful employment of tubes and sheets made from a material called POLYSAR® X-414 synthetic rubber, a resin available from the Polymer Corp. of Sarnia, Ontario, Canada. Johnson & Johnson of New Brunswick, N.J., has made this thermoplastic available in sheet form. Recently, Delford Industries of Middletown, N.Y., has been extruding tubes made from POLYSAR® X-414; such tubes are now available from the U.S. Manufacturing Co. of Glendale, Calif.

Presented in this article is a description of the use of tubes made from this particular synthetic balata (rubber) in direct forming of sockets on below-knee amputation stumps. An evaluation of this procedure and the material is now being conducted by the Committee on Prosthetics Research.

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and Development, National Academy of Sciences—National Research Council. Five clinic teams in the United States are fitting patients following the procedure described in this article. New York University's Prosthetic Research Study is evaluating the use of the thermoplastic tubes in forming below-elbow sockets directly on amputation stumps. It is expected that these evaluations will proceed expeditiously and that sometime during 1969 results can be made available to clinicians and practitioners throughout the world.

Mr. Henry Gardner of the VA Prosthetics Center presented a demonstration of direct forming at the 1968 National Assembly of the American Orthotics and Prosthetics Association. It is believed desirable to support that presentation with the material presented here. Eventually, after the evaluations described above are completed, step-by-step manuals will become available. Hopefully, university and college educational programs will consider presenting this or a similar technique in their curricula.

In the meantime it would be advisable for prosthetists and orthotists to give some consideration to the information contained in this article. It is believed that this procedure or one like it with the same material can expedite the provision of prostheses for patients who now sometimes have to wait an excessively long time for a limb. The prosthesis as described seems to offer improvement over present types of temporary prostheses. It is also believed that there are possibilities for using this type of device in "semi-permanent" and definitive prostheses. But most important is the possibility of accelerating the processing of amputee rehabilitation.

THE SIGNIFICANCE OF THE METHOD

Experience suggests that use of tubes made from POLYSAR* X-414 synthetic rubber in the direct forming of below-knee sockets will expedite prosthetic care for patients. The presently described method of direct forming can be used at least for temporary below-knee sockets in conjunction with a metal skeletal (pylon) structure. Moreover, it seems possible to use the same plastic in forming sockets for definitive prostheses, provided a reasonably simple cosmetic treatment can be applied to the skeletal structure. One method for doing this is given below. With cases for whom so-called temporary prostheses may be used, it often is desirable to render a cosmetic treatment to the limb either while a permanent or definitive prosthesis is being formed or for the period when prescription of a definitive limb is questionable. The method of finishing described here might be used for such situations.

Some researchers are interested in the possibility of using the socket forming method described here or a modified method, but with the same material, to form sockets at some point in the immediate postsurgical prosthetic

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fitting routine. It is certain that attempts will be made to use this particular synthetic rubber or a material like it at the time of the first rigid dressing change. Indeed several research groups are interested in the possibility of using this material in tubular form for the first rigid dressing. Careful and very deliberate technique development is certainly required before such applications become routine.

The possibility therefore exists of developing a thermoplastic rigid dressing which could gradually be modified to a below-knee weight-bearing socket for early ambulation. Then it can be subsequently altered as needed for the definitive socket. Throughout, the same "pylon" structure can be used from time of surgery to and including employment of the definitive prosthesis. Because of the ability to alter the contours of a thermoplastic socket through postforming, and also because the "pylon" structure contains alignment adjustability, practitioners may eventually have available a reasonably adjustable prosthesis as amputee stump changes take place and as amputee capability improves. The prosthodontist can thus alter the biomechanics of the prosthesis as needed through changes both in fit and alignment. Also, later during the use of the definitive prosthesis, the ability to adjust both fit and alignment would be beneficial in allowing simple corrections to overcome some of the socket comfort problems normally seen in clinics.

Thus, forming sockets directly on amputation stumps is a potentially valuable procedure offering possibilities for improved socket fit, easier socket modification, and substantial reduction in fabrication time. The techniques may also be more readily mastered than those used for fabrications in the conventional manner as when an intermediate plaster-of-paris replica must be formed.

The direct-forming process depends on the use of a material which: a. is plastic at temperatures moderately above ambient but requires reasonably high temperatures to soften subsequently; b. is easily worked under conditions found in most limb shops; c. has a “poor memory,” i.e., once set, it should not change its shape; d. exhibits minimum “creep” or deformation under load even at temperatures slightly above body temperature; e. is nontoxic; f. has a reasonable strength-to-weight ratio; g. is reasonably flexible in its “hardened” state.

THE MATERIAL, POLYSAR® X-414

POLYSAR® X-414, a synthetic similar to natural rubber, possesses most of the necessary properties for forming a socket directly on a stump. At temperatures between 160 deg. F. and 180 deg. F. it becomes plastic. It does not give up its heat readily and thus can be applied to the amputation stump within a minute or two after softening. It remains reasonably plastic

* Registered trademark of the Polymer Corp. Ltd.
after its surface temperature drops 20 to 30 deg. When plastic, it exhibits extraordinary cohesive properties.

Laboratory tests indicate that after it cools and becomes nonplastic, it maintains its shape even under stress and subsequent heating to temperatures of 120 deg. F. Other tests have shown that conventional fastenings, rivets, and screws are adequately retained so that it is possible to use all conventional components and accessories with sockets made using this particular synthetic rubber.

Clinical findings indicate that the sockets will remain durable provided excessive heat exposures are avoided. Leaving the limb in the sun, in the trunk of a car on a hot day, or leaning against a house radiator can cause distortions. Amputees should be cautioned about such situations.

Excessive exposure to perspiration may also cause erosion of the material after about a year. Normally stump socks will act as adequate barriers.

The synthetic rubber is quite flexible, not presenting the rigid, unyielding typical of most plastic laminates. Indeed, this characteristic of the thermoplastic used in this procedure may be one of its major advantages.

THE DIRECT-FORMING METHOD

When using tubes made from this resin, forming of a socket directly on the stump is reasonably simple. One step with this material is equivalent to the whole process of fabricating a conventional socket, thus making it unnecessary to: a. make a plaster-of-paris wrap cast; b. pour a positive cast; c. modify the positive cast; and d. laminate. These steps with modified stump replicas are certainly error prone, based wholly on hand-formed contours. It seems desirable to eliminate the dependencies on cast taking and the lamination process in forming artificial limbs.

Regardless of the material used, obtaining a perfect replica of the below-knee stump is extremely painstaking. Even if it were simple, such a replica would not represent the best biomechanical shape for sound weight bearing and control. When casting the stump, consideration must be given not only to the distortions caused by pressures upon the passive stump mass but also to the special requirements of weight bearing and control during ambulation.

When using conventional hand casting procedures, the stump is subjected to pressures of unknown magnitude and distribution yielding a contour which may provide the proper forces for prosthesis control and support of body weight in the socket. However, when the stump is subjected to generally equal pressure as in the method described here, deformations will take place as a function of the resistive characteristics of the underlying tissues. The bony tissues of the stump will tend to protrude more as the soft tissues are compressed. (The pressure on the fleshy tissues will tend to reduce any edema present; the socket contour so determined will then maintain some control of edema.)
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Experimentation with various pressure casting methods has been carried on for several years. In 1958, Mr. Paul Leimkuehler of Cleveland, Ohio, used a vacuum system for casting below-knee stumps. His system was based upon the "dilatancy" principle. In 1960, Mr. Colin McLaurin then at Northwestern University experimented with a hydraulic method of pressure casting. In 1963, Mr. T. Meyer of Detroit, Mich., also used a hydraulic method of casting. All of these methods required the use of a canister or rigid pressure chamber and a casting stand. The complexity of the techniques discouraged further development. With the availability of materials such as POLYSAR® X-414, a renewed effort was made to develop an adequate pressure-casting method. This led to the design and application of a pneumatic pressure system. The pneumatic pressure-forming apparatus was designed to control the external pressures used to form the plastic socket over the below-knee amputation stump. However, using this method the socket contours obtained were soft, redundant stumps were biomechanically inadequate. As a result, a simple hand wrapping technique was developed using pressure-sensitive tape over the heated tube (Fig. 1) to provide the external pressures necessary to control stump volume. The socket is then hand molded into the desired shape.

PREPARATION OF THE PATIENT FOR SOCKET FORMING

A careful evaluation of the stump must be conducted prior to forming the socket. All stump characteristics, especially conditions which require special considerations for socket comfort, must be noted. Other usual prosthetics data such as the measurements required for the fabrication of the prosthesis are also essential.

![Figure 1.—Elastic tape wrapped over softened plastic material supplies socket forming pressure.](image)

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With the patient seated, a lightweight cast sock is applied snugly (Fig. 2) to maintain tension. The top of the sock is clamped to a strap encircling the patient's hips. The strap is made up of two halves of mating Velcro for easy adjustment behind the patient's back. The two free ends are equipped with Yates clamps for holding the socks. The clamps are placed medially and laterally at the top of the sock.

A strip of $\frac{1}{4}$-in. felt cut to form a tibial crest relief is positioned from the superior border of the tibial tubercle to over the end of the stump (Fig. 3). The portion of the tibial relief pad over the tubercle is made approximately 1$\frac{1}{4}$ in. wide. It tapers down to a $\frac{3}{8}$-in. width for the entire length of the tibial crest relief. All edges are carefully skived. If adhesive-backed felt is not available, medical adhesive may be used to attach the pad.

A second lightweight cast sock is pulled snugly over the tibial relief and fastened in the same manner as the first sock (Fig. 4).

The anterior-to-posterior knee measurement is recorded at the level of
the patellar tendon using the VAPC knee caliper (Fig. 5). The medial-to-lateral dimensions of the epicondyles of the femur are measured in the same manner. These dimensions are useful in determining the accuracy of the socket. The maximum depth of the patellar ledge is established by this measurement.

**SOCKET FORMING**

A section of ¾-in. wall synthetic rubber tubing is selected. Its length should be approximately 1½ times the distance measured from the top of the knee to the end of the stump (Fig. 6). The diameter of the tube selected should be one-third of the mid-stump circumference.

A section of Helanca stockinet 3 ft. in length is used to pull the heated tube over the stump. One end of the stockinet is pulled up on the stump as shown in Figure 7. The other end is passed through the heated tube.

The inside surface of the tube is carefully cleaned to remove all plastic dust created by cutting and drilling. *When heated, the dust will cohere to the inner walls causing undesirable irregularities in the surface.*

The tube, thoroughly free of dust, is softened by immersing it completely in water heated to a temperature of 180 deg. F. or just under the boiling point for 4 to 6 minutes. *The inner walls of the heated tube must be prevented from touching since they will cohere instantly.* This may be prevented by standing the tube on its end in the water container. After heating, the tube is removed from the container.

Part of the tube is preshaped into a cone prior to placing it over the stump. With the hands together (palms out), the upper half of the tube is stretched into a cone to facilitate slipping it over the knee. The loose end of the stockinet hanging from the stump is threaded through the heated tube. The tube is pushed to the end of the stump and carried up over the stump by a continuous pull on the stockinet (Fig. 8).
Twists or folds in the stockinet should be avoided while drawing the stockinet and plastic tube over the stump. The forming pressures which compress the soft thermoplastic produce a slight imprint of the stockinet material on the inner surface of the socket. *Any folds or twists in the stockinet will cause undesirable irregularities in the inner socket wall.* The top of the stockinet is then clamped in the same manner as the cast socks.

The upper socket borders are trimmed with a pair of bandage shears leaving the posterior borders approximately $\frac{1}{2}$ in. higher than required for later rolling out of the material to form a relief for the hamstrings (Fig. 9). The remainder of the socket border is cut transversely above the superior pole of the patella. The tube and the stockinet extending past the end of the stump are trimmed to provide an extension of 3 in. beyond the stump end.

The stump is held relaxed in 5–10 deg. of flexion. Starting approximately $\frac{1}{2}$ in. above the stump end, a snug wrap of 1 in. pressure-sensitive tape is applied over the tube with increasing tension as the wrap reaches the level of the medial tibial flare and up over the knee (Fig. 10). The wrap is made in a continuous spiral from the anterior to medial direction. Tension is best controlled when one hand stabilizes the socket while the other wraps one-half of the circumference. The hands then change functions to wrap the other half of the circumference.

The section of soft tubing extending past the stump end will tend to sag. This must be prevented by supporting this section until it cools while molding the material to provide freedom over the anterior end of the tibia. Approximately 10 minutes is required for the material to harden. During
A heat gun is used to modify the socket. To focus the output of the heat gun, a metal cone is made to fit over the end of the gun (Fig. 12). The hand should be placed inside the socket against the surface to be modified. Heat is directed to the immediate area from close range until the heat is sensed by the fingers through the socket wall. Large areas should not be heated nor should heat be directed against the socket for a prolonged period of time. Excessive temperature will cause the plastic to boil and discolor. When molding for a pressure point, one finger should press from
inside the socket, and the surrounding areas should be supported on the outside of the socket with the fingers of the other hand. After the molded area has cooled sufficiently to retain its shape, the socket should be chilled with cold water or refrigerated for a short period of time to reset the plastic. **Caution must be exercised to avoid heating the entire socket. The heat should be concentrated on the one spot until the pressure applied with the fingers on the hand inside the socket causes the material to yield.**

A similar procedure should be followed if a more pronounced patellar-tendon ledge is required. The previously obtained anterior-posterior measurement will determine the depth of the patellar ledge. For patients who have previously worn prostheses, the anterior-posterior measurements obtained by caliper are used to determine the depth of the ledge. For patients who have had recent amputations, the patellar-tendon ledge is not molded to the maximum depth in one adjustment. Instead three or more adjustments at intervals of 1 month should be made until the recorded anterior-posterior dimension is reached.

The posterior socket border is heated and rolled out to form a smooth radius for comfortable knee flexion (Fig. 13). The posterior socket level is maintained at approximately the patellar-tendon level.

An adjustable pylon is prepared with a wood socket attachment block 1½ in. thick and 3 in. in diameter with a ¼-in. deep circumferential groove midway along the length of the block. The wood block is tapered to form a slightly smaller diameter around the bottom. Then the wood block is fastened permanently to the pylon with bolts and cement (Fig. 14).
The tube end extending distally from the socket is heated and then is fitted over the wood pylon attachment block with the groove helping to make a good bond. A 1-in. space between the stump end and attachment block must be maintained. The tube is taped tightly to the wood block and permitted to cool (Fig. 15). Any excess tubing extending below the wood can be trimmed while the plastic is still soft. When hardened, the tube is fastened permanently to the wood block with four wood screws set through the plastic into the wood at 90 deg. angles to one another.

Several kinds of PTB suspension can be provided with this socket. The socket can be trimmed at the regular PTB level and a separate cuff used above the knee. Or a suprapatellar-supracondylar suspension can be provided as follows: The patient's stump is covered with two cast socks. The upper socket walls above the level of the upper border of the patella are softened by holding the socket bottom up in hot water. When the socket top is heated, the socket is placed on the patient seated in a chair with his knee flexed at approximately 45 deg. His stump is pushed firmly into the socket. The plastic is molded against the thigh over the condyles by wrapping tightly with pressure-sensitive tape and hand molding.

After the patient has been fitted and the prosthesis aligned, the bottom of the socket chamber should be foamed to obtain a total-contact fitting. Three \( \frac{3}{8} \)-in. holes are drilled through the socket wall where the extension was blended into the stump contour. A PVA cap is formed over the stump sock-covered stump. A foam mixture is prepared and poured into the socket (Fig. 16). The patient's stump is inserted into the socket and the patient stands quietly until the foam has set. The foam mixture may vary, depending upon the type of stump and condition of the distal tissues. Usually, a
A semirigid foam leg shape can be made from prefabricated sections of a B. F. Goodrich Co. foam product called Koroseal "Spongex.

Beginning at the level of the patella, a paper pattern is cut to fit around the socket at this level. The pattern is traced upon the first foam section (Fig. 17). The foam is carefully sanded to form a hollow for the socket. It is necessary to obtain a tight "gap-free" fitting of the foam to the socket. Best results are obtained from a slight stretch fit. For this, the foam is heated in an oven at 180 deg. and then placed over the socket.

To cover the remaining part of the pylon, a foam block is cut long enough to match the distance between the bottom of the foam surrounding the socket and the top of the foot plus ¼ in. A hole is made through the length of the foam large enough to receive the pylon tube. Since the foam is semirigid, the cutout areas for the alignment coupling and ankle plug of the pylon are made slightly undersize to form a snug fit about the pylon (Fig. 18).

A ½-in. hole is bored transversely through the foam block to permit entry of a screw driver to fasten the tube clamp. The bottom foam block is not glued to the top foam block. Compression of the extra-length foam block between the socket base and the foot will prevent any movement of the foam and permit easy removal for alignment adjustments.
Figure 17.—Foam blocks prepared for fitting over pylon and socket.

Figure 18.—Foam blocks fitted over socket and pylon and rough shaped.

Shaping is done by a band saw or knife and final sanding with a drum or cone sander. A flexible polyurethane coating over the foam or a stocking cover is recommended for cosmesis (Fig. 19).

Figure 19.—Flexible plastic coating over stocking-covered foam.

*b See cosmetic finish procedure.
COSMETIC FINISHING PROCEDURE
FOR
SOFT-VINYL FOAM-TYPE PROSTHESES

I. Materials Required
   a. Chemical name:
      Methyl Ethyl Ketone (MEK) to clean brushes.
      Methyl Isobutyl Ketone (MIBK) to slow solvent evaporation (for final coat).
      Tetrahydrofurane (THF) to accelerate solvent evaporation.
      Low Modulus Urethane (LMU) to improve resilience of foam.
      Urethane Coating (uc) (available in caucasian or negroid) to obtain a flexible-durable cosmetic finish.
   b. Uniform finish mat:
      L/E (nylon—seamless woman’s stocking).
      U/E (Helanca armlet).

II. Procedure
   a. Completely cover the foam with one coat of LMU and allow to dry (approximately 5–10 minutes).
   b. Pull the nylon stocking or armlet over the LMU coated prosthesis.
   c. Coat the prosthesis with four coats of urethane coating (uc).
   d. Final coat, add some MIBK to the uc and coat the entire prosthesis, yielding a smooth external finish.

III. Source of Supply
   a. Chemicals:
      U.S. Manufacturing Co., 623 S. Central Avenue, Glendale, Calif. 91209.
   b. Uniform Finish Mat:
      U/E—Nylon Armlet RN—23952