

# AIR-CUSHION SOCKET FOR PATELLAR-TENDON-BEARING BELOW-KNEE PROSTHESIS

## Principles and Fabrication Procedures<sup>ab</sup>

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### I. INTRODUCTION

One of the most significant improvements in lower-extremity prosthetics in recent years has been the introduction of the patellar-tendon-bearing below-knee prosthesis (1). Elimination of the thigh corset as a weight-bearing element of the prosthesis results in increased freedom of movement and, when total contact between socket and stump is also provided, in improved circulation and control of edema.

Although thousands of amputees have been successfully fitted with the PTB prosthesis, problems related to edema or to excessive pressure on the distal end of the tibia, the fibula, or both still occur in some cases.

Foort and Johnson (2) have shown that a lack of stump/socket pressure over part or all of the distal area is the cause of most cases of edema occurring in the stump when a prosthesis is worn. Such edema can usually be eliminated by the establishment of intermittent distal stump/socket pressure of approximately 2 p.s.i. Edema can also be caused by excessive

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proximal stump/socket pressure, which creates an increase in the pressure difference between the distal and the proximal portions of the stump, with resulting accumulation of fluid distally. This problem often arises as a result of the provision in sockets of relief areas for the pressure-sensitive spots which occur in some stumps over the distal ends of the tibia and/or fibula. If these relief areas are excessive, the possibility of having sufficient pressure on the distal portion of the stump is reduced, and a need for a tighter fit in the proximal area, with increased risk of edema, is introduced. In addition, there is an increased possibility of skin damage as a result of tension and abrasion over the ends of the bones as the stump moves distally during weight bearing.

Although some of these problems obviously are a result of incorrect fitting, it is evident that most of them could be avoided with use of a socket designed to increase distal stump/socket pressures in a comfortable manner and at the same time reduce proximal pressures.

The air-cushion socket incorporates an internal elastic sleeve (made by lamination of a knitted nylon stockinet with room-temperature-vulcanizing (RTV) silicone rubber) which encloses the distal end of the stump below the level of the tibial tubercle. The elastic sleeve is attached to the proximal part of the external socket shell. Thus, the elastic sleeve provides support distally in two ways: through tension in the elastic sleeve itself and through the variable pressure generated within a sealed air volume beneath its end as the amputee walks; the compressed air volume provides a considerably increased but comfortable pressure on the distal end of the stump, so that pressures on the patellar tendon and on the popliteal area may be reduced. Furthermore, the elasticity of the sleeve reduces the tendency for skin to stretch over the distal end of the tibia and/or fibula and eliminates abrasion due to rubbing of skin against the internal surface of the socket.

This report describes in detail the functional advantages of this modified PTB socket, amputee experience with it, techniques for stump casting, necessary cast modifications, and materials and methods for its fabrication.

## **II. PRINCIPLES OF DESIGN AND FUNCTION**

### **A. Description**

The air-cushion PTB socket (Fig. 1) consists of an external, rigid, polyester-laminated shell and an internal, elastic RTV silicone rubber-stockinet/laminated sleeve which are joined at the level of the tibial tubercle. The rigid socket shell provides direct support for the stump area proximal to the level of the tibial tubercle and extends distally on the outside of the elastic sleeve to about 1 in. above the distal end of the tibia. The elastic sleeve encloses the distal part of the stump below the level of the tibial tubercle. A polyester-laminated cap bonded to the outside of the

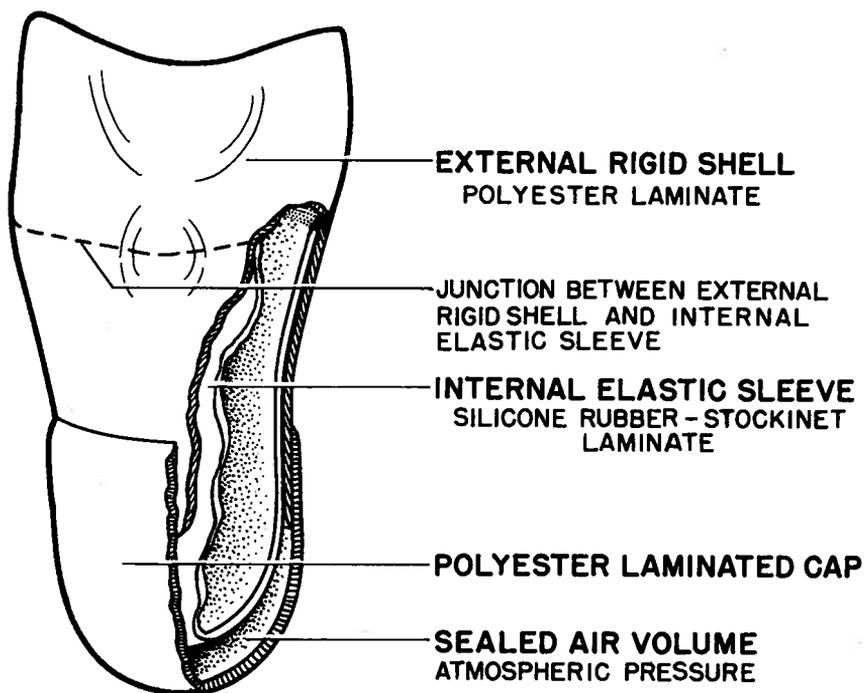


FIGURE 1

distal portion of the rigid socket shell provides a small sealed air volume distal to the elastic sleeve.

### B. Functional Characteristics

Use of this socket design requires minor changes from the cast-modification procedures described in "The Patellar-Tendon-Bearing Below-Knee Prosthesis (1)." Because these changes are essential to the function of the socket, a thorough understanding of its functional characteristics is necessary before modification of the cast can be done correctly.

Since the internal elastic sleeve and the external rigid socket shell are joined at the level of the tibial tubercle only, the elastic sleeve is able to move distally from the line of junction, while lateral movements are controlled by the rigid socket shell.

The socket (without the cap) is constructed to be somewhat shorter than the actual stump length. Therefore, during weight bearing, when the stump moves distally with respect to the socket, the elastic sleeve stretches, thus providing increasing support of the distal end of the stump. Simultaneously, the elastic sleeve tends to contract around the stump, with this tendency gradually decreasing toward the junction between the elastic sleeve and the rigid socket shell. This effect is, in principle, similar to that which

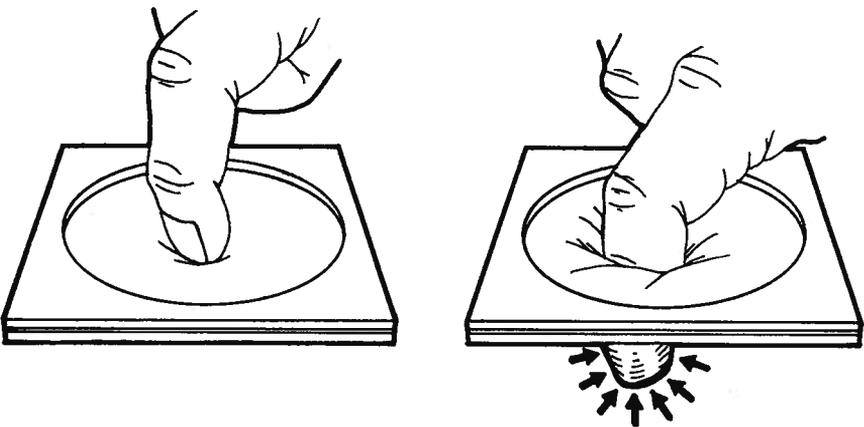
occurs when a finger is pushed against a suspended sheet of elastic material (Fig. 2).

An additional source of stump/socket pressures is the sealed-in air volume distal to the elastic sleeve. Since volume and air pressure are inversely proportional at constant temperature, the pressure in the closed air chamber will increase as the elastic sleeve stretches distally under load—unless the contraction in the transverse plane, which occurs simultaneously, neutralizes the volume change caused by longitudinal stretching.

Recordings of this air pressure made with a pressure transducer on several amputees have shown that maximum values of 1.0 to 2.0 p.s.i. of positive pressure and 0.5 to 1.2 p.s.i. of negative pressure are produced during the stance and swing phases of the walking cycle, respectively. These recordings indicate that the stump is in close contact with the socket during the complete walking cycle, that an air-cushion effect is generated in stance phase, and that negative pressure contributes to the suspension of the prosthesis during swing phase. A typical curve of magnitudes of air pressures generated in the closed air chamber is shown in Figure 3.

The magnitude of the air pressure depends on the size of the air volume provided, the elasticity of the sleeve, the overall condition of the stump, the weight of the amputee, and the fit of the socket. Because of all these variables, no exact air-pressure magnitude can be predetermined. However, when the recommended procedures for cast modification and socket fabrication are followed, air pressure within the ranges mentioned should result.

In order to compare the total axial load supported by the combination of the elastic sleeve and the air cushion with the total load supported by the entire socket, a force-moment transducer and a special frame to incorporate



**FIGURE 2**

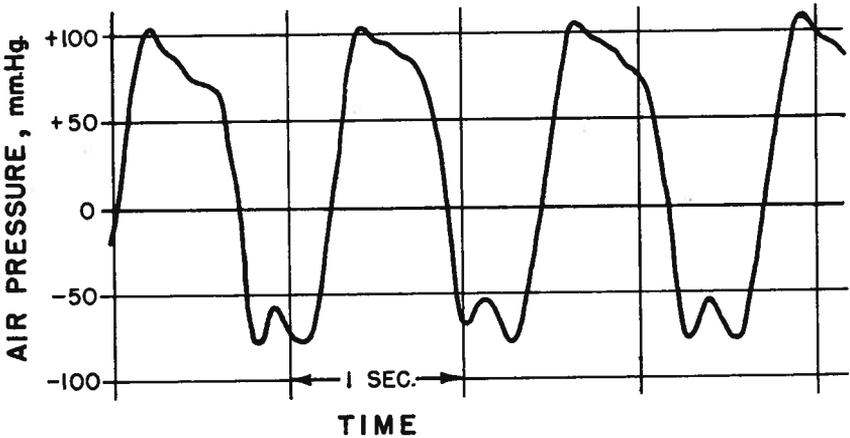


FIGURE 3

an air-cushion socket were designed and measurements taken with one amputee subject. The results of this study of dynamic stump/socket contact forces and pressures in the air-cushion socket (3) have shown that the total dynamic axial load during level walking was 120 percent of the static body weight,  $W$ . The elastic sleeve and the air cushion carried 61 percent of the dynamic load ( $0.73W$ ) on the distal two-thirds of the stump. The proportion of distal stump support due to the air-cushion effect in comparison with the total distal stump support is not known exactly, but from estimates of the distal stump cross-sectional area multiplied by maximum air pressure a value of approximately 15 percent of the dynamic load ( $0.18W$ ) appears reasonable. The remaining 44 percent of the dynamic load carried distally ( $0.55W$ ) is carried by tension in the elastic sleeve.

The higher pressure on the distal as compared with the proximal portion of the stump minimizes the risk of development of edema. The possibility of skin damage caused by stretching of the skin over the distal end of the tibia and/or fibula is reduced because the elastic sleeve moves distally with the stump during weight bearing. It is also possible that the gradually increasing pressures exerted around the stump by the elasticity of the sleeve and the increased air pressure between the socket and the sleeve contribute to the reduction of skin movements relative to the bony structures.

### C. Modification of Plaster Stump Model

Maximum socket function, achieved by certain changes in the model modification procedure, is provided by a combination of increased distal socket pressures and reduced (but not eliminated) pressures on the patellar tendon and the popliteal area. The stump model is shortened an average of

$\frac{1}{8}$  in., a procedure which eliminates the possibility of lack of contact between any part of the distal stump area and the elastic sleeve even when only a minimum of weight is supported.

The ability of the elastic sleeve to conform to the stump increases considerably the area and magnitude of distal stump/socket pressures, resulting in a more functional and comfortable partial end-bearing socket. The increased support on the distal portion of the stump makes it possible to reduce the prominence of the patellar-tendon protuberance by  $\frac{1}{4}$  in. without apparent increase in piston action between stump and socket.

### **III. CLINICAL EXPERIENCE WITH AIR-CUSHION PTB SOCKET**

#### **A. Amputee Reactions**

During the initial research program, a total of 15 amputees were fitted with the air-cushion PTB socket and results have proved that this particular kind of socket construction was superior to that of the standard PTB socket.

All of the amputees studied had fitting problems such as edema, ulceration, and areas of hypersensitivity on the distal end of the stump, and all were considered difficult to fit. All of them had previously worn either standard PTB prostheses or conventional below-knee wooden prostheses with thigh corsets.

Five amputees were first fitted with PTB prostheses with standard sockets. The fittings were done according to the best standards of current practice and were considered highly successful by the amputees as well as by the staff. The prostheses were worn for normal daily activities over periods of 4 to 8 months. During this time experimental air-cushion PTB sockets were fitted and tried in the laboratory but not used for routine activity. The air-cushion PTB sockets were made as duplicates of the standard PTB sockets worn by the amputees, except that the plaster models were shortened  $\frac{1}{8}$  in. by the removal of plaster from the distal end of the cast prior to socket fabrication.

The final air-cushion sockets were delivered at the end of the 4-to-8-month experimental period. All five amputees experienced a comfortable increase in distal stump/socket pressure. Moreover, all felt that a further increase in pressure would be beneficial. This was provided for by a  $\frac{1}{4}$  in. reduction of the prominence of the patellar-tendon protuberance. All amputees reacted favorably to this adjustment. In one instance, the patellar-tendon protuberance was later completely removed. The immediate effect for this amputee was further increase in comfort; however, after he had worn the prosthesis over a weekend which was occupied with work around his house, he felt that some pressure on the patellar tendon would be advantageous.

One of the five cases, which was considered to be the most difficult, presented serious problems which were described in the medical examination as follows:

Right BK amputation. Distal 1 in. of the stump is indurated, with multiple crevices in the thickened skin. A 1-in. long, deep crevice is surrounded by white, chronically soaked, thickened tissue. Serous exudate is seen on the 3-in. by 3-in. area of the base of the stump sock. The stump is about 7 in. long and is in good condition except for the end. No popliteal pulsation is felt.

The amputee wore the standard PTB prosthesis for 4 months, during which time the stump conditions improved only slightly. An air-cushion PTB socket was then delivered to him. After he had worn this socket for 4 months, the report of a new medical examination was as follows:

The stump is completely healed. There are three crusts at the tip, the largest of which is 1/8 in. by 3/16 in. There is no tenderness, redness, or edema and there are no complaints. The subject reports that his stump has not been in such good condition in years.

The amputee, who is a prosthetist, continued working during the entire test period. He described his condition while using the new type of socket as comfortable, and also mentioned that perspiration had decreased.

An additional 10 amputees were fitted directly with the air-cushion PTB socket according to the procedures described in this report. All 10 fittings were classified as successful by both the amputee and the staff of the Biomechanics Laboratory. No child amputees were included in the research program.

It can be concluded that the increased comfort experienced by all amputees fitted with the air-cushion PTB socket is a result of increased distal stump/socket pressures and decreased pressures in the proximal area. No increase in perspiration has been observed.

## **B. Criteria for Prescription**

It can be concluded that all amputees fitted with the air-cushion socket in this research study have experienced improved comfort as a result of intermittent pressure against the distal stump tissues. As stated earlier, no increase in perspiration has been observed.

Clinical experience with this technique in some centers has indicated that there may be difficulty in maintaining the proper fit in certain patients because of rapid stump shrinkage. For this reason the air-cushion socket may be contraindicated as the first permanent socket in an immediate postsurgical fitting or in any fitting where rapid shrinkage is anticipated. The ability to alter the fit with an insert, which can be done with the standard PTB socket, is a definite advantage in these cases. Obesity, a painful neuroma, or other conditions which limit distal contact may also be reasons for contraindication in individual cases.

#### **IV. PLASTER BANDAGE WRAP CAST PROCEDURE**

##### **A. Materials Required for Taking Wrap Cast**

1. One or (for very long stumps) two rolls of orthopedic plaster bandage, 4-in. width. (Elastic plaster bandage is not recommended.)
2. Basin of clean water at room temperature
3. One thin cast sock that fits snugly over the stump and covers the thigh well above the knee
4. One 4-ft. length of 1-in. webbing
5. Two harness clamps
6. Indelible pencil
7. VAPC caliper
8. Combination square with 12-in. blade
9. Plywood 20 deg. protractor (as illustrated in Fig. 6)
10. Prosthetic Information Sheet

##### **B. Procedure for Taking Cast**

This procedure, when used in conjunction with the methods described later for modification of the plaster model of the stump, will result in a satisfactory fit of the air-cushion socket. Other methods of taking the wrap cast will necessitate deviations in the modifications of the plaster model of the stump from those described in this manual and, in general, will not give optimum results.

Hand-wrapping a below-knee stump with plaster-of-paris bandages has certain advantages. A knowledgeable and experienced prosthetist can, during the wrapping procedure, 1. mold the cast to take maximum advantage of the pressure-tolerant areas of the stump, 2. visually locate important contours of the stump and palpate for location of bony prominences and the patellar tendon, 3. shape the proper contours into the cast, 4. have complete control over the orientation of the cast to the stump in relation to the line of progression, and 5. analyze the stump in terms of modifications that will be needed on the plaster model in order to reduce the extent of such modifications.

Be sure that the Prosthetic Information Sheet is completely filled out; all information required for fabrication of the prosthesis should be obtained at this time.

##### *1. Posture of Amputee*

With the amputee seated on a table, position the amputated leg so that the midline of the thigh is perpendicular to the front edge of the table, and the back of the knee is approximately 4 in. from the edge (Fig. 4). This will position the stump for wrapping so that the finished socket is in the correct relationship to the line of progression during walking.

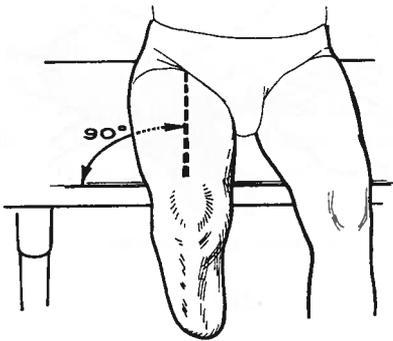


FIGURE 4



FIGURE 5

## 2. Application of Cast Sock

Roll a thin, moistened cast sock over the stump with firm, uniform tension. A snug fit over the entire stump, without excessive tension, must be maintained. The fit may be checked by pinching the cast sock to form a fold which is pulled away from the surface of the stump. The sock should snap back against the stump when released. This snug fit will prevent shifting of the cast sock so that the markings to be made later will remain in correct position over the anatomic features of the stump. Keep the sock in position with a strap or belt around the pelvis (Fig. 5). When there is a large amount of body hair, removal of the cast is facilitated by first coating the stump with petroleum jelly or a similar parting agent.

## 3. Establishment of Angle of Knee Flexion

A simple 20 deg. plywood protractor with a cutout to eliminate contact with the patella is useful for checking the angle of knee flexion during the wrap-cast procedure. With the protractor as a guide, position the stump with a 20 deg. angle between the anterior surface of the thigh and the anterior crest of the tibia as shown in Figure 6. Instruct the amputee to maintain this position, with as little muscle tension as possible, during the complete casting procedure. Ask the amputee to hold the protractor and check this flexion angle frequently and carefully during the casting. A change of as little as 1 deg. in the stump-thigh angle during the casting procedure can result in a noticeable shift of indelible markings and an unsatisfactory cast.

## 4. Measurement with VAPC Caliper

The mediolateral measurement is made across the epicondyles of the femur (Fig. 7).

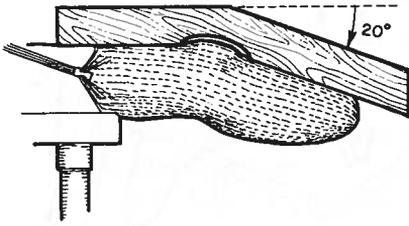
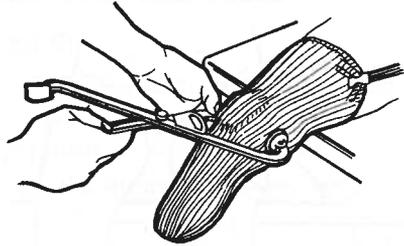


FIGURE 6



MEDIOLATERAL MEASUREMENT

FIGURE 7

The anteroposterior measurement is made while the stump is supported by the prosthetist's hand, to allow relaxation of the patellar tendon. Position the caliper so that the popliteal pad is correctly placed (about  $\frac{1}{2}$  in. distal to the patellar bar) and the patellar bar indents the patellar tendon (Fig. 8).

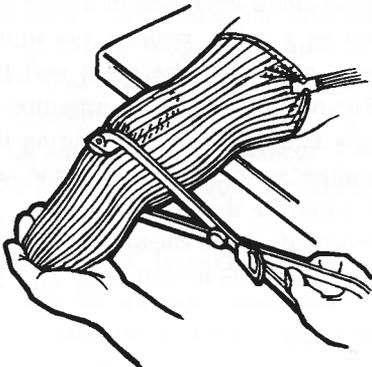
The VAPC caliper has a 3-lb. tension which will give accurate and constant measurements of these dimensions.

#### 5. Marking of the Cast Sock

Check the 20 deg. flexion of the stump. Remind the amputee again to maintain this position.

Use the indelible pencil to mark the moistened cast sock as follows (Fig. 9). These markings will serve as a guide to removal of plaster in the model modification procedure.

- a. Outline the patella.
- b. Mark the most prominent point and outline the tibial tubercle and the head of the fibula. Be sure the entire fibular head is outlined.



ANTEROPosterior MEASUREMENT

FIGURE 8

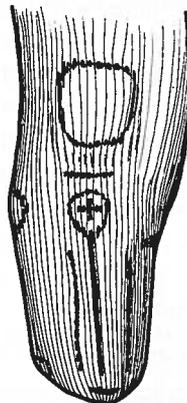


FIGURE 9

c. Draw a line across the anterior surface of the patellar tendon midway between the inferior border of the patella and the prominence of the tibial tubercle. Test by locating the condylar “notch” on either side of the patellar tendon before making the mark.

d. Draw a line down the anterior crest of the tibia and draw a transverse line at the distal cut end of the bone if this is prominent.

e. Draw lines down both the anterolateral and anteromedial crests of the tibia at the junction between the bony ridge and the neighboring soft tissue. Locate the end of the fibula and draw a transverse line at that level.

f. Draw a line to define the potentially good area for bony support on the medial flare of the tibial condyle. Mark the line where the underlying structure changes from bone to soft tissue. This line indicates the distal limit of support on the medial flare of the tibial condyle.

g. Outline any areas of increased prominence or sensitivity such as may be noticeable over the tibial crest, as well as sites of bone spurs or neuromas.

#### 6. Measurement of Length of Stump

Measure the length of the stump, parallel to the crest of the tibia, to the midpatellar-tendon mark (Fig. 10). This measurement aids in placing the thumbs in the correct position during casting. It is also used to establish the proper length of the finished socket to insure that the distal end of the stump has the correct amount of support during stance phase.

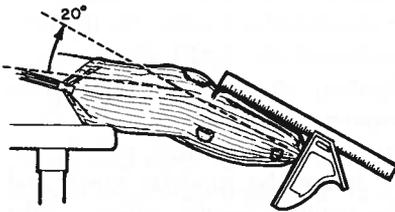


FIGURE 10

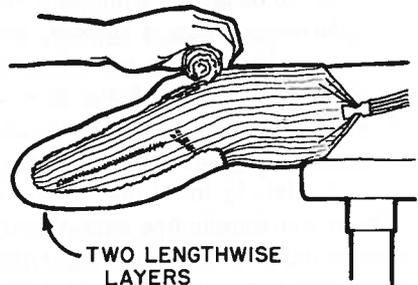


FIGURE 11

#### 7. Wrapping of Stump

Soak plaster-of-paris bandage in cold water. Do not squeeze excessively—use dripping wet. Begin the wrap by laying on two layers of plaster bandage lengthwise. If rubbed well into the cast sock, they will stay in place (Fig. 11).

Begin the circumferential wrap starting at the upper border of the patella and, using a figure-of-eight pattern with moderate tension, smoothly apply five layers of plaster bandage. Rub the bandage well between layers

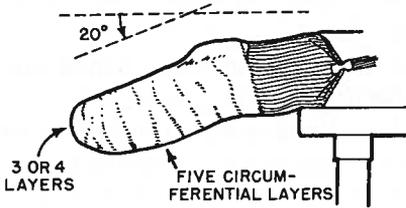


FIGURE 12

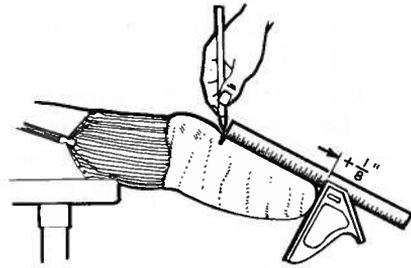


FIGURE 13

to insure a smooth, even cast. Proceed to spiral down the stump with about a 1-in. overlap. Keep the wrap smooth by taking tucks as required and rubbing well between layers. Do not make ridges in the cast by excessive tension during wrapping. Continue over the end of the stump, tucking the bandage to conform, until the distal end is covered with the equivalent of 3 to 4 layers—thickness of approximately  $\frac{1}{8}$  in. (Fig. 12). Cut off any remaining bandage. This procedure will result in a thin and uniform cast.

#### 8. Molding of Wrap Cast

Before the plaster hardens, mold the wet wrap to the stump. Care should be taken *not* to work or rub the cast excessively, as this will cause the wrap to enlarge. Rub only enough to saturate the wrap uniformly with plaster to insure a smooth, bubble-free interior surface. With slight pressure, mold the wrap to outline the patella and define the medial flare of the tibial condyle. Mark the level of the midpatellar tendon on the cast, using the same technique as was used to measure the length of the stump but changing the setting of the combination square to allow for the approximately  $\frac{1}{8}$  in. of plaster over the distal end of the stump (Fig. 13).

Place the thumb tips over the midpatellar mark at either side of the patellar tendon and, using light pressure, locate the condylar notch and indent the soft tissue on each side of the patellar tendon, using a light pressure exerted by the tips of the thumbs only. The object is to locate the notch, not to form a patellar-tendon indentation.

After the patellar tendon is located, the fingers should form the popliteal area (Fig. 14). (Note position of thumbs; only enough pressure is exerted to maintain position.) Again, only light pressure should be used posteriorly so that indentation of the popliteal area does not cause bulging of the wrap over the epicondyles of the femur. Be sure the popliteal area is formed perpendicular to the line of progression and with the deepest indentation at least  $\frac{1}{2}$  in. below the patellar indentations. The forefingers should be approximately  $\frac{1}{2}$  in. distal to the thumbs.

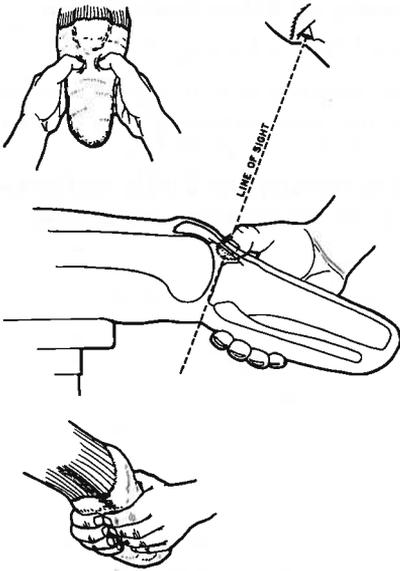


FIGURE 14

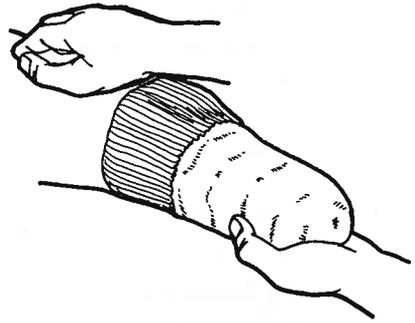


FIGURE 15

### 9. Removal of Wrap Cast

Since the cast is thin, it should be quite hard before it is removed from the patient. This thin cast will conform closely to the stump contours; in many cases it will be possible to see the outline of the bony prominences. These advantages outweigh the small additional time (5 to 10 minutes) that the cast should be on the stump before removal.

Support the stump with one hand and instruct the patient to relax and not to attempt to assist in removing the cast. Reflect the cast sock over the cast, and pull the skin loose from the proximal portion of the stump over the patella (Fig. 15).

Holding both hands in the cast-molding position (thumbs in the thumb indentations and fingers in the popliteal area) rock the entire cast down and off the stump. When the hands are in this position, it is possible to feel whether the cast is being deformed by the amputee moving his stump during the removal process. If this happens, stop immediately to prevent damage. Usually, difficulty is encountered only if the patient tenses his muscles.

### 10. Checking the Cast

Remove the cast sock and check the interior of the wrap cast to be sure that the cast sock and its markings have not been shifted out of the correct position. The interior of the cast should be smooth, free of bubbles, and free of pressure ridges. The thumb-tip indentations should be located on the midpatellar-tendon marking.

**C. Common Errors Made During Wrapping of Below-Knee Stumps**

*1. External Rotation of Amputee's Femur During Casting*

This causes a wrong orientation of the popliteal area in relation to the line of progression. It may also cause the indentations of the patellar tendon to be misaligned.

To aid in preventing this, the midline of the amputee's thigh should be perpendicular to the edge of the table and held there during the casting.

*2. Cast Sock Too Loose*

Since a moistened sock tends to adhere to the stump, there may be adequate tension at the proximal end with looseness distally. The cast sock must be applied in such a manner that there is tension in all parts of the sock as it is applied to the stump. The sock should be applied in much the same way as a woman dons nylon hose. The fingers may be moved back and forth inside the sock as it is being applied.

*3. Stump at Incorrect Angle of Flexion*

Too much flexion tends to cause gapping of the socket at the midpatellar level in the finished socket. The brim of the popliteal impression may be at an incorrect level in relation to the patellar shelf. However, the proper amount (20 deg.) of flexion is necessary to emphasize certain bony prominences, to aid in the definition of the patellar tendon, and to locate the insertions of the hamstring tendons. The flexion angle *must be maintained constant* during the wrap-casting procedure.

*4. Plaster Bandage Too Tight or Too Loose*

When the bandage is applied too tightly, the wrap cast will have pressure ridges. If the bandage is wrapped too loosely, wrinkling and air bubbles in the cast will result, especially over the distal third of the stump. The cast will also be too large. The wrap should be applied with moderate tension and with tucks in the bandage to allow it to lie flat against the stump and to result in a uniform thickness.

*5. Position of Hands Incorrect for Molding Anteroposterior Dimension, or Application of Pressure Incorrect*

The thumb positions are best located by checking the stump length with a combination square. Some bony stumps may provide enough contour to make it possible to place the thumbs correctly, but even in these cases, the placement may not be correct. Stumps with heavy tissue must always be measured and marked for thumb position. The fingers should form the popliteal area so that it is perpendicular to the line of progression.

Too much pressure with the thumb tips and fingers is a common error. The thumb tips should be placed and the anterior indentations made before any pressure is applied to the popliteal area. The thumb tips

should not depress or distort the patellar tendon; rather, the indentations should be in the soft tissue on either side of the tendon. After the thumbs are positioned, the fingers should indent the popliteal area without expanding the width of the cast over the epicondyles of the femur.

6. *Insufficient Wrap Over End of Stump, Too Much Wrap Over End of Stump, or Wrap Not Uniform*

The plaster bandage should extend down the stump in a uniform manner, with each wrap approximately 1 in. below the preceding one, and should extend over the end with uniform tucks to a thickness of 3 to 4 layers (approximately  $\frac{1}{8}$  in.) and with the remaining bandage cut off.

If the build-up over the end of the stump is greater or less than described above, the thumb positions will be incorrect, and the length of the finished socket will be altered with respect to the patellar shelf.

If there is not sufficient plaster bandage over the end of the stump, the end will collapse when the cast is removed.

7. *Rubbing or Molding of Cast After It has Started to Harden*

Rubbing or molding the wrap cast after it has started to harden causes distortions in the cast that are usually undesirable. It also causes the cast to enlarge. This error is usually made by an inexperienced prosthetist who hopes that extra work on the cast will produce a better fit.

8. *Removal of Cast from Stump Before Cast is Hard*

Various distortions may occur in the cast if it is removed too soon. Examples are enlargement of the proximal third, collapse of the bottom, and obliteration of the contours molded in by the prosthetist. This is not an uncommon error, but for successful fitting it is essential that the cast become hard before it is removed from the stump.

9. *Use of Excessive Pressure Causing Wrap Cast to be Pushed onto the Stump*

This usually occurs when the thumbs are used to distort the patellar tendon. The thumbs should be placed over the soft area adjacent to the tendon and exert a slight pressure directly inward. Thumb pressure directed proximally on the cast may elongate it, with the result that the finished socket will be too long in relation to the patellar protuberance in the socket.

10. *Markings Incorrectly Located after Casting*

This error most commonly results from looseness of the cast sock or movement of the stump by the amputee after the markings have been made. Rubbing and molding the cast may also cause shifting of the markings. Molding of the cast to define bony prominences should be held to a minimum after the prosthetist has insured a smooth and bubble-

free cast. Maintenance of the stump at a constant 20 deg. angle of flexion is essential to prevent a shift of stump markings.

## **V. MODIFICATIONS OF PLASTER MODEL**

The model-modification procedure for the air-cushion PTB socket is essentially the same as for a standard type of PTB socket, but changes in the amount of plaster to be removed from certain areas as well as shortening of the model are of utmost importance for the achievement of maximum function of the air-cushion socket.

Only those procedures which deviate from those described in the manual, "The Patellar-Tendon-Bearing Below-Knee Prosthesis," (1) are emphasized below.

### **A. Shaping of Patellar-Tendon Area**

Modify the patellar-tendon area by cutting away midway between the lower border of the patella and the anterior tibial crest to a depth of  $\frac{1}{4}$  in. (as compared to  $\frac{1}{2}$  in. for the standard PTB socket) (Fig. 16).

If impressions made by the thumbs when taking the wrap cast still remain in the model after this modification has been made, they should be filled with plaster, since such impressions indicate that too much pressure has been exerted.

### **B. Shaping of Anteromedial and Anterolateral Surfaces**

Modify the anteromedial and anterolateral surfaces of the stump model conservatively. The amount of plaster to be shaved off should not exceed  $\frac{1}{8}$  in. on the anteromedial and  $\frac{1}{4}$  in. on the anterolateral surface (Fig. 17).

### **C. Shaping the Popliteal Area**

In smoothing the popliteal area, be sure to remove only a minimum of plaster. A definite flare of the posterior socket brim should be provided for, beginning approximately 1 in. below the level of the patellar-tendon protuberance, with plaster added to form a flare posteriorly extending  $\frac{1}{2}$  in. above the level of the protuberance.

### **D. Shaping Relief Areas**

Make minor relief areas only for the anterior tibial crest, the tibial tubercle, and the head of the fibula (a maximum of  $\frac{1}{16}$  in. added material). The anterior prominences of the lateral and medial tibial condyles should be relieved only if they project excessively or are sensitive to pressure.

Do not make relief areas for the distal ends of the tibia and the fibula.

Shorten the stump model by shaving away  $\frac{1}{8}$  in. of plaster from the distal end (Fig. 18). For short stumps with minimum soft tissue distally, the amount of length reduction may be less than  $\frac{1}{8}$  in. For long stumps (10 to 12 in.), the stump model may be shortened as much as  $\frac{1}{4}$  in.

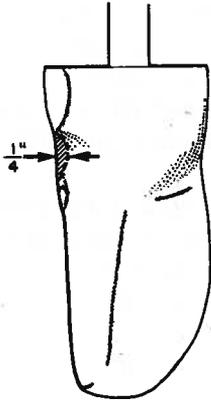


FIGURE 16

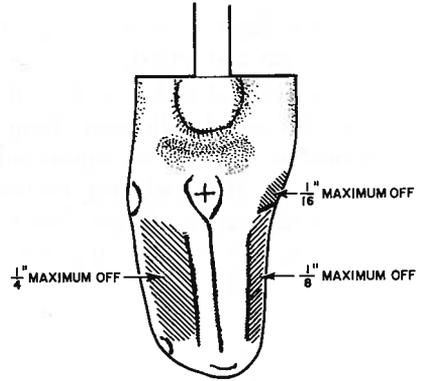


FIGURE 17

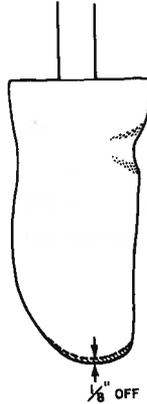


FIGURE 18

## VI. FABRICATION OF SOCKET

### A. Materials Required for Socket Fabrication

1. PVA sheet and PVA bags
2. Nylon stockinet 2 in., 3 in., and 4 in. wide
3.  $\frac{1}{8}$  in. Dacron felt ( $\frac{1}{2}$  oz.)
4. Glass-fiber cloth
5. Polyester resin (Laminac 4110 or equivalent)
6. Dow Corning Silastic 384 or Silastic 388
7. Dow Corning Medical Fluid 360
8. Vacuum system

All these materials, with the exception of Silastic 384, are used routinely in any modern limb shop and need no further description.

If Silastic 384 is not available, another of Dow Corning's products, Silastic 388-Denture Release, has served as an excellent substitute.

Silastic 384 and Silastic 388 have the same characteristics for lamination. They both have a shelf life of 12 months when stored under refrigeration. Silastic 384 can be obtained from prosthetic suppliers, and 388 can be purchased in most dental supply stores.

Like other RTV silicone rubbers, the 384 system is composed of a base material and a catalyst. For a desired working time of approximately 10 minutes, one drop of catalyst should be used with each 10 gm. of the base. The catalyst must be mixed thoroughly into the fluid base, with the trapping of air bubbles carefully avoided.

Dow Corning 360 Medical Fluid may be used as a thinner but should not exceed 10 percent by weight of the base. If thinner is used, it must be added to the base and mixed thoroughly before the catalyst is added. Curing time is approximately 45 minutes.

*Caution:* The relation between base, catalyst, and working time does not correspond with the manufacturer's recommendations, since our specifications for working time differ from those required with other uses of the material.

The lamination of Silastic requires use of a vacuum source, since the viscosity of Silastic is much higher than that of polyester resin and makes complete saturation of the lay-up more difficult. The procedures described in this publication assume a dual-vacuum source with a high vacuum

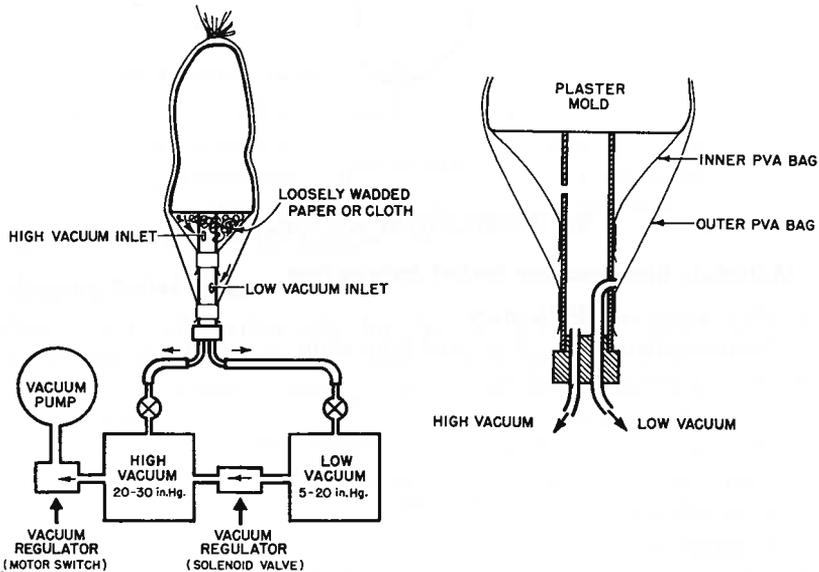


FIGURE 19

equal to 20 to 30 in. Hg separate from a low vacuum equal to 5 to 20 in. Hg. However, the procedures can be followed also when a single vacuum source is used and an equal vacuum applied to both inner and outer bags. Figure 19 is a schematic illustration of the dual-vacuum system.

## B. Fabrication of the Inner Elastic Sleeve

### 1. Preparation of Plaster Model

If the mold is wet, it must be sealed first with ambroid varnish or similar coating. Before application of this coating, small grooves must be scribed from the depressions in the popliteal and the patellar-tendon areas to the edge of the mold to allow the PVA to be pulled in.

As separator over the plaster-of-paris mold, use a PVA bag with a cap, or cut a sheet of PVA approximately 20 in. by 20 in. and moisten by wrapping in a wet towel for approximately 1 minute. Pull the sheet over the mold until all wrinkles are below the mold, then tie (Fig. 20). Apply the high vacuum to this inner bag.

### 2. Construction of Elastic Sleeve

If the amputee's body weight is greater than 150 lb., 3 layers of stockinet are used; if less than 150 lb., 2 layers.

Cut two or three pieces of nylon stockinet 6 in. longer than the mold and 2 in., 3 in., or 4 in. wide, depending on the circumference of the stump (use table below as a guide).

Circumference of mold midway between tibial tubercle and distal end, in.	Width of stockinet, in.
less than 9	2
9-12	3
more than 12	4

Sew one end of each piece in a semicircle (Fig. 21). Pull the nylon socks over the mold with only enough tension to avoid wrinkles. Turn second and third nylon socks inside out and arrange the seams in a crossed pattern as shown in Figure 22. Do not stretch the socks excessively, since this will reduce the elasticity of the Silastic/nylon laminate.

Tie the socks below the mold.

### 3. Lamination of Elastic Sleeve

The laminating procedure is the same for either the 2-layer or the 3-layer version.

Pull a slightly moistened PVA bag over the lay-up. (It is easier to laminate with Silastic in an almost dry outer bag.)

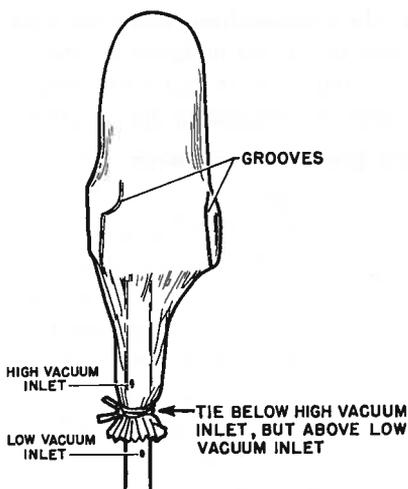


FIGURE 20

SEW ONE END OF EACH PIECE IN A SEMICIRCLE

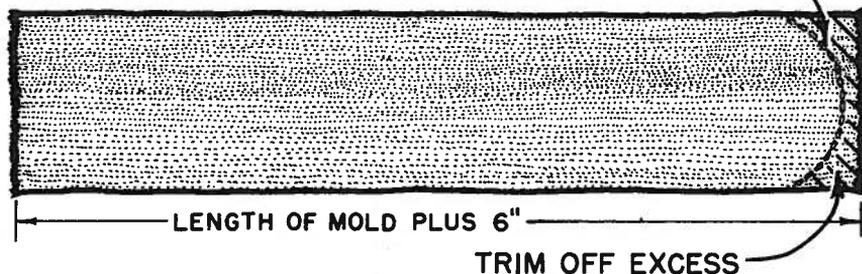


FIGURE 21

Tie the bag below the mold in such a way that the low vacuum can be applied to the nylon stockinet. Tie the bag above the mold with either a wedge lock clamp or a PVA strip. If a strip is used, it must untie easily (Fig. 23).

Apply low vacuum adjusted to 20 in. Hg to the nylon stockinet between the inner and outer PVA bags.

Draw a line on the PVA bag at the level of the tibial tubercle, using a felt marking pen (see Fig. 23). This line indicates the level of the Silastic lamination.

To prevent flow of Silastic below the reference line, a tie must be made at this level. Use rubber wedges to fill the depressions on the mold (Fig. 24). Hold them in place with masking tape and use an elastic tie, such as  $\frac{1}{8}$  in. polyethylene tubing, on top of the tape (Fig. 25).

ARRANGEMENT OF SEAMS:

TWO NYLON SOCKS



THREE NYLON SOCKS



FIGURE 22

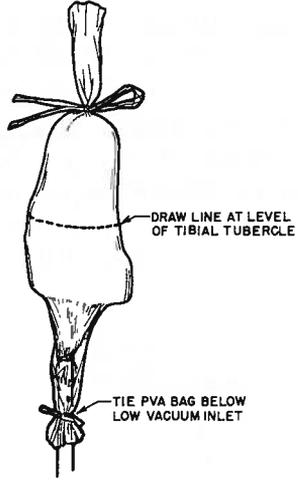


FIGURE 23

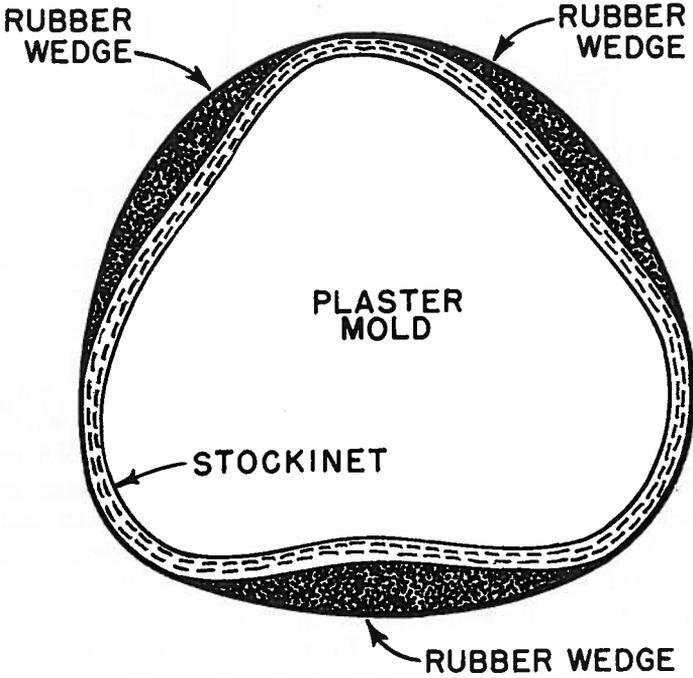


FIGURE 24

Attach a funnel to the upper end of the PVA bag.

Prepare: 100 gm. Silastic for small size sockets,  
150 gm. Silastic for medium to medium-long sockets,  
200 gm. Silastic for extra-long sockets

Mix Silastic, thinner, and catalyst according to recommendations in Section VI.A.

Pour the Silastic into the reservoir and force it down to the tie above the mold. Tie the upper end of the bag slightly below the top level of the Silastic to avoid air bubbles (Fig. 26).

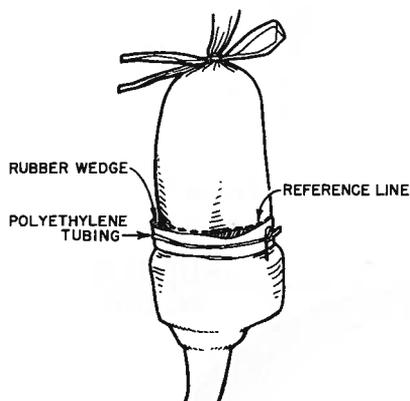


FIGURE 25

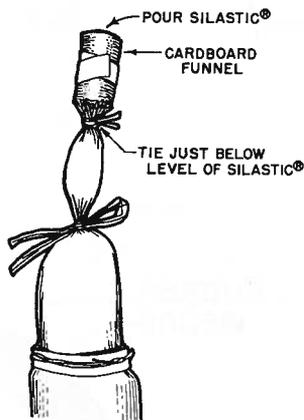


FIGURE 26

Remove the tie below the reservoir of Silastic and strip the material into the nylon stockinet (Fig. 27). Work the Silastic very thoroughly, since it is difficult to achieve complete impregnation. Keep the Silastic  $\frac{1}{4}$  to  $\frac{1}{2}$  in. away from the reference line so that it will not bleed under the tieoff. When the Silastic begins to set (about 20 min.), complete the lamination to the reference line at the level of the tibial tubercle. Strip excess material to the distal end of the mold and tie the PVA bag with the excess material distal to the tie (Fig. 28). As the last step, to insure a leak-tight junction between the Silastic and the polyester laminate, strip enough Silastic to the reference line to form a definite bulge under the PVA bag. This must be done when the Silastic is very stiff or the material will be forced under the barrier and a ragged junction line will result.

When the Silastic has set, cut the PVA bag just below the tie (Fig. 29). Remove the tie and wedges at the level of the tibial tubercle.

Remove the PVA bag from the proximal part of the mold, starting at a level  $\frac{1}{4}$  in. distal to the Silastic junction line (Fig. 30). When trimming the PVA bag at that level, be careful not to damage the Silastic laminate.



FIGURE 27

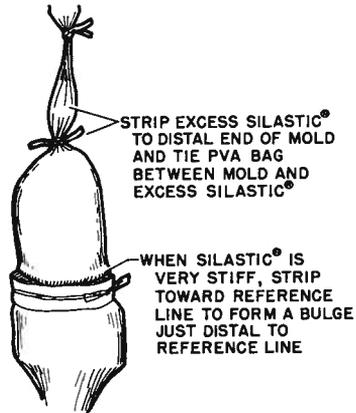


FIGURE 28

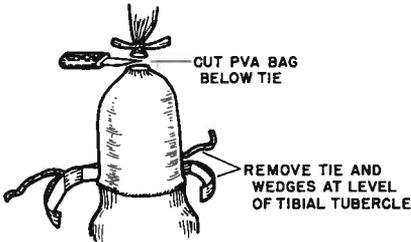


FIGURE 29

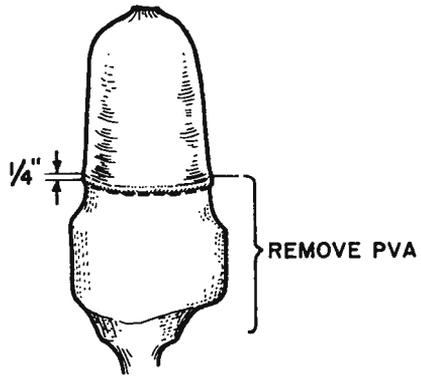


FIGURE 30

### C. Fabrication of Laminated Socket

#### 1. Construction of the Socket

Cut a piece of nylon stockinet, of the same width as was used for the Silastic lamination, to a length twice that of the mold plus 11 in.

Pull the stockinet over the mold to approximately 4 in. below it (Fig. 31).

Apply four  $\frac{1}{8}$  in. Dacron felt sleeves with the seams aligned to the posterior aspect of the mold. The first Dacron sleeve extends from a line  $\frac{1}{2}$  in. proximal to the distal end of the mold. The second sleeve extends from  $\frac{1}{4}$  in. below the first sleeve and the third and fourth are staggered as shown (Fig. 32). All sleeves extend to approximately 3 in. below the mold.

Tie the nylon stockinet and the first Dacron sleeve just distal to the second Dacron sleeve and  $\frac{3}{4}$  in. proximal to the distal end of the mold. Use a loop formed from thin nylon string.

Reflect the free part of the nylon stockinet down over the lay-up and tie below the mold (Fig. 33).

The free portion of the first Dacron sleeve will now form a smooth distal edge in the final lamination.

**2. Lamination of Socket**

Powder the inside of a moistened PVA bag and pull it over the lay-up.

Apply low vacuum adjusted to 7 in. Hg. Pour polyester resin into the bag and laminate as usual. Be sure the fabric is well impregnated with resin.

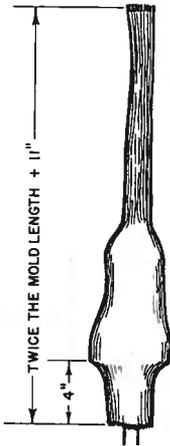


FIGURE 31

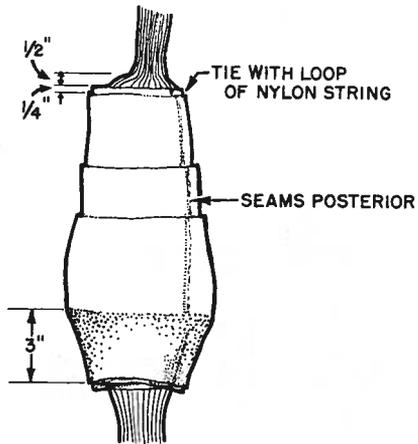


FIGURE 32

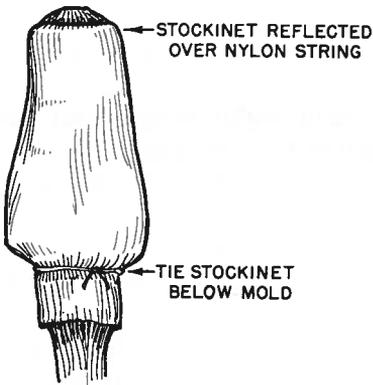


FIGURE 33

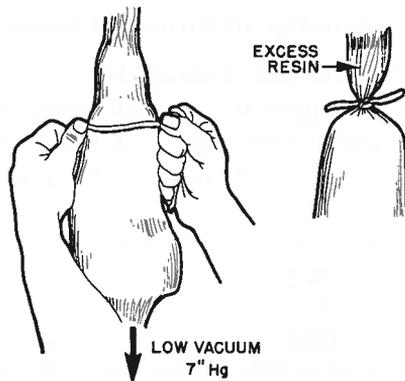


FIGURE 34

Tie the bag off at the distal end of the mold leaving the excess resin above the tie (Fig. 34).

When the polyester resin has set, remove the outer PVA bag completely and the inner bag below the mold (Fig. 35).

Clean the exposed Silastic laminate of any polyester resin, exposed PVA bag, and excess Silastic. Use a sharp knife to remove the excess Silastic. *Be very careful* not to cut into the impregnated fabric.

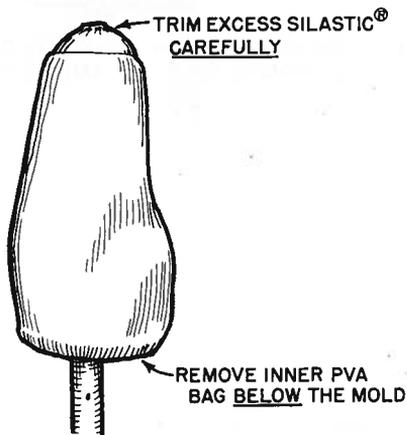


FIGURE 35

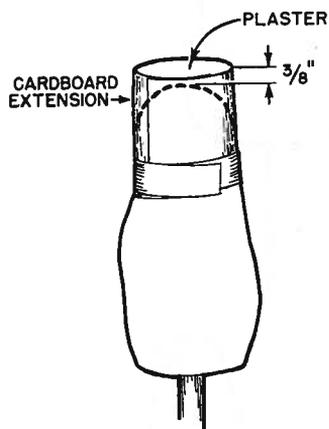


FIGURE 36

## D. Fabrication of Laminated Cap for Socket

### 1. Preparation of the Model

To provide for the closed air chamber below the Silastic, apply a cardboard extension to the end of the socket. Cut the cardboard  $\frac{3}{8}$  in. above the Silastic and fill the extension with plaster of paris (Fig. 36).

When the plaster of paris has hardened, remove the cardboard and shape the extension to the contour of the socket. Be sure to leave  $\frac{3}{8}$  in. of plaster at the top and at the anterodistal aspect of the tibia (Fig. 37). Approximately  $\frac{1}{4}$  in. should be left halfway down the sides.

Seal the plaster-of-paris extension with ambroid varnish or similar coating.

Pull a moistened PVA sheet over the socket and apply high vacuum (Fig. 38).

### 2. Construction of the Cap

It is necessary to make a strong cap; otherwise, it might deform during the process of foaming the socket extension block.

Cut three pieces of nylon stockinet of the same width as used in the Silastic lamination. One piece should be 4 in. longer than the socket, the others 1 in. shorter than the socket. Sew one end of each in a semicircle.

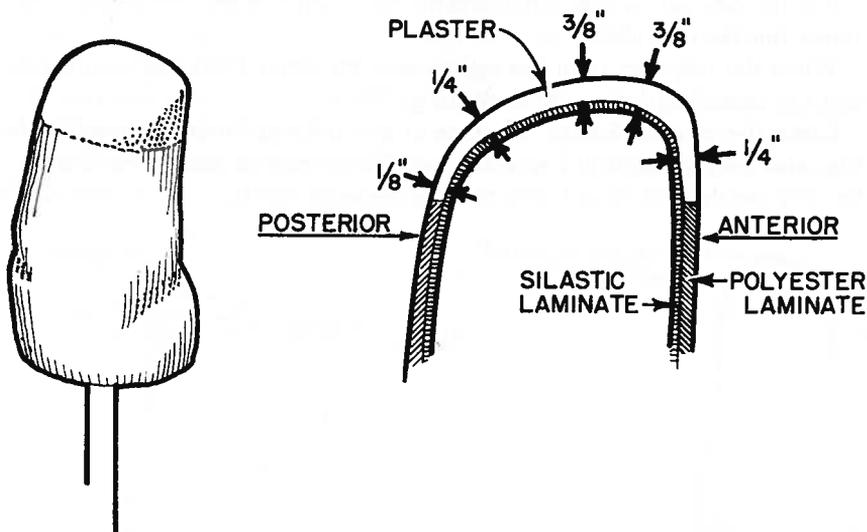


FIGURE 37

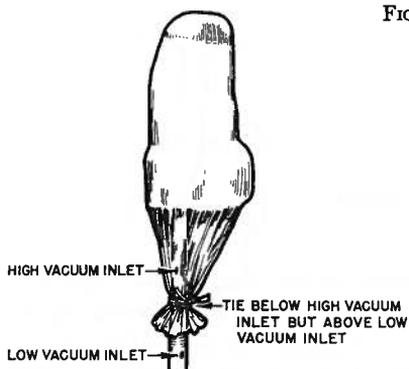


FIGURE 38

Pull one of the short nylon socks over the socket. Lay a cap of glass cloth on top of the nylon sock extending approximately  $2\frac{1}{2}$  in. down from the end. Pull the other short nylon sock over the glass cloth and lay a similar glass cap on top. Pull the long nylon sock over the second glass cap and tie below the socket (Fig. 39).

### 3. Lamination of the Cap

Pull a PVA bag over the lay-up and laminate with polyester resin.

When the resin has set, but is still somewhat soft, cut the lamination approximately  $3\frac{1}{2}$  in. from the end (Fig. 40).

Remove the excess part of the lamination proximal to the cap, but leave the cap on until the resin is completely cured.

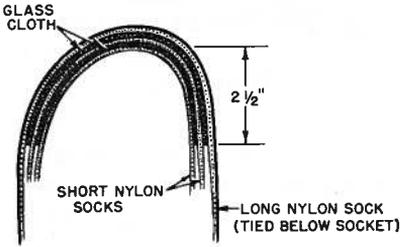


FIGURE 39

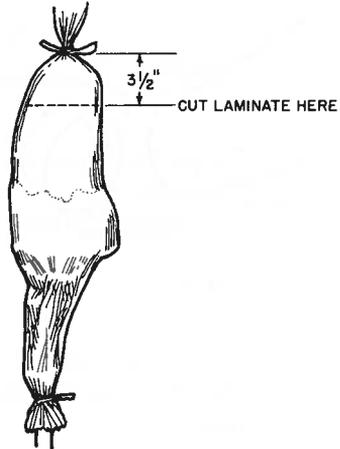


FIGURE 40

When it is completely cured, remove the cap and plaster-of-paris extension and knock the plaster out of the socket. Be careful not to damage the Silastic.

**E. Final Shaping and Assembly**

Trim the proximal brim of the socket (Fig. 41). Turn the Silastic back and sand the distal end of the plastic socket. Round the edge from inside to prevent cutting of the Silastic during weight bearing (Fig. 42).

Trim the cap so that it extends to a line 1 to 1 1/2 in. proximal to the distal end of the plastic socket. Sand the inside of the cap and the outside of the plastic socket as shown in order to obtain a better surface for bonding (Fig. 43).

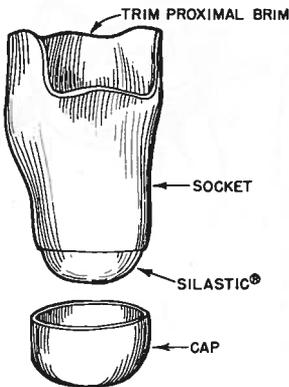


FIGURE 41

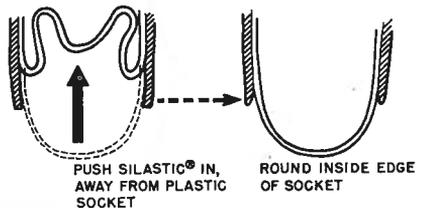


FIGURE 42

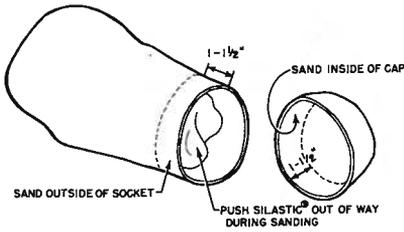


FIGURE 43

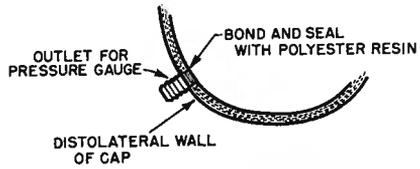


FIGURE 44

If the air pressure generated in stance phase is to be measured in order to control socket fit, an outlet must be installed in the distolateral wall of the cap as shown in Figure 44. Use polyester resin to bond and seal the outlet, which should be of the same size and shape as that on the pressure gage.

Holding the socket with its distal end up, paint a thin coat of polyester resin on the sanded surface, leaving  $\frac{1}{4}$  in. from the edge free of resin (Fig. 45).

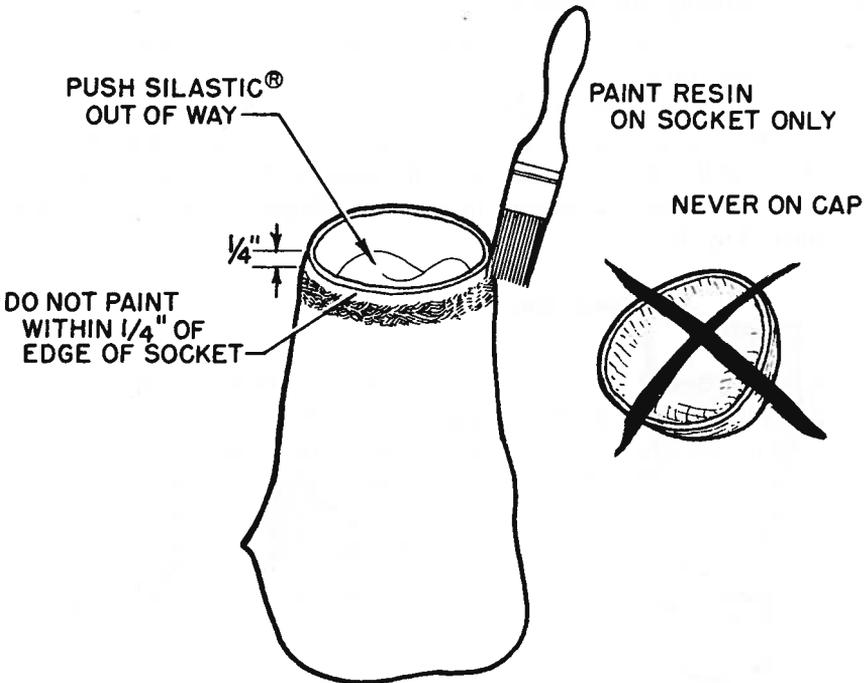


FIGURE 45

Position the cap in place and leave to set.

Never add resin to the inside of the cap. It is very important that no resin goes in between the Silastic and the hard socket shell.

When the polyester resin has set, sand the outside of the socket to provide a better bond with foam.

The measurement of the air pressure generated in stance phase serves as an indication of socket fit and function and can be done easily in any prosthetics workshop with the pressure gage from a "Jobst" unit or with a similar gage. The pressure gage must be connected to an outlet in the polyester cap enclosing the air volume. The connecting tube should be as short as possible to prevent unnecessary increase in the volume of air (Fig. 46).

Although direct visual reading of the pressure gage while the amputee walks is difficult, the accuracy is sufficient for checking the fit of the socket. If no pressure is indicated immediately after heel contact, the socket is too loose around the distal portion of the stump or too tight around the proximal portion, assuming that the air volume has been provided as described in the section on socket fabrication and that the socket is properly sealed to the cap.

The socket extension can now be foamed into a block. Fitting, aligning, and finishing procedures can be completed as usual.

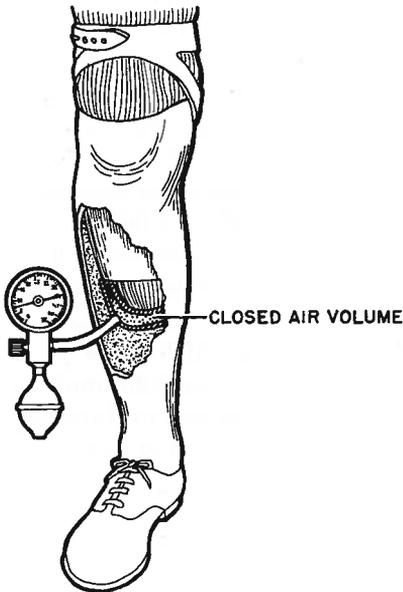


FIGURE 46

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<sup>e</sup> Available from The University of California Press, Berkeley, California. \$3.00