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AN EVALUATION OF THREE CASTING TECHNIQUES FOR PATELLAR-TENDON-BEARING PROSTHESES[1]

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Until relatively recently, most sockets for below-knee prostheses were carved from wood (*12,17*), a process that required considerable skill. "Thigh corset" and "side bars" to take most of the weight-bearing load off of the stump were used almost universally.

Plaster-of-Paris impressions to define the stump and, thus, socket configurations were used from time to time (*11*), but it was not until 1959 with the introduction of the so-called patellar-tendon-bearing prosthesis by Radcliffe and Foort (*7,13,18*) that "casting" or impression of the limb remnant became routine in below-knee prosthetics. This procedure calls for wrapping the limb remnant with plaster-of-Paris bandages, using the npression to cast a positive model of the limb emnant (Fig. 1). In order to arrive at a socket that will provide tolerable weight-bearing loads, certain modifications have to be made to the positive model before it can be used to form a plastic socket over it.

Modification of the positive model, in light of our present knowledge, requires a good deal of skill, and many approaches have been made in order to reduce the skill required.

One approach has been to add build-ups of felt or other material to the limb remnant itself so that a positive model from the female mold or wrap will not have to be altered to provide an adequate socket. Fillauer first suggested this (*11*), and Traub and Zettl, who called it the "pre-modified method," found the technique to be useful in fitting patients immediately after surgery (*19*) (Figs. 2 and 3).

In 1971, Fillauer (*6*) described a technique that utilizes plaster splints to form a pretibial shell that defines the anterior structures of the below-knee leg remnant, followed by a circumferential wrap to enclose the soft posterior tissues (Figs. 4, 5, and 6). He claims an improved definition of the bony structures with this technique. In 1972, Gleave (*8*) also described a technique utilizing splints placed anteriorly over an elastic prosthetics sock, followed by a circumferential wrap.

The original UC-BL technique, the two-part procedure described by Fillauer (hereafter referred to as the two-part technique), and variations of the pre-modification technique are used widely today.

Educational programs largely teach the method that the chief instructors prefer, their choice being based on their own personal experiences and feedback from other clinicians. At the Workshop on Below-Knee and Above-Knee Prostheses sponsored by the Committee on Prosthetics Research and Development in January 1973 (*4*), New York University requested that CPRD conduct an evaluation of the three commonly used casting techniques. Other members of the University Council on Orthotics-Prosthetics Education (UCOPE) concurred.

Although many studies have been conducted to evaluate socket fit by using pressure transducers (*1,5,15*), radiographic techniques (*16*), and dye-impregnated prosthetics socks (*2,3*), none has attempted to relate the casting technique to the socket fit.

The staff of the Amputee and Problem Fracture Service of Rancho Los Amigos Hospital, Downey, California, were asked to assist in the evaluation, since that group had the capability for measuring pressure and temperature, and had

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pioneered the use of transparent check sockets (*10,14*). Besides, Rancho Los Amigos Hospital receives support from the Social and Rehabilitation Service of the Department of Health, Education, and Welfare to conduct clinical evaluations of prosthetics and orthotics techniques. The staff at Rancho who conducted the evaluation consisted of Vert Mooney, M.D., Roy Snelson, C.P.O., Richard Voner, C.P.O., John Rogers, M.S., and Donald Colwell, C.P.

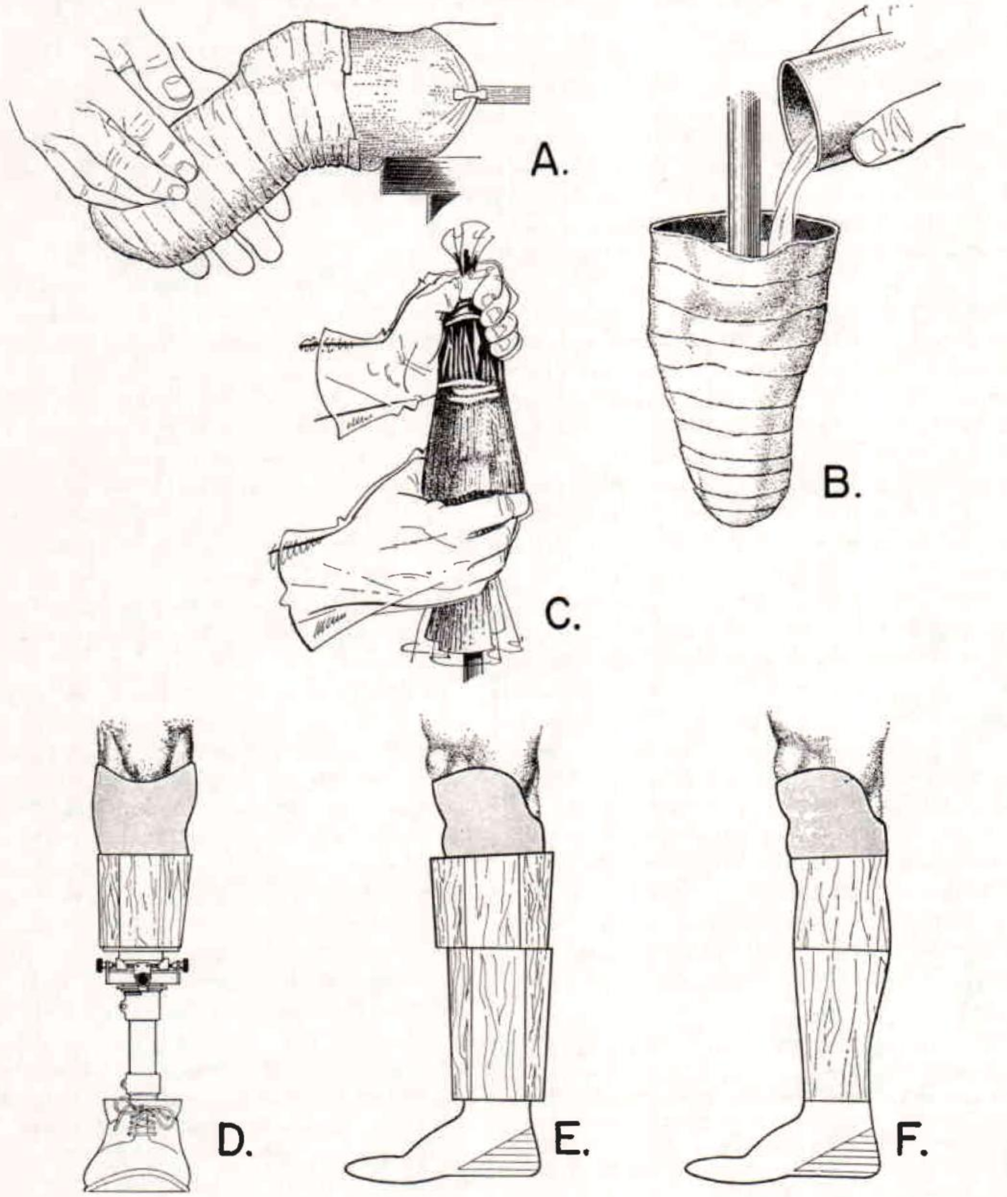

Fig. 1. Some of the major steps involved in the fabrication and fitting of the standard patellar-tendon-bearing prosthesis: *A*. Wrapping the limb remnant with plaster-of-Paris bandage to obtain a female, or negative cast. *B*. Pouring plaster-of-Paris solution into female cast to produce a male model. *C*. Making a plastic-laminate socket of the male model. Not shown are modifications that need to be made to the male model to insure a socket shaped to provide tolerable distribution of loads between the socket and the limb remnant. *D*. Socket mounted on adjustable leg for trial fitting and alignment. *E*. Replacement of adjustable unit with wooden shank piece. *F*. Leg shaped ready for finishing.

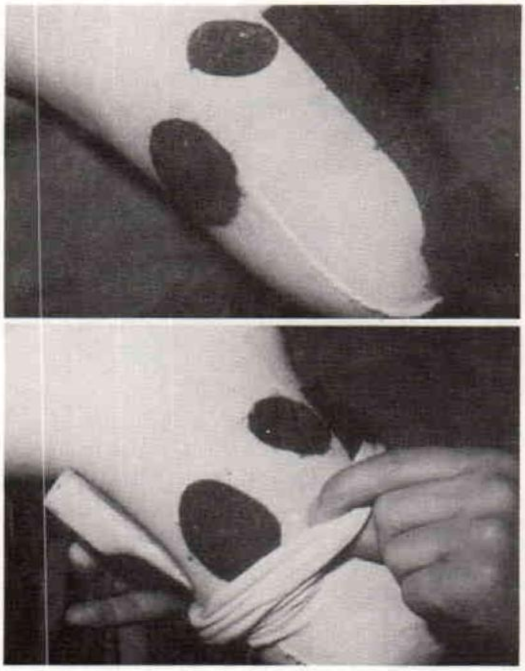

Fig. 2. *Top*—Application of felt pads over first cast sock in the premodified casting technique. *Bottom*—Application of hamstring relief pad and second cast sock.

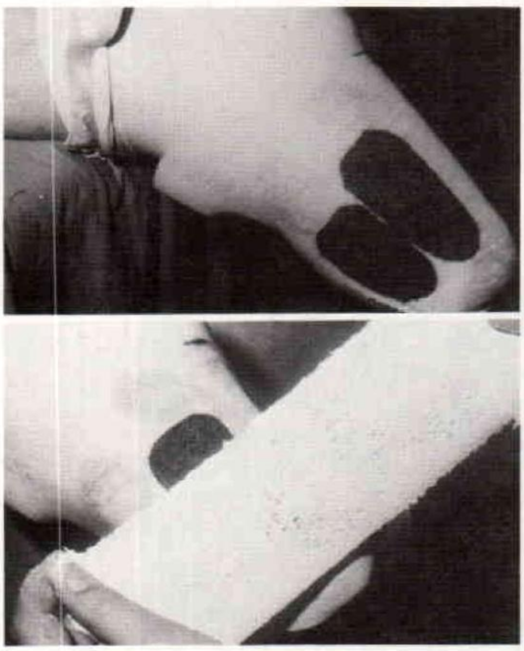

Fig. 3. *Top*—Application of felt pads over second cast sock in the premodification casting technique. *Bottom*—Application of plaster-of-Paris bandage.

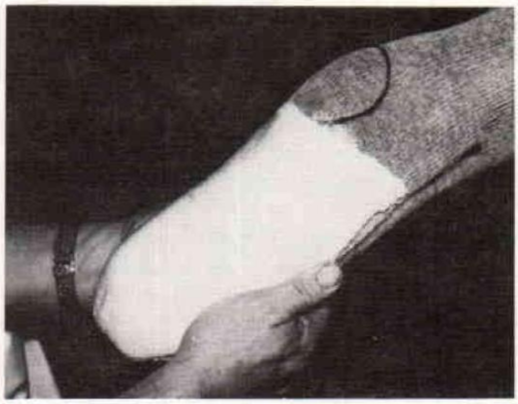

Fig. 4. Formation of the pretibial shell in the Fillauer two-step procedure.

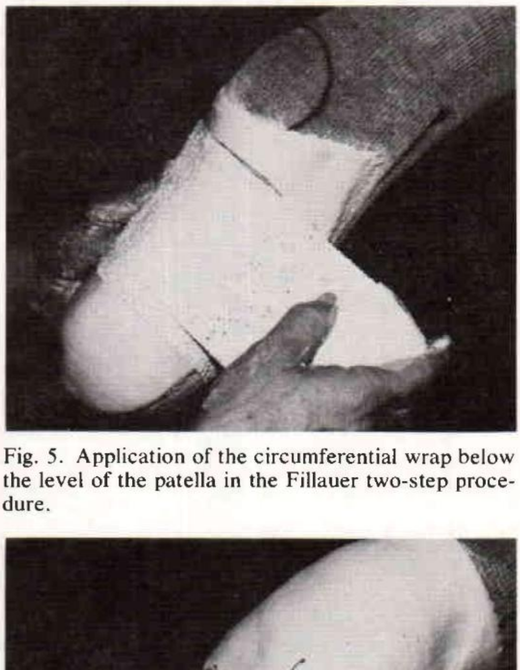

Fig. 5. Application of the circumferential wrap below the level of the patella in the Fillauer two-step procedure.

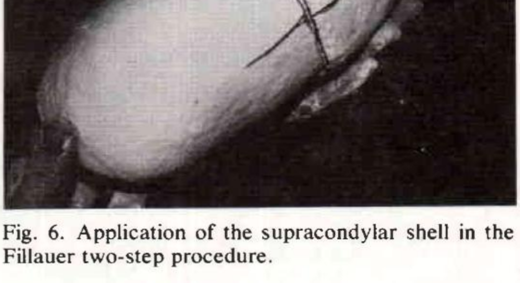

Fig. 6. Application of the supracondylar shell in the Fillauer two-step procedure.

METHOD

A method for evaluating the two-part technique, the pre-modified technique, and the standard technique was devised by Maurice LeBlanc, C.P., then Staff Engineer, CPRD. The method was modified and then approved by CPRD's Subcommittee on Evaluation. Each of six patients was provided with three prostheses each containing a socket formed by one of the three methods (Fig. 7). Thus, a total of 18 prostheses was involved. Casts and modifications of the male model were to be made by Carlton Fillauer, C.P.O., Leigh Wilson, C.P., formerly of the UCB staff, and Joseph Zettl, C.P.

The following assessment techniques were to be used:

1. Comparison of length, width and circumference of unmodified and modified models.
2. Comparison of medial tibial flare contour of modified model to template made on patient's limb.
3. Comparison of volume of model before and after modification.
4. Observations made when a transparent socket was used.
5. Patient comments concerning relative comfort and fit.
6. Observations normally used by a prosthetist.
7. Temperature differentials on a patient's limb after wearing socket and walking a specified distance.
8. Two-week trial wear period of each prosthesis by the patients.

All patients were to use the same type of artificial foot (SACH) and the same type of suspension (cuff). Shoes for each patient were transferred from prosthesis to prosthesis, and hard sockets were used.

The time required for casting and modification, the "teachability" of each technique, and the practicality of each technique were to be assessed by the staff of Rancho Los Amigos Hospital.

On August 15 and 16, 1973, Leigh Wilson, C.P., who was associated with the development of the UC-BL casting technique, took the casts of six patients at Rancho, and modified the positive molds. Joseph Zettl, C.P., the co-developer of a pre-modification technique, and Carlton Fillauer, C.P.O., developer of the two-part technique, also came to Rancho on consecutive two-day visits to take casts of the same patients and to modify the positive models. Transparent check sockets (*10, 14*) of Lexan were formed over the modified positive models (Fig. 8).

Some characteristics of the subjects are given in Table 1.

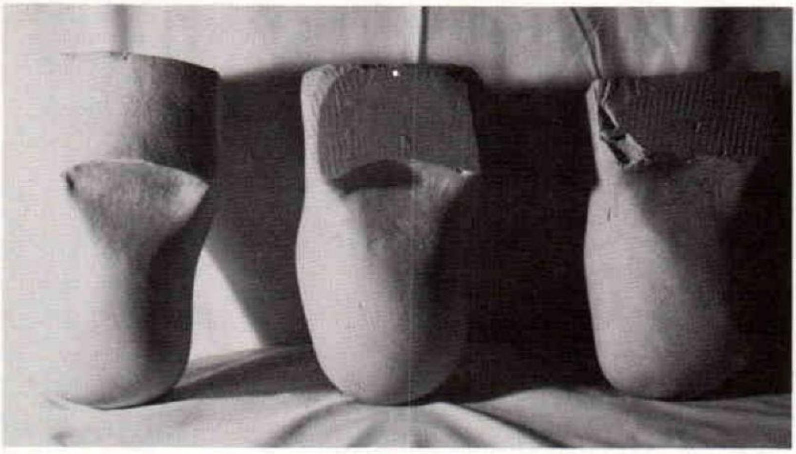

Fig. 7. Posterior views of three molds of the same patient modified using three different modification techniques.

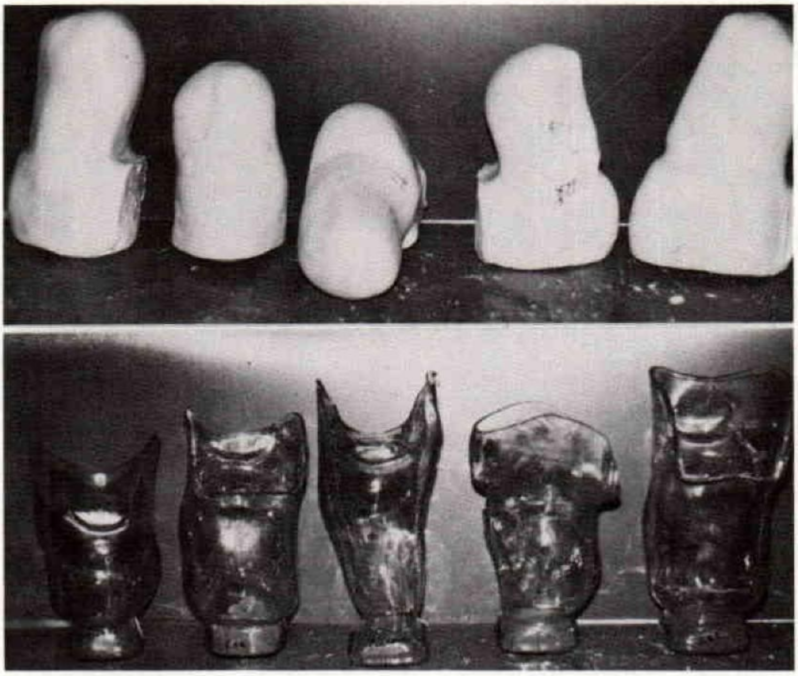

Fig. 8. *Top*—Modified positive molds for five patients. *Bottom*—Polycarbonate check sockets with distal extensions for attachment to the pylon.

Table 1. Characteristics Of Subjects Used In The Study

Subject	Age	Date of Amputation	Reason for Amputation
N.B.	55	8/71	Diabetic/gangrene
D.B.	32	6/71	Osteo./trauma
N.J.	66	1971	Diabetic/gangrene
W.M.	72	1971	Circulation prob./ gangrene
L.M.	67	1968	Diabetic/osteo.
A.P.	65	1967	Diabetic/gangrene

Volume measurements of each socket were made and the sockets were attached to an endoskeletal shank[4] and SACH foot, and statically aligned. Socket modifications and fitting problems were recorded by the prosthetist during the fitting procedure. Holes were drilled in the transparent check sockets when necessary in order to palpate the limb in areas where either excessive or inadequate pressure was suspected. This information was recorded and used later to modify the positive mold after the check socket was filled (Figs. 9, 10, 11, and 12).

Patients were then scheduled for four visits each to have skin stress measurements made, using the temperature differential technique. Following the completion of these visits the patients were provided with polyester laminate sockets and requested to use them for two-week trial wear periods.

During the twelve-month course of the evaluation, each patient made approximately eleven visits to the Amputee and Problem Fracture Service. Three of these visits were for casting and initial evaluation, one for initial fitting (Fig. 9), four for temperature differential measurements, and three during the trial wear periods.

[4]Otto Bock Modular System.

Fig. 9. Patient ambulating during dynamic alignment.

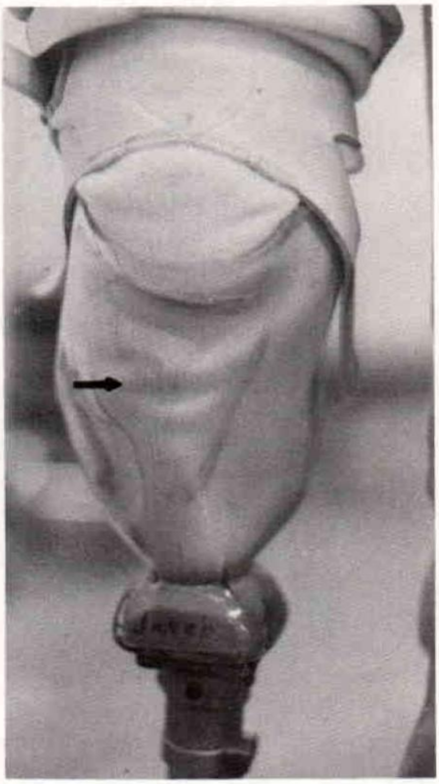

Fig. 10. Excessive relief over the proximal tibia is seen as looseness and wrinkling of the prosthetics sock.

RESULTS

VOLUME MEASUREMENTS

The volume of each check socket was measured by filling the sockets with water to the mid-patellar-tendon level and then pouring the water into a measuring beaker. The volumes were then compared to the volumes recorded for the unmodified model. As can be seen from Table 2, the volumes of the models taken by standard and pre-modification techniques decreased an average of 3.2 and 3.3 percent respectively, while the volume of the models made using the two-part technique decreased by an average of 6.1 percent. In addition, the models made using the two-part technique were an average of 40-50 milliliters (ml) less than the other techniques. The change in volume of the model taken with the premodification technique could be expected to be small, since most modifications are made in the initial casting procedure. In fact, the volume decrease indicates that additional modifications had been made after casting.

Comparing the original unmodified models, the models taken with the two-part technique were an average of 9.1 percent smaller than those taken with the standard technique, and 5.5 percent smaller than those taken with the premodification technique. After modification the volume of the model modified by the two-part technique was 11 percent smaller than the standard technique and 8.5 percent smaller than the pre-modification technique.

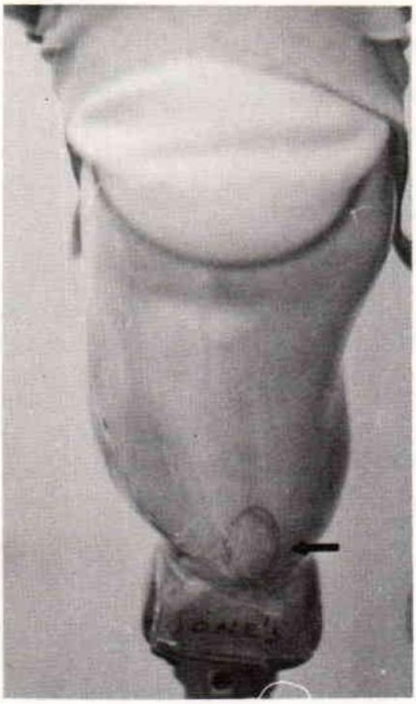

Fig. 11. Discomfort at the medial tibial flare is caused by an uneven socket contour. The weave of the prosthetics sock can be "read" like a contour map to identify potential problem areas.

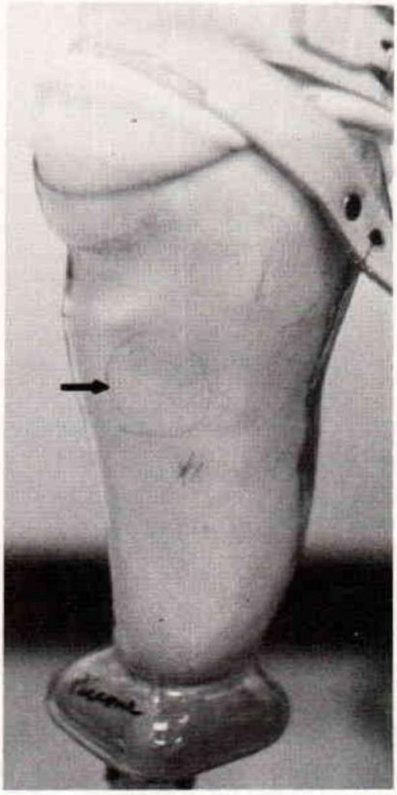

Fig. 12. Pressure over the distal tibia is seen as a localized area of compression of the prosthetics sock.

Table 2. Volumes Of Sockets From Three Casting Techniques Before And After Cast Modification In Milliliters*

	UNMODIFIED MOLD			MODIFIED MOLD			DECREASE IN VOLUME (ACTUAL)			DECREASE IN VOLUME (%)		
Patient	Standard	Pre-Mod.	2-Part	Standard	Pre-Mod.	2-Part	Standard	Pre-Mod.	2-Part	Standard	Pre-Mod.	2-Part
N.B.	1180	1160	1070	1120	1120	970	60	40	100	5.1%	3.5%	9.2%
D.B.	1050	950	880	1020	880	850	30	70	30	2.8%	7.4%	3.5%
N.J.	760	770	730	740	760	680	20	10	50	2.6%	1.3%	6.9%
W.M.	770	710	710	720	710	680	50	0	30	6.5%	.0%	4.2%
L.M.	670	660	630	660	650	600	10	10	30	1.5%	1.5%	4.8%
A.P.	790	780	720	790	740	675	0	40	45	0%	5.1%	6.2%

*One milliliter = .001 liter
One liter = 1.057 quarts liquid

LENGTH, WIDTH, AND CIRCUMFERENCE MEASUREMENTS

No correlation could be found betwen A-P, M-L and length measurements and the volume differences, even though relatively large differences were found. The difference in A-P measurements taken by two prosthetists on one patient was ½ in., M-L differences of ⅜ in. occurred twice, and length measurements varied up to 9/16 in. The only consistency in measurement techniques was that the A-P and length measurements taken for the pre-modification techniques were generally the largest, and the M-L measurements for the two-part technique were always the largest.

USE OF PROSTHETICS SOCKS

The use of prosthetics socks is related to the volume measurements in general, but not directly. The assumption is made that the greater the number of plies needed, the larger the socket is in relation to the patient's limb. Prosthetics socks are often used to fill or pad sockets when the patient's limb shrinks or cushioning is needed for a specific area. Patients fitted with sockets made using the pre-modification technique used an average of 8.5-ply socks. Four of these patients used 10-ply socks, one used a 6-ply, and one used a 5-ply sock. However, sockets made from the standard technique had the highest volumes in all but one case.

The average ply of prosthetics socks used by patients in the standard technique category was 5.2, although the average volume of the sockets made by this technique was 34 ml greater than those made following the pre-modification technique. In four out of the six patients, however, the A-P was greater on the pre-modification socket than on the standard.

Patients fitted with sockets made with the two-part technique used an average of 2.8-ply prosthetics socks. The average volume of the sockets was 99 ml less than the standard technique and 67 ml less than the pre-modification technique, so a relationship between volume and the number of ply used could be made in this case.

No consistent direct relationship between volume of sockets and prosthetics sock use can be made from this study. In one case, the same patient with a 675 ml volume socket used a 3-ply sock, with a 740 ml volume socket used 10-ply, and with a 790 ml volume socket used a 5-ply sock.

MEASUREMENT OF TEMPERATURE DIFFERENTIALS

The Tissue Trauma Group at Rancho Los Amigos Hospital has been measuring temperature rises in skin subjected to either constant or intermittent pressure. The group has begun its work as a result of the findings of Paul Brand (*3*). Dr. Brand states that "perhaps the best index of commencing tissue damage is commencing hyperemia."

John Rogers, Director of the Tissue Trauma Group, measured the difference in temperature between points on the patient's residual limb and the temperature at the elbow crease after the patient walked a specified distance. This temperature difference was taken for the patient's original prosthesis and for the prostheses used in the evaluation. A comparison was then made of the differences.

Differential temperatures were measured at each patient's patellar tendon, popliteal fossa, distal tibia, fibular head, medial flare, medial femoral condyle, anterior tibia and gastrocnemius. Patients were requested to walk a specified distance (600 yd), but distances varied according to physical tolerance and the fit of the prosthesis. Patients were not forced to walk the full distance on uncomfortable prostheses in order to avoid any tissue breakdown that may result. Distances walked ranged from 150 to 600 yd. Trauma was not sufficient to cause tissue breakdown in any patient.

The following observations are made from the temperature differential measurements:

1. The average frequency of temperature "rebound" was approximately one cycle every 45 minutes. Temperature "rebound" is the tendency for the temperature of traumatized skin to return towards normal periodically and then rise again towards the original level.

2. Differential temperatures taken 90 minutes after trauma was discontinued were consistently different than when the patients were using their regular prostheses. This is demonstrated in Figure 13, where it can be seen that temperatures of

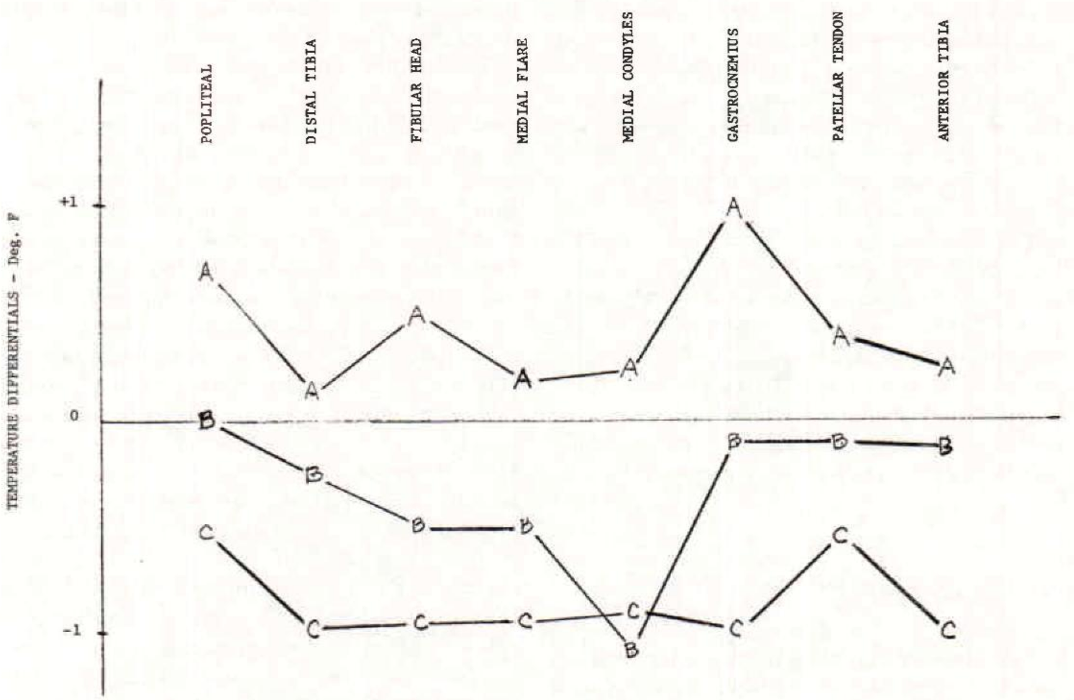

Fig. 13. Differences in temperature on various points of the stump between the use of experimental prostheses and their own. All temperatures were taken after 90 minutes of walking. The zero or base line represents the temperature after use of the regular prosthesis. *A*—Premodification Technique; *B*—Two-Part Technique; *C*—Standard University of California-Berkeley Technique.

patients using pre-modification technique sockets were warmer than after wearing their own prosthesis, and patients using the standard and two-part technique sockets were cooler. Average temperatures of patients using the pre-modification technique would have been higher, had not one patient been consistently much cooler than the others. The medial femoral condyle measurement on patients using the two-part technique sockets was noticeably cooler than their normal prosthesis. Measurements of the sockets indicated that the M-L dimension was widest on all sockets made with the two-part technique.

OBSERVATIONS BY PROSTHETISTS

Patients were fitted with hard sockets made of Lexan (polycarbonate), cuff suspension, Bock endoskeletal pylons, and SACH feet. The use of transparent check sockets aided the evaluation of socket fits.

In general, sockets made by the two-part technique were too tight initially; one patient was not able to get in the socket at all until the socket was relieved. After weight-bearing for about five minutes, the other patients did settle into the sockets. By the end of the alignment procedure, four of the patients were able to comfortably wear a 3-ply wool sock or a Daw sheath with 2-ply cotton socks. The most common socket reliefs needed for pressure were over the distal tibia (four patients). This pressure can be seen through the transparent check socket as an area of increased compression of the sock. Increasing the radius at the medial and lateral posterior walls was the second most common relief needed (three patients). Areas of excessive buildup were not noticed on any of the sockets.

The pre-modification technique sockets had the best fit initially for two patients and the worst fit for one patient. Patients generally used a 5-ply sock at the initial fitting. Additional socket relief was needed for only one patient, but excessive reliefs were noted over the tibial tubercle area on many of the patients. Excessive reliefs are seen through the clear check socket as a looseness or wrinkling of the prosthetics sock (Fig. 10). Patients usually progressed to 8-10 ply by the time alignment was complete.

The standard technique sockets provided the best fits initially. Patients used a 3-ply sock and worked up to a 5-ply by the end of the alignment period. Three patients needed relief over the femoral condyles, and in each case the M-L measurements over the femoral condyles was ⅛ to ¼ in. smaller than the other two sockets. On the remaining three sockets the M-L measurement was the same as the pre-modification technique.

PATIENTS' REACTIONS

Patients were requested to use each prosthesis for a two-week trial wear period. Between each trial wear period the patient wore his own prosthesis for at least one week.

The transparent check sockets were replaced by polyester-laminate sockets since prior work at Rancho Los Amigos Hospital demonstrated that the polycarbonate sockets can crack under certain conditions.

Results from the trial wear period merely indicate that the patients were able to tolerate the prostheses for two weeks. In no case was there a tissue breakdown. Two patients could not wear the prosthesis all day and reverted to their original prosthesis. The comment most often heard was: "This prosthesis is good, but I still like my old one better."

DISCUSSION

The evaluation attempted to define specific advantages or disadvantages of each casting technique by relating the technique to the patients' outcome. No relationship could be found. The reasons for this were defined at the final meeting of the participants in August 1974.

The attempt to eliminate variables actually introduced variables. In retrospect, the requirement that all patients use the same type of foot, suspension, pylon, and hard socket introduced more variables than it eliminated. In addition, some patients used Greissinger "Five-Way" feet. After the evaluation the patients using Greissinger feet had them transferred to their evaluation prostheses in order to observe the difference. In every case, and not surprisingly, the patient stated the prosthesis was more comfortable with the foot he was used to. Probably, only the socket should be changed in such an evaluation so that it is the only variable to be considered. However, this procedure is questionable because worn feet can cause problems in alignment, and the use of inserts, whether old or new, introduces intangible factors.

Objectivity is nearly impossible to achieve. Despite measuring techniques such as x-rays, volume studies, temperature studies, etc., there is a point when someone must decide if the fit is acceptable. When the patient has sensation, the feedback from the patient is a strong factor that aids the prosthetist's decision concerning the adequacy of the fit.

Follow-up by the same prosthetist who originally made the cast of the patient was not possible. The three prosthetists came from different areas of the country so they were only able to cast the patients and modify the models. Fittings were performed by a disinterested prosthetist who was not totally familiar with the three techniques, although his experience as a prosthetist is extensive.

The socket volume measurements and the number of ply of prosthetics socks used did not always reflect the experience of the practitioners, as only heavy cast socks were available for casting in one instance, when the practitioner preferred to use light cast socks.

Logistical problems added complications, as patients would not always keep appointments or medical problems would interrupt the schedules. The amount of time needed from casting to the final meeting was 12 months, which reflects the unpredictable scheduling and coordination problems that were encountered.

CONCLUSIONS AND RECOMMENDATIONS

It is difficult, if not impossible, to relate patient outcome to one aspect of prosthetics fabrication. Future studies should consider all of the aspects of patient management. Fabrication techniques are only one small segment. Counseling, therapy, training, timing and understanding are the aspects of patient management that affect the patient outcome more than the physical design of the prosthesis. After all, many patients are mobile and well adjusted in wheelchairs. This study showed large volume and dimensional differences in the sockets, but the patient outcome was not affected by these differences.

The two-part technique reproduced the contours of the tibia more closely than the other techniques, was relatively easy to use, and consistently resulted in a mold with less volume than the other techniques. Therefore, it is recommended that this technique be used by teaching programs in prosthetics and orthotics. The use of transparent check sockets to evaluate socket fit is also encouraged because problem areas can be identified with a greater degree of accuracy.

This project illustrates the great difficulty in evaluating, objectively and subjectively, prosthetic devices and techniques. In nearly every instance the number of factors involved in successful use of an artificial limb is so great and so many of these factors are interdependent that it soon becomes impractical to eliminate the variables involved.

In this case it was considered best to provide each patient with a SACH foot in order to eliminate at least one variable. In retrospect, it may have been better to use the same type of foot each subject was accustomed to.

The volumetric and linear measurements recorded here are probably the most accurate ever made in a study of this type. Yet, they are not of much help in determining proper or adequate fit. They do reveal, though, once again that considerable variation in socket configuration is acceptable to the patient, but we are yet unable to determine these tolerances. Further work in this area is encouraged.

The temperature studies failed to yield any useful information although the potential usefulness of skin-temperature measurements is great. It is felt that thermograph pictures of the entire limb remnant would have given useful information but a suitable machine was not available. Certainly the use of thermography (*9*) as a means of evaluating the socket-stump relationship should be studied carefully, especially in conjunction with transparent sockets.

The difficulties found in evaluation of fitting techniques reflect both the complexity of socket fit and prosthesis alignment and our ignorance of just what constitutes "correct" fitting and alignment. Even though a great deal of progress has been made during the past 25 years in the development of rational approaches to fitting and alignment of artificial limbs, there remains the need for a great deal of art in the provision of a satisfactory prosthesis.

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