

The PTB Supracondylar-Suprapatellar Air-Cushion Socket

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The patellar-tendon-bearing supracondylar, suprapatellar air cushion (PTS-AC) below-knee (BK) prosthesis is a special modification of the supracondylar, suprapatellar suspension and the air cushion socket. The air cushion principle in combination with the patella tendon-bearing (PTB) prosthesis was introduced by Lyquist, Wilson, and Radcliffe (Fig. 1), (2) in 1965. It requires more accurate casting, fitting, and fabrication, and importantly, final reduction of stump edema. We have added a refinement to the fitting and the final fabrication of prostheses for BK amputees—the “check-socket” technique, whereby during the fitting period the patient walks in the prosthesis approximately two hours, has periodic examinations for areas of irritation or excess pressure on the stump, and has adjustments made immediately.

Lyquist, Wilson, and Radcliffe (2) documented the results of improved comfort and decreased proximal pressure in a controlled clinical study of five amputees, each of whom for an initial period had worn a PTB hard socket prosthesis and then each was fitted with a PTB-air cushion prosthesis. They highlighted their report with evidence that a

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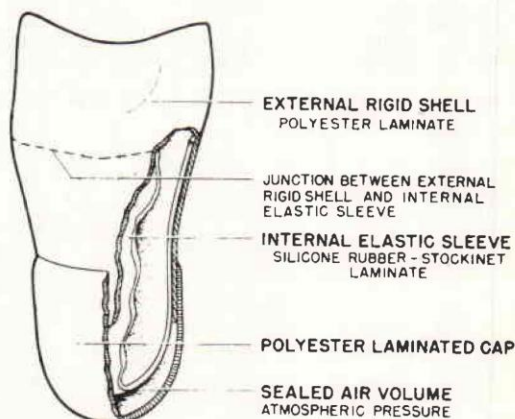


Fig. 1. The Air-Cushion Socket, From (2).

former ulceration located at the distal end of a stump healed while the patient was wearing the air cushion socket. Our experience supports their observations. We are now using the air cushion prosthesis with the supracondylar, suprapatellar suspension mechanism with increasing success. We propose that our modifications of fitting and fabrication with the check-socket technique are responsible for this success. The purpose of this paper is 1) to review the concept of the PTB, and the PTB-air cushion prosthesis 2) to describe the fitting and fabrication of the PTS-AC prosthesis, 3) to compare the responses of a group of patients wearing PTB



Fig. 2. Condition of below-knee stump prior to fitting with a PTS-AC socket.

prostheses to a group wearing the PTS-AC prostheses, and 4) to point out with illustrative cases the individual indications and accomplishments of the PTS-AC prosthesis. We have two examples of additional modifications. The emphasis of this paper will be on the fabrication of the PTS-AC prosthesis and the value of the "check-socket" technique.

PRINCIPLES OF THE PTB PROSTHESIS AND THE AIR CUSHION SOCKET

Lyquist *et al* had noted the advantages of the PTB prosthesis, particularly the elimination of the thigh corset thus permitting greater freedom of movement for the wearer, and total contact between socket and stump to improve circulation and help control edema. Even with the improvements, they noted that some patients still had edema or excessive pressure on the distal end of the stump. Lack of stump contact, as explained by Foort and Johnson³, is the cause of most cases of stump edema. Elimination of this type of edema is accomplished by having an

ideal stump-socket pressure relationship. This, of course, was the designers' premise for the development of the air-cushion feature of the PTB prosthesis. It was their intention, as well, to reduce proximal stump constriction. A tighter, more secure proximal fit had been used in order to avoid distal friction but had resulted in an increased risk of distal edema.

The PTB air-cushion socket (without the cap) was constructed somewhat shorter than the natural stump length so that when the stump moved distally in the socket with weight bearing, the elastic sleeve would stretch and provide increased pressure on the distal end of the stump, simultaneously contracting around the stump. The effect is similar to that which occurs when a finger is pushed against a suspended sheet of elastic material. An additional source of stump socket pressure is the sealed-in air volume distal to the elastic sleeve. Since volume and pressure are inversely proportional at constant temperature, the pressure in the closed air volume chamber increases as the elastic sleeve stretches under load. Recordings of this air pressure made by the original designers showed that maximum values of 60 to 100 mm Hg (positive) and 30 to 60 mm Hg (negative) pressures are produced during the stance and swing phases of the walking cycle. An air-cushion effect is generated in the stance phase and the negative pressure contributes to the suspension of the prosthesis during the swing phase.

In principle, the ability of the elastic sleeve to conform to the stump increases the area of the distal stump in contact with the socket, and therefore a better functioning, more comfortable, partial end-bearing socket is the result. Reduction of the pressure difference between the distal and the proximal portion of the stump further minimizes the risk of edema. The possibility of skin damage over the distal end of the tibia or fibula is reduced because the elastic sleeve moves distally and encompasses the stump during weight-bearing. It is probable that the gradually increasing pressures exerted around the stump by the action of the elastic sleeve contributes to the reduction of skin movement relative to bony structures.

PRINCIPLES OF THE PTS-AC PROSTHESIS

Our concept and principles of the PTS-AC

prosthesis can be stated in four points which are refinements to the fitting and fabrication process of the PTB air cushion prosthesis of Lyquist *et al*²: 1) We have a different method of suspension—supracondylar, suprapatellar. 2) The Silastic sleeve inside the PTS-AC prosthesis is not as long, i.e., it is not brought up inside the socket as high as the fibula head or the tibial tubercle. Thus, any possible irritation of these critical areas is avoided. 3) The socket is contoured to fit exactly the patient's stump, in contrast to the PTB air-cushion prosthesis where the socket is constructed shorter and then covered by an external cap that creates a space to allow for stretch of the Silastic sleeve. We provide this space by adding wax and then melting it out, thereby providing room for the distal movement. Thus the principle proposed initially is fulfilled, but with a more critical fit of the patient's stump. 4) Our check-socket technique permits altering the fit of the prosthesis before final fabrication. In essence, the first negative model without the Silastic sleeve is fitted to the patient, and he walks in this model for approximately a two-hour period. Frequent examinations are made of the stump to determine areas of rubbing or incomplete contact. After these are relieved, or built up, as necessary, a new positive is made. The Silastic is added during the final fabrication process.

FABRICATION

Materials and Equipment:

Cast sock	Cast cutter
Plaster, 4-inch rolls	Silastic, 384 Dow Corning
Water	Paraffin wax
Model plaster	Glass cloth
Surface-forming files	Styrofoam
Plaster knife	Adjustable walking leg
Abrasive screen	Vertical fabrication jig
Wet-or-dry sand-paper	Vacuum machine
Parting lacquer	Hot plate and pot
PVA film	Sanding machine
Dacron felt, ½ oz.	Hose clamp
Nylon stockinette	Foot (i.e. SACH foot)
Polyester resin:	Ankle block and bolt
flexible 4134	Scissors
rigid 4110	Plastic knife
Wood shin block	Hammer
Clay, oil-based	
Masking tape	

PROCEDURES

The primary dissatisfaction that prosthetists have had with the air-cushion prosthesis has been the problem encountered in making adjustments to the socket. With the check-socket technique we attempt to make all the necessary changes before adding the Silastic and completing the air-cushion design. An illustrative example is a patient who had been wearing a PTB prosthesis which no longer fitted. His stump showed distal induration, edema, and local cellulitis (Fig. 2). We prescribed for him a PTS-AC prosthesis.

The steps of fabrication are:

Step 1. Place stockinette on the stump. Hold the knee in approximately 20 degrees flexion. (This will vary with the stump length—as length decreases, the amount of flexion increases.)

Step 2. Wrap plaster on the stump. Define the head of the fibula, the proximal border of the medial femoral condyle, and the patellar tendon.

Step 3. Remove cast from the patient's stump. Fill with model plaster. Modify positive model, as required. Paint with parting lacquer and cover with polyvinyl alcohol film under vacuum.

Note. Usually the prosthetist fabricates the air-cushion socket at this point, relying on the cast and his measurements to obtain the proper fit. By using the check-socket technique, we believe a more accurate socket fit can be obtained and distal pressures will be within the tolerance of the patient. With the check socket a true mold of the distal stump is obtained under weight-bearing while walking over approximately a two-hour period (between Steps 3 and 13 of the fabrication process).

Step 4. Place three layers of one-half-ounce Dacron felt and two layers of nylon stockinette on the model (Fig. 3, left).

Step 5. Place a PVA bag under vacuum over model.

Step 6. Impregnate a mixture of 60 percent rigid, 40 percent flexible polyester resin into this material (Fig. 3, right). After the resin is cured, break out the plaster model and trim the proximal border of the socket.

Step 7. Install the check-socket into a wooden block and statically align it on an adjustable BK leg with a foot of the correct size (Fig. 4).

Step 8. Place the prosthesis on the patient and check the fit of the socket.

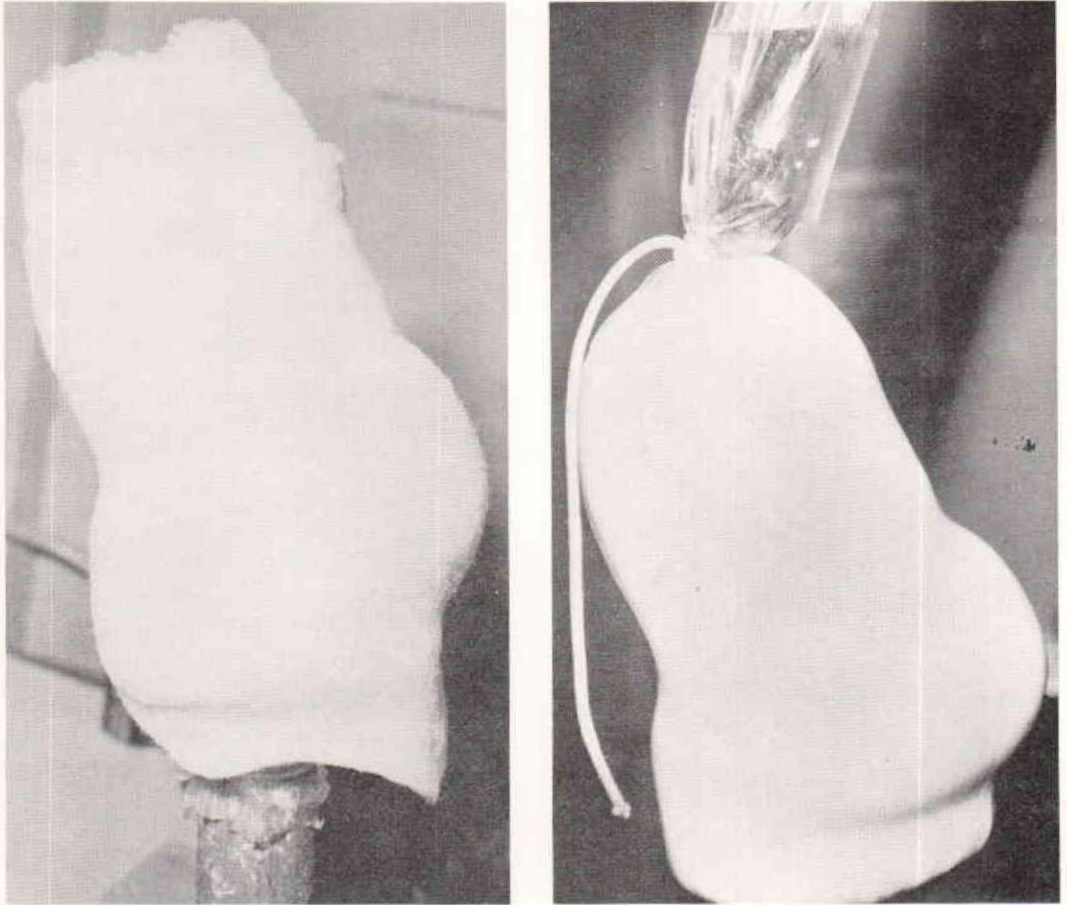


Fig. 3. Left, Model of stump covered with three layers of one-half ounce Dacron felt and two layers of nylon stockinette; Right, Impregnation of Dacron felt and nylon stockinette with a 60-40 mixture of rigid and flexible polyester resins to provide the check socket.

Step 9. Align the prosthesis dynamically (Fig. 5). Examine the stump for signs of irritation or pressure.

Step 10. Adjust the socket by adding leather fill to correct loose areas (Fig. 6) or by grinding where there appears to be pressure sites.

Step 11. Add small amounts of oil-based clay to the distal portion of the socket (Fig. 7).

Step 12. After the patient has walked on the prosthesis, ideally for two hours, check the distal socket for imprint, and add clay until firm, even contact is obtained. Examine the stump at intervals of time for areas of irritation or excess pressure. Analyze the impression of the stump sock in the clay. When the fitting is complete, the clay in the distal portion of the socket will show sock marks evenly, and will blend into the plastic walls of the socket (Fig. 8).

Step 13. Mark the foot-socket relation-

ship, remove the foot, and place the prosthesis in the vertical fabrication jig.

Step 14. Extend the proximal border of the socket with tape, and fill the socket with plaster.

Step 15. After the plaster has hardened, remove the adjustable leg and wood block, and bivalve the socket (Fig. 9).

Step 16. Remove the socket from the plaster model and sand the model with fine wet-or-dry sandpaper.

Step 17. Paint the prepared model with a parting agent. Now the fabrication of the air cushion socket begins.

Step 18. Place three layers of nylon stockinette over the model.

Step 19. Pull a PVA bag over model. Place under vacuum. Attach a hose clamp lined with rubber, and tighten (Fig. 10). This will determine the proximal border of the Silastic sleeve.

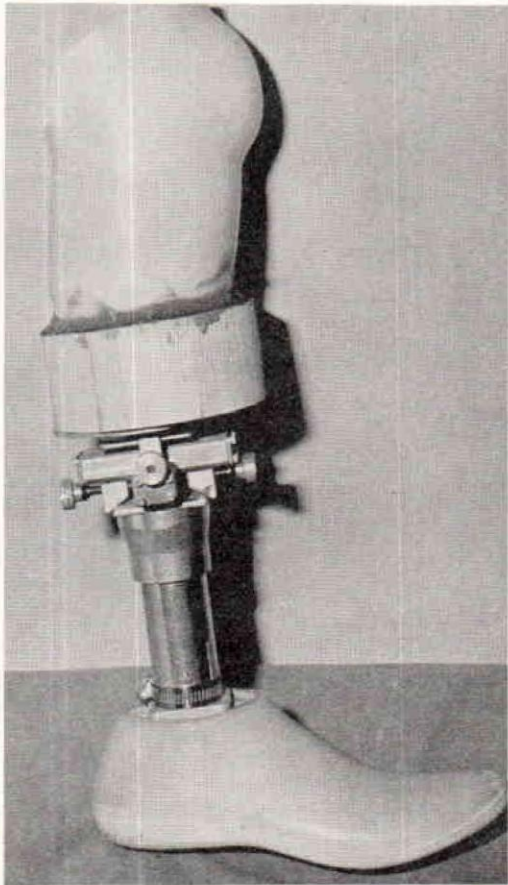


Fig. 4. The check socket mounted on a below-knee adjustable leg.

Step 20. Impregnate into the nylon a mixture of Dow Corning Silastic #384.

Step 21. When the Silastic has hardened, build up the distal end of the model with paraffin wax to the thickness of one-half inch and taper it up the walls (Fig. 11).

Step 22. Cover the wax portion with glass cloth to add strength.

Step 23. Add three more layers of stockinette and laminate with a mixture of 35 percent flexible and 65 percent rigid polyester resin.

Step 24. When the plastic has set, cut a hole in the end of the socket (Fig. 12).

Step 25. Place the socket in hot water to melt out the wax. Seal the wax escape hole to create the sealed air chamber.

Step 26. Place the socket back in the vertical fabrication jig in the same position that the final dynamic alignment was obtained. Replace the adjustable leg with Styrofoam.

Step 27. Shape the prosthesis.



Fig. 5. Dynamic alignment of the temporary prosthesis.

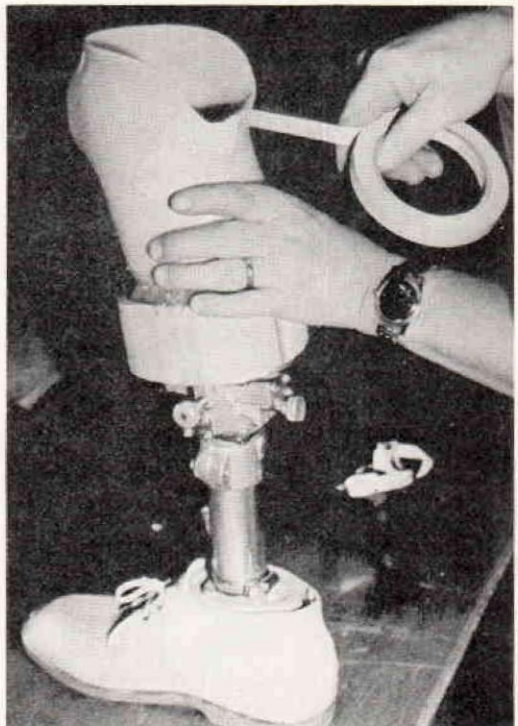


Fig. 6. Leather is used to fill loose areas when they exist.

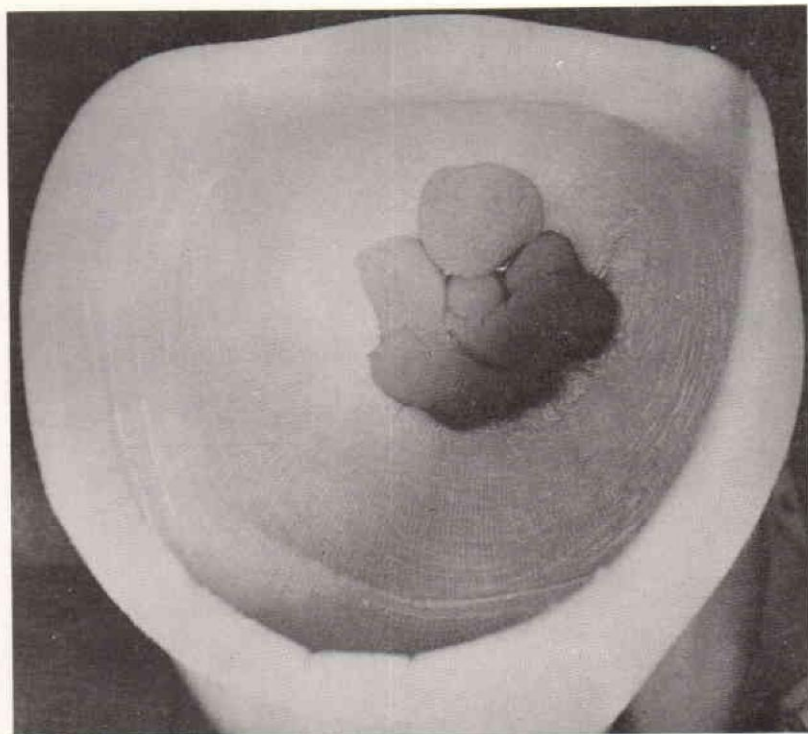


Fig. 7. Oil-based clay is placed in the distal portion of the socket to determine adequacy of socket fit in the distal portion.



Fig. 9.

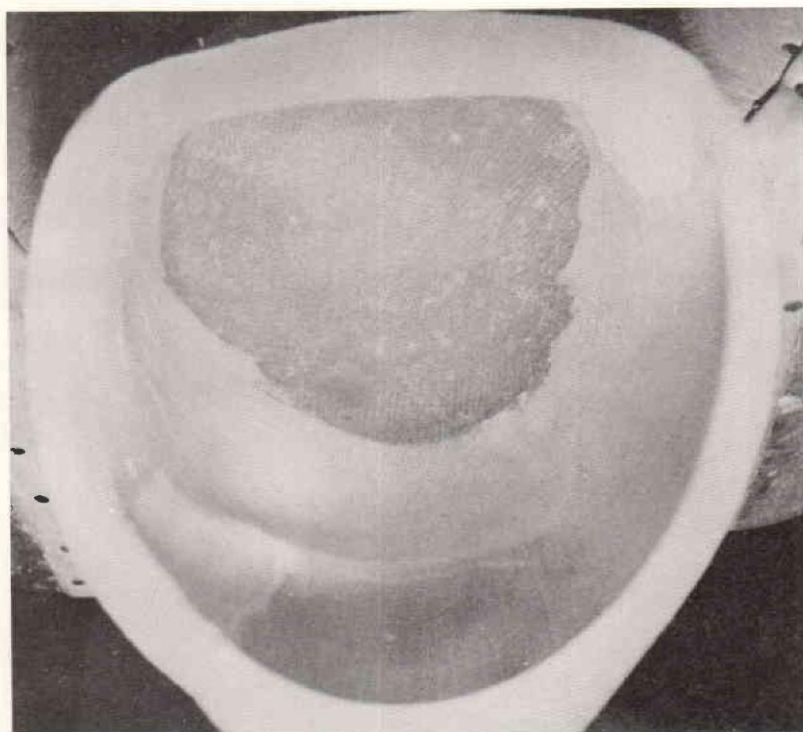
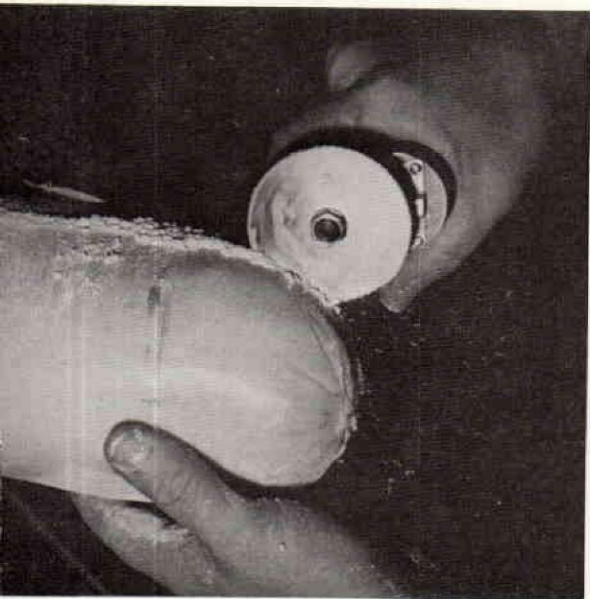


Fig. 8. Oil-based clay is blended into socket wall by pressure from the stump. A perfect mold is attained when sock marks are even.



Divalving the "check-socket" from the new positive mold.

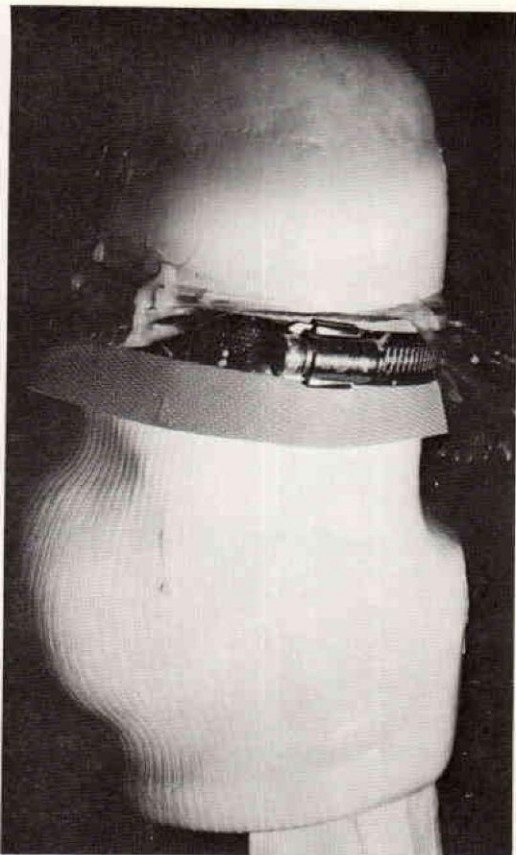


Fig. 11. Addition of wax to build up the distal socket area to create the space for the sealed-in air chamber.

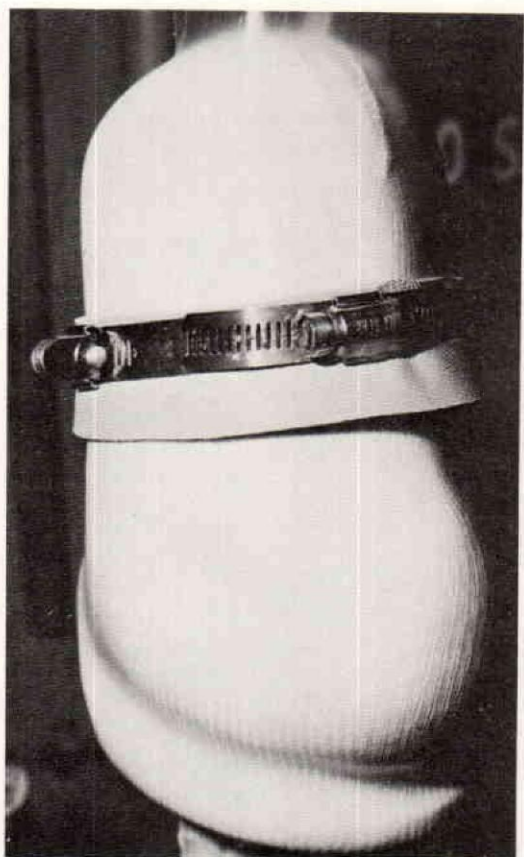


Fig. 10. Stockinette, PVA bag, and hose clamp lined with leather in place in preparation for adding Silastic. Hose clamp defines proximal border of Silastic sleeve.



Fig. 12. A hole is cut in the socket end to provide escape for melted wax.

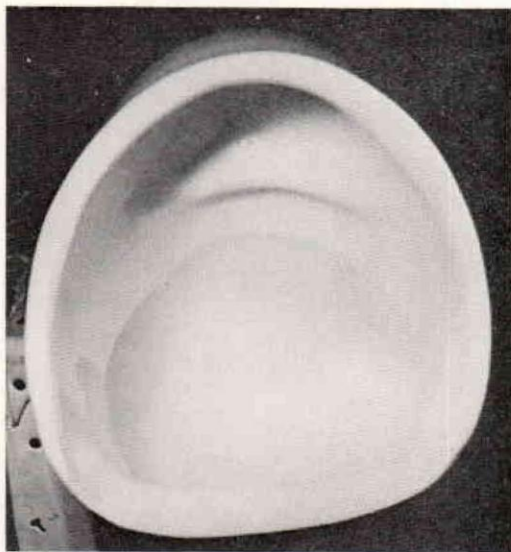


Fig. 13. Finished prosthesis smoothed and ready for delivery. Internal contour of Silastic sleeve can be seen.

Step 28. Complete the lamination with two more layers of nylon stockinette.

Step 29. Break out the plaster model and smooth the proximal edges of the socket. The Silastic sleeve, which can be seen from the inside, is contoured to the patient's stump (Fig. 13).

Step 30. Place the foot on the prosthesis and deliver the prosthesis to the patient (Fig. 14.).

Figure 15 shows the patient's stump after he had been wearing the PTS-AC prosthesis for three weeks.

The check-socket technique requires two to three hours additional fabrication time, but we believe that this is well worth the effort because a more satisfactory fit is obtained, and the number of return visits for readjustment are reduced.

RESULTS

We were able to canvas 21 of our amputees—10 wearing PTS-AC prostheses and 11 wearing patellar tendon-bearing prostheses. Although the numbers were not within the realm of statistical analysis, we can present the results of our questionnaire (Table 1) and comment on the trends of function, durability, and cosmesis. Cases are reported to illustrate the trends.

THE SURVEY

Each group of amputees disclosed in the questionnaire the number of hours the prosthesis was worn daily. The PTS-AC and PTB wearers claimed approximately the same



Fig. 14. Patient walking with a PTS-AC prosthesis.

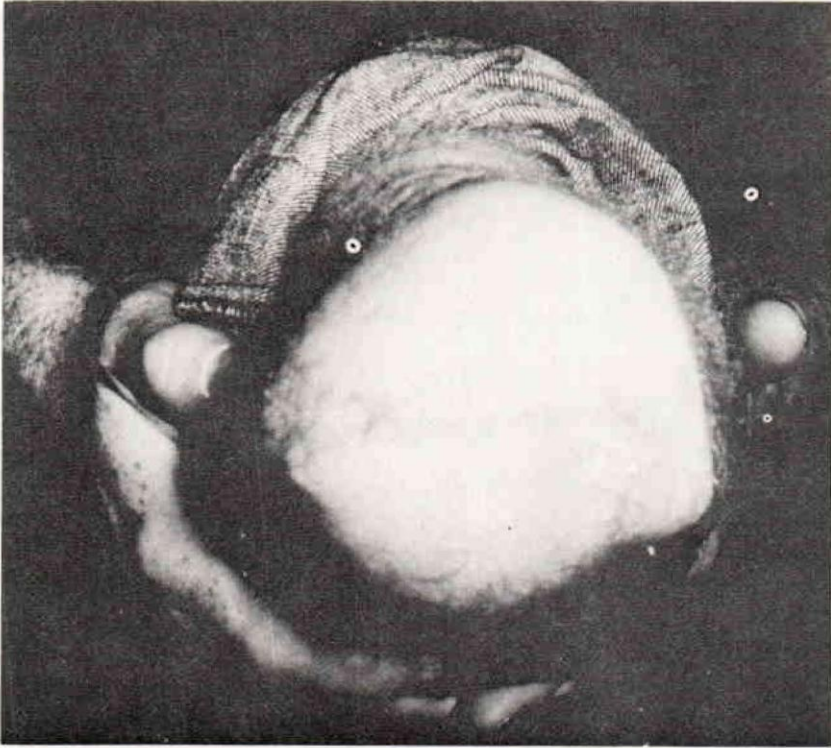


Fig. 15. Patient's stump after wearing PTS-AC prosthesis for three weeks. Inflammation and edema have resolved.

length of time per 24-hour period (averages, 14.1 and 15.2 hours).

Seven PTS-AC wearers had no distal stump breakdown. Three reported "slight" breakdown. Two of these decreased the size of their stump breakdown while wearing the PTS-AC prosthesis. One of these had formerly worn a conventional below-knee prosthesis with slip socket, external joint, and thigh lacer. A two centimeter distal ulcer had been a chronic problem for him. A PTS-AC prosthesis was prescribed following control of infection; no further ulceration has occurred. Of the PTB prosthesis wearers, four reported no breakdown, two slight, and five reported ulcers greater than one-inch in diameter.

Each group reported good to excellent results on hard flat surfaces and each had comparable results on irregular hard surfaces. On irregular soft surfaces and hilly terrain, the PTB user is slightly less stable. The supracondylar suprapatellar suspension, as well as the air cushion principle, probably is the explanation for the increased stability.

The PTS-AC prosthesis was not as accommodating to the wearer when kneeling. Many had discomfort and some felt considerably

unstable. In comparison, no PTB wearer reported that he was unable to kneel, and only a few indicated discomfort.

A minor difference in the patients' satisfaction with cosmesis existed in these two groups. Two of eleven PTB wearers desired an improvement. Although this is not a significant concern of most of our patients, the supracondylar, suprapatellar construction does improve appearance, a simple but important esthetic consideration.

There appeared to be minimal difference in restriction of knee motion in these two groups during ambulation and stairclimbing; and there was little variation in the patients' reports of prosthetic security.

Only one patient in the PTS-AC group expressed a desire for additional suspension. All patients in the PTB group used a supracondylar suspension strap, and seven expressed either a desire for additional suspension or a dissatisfaction with the strap. After accidental falls several patients in the PTS-AC group reported dislodgement of their prostheses. Whether this is an advantage or a disadvantage could not be determined.

The PTB wearers required more adjustment to their prostheses than did the PTS-AC group (16 visits compared to 8).

ILLUSTRATIVE CASE REPORTS



Fig. 16. *Case No. 1*. Note the pleasing cosmetic appearance.

Case No. 1

A 44-year-old housewife sustained a left below-knee amputation in an automobile accident when she was a teenager. She was fitted with a conventional below-knee prosthesis with thigh lacer and external knee joints. After a long period of use, two attempts to convert her to a PTB prosthesis wearer were unsuccessful. Local stump pressure, secondary to bony prominence, was a problem. She was fitted successfully with a PTS-AC prosthesis approximately eight months ago. She is highly satisfied with this prosthesis as to comfort, weight, and cosmesis (Fig. 16). Since wearing the PTS-AC prosthesis she has had an increase in the size of the quadriceps muscle to the extent that when she donned her former prosthesis, a thigh roll was created proximally (Fig. 17).



Fig. 17. Added quadriceps muscle bulk demonstrated by Case No. 1 (Fig. 16) when she donned her former conventional BK prosthesis after wearing the PTS-AC for eight months.

Case No. 2

A 21-year-old Vietnam veteran sustained an open devitalizing wound approximately one year before he was fitted with the PTS-AC prosthesis (Fig. 18). Chronic distal

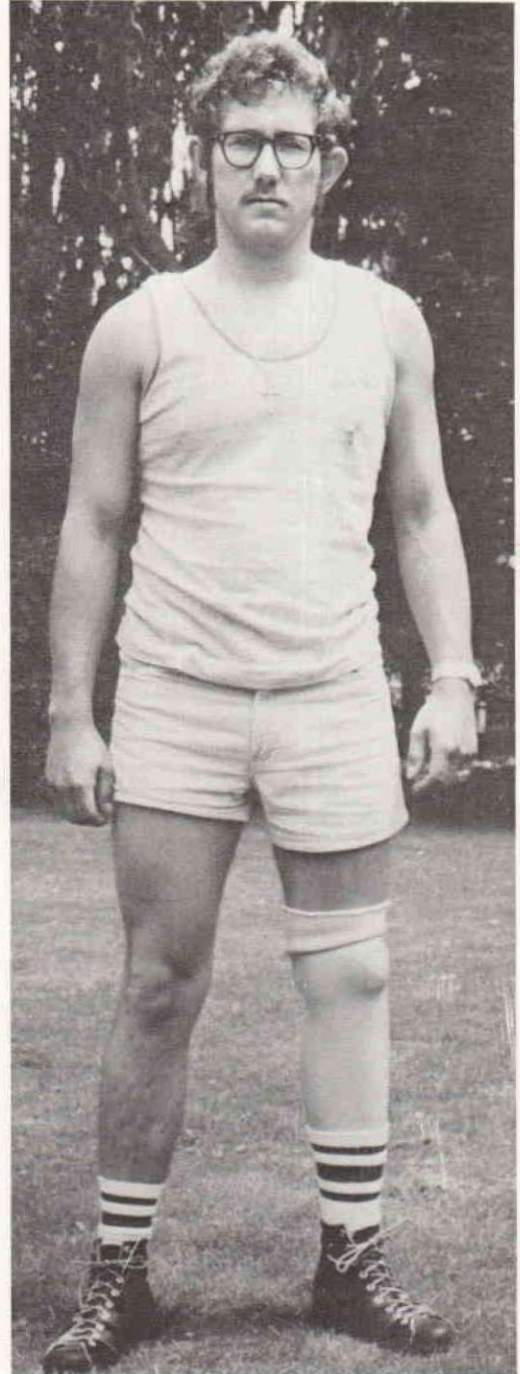


Fig. 18. *Case No. 2.* Secure fit of prosthesis is provided for demanding activities.

induration has subsided while wearing the PTS-AC prosthesis. He is employed now as a salesman, wears his prosthesis an average of ten hours per day, and drives daily a pick-up truck with a standard shift transmission.



Fig. 19. *Case No. 3.* Teacher and part-time interscholastic coach who has excellent functional result.

Case No. 3

A 24-year-old soldier sustained an open devitalizing wound secondary to a land mine explosion. After using a PTB prosthesis for three months he was fitted with a PTS-AC prosthesis. This patient has demonstrated an excellent gait pattern for a below-knee amputee. Presently, he is a teacher of biology and mathematics, and works two to four hours per day on the athletic field as an interscholastic football coach (Fig. 19).

Case No. 4

This patient has a left above-knee and a right below-knee amputation resulting from injuries suffered during combat in Vietnam. He is presently fitted with a left above-knee prosthesis with suction socket, hydraulic "SNS" knee unit, and SACH foot. His four-



Fig. 20. *Case No. 4.* Above-knee and below-knee amputee wearing a PTS-AC prosthesis.



Fig. 21. Case No. 5. Three-inch right BK stump which is nearly totally covered by split thickness skin graft.

inch BK stump is fitted with a PTS-AC prosthesis (Fig. 20). Initial distal stump edema and breakdown associated with infection has completely resolved while wearing this PTS-AC prosthesis (Figs. 1 and 15).

Case No. 5

This 24-year-old Vietnam veteran has a two-inch below-knee amputation which is

nearly completely covered with split thickness skin graft (Fig. 21). Several areas of breakdown complicated by *Staphylococcus aureus* infection protracted his fitting and ambulation. A PTS-AC prosthesis improved the condition of his stump and allowed longer periods of walking, but his requirements for this labile stump to stand up to the pressures



Fig. 22. Case No. 6. Popliteal scarring in a short BK stump with posterior and distal split thickness skin graft.

in snow and water skiing, golf and camping were not completely resolved with the latter prosthesis. The patient is presently wearing a patellar tendon-bearing supracondylar, suprapatellar soft socket BK prosthesis with KEMBLO liner. This has been the most satisfactory prosthetic prescription for him to date. The various legs provided by several fittings can be used on demand.

Case No. 6

This 23-year-old Vietnam veteran had the complications of popliteal scarring and of split thickness skin graft stump coverage (Fig. 22). He was bothered by scar sensitivity and a prominent distal fibula in his PTB prosthesis. A PTS-AC prosthesis was more comfortable and allowed longer periods of ambulation, but further modification was necessary. A patellar-tendon-bearing supracondylar suprapatellar soft socket BK prosthesis with KEMBLO liner has resulted in a more satisfactory prosthetic prescription.

COMMENT

A specialized below-knee prosthesis which combines the modifications of supracondylar,

suprapatellar suspension and the air-cushion socket design has been described.

The theoretical function and basic design, along with our present method of fabrication and alignment, stressing the importance of the check-socket technique is presented. A comparison of two groups (10 wearing PTS-AC prostheses, 11 wearing PTB prostheses) in eleven categories provides a generalized evaluation of the clinical applications of each type. Several successful fittings have been presented, highlighted by the control and elimination of ulceration and edema and by the conversion of two patients from conventional BK prostheses (thigh lacer and external joints). Two cases required additional prosthetic consideration—the first because of complete stump split thickness skin graft coverage coupled with his active avocational interests; the second because of scar sensitivity.

Although we use the prosthesis most successfully in the short BK stump, when bony prominences exist and when skin cover is less than ideal, we see no reason why the PTS-AC prosthesis could not be used for any BK amputee.

TABLE 1
Results of a Questionnaire

QUESTIONS	PROSTHESIS	
	PTS-AC*	PTB**
Average number of hours worn in 24-hour day	14.1	15.2
Stump breakdown		
None	7	4
Slight	3	2
Ulceration (1" in diam.)	0	5
Usability		
Hard flat surfaces	G to E	G to E
Less hard flat surfaces	G to E	G to E
Irregular hard surfaces	F to G	F to G
Irregular soft surfaces	F to G	
Hilly surfaces	F to G	F
Stair climbingNo difference.	
Kneeling	Discomfort Unstable	Less discomfort Less unstable
CosmesisMinor difference.	
Restriction of knee motionNo difference.	
Security		
When straight	E	G to E
When bent	G	G
Suspension	G	Desire more
Prosthesis came loose after accidental fall	Several "yes" Less than PTS-AC Advantage?/ disadvantage?	
Revisits for adjustments to prosthesis	8	16

*PTS-AC = patellar-tendon-bearing-supracondylar, supra-patellar air cushion prosthesis, 10 patients surveyed.

**PTB = patellar-tendon-bearing prosthesis, 11 patients surveyed. Other abbreviations: E=Excellent, G=Good, F=Fair.

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