Recent Advances in Below-Knee Prosthetics

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The concept of constructing a below-knee prosthesis with side joints and a thigh lacer was set forth by the Dutch surgeon Verduin in 1696 (Fig. 1) and followed universally until the advent of the patellar-tendon-bearing prosthesis in the late 1950's (7). Although other innovations such as contact over the distal end of the stump, suction suspension, and "muley" sockets were introduced from time to time, they were never widely used, possibly because principles governing their use were not set forth in a systematic manner.

In 1957, the predecessor of CPRD, the Advisory Committee on Artificial Limbs, encouraged the University of California at Berkeley to study the problems of the below-knee amputee and to improve the then current management practices. As a result, some of the leading prosthetists in this country were invited to Berkeley later in 1957 for the express purpose of examining in detail the prosthetics practices for BK amputees and rationales for those practices *(17).* An analysis of the findings of that conference led to the development of the patellar-tendon-bearing prosthesis, known now as the PTB prosthesis.

The original version of the PTB prosthesis was a plastic laminate socket which was formed over a modified plaster-of-Paris model of the stump, and which contained a soft inner liner that contacted the entire surface of the stump *(22,23).* The major weight was borne by the medial flares of the tibia and the patellar tendon. No knee joints or thigh corsets were used, suspension being effected by a fabric strap around the thigh just above the femoral condyles (Fig. 2).

The PTB concept was offered in formal education programs in this country and gradually gained acceptance, so that by 1961 slightly more than half of the below-knee prostheses provided in the United States were of that type *(16).* The concept also has been accepted widely in other countries, and the PTB now is generally considered to be the standard prosthesis for below-knee amputations.

In recent years, research groups and individual prosthetists have introduced improvements to the basic concept *(6).* This article describes the advanced practices in the management of the below-knee amputee that have been developed since the introduction of the PTB prosthesis.

THE HARD SOCKET

The original PTB socket design called for a lining of leather or Naugahyde backed by sponge rubber. Perspiration caused problems in many instances, however, because Naugahyde does not "breathe" and leather deteriorates rapidly in the presence of sweat. This problem prompted some prosthetists to eliminate the liner, and the "hard" PTB socket has become increasingly popular.

THE PTS SOCKET

The suspension strap for the PTB prosthesis, as designed originally, was usually satisfactory, but there were enough dissatisfied amputees to prompt a number of

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Fig. 1. Verduin leg (1696). From MacDonald, J., *Amer.J. Surg.,* 1905.

prosthetists to seek improved suspension methods. In addition to developing different strap designs (Fig. 3) (5), several groups experimented with new configurations for the proximal border of the socket. The research team at Nancy, France, introduced the "prothese tibiale a emboitage supracondylien," popularly known as the PTS, in which the proximal border extends above the patella and the femoral condyles (Fig. 4) *(20),* thus holding the socket on the stump. This concept was introduced into the United States by Nitschke and Marschall *(18,19)* and the PTS prosthesis is being used at an increasing rate in the United States. The technique may be used with or without a liner. Hamontree *(12),* in reporting his experiences with 94 cases, noted that, although he believed that the majority of the patients could have been satisfied with the original version of the PTB, a certain percentage could have been successfully fitted only with the PTS version.

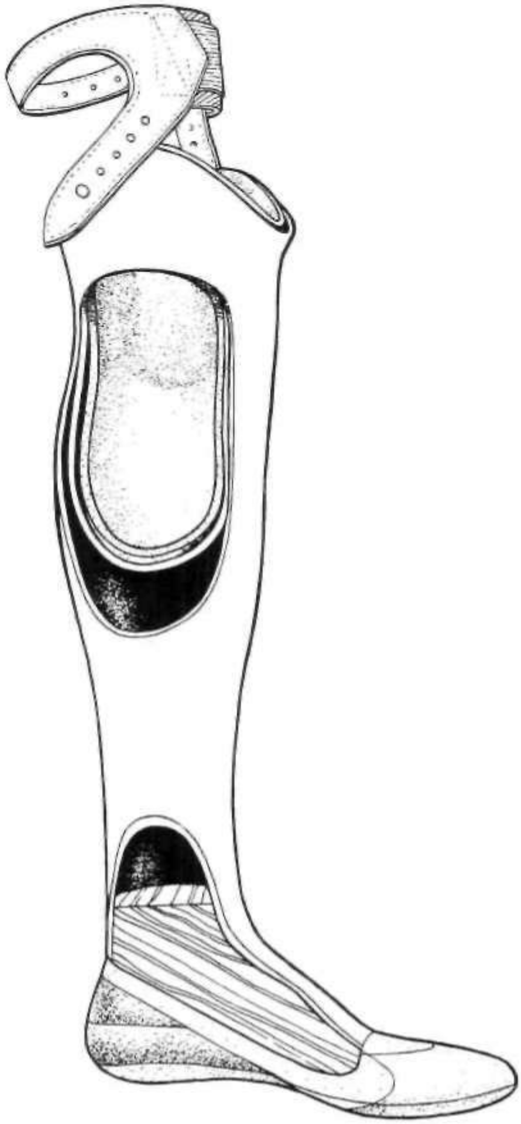

Fig. 2. Cutaway view of the original patellar-tendon-bearing (PTB) prosthesis.

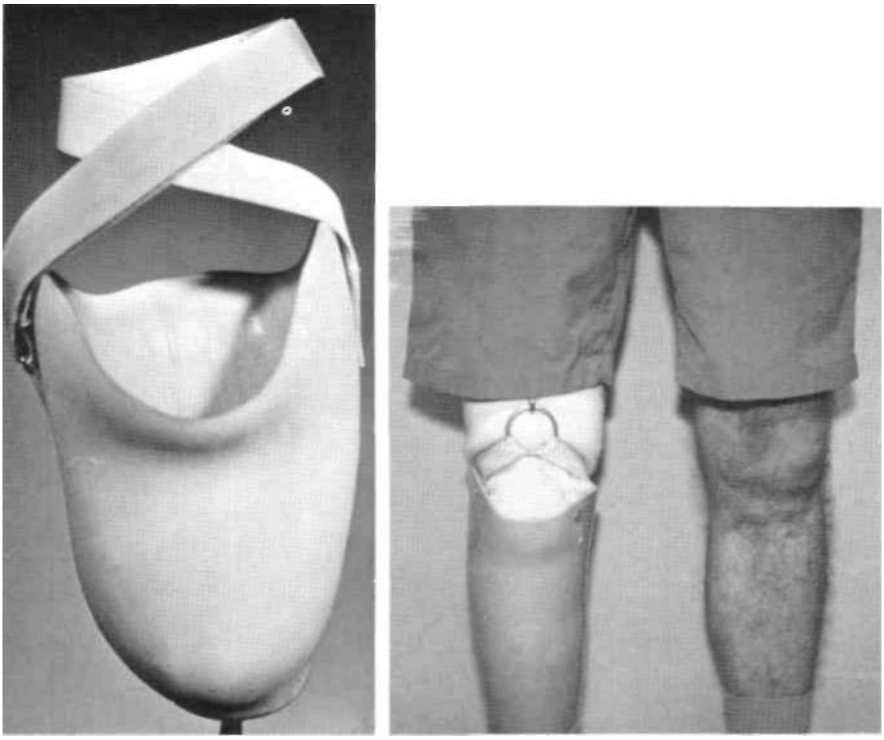

Fig. 3. *Left,* continuous-strap suspension arranged in a figure eight with Velcro for adjustment; *right,* anterior view of two inverted V-straps looped through a ring and attached inside a hard socket close to the brim.

WEDGE SUSPENSION SOCKET

Another attempt to improve upon the strap type of suspension resulted in the KBM (Kondylen Bettung Munster) prosthesis *(15),* in which a small wedge is inserted between the proximal area of the socket and the area of the stump along the medial condyles of the femur (Fig. 5). Developed at the University of Miinster, this concept was introduced into the United States by Fillauer *(10)* and is now known as the supracondylar-wedge suspension system. The wedge system may be used with or without a socket liner, but generally no liner is used.

AIR-CUSHION SOCKET

In an effort to develop a socket that would permit the stump to bear the optimum amount of the weight load over its distal end, Wilson and his associates *(25)* designed and developed the "air-cushion socket" (Fig. 6), which reduces the magnitude of the vertical components of weight-bearing forces at other points on the stump.

The air-cushion PTB consists of an elastic inner sleeve (stockinet impregnated with silicone rubber) suspended from the level of the tibial tubercle in a rigid outer shell that is closed distally. Stump support is provided by the tension of the sleeve itself and by the compression of the air in the chamber between the inner sleeve and outer cap.

Trials in the United States, Denmark, and Yugoslavia *(6)* have shown that the air-cushion version of the PTB is particularly useful for patients with very sensitive stumps. In fact, there appear to be few, if any, contraindications to the use of

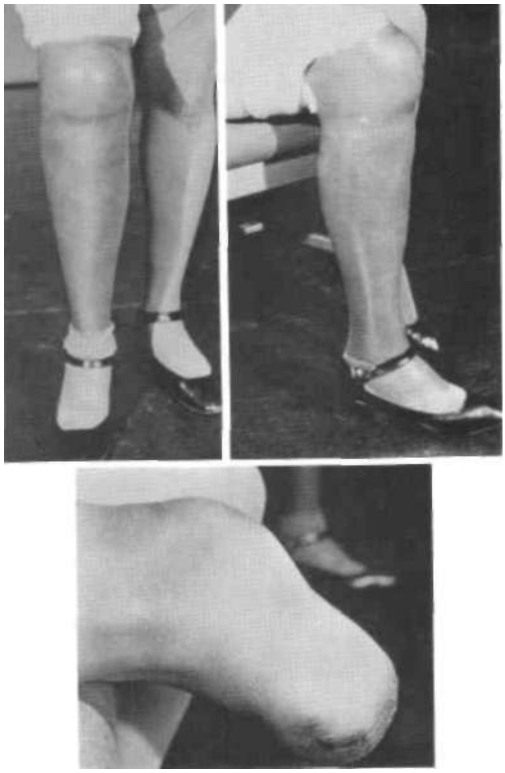

Fig. 4. A right, below-knee stump and the amputee wearing a PTS-socket prosthesis.

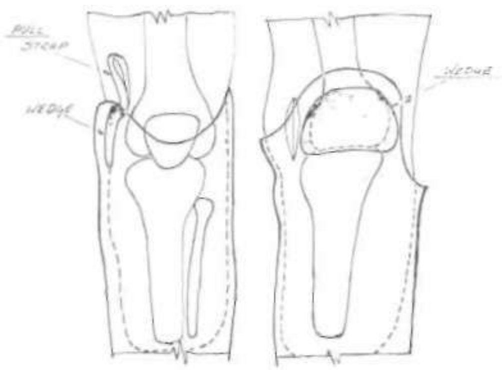

Fig. 5. The supracondylar-wedge suspension method.

the air-cushion socket, the only disadvantages being that slightly more time is required to fabricate the socket and that few modifications can be made after it has been fabricated.

POROUS SOCKET

In seeking ways to alleviate the problems caused by perspiration, the U. S. Army Medical Biomechanical Research Laboratory developed a porous plastic laminate *(9,14,21).* Conventional epoxy resins and filler materials are used in the fabrication, but special care must be taken in controlling the proportions of the ingredients and in curing. The first porous laminates developed by AMBRL were satisfactory for upper-extremity sockets, but they were not strong enough for routine use in lower-extremity sockets. Subsequently, the technicians developed a fabrication technique using epoxy resins that overcame the major shortcomings of the earlier laminates *(21).* New York University, after studying 20 children and young adults, reported that the porous-laminate socket appeared to be a "significant and worthwhile addition" to below-knee prosthetics specifically and to limb prosthetics generally *(9).* There were fewer problems with perspiration, and skin eruptions were ameliorated. In addition, the prostheses with porous-laminate sockets weighed less. When perspiration was a major problem, the two disadvantages cited—slightly increased fabrication time and greater difficulty in maintaining socket cleanliness—were far outweighed by the advantages.

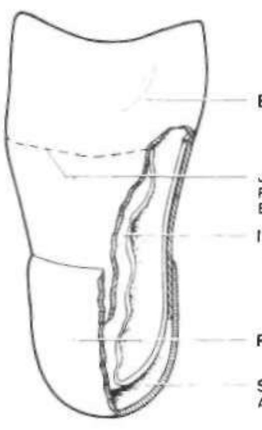

Fig. 6. Cutaway view of the air-cushion socket.

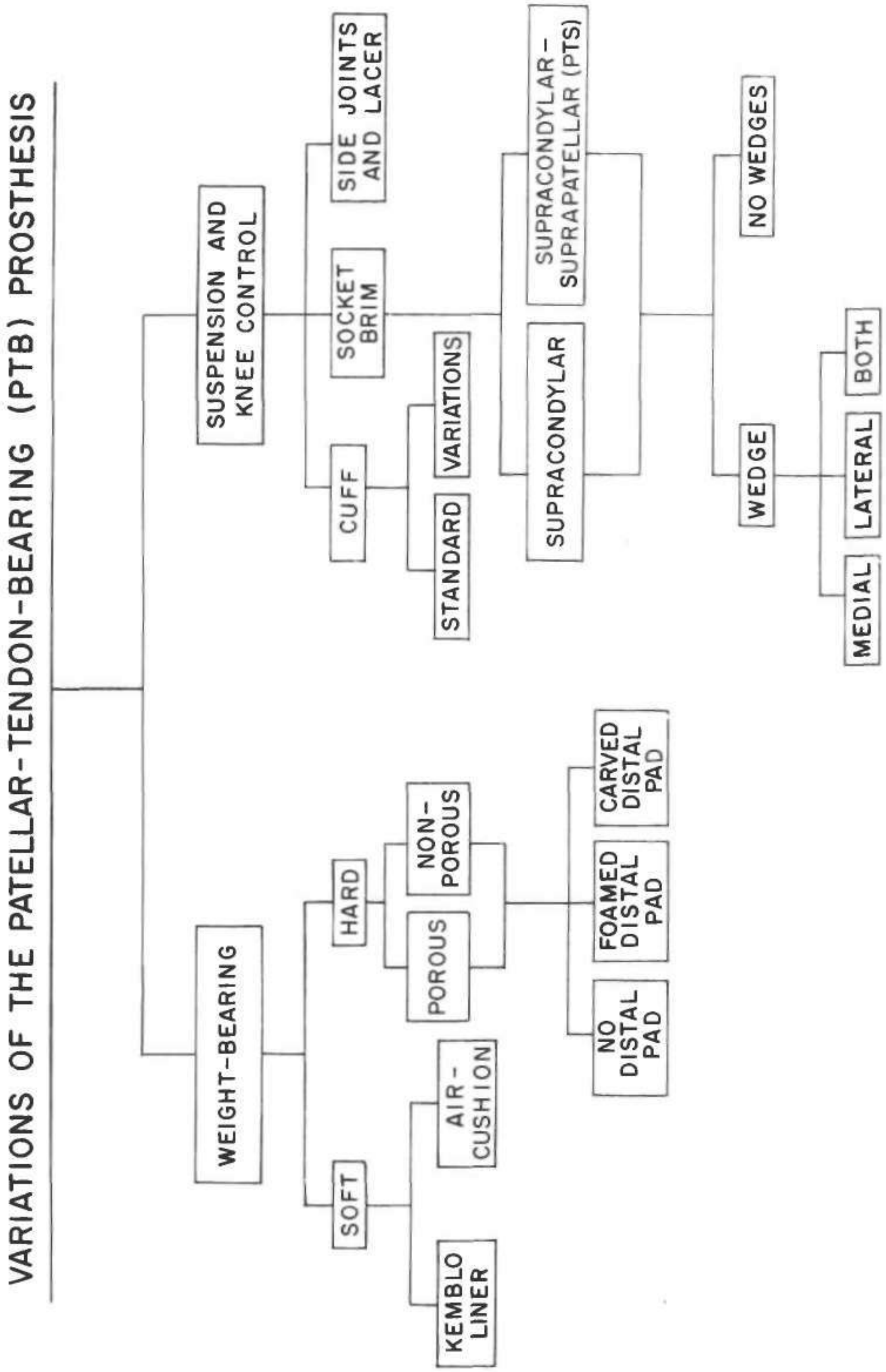
VARIATIONS OF THE PATELLAR-TENDON-BEARING (PTB) PROSTHESIS
WEIGHT-BEARING
SUSPENSION AND KNEE CONTROL
SOFT
HARD
KEMBLO LINER
AIR-CUSHION
POROUS
NON-POROUS
NO DISTAL PAD
FOAMED DISTAL PAD
CARVED DISTAL PAD
CUFF
SOCKET BRIM
SIDE JOINTS AND LACER
STANDARD
VARIATIONS
SUPRACONDYLAR
SUPRACONDYLAR-SUPRAPATELLAR (PTS)
WEDGE
NO WEDGES
MEDIAL
LATERAL
BOTH

Fig. 7.

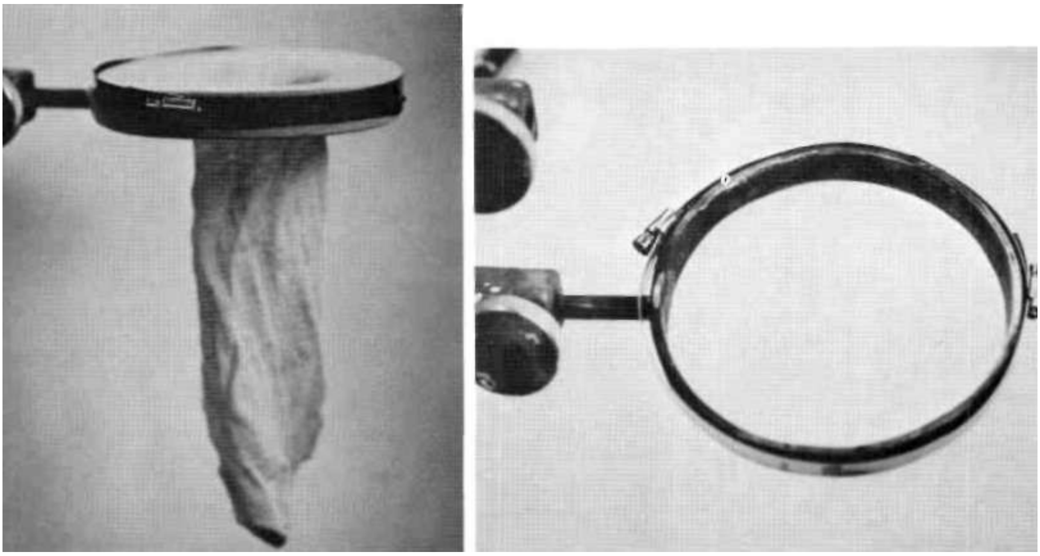

Fig. 8. Ring and sock for suspension casting of the below-knee stump.

Because most of the innovations to the original PTB design are not mutually exclusive, it was possible to develop a chart showing the combinations of features that can be used to devise a below-knee prosthesis that best meets the needs of the individual patient (Fig. 7).

CASTING METHODS

The method for obtaining a model of the stump for fabrication of the PTB socket, as described in the original manuals, consisted of wrapping the stump with plaster-of-Paris bandages, shaping the wrap with the fingers, and subsequently modifying the male mold produced from the female cast, or wrap. Any number of attempts have been made to devise a procedure that would require less skill. One such method that has been accepted by many prosthetists is the sling-casting, or suspension-casting, technique developed by Hampton *(13)* (Fig. 8).

In the suspension-casting technique, the stump is wrapped while it is held in a vertical position that simulates weight-bearing during standing. Felt patches to provide relief for sensitive areas of the stump can be applied directly to the stump, and a minimum amount of modification is necessary, although the need for modification is not eliminated entirely.

Research workers and clinicians have been searching for years for a material that will enable the prosthetist to form a socket directly over the stump, thereby eliminating the need for plaster wraps and male molds. Experience with a synthetic rubber, Polysar[2] X-414, has shown that this material definitely has a place in the fabrication of sockets *(24).* Temporary, or provisional, below-knee prostheses consisting of a synthetic-balata socket and pylon-type components are proving to be useful. Because it becomes pliable at temperatures easily tolerated by the skin, synthetic balata can be applied directly over the stump. Extruded tubing of various diameters with walls 1/4-in. thick is available. A piece of tubing slightly smaller in diameter than the stump is heated in water to about 160 deg F, then forced over the stump, which has been padded in appropriate areas (Fig. 9). To give proper shape to the socket, a length

[2] Registered trademark of Polymer Corporation Limited.

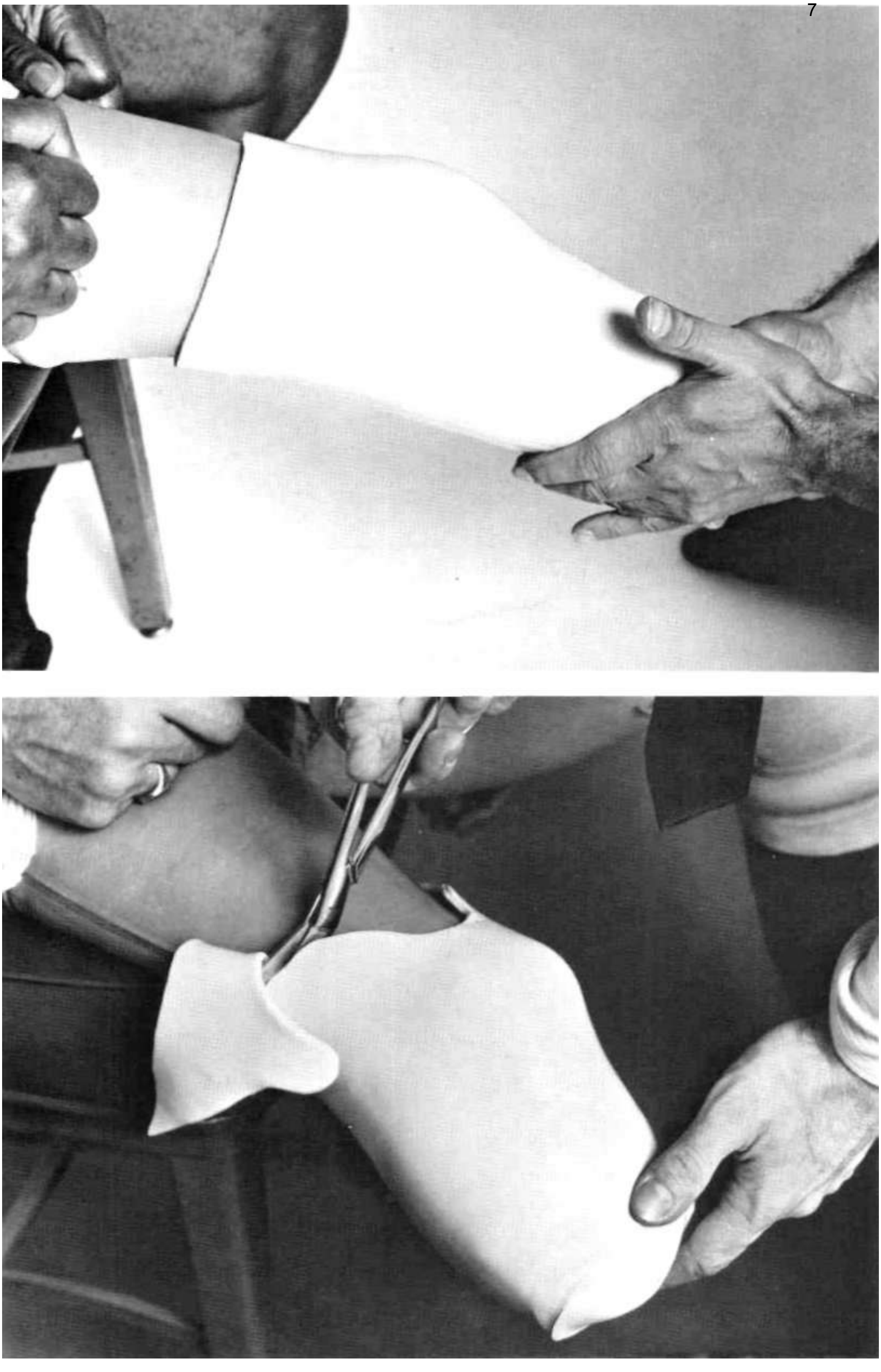

Fig. 9. *Top,* application of socket tube to the stump; *bottom,* trimming of socket brim prior to final molding.

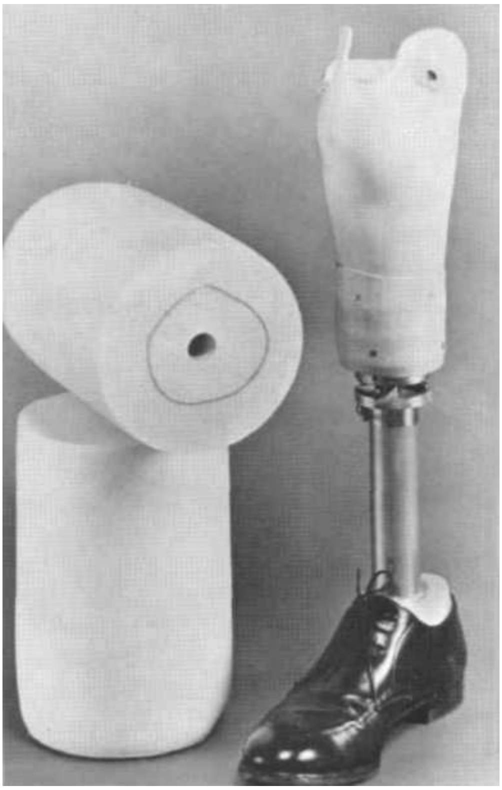

Fig. 10. Foam blocks for fitting over pylon and socket.

of pressure-sensitive tape, 1 in. wide, is wrapped over the outside, and final forming is carried out manually. To provide total contact, the distal end is filled with "foam-in-place" silicone. The socket is easily mounted on a pylon unit for use as a temporary prosthesis, or a more permanent one if desired. The prosthesis can be given a natural appearance by applying and shaping semirigid blocks of Koroseal "Spongex"[3] (Fig. 10). Contours of the socket can be changed at any time by heating the area with a heat gun and reshaping it manually.[4]

[3] B. F. Goodrich Co.

[4] Sockets of this material should not be left near radiators or in an abnormally warm environment, such as the interior of a closed automobile parked in sunlight on a warm day, because synthetic balata becomes pliable at temperatures as "low" as 120 deg F.

TIME OF FITTING

During the past decade, the advantages of fitting a prosthesis as soon after amputation as possible have been demonstrated repeatedly. Goldner and his associates *(11)* demonstrated that "early" fitting—that is, providing the patient with a temporary prosthesis as soon as the wound has healed rather than waiting for a maximum amount of shrinkage to take place—could drastically reduce time and costs of rehabilitation. Even more dramatic results have been obtained by fitting artificial limbs immediately after surgery, especially with below-knee amputees *(2-4,8)* (Fig. 11).

The technique of immediate postsurgical fitting was originated in France by Berlemont, was carried further by Weiss in Poland, and, after a considerable experimentation period in the United States, is now being taught routinely in the prosthetics education programs in this country *(7).* The technique consists of applying a rigid dressing over the stump and attaching an adjustable pylon and foot. Standing and ambulation is begun as soon as the patient's condition permits. For young, otherwise healthy patients, some ambulation can begin on the day following amputation.

Usually the rigid dressing is left in place until the wound has healed and the sutures can be removed—about 10-14 days postoperatively. A second rigid dressing is provided for another 10- to 14-day period, at which time a "permanent," or definitive, limb can be provided. The advantages of immediate postsurgical fitting include reduction of edema, less pain, shorter periods of hospitalization and therapy, and fewer contractures. The technique has become standard practice in many centers with trained teams (7).

HARDWARE

To make early fitting and immediate postsurgical fitting easier, a number of adjustable pylons have been developed. Those currently available are shown in Figure 12. Some of their characteristics are given in Table 1. These units are strong enough and light enough for extended usage with or without some sort of cosmetic cover. A number of approaches to cosmetic treatment such as the use of

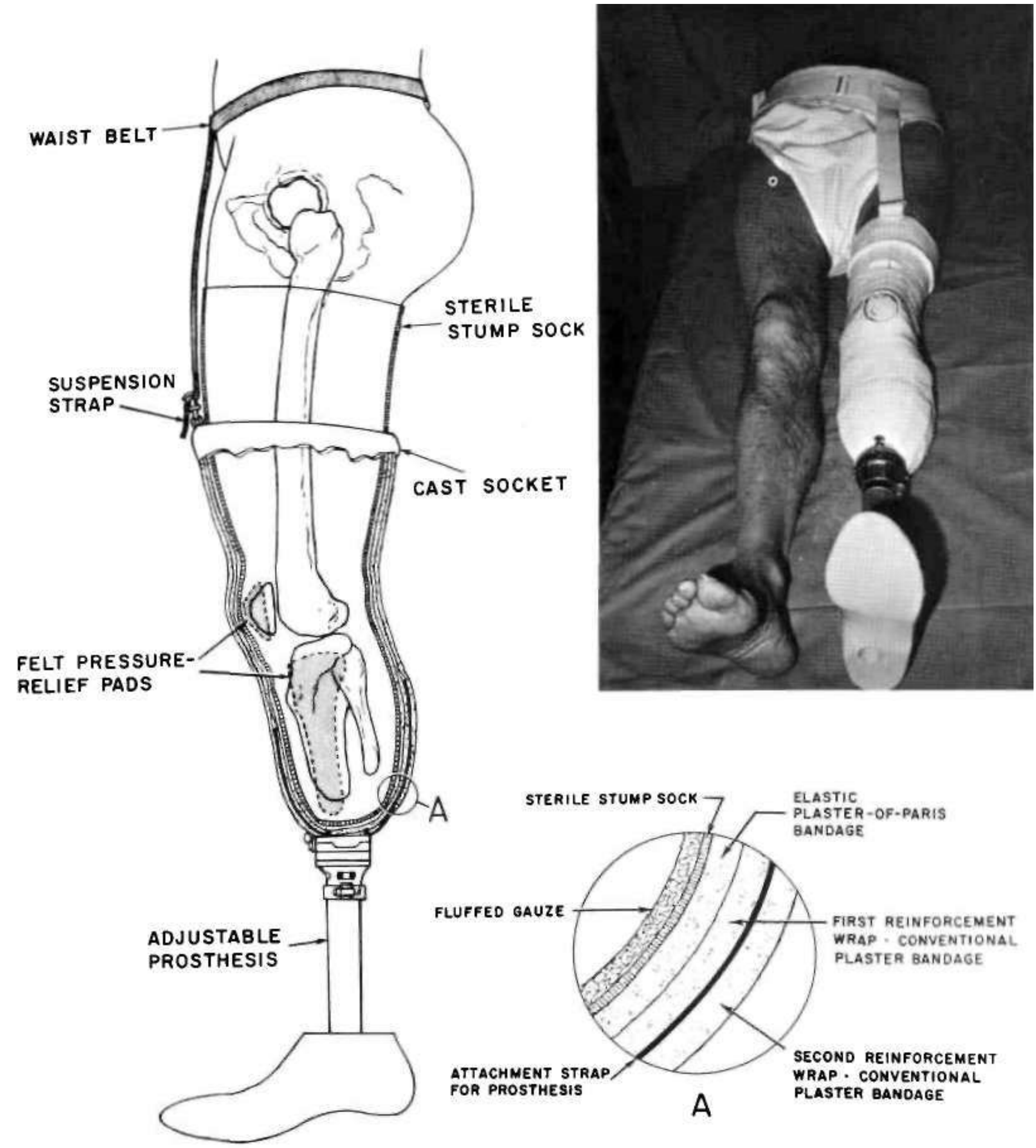

Fig. 11. Schematic cross section showing the major elements of a prosthesis as applied immediately following surgery to a below-knee amputee. The suture line, silk dressing, and drain are not shown. The fluffed gauze does not extend beyond the area indicated in "A." *Inset:* A below-knee amputee fitted with the immediate postsurgical prosthesis.

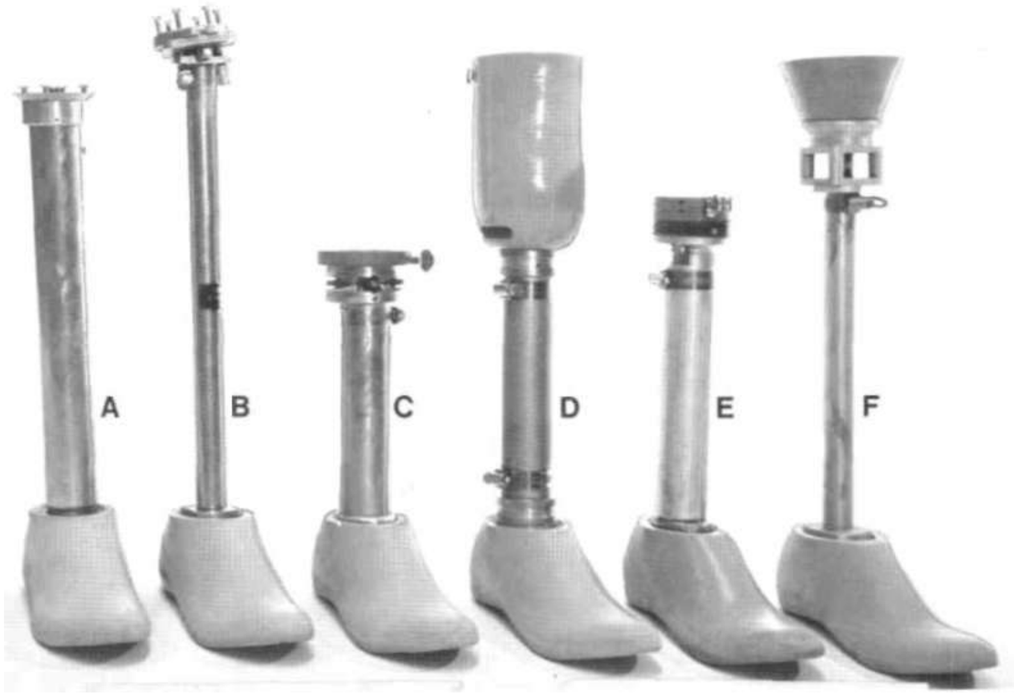

Fig. 12. Below-knee pylon-type prostheses that can be used for fitting immediately after surgery. *A*, Hosmer Postoperative Pylon; *B*, Northwestern Pylon (Hosmer); C, Veterans Administration Prosthetics Center (VAPC) "Standard" Pylon; *D*, Canadian "Instant" Prosthesis (Hosmer); *E*, United States Manufacturing Co. Pylon; *F*, Finnie-Jig (Arthur Finnieston Co.). Metal straps for attachment to a plaster-of-Paris socket are available, but not shown. *Courtesy of Veterans Administration Prosthetics Center.*

TABLE 1. SOME CHARACTERISTICS OF AVAILABLE BELOW-KNEE PYLON-TYPE PROSTHESES

	Hosmer Postoperative Pylon	Northwestern Pylon	VAPC "Standard" Pylon	Canadian "Instant" Prosthesis	U S Mfg Co Pylon	Finnie-Jig
Weight without tubes and straps (lb)	0.5	0.75	0.75	1.0[a]	0.75	1.0
Wall thickness of tube (in.)	0.0625	0.0625	0.0625	0.0625	0.0625	0.09375
Outside dia. of tube (in.)	1.625	1.0	1.625	1.625	1.625	1.0
Length of total assembly without tube (in.)	4.0	5.0	3.75	5.0	4.5	6.0
M-L adjustment range (in.)	1.0[b]	1.25	0.75	1.0[b]	0.875	0.875
A-P adjustment range (in.)	1.0[b]	1.0	0.75	1.0[b]	0.875	0.875
Socket flexion-extension adjustment range (deg)	10[b]	10	8	10[b]	10	10
Socket abduction-adduction adjustment range (deg)	10[b]	10	8	10[b]	10	10
Quick disconnect for socket removal?	Yes	No	Yes	No	Yes	No

[a] With plastic socket.

[b] Linear adjustments must be subtracted from angular adjustment or *vice versa* because the adjustments are not independent of each other.

Spongex, mentioned above, have been offered, but none have been accepted widely by prosthetists. Work on this problem is continuing.

EDUCATION AND RESEARCH NEEDS

At the December 1968 "Symposium on Below-Knee Prosthetics" *(6),* sponsored by the Committee on Prosthetics Research and Development, a number of suggestions for improving prosthetics education and practice were offered.

1. The body of knowledge about BK prosthetics that has been developed in recent years should be made available to practicing prosthetists and other clinicians.
2. All institutions offering prosthetics-education courses should include the information presented at the symposium in their curricula.
3. Opportunities for continuing education, such as postgraduate-type courses for clinic teams in the latest prosthetics techniques, should be provided.
4. Additional manuals and other instructional materials should be prepared. In addition, a central group that would be responsible for the orderly preparation and dissemination of technical information is needed.
5. Current research efforts in BK prosthetics should be continued, but with emphasis placed on the development of a truly refined theory of fitting.

Because most of the recent improvements to the design of the below-knee socket, especially in suspension techniques, have been accomplished by practicing prosthetists, there is little need for the research centers to devote their time to developing additional improvements. On the other hand, there is very little knowledge about the basic principles underlying optimum fitting of prostheses. Therefore, the research centers should be encouraged to obtain basic information about the effects of pressure and shear forces on tissues, and to more clearly indicate the biomechanical forces required in the various phases of walking. Following that work, methods by which those principles could be put into practice should be developed, including the use of hydrostatic sockets and other methods that might provide automatic adjustment.

As a result of these suggestions, a pilot course in advanced below-knee prosthetics practices was held at Northwestern University (see "News and Notes") on August 4-13, 1969, for prosthetist instructors from the University of California at Los Angeles, New York University, and Northwestern University. The University Council on Prosthetics Education is now developing a curriculum for short-term postgraduate courses in below-knee prosthetics. The advanced techniques will also be offered in regular courses in below-knee prosthetics.

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