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THE CONNECTION[1]

A. BENNETT WILSON, JR.

The functions provided by the connection between an amputee and his artificial leg are primarily: transfer of weight-bearing loads to the ground through the distal portion of the prosthesis; the transmission of power from the body to the prosthesis for actuation and control of the prosthesis; and the provision of suspension of the prosthesis when it is not in contact with the floor or ground.

The only successful way of providing these functions to date is by means of a tubular, cup-like receptacle, known as "the socket", that encases the amputation stump. Sometimes all or part of the suspension function is provided by straps over other parts of the body.

No single factor is more important in lower-limb prosthetics than the relationship between the amputation stump and the socket. Proper fit has yet to be defined quantitatively. But the most sophisticated mechanical components are of little use when the artificial leg is attached to the patient so loosley that control is inefficient. Conversely, when, in an effort to provide stability, the socket fits so tightly as to restrict blood flow in the stump, the prosthesis must soon be abandoned.

The most significant contributions of the American and Canadian research programs in limb prosthetics (Wilson 1970) are considered by many to be socket designs, methods of socket fitting and fabrication, and principles of prosthesis alignment. The outstanding examples are Canadian-type Plastic Syme's prosthesis (Fig. 1) and its variants, the patellar-tendon-bearing (PTB)

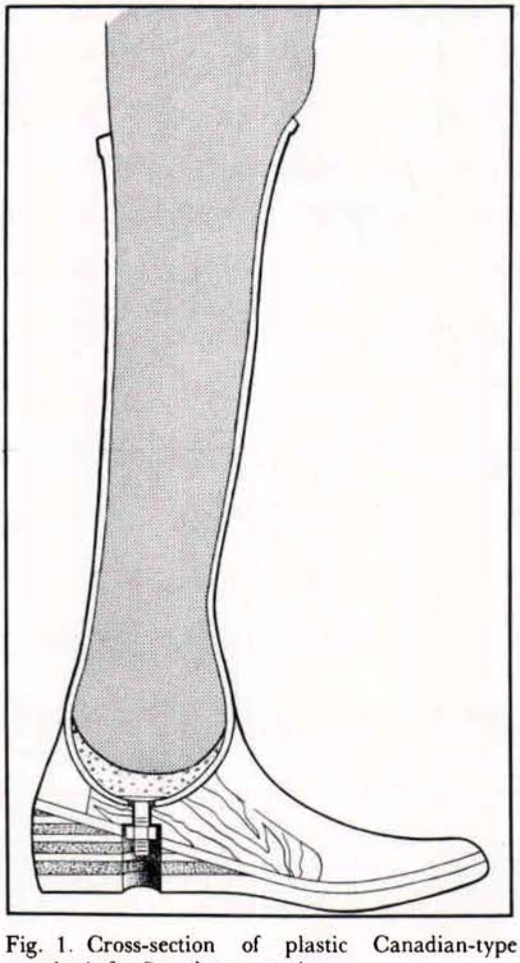

Fig. 1. Cross-section of plastic Canadian-type prosthesis for Syme's amputation.

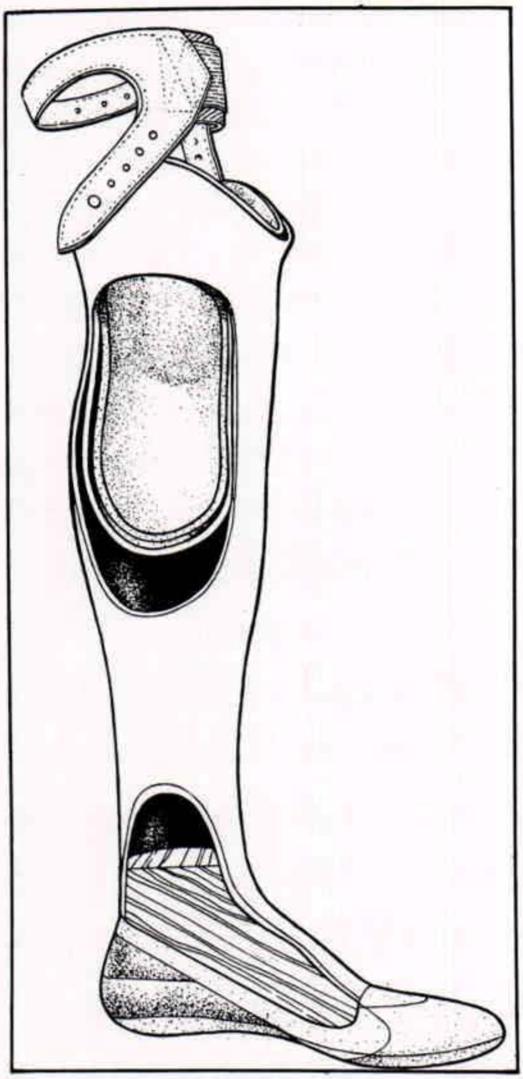

Fig. 2. Cross-section of standard patellar-tendon-bearing (PTB) prosthesis developed at the University of California, Berkeley and San Francisco.

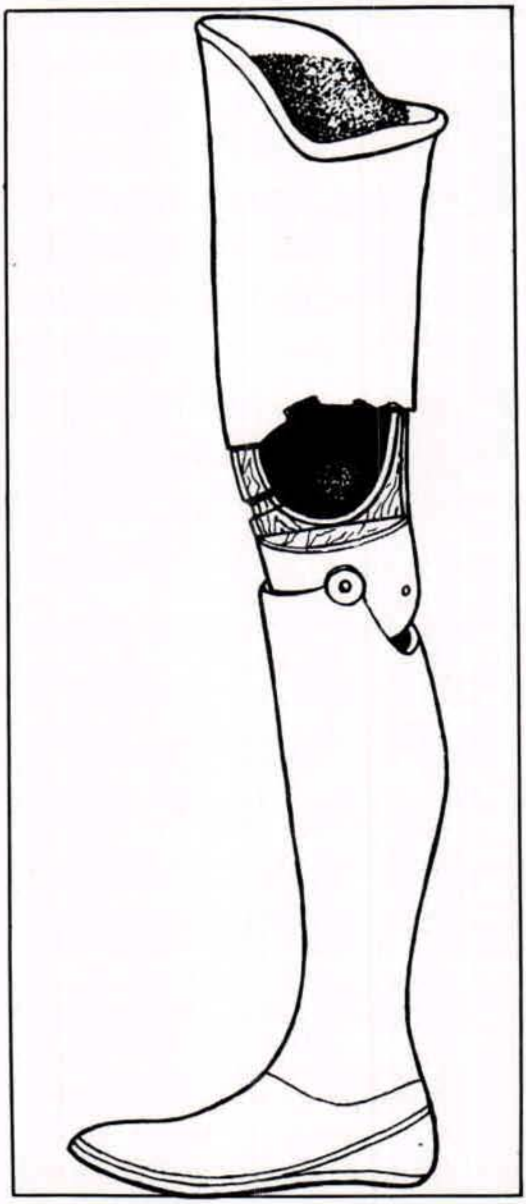

Fig. 3. Total-contact, quadrilateral socket for above-knee amputations developed at the University of California, Berkeley and San Francisco.

below-knee prosthesis (Fig. 2) and its variants, the quadrilateral sockets (Fig. 3) with and without suction, with and without total contact for above-knee amputees, and the Canadian-type hip-disarticulation (Fig. 4) and hemipelvectomy prostheses (Wilson 1968, 1969, 1970).

The instructions set forth in manuals used in educational programs, when followed closely by skilled prosthetists, result in adequate prostheses for patients

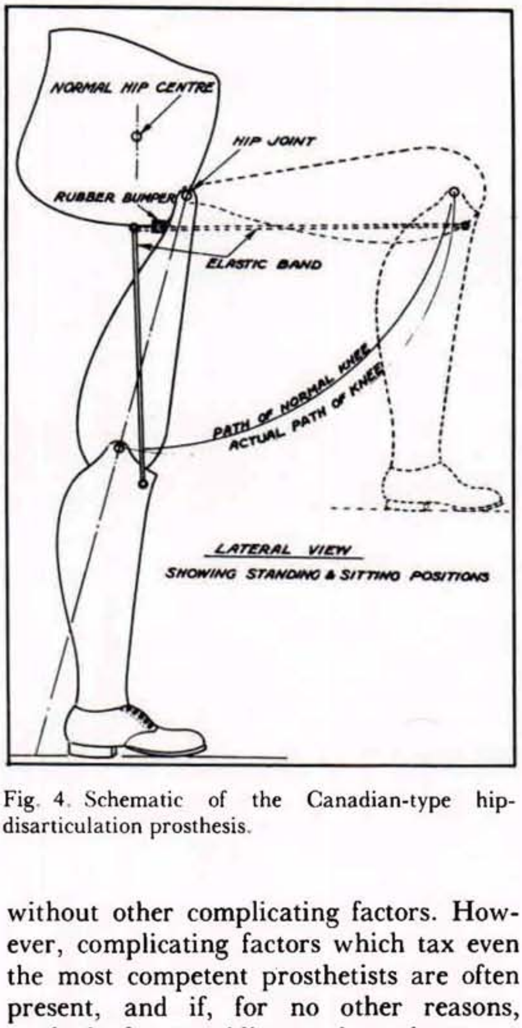

Fig. 4. Schematic of the Canadian-type hip-disarticulation prosthesis.

without other complicating factors. However, complicating factors which tax even the most competent prosthetists are often present, and if, for no other reasons, methods for providing sockets that meet more adequately the demands of all amputees are needed.

Socket Design

To provide better criteria for socket designs, it seems obvious that we need to know a good deal more about the mechanisms of edema and the circulation of body fluids than we do at present. One reason we lack knowledge in these areas is that we do not have the means to measure efficiently the pressures between the stump and the socket, or the methods of measuring effectively the results of the application of pressure.

These problems have been recognized for many years, and some efforts, though with little useful results, have been made in determining the distribution of forces over the amputation stump (Appoldt 1969, 1970). Pressure transducers that have been used to date have been either unreliable or used improperly, and up to this point few ideas have been set forth in reference to practical ways to measure the effects of pressure on the soft tissues of an amputation stump (CPRD 1972).

Several independent developments have taken place through the years that, if combined, might lead to relatively inexpensive studies that might in turn lead to improved connections between patient and prosthesis.

One of the deterrents to studying the effect of changes in socket shape on the amputation stump has been the cost of making individually tailored sockets, and fitting and aligning them with other components to provide prostheses suitable for experimental purposes.

The dilatancy technique for taking impressions of amputation stumps has been refined in recent years, especially by Germans et al. at the Medical Physics Institute in Holland, and Hagglund in Sweden. This technique offers a very inexpensive way of obtaining casts and models of stumps, for the production of experimental sockets (CAL 1947, Koster 1972), Hagglund 197) (Fig. 5).

The work of Snelson & Mooney (1972) has shown that for practical purposes not only can the time required for lamination be eliminated, but a transparent socket as well can be had quite inexpensively by vacuum-forming techniques (Fig. 6). A transparent socket clearly offers the opportunity not only for visual observation, but also an opportunity for the investigators to ensure that the pressure transducers are always in the same location and that the socket is

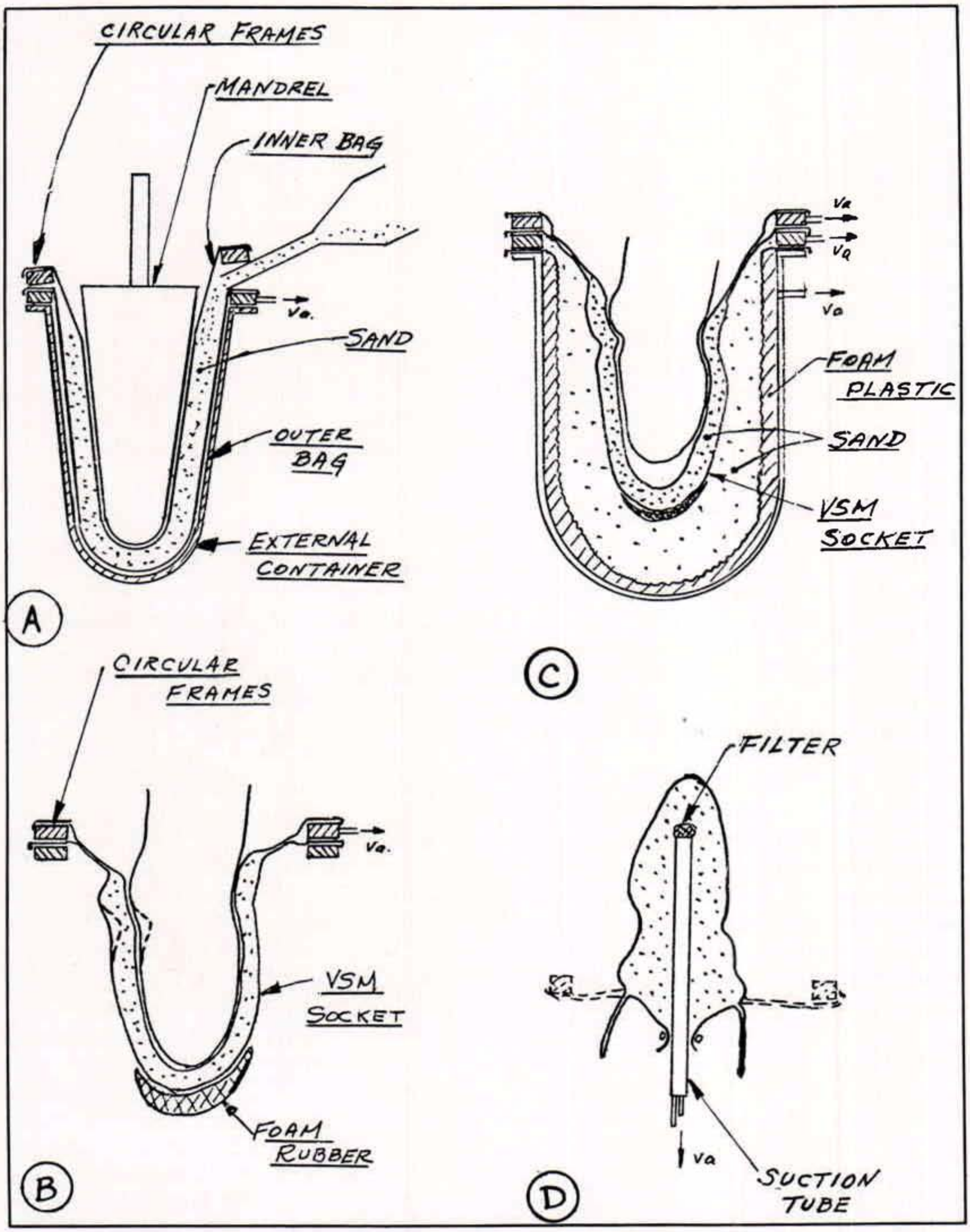

Fig. 5. Steps in dilatency casting of stump and production of a positive model.

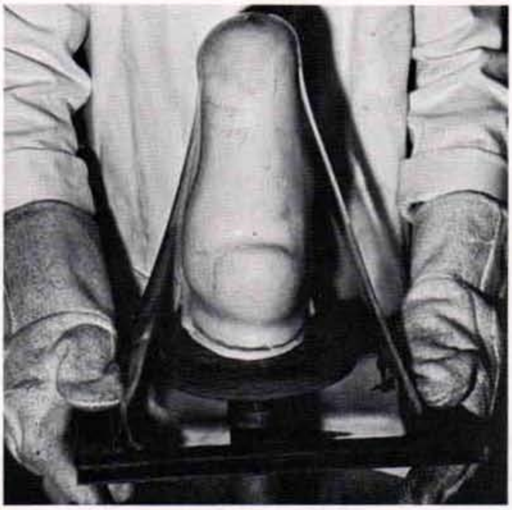

Fig. 6. Vacuum forming a transparent socket for a below-knee prosthesis.

in the same relationship with the stump during each trial (Fig. 7).

Lightweight, inexpensive, endoskeletal components for lower-limb prostheses that permit all adjustments required for proper alignment are now available commercially (Wilson 1968, 1969), so that, coupled with dilatancy-casting and vacuum-forming of sockets, a feasible means of providing many experimental socket shapes for the same group of subjects is readily available.

A few years ago the pressure transducers considered useful for measuring pressure between the stump and the socket cost more than $300 per unit, and the area covered was less than 1.28 cm^2. There is some question about the size of the area that will provide a useful measure, but certainly 1.28 cm^2 is too small to be practical or desirable, even when the pain threshold is not exceeded.

An approach not yet tried scientifically is the measurement of forces over components of a segmented socket. It would seem that this is a more logical approach than measuring pressures over pinpoint-size areas.

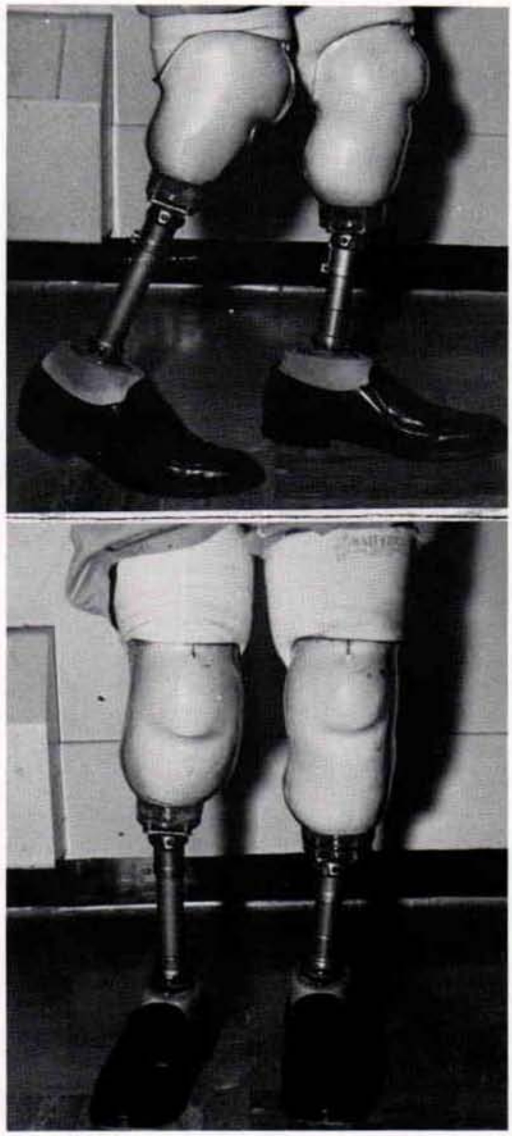

Fig. 7. Transparent sockets fitted to a bilateral below-knee amputee for extensive checkout.

Visual observation through a transparent wall of a socket will of course help in observing the outward effects of pressure on the soft tissues of the stump, but it would seem that one of the most logical methods available to measure and record these effects is the Thermograph camera (Brand 1969, 1970). A complete record of skin temperatures can be made very rapidly by use of thermography without danger or discomfort to the patient. Brand, in working with leprosy patients, has pointed the way for use of this technique.

Another development that has been suggested over the years, and one that is gradually being learned about, is the use of inflated pads on the inner surface of the socket to provide an adjustable range of pressure. Newer materials and more awarness of the way inflated units work, coupled with the suggestions given above, should make this approach more attractive as time goes on.

New sheet plastics that have better properties seem to be introduced rather constantly. Yet polypropylene, polyethylene, and other materials have not been tried thoroughly, although they are used in orthoses routinely in some institutions. Their combination of flexibility and tensile strength seems to have much to offer when studying the advantages that might be provided by socket walls that have a stiffness gradient—one that becomes more flexible in the proximal direction (Murphy 1960).

Surgery

It has been stated many times that surgical procedures have a great effect on the stump and the consequent fitting of the socket. This of course is true especially in reference to invaginated scars and obviously poorly placed incisions. Not so clear are the advantages of myoplasty, myodesis, and osteoplasty (Burgess 1969, Dederich 1970, Loon 1962, Swanson 1966, Weiss 1971). We all have our clinical impressions, but to date no one has carried out a scientific evaluation of these techniques. This is most unfortunate because the means of doing this are available.

Not so easy to assess is the idea of "skeletal attachment", or the connection of the prosthesis directly to the long bone of the amputation stump. This idea is not new, but if it would be made practical, the connection problem for the majority of amputees would be solved, and the engineers could devote more time to the design of other mechanisms and components.

The problem can be divided into two parts: attachment to the bone, and the exit through the skin and the superficial soft tissues.

The first reference to skeletal attachment came from Germany (Cutler 1945, Murphy 1960) in 1945 but little work seems to have been carried out since then in any place but the United States. Esslinger (1970), influenced by Stone's work with the human eye, showed that certain Silicone compounds were compatible with both osseous and soft tissues, and he had some success with percutaneous plastic strips staying in place along the backs of dogs, but did not collect sufficient data to make follow-up studies of his techniques attractive. Hall* used Dacron velour in treating a horse with some success. Mooney (1971) has been experimenting with ceramic structures and vitreous carbon as the percutaneous materials.

In all of the experiments, encouraging results have been obtained. It is, of course, difficult to find human subjects for these kinds of experiments, and animal studies leave much to be desired. Nevertheless, research in skletal attachment of external prostheses is encouraging and should be supported.

Summary

The need for improved designs for sockets for artificial legs is stated, and suggestions for research that will lead

to more functional connections between the patient and the prosthesis are set forth.

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*Southwest Research Institute, San Antonio, Texas.

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[2]Director of Rehabilitation Engineering, Division of Orthopedic Surgery, University of Texas Health Science Center at Dallas.