PREFABRICATED BELOW-KNEE SOCKETS FOR THE MATURING STUMP

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The concept of prefabricated below-knee sockets was introduced in Canada by Foort (1) in 1967. Since then prefabricated sockets have not gained wide acceptance in clinical practice, largely because a suitable range of sockets have not been readily available and because they require modular systems which are still at an early stage of development (2).

As these difficulties are overcome, this approach offers real hope that the management of the below-knee amputee should be improved through the possibilities of speedier fitting, earlier ambulation, more rapid rehabilitation, and at a lower overall cost. For these reasons, it is logical to attempt to resolve the existing problems with prefabricated sockets and modular prosthetic systems.

Foort, while working at the Prosthetic Research Unit in Winnipeg, developed a system of modular prostheses (3) and a range of below-knee prefabricated sockets which included 19 right and 19 left sizes (1, 3). At the present time, however, it is only possible to purchase six sizes each for right and left stumps from the Winnipeg group.

The author was involved in the clinical testing of these prefabricated sockets while working with Foort, and has continued to use these since 1967 on new amputees. Early in the clinical testing, the following limitations of this range of socket sizes were noted: 1. the sockets dimensions did not follow the changing shape of a maturing stump and 2. the larger sizes did not offer an acceptable cosmetic restoration.

Consequently, a study for the collection of anthropometric data on below-knee stumps was begun. It is the purpose of this paper to report these findings and present proposals for a series of 14 prefabricated below-knee sockets (seven right and seven left), for use in the maturing below-knee stump. It appears to the author that a need for prefabricated sockets would be accepted for stump maturation, but understandably
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there is skepticism about prefabricated sockets used on a permanent basis.

**STUMP MATURATION**

In recent years, as the trend towards immediate postoperative fitting has gained acceptance, the prosthetist has faced new problems related to the fitting of patients with stumps at varying stages of healing, following amputation surgery. The stage of maturation of this healing process has important implications for the prosthetist and for the design of the prosthetic socket.

We believe it is convenient for the prosthetist to classify stump maturation as follows. An immature stump is one within 3 months of amputation. A maturing below-knee stump refers to one which is being fitted between 4 months and 2 years after surgery. A mature stump is one at least 2 years after the amputation and which has been fitted with a prosthesis.

During the first 3 months following surgery healing is incomplete, postsurgical edema is a problem, and rapid stump shrinkage tends to occur. The musculature of the stump goes through a process of initial atrophy, and the stump has to adapt to a new function of weight-bearing when a prosthesis is worn.

The rate at which the stump heals and adapts to prosthetic fitting and use will depend on many factors, including the age and general health of the amputee, the vascular supply to the limb, the technique employed in the amputation surgery, and the method of prosthetic management.

As the patient’s stump matures, it becomes time-consuming to maintain a comfortable fit compatible with the patient’s increased level of activities, and often many socket changes are necessary. The anthropometric data collected in this study have been designed to permit us to fit a group of patients with maturing stumps more comfortably and to allow these amputees to be more active in a prefabricated socket until full maturation of the stump has occurred. We are also reasonably confident that prefabricated sockets of this type should eventually be suitable as permanent sockets for older, less active below-knee amputees. At the present time, we realize that custom-made permanent sockets will still be required for the younger, more active below-knee amputee.

**ANTHROPOMETRIC STUDIES**

During the last 5 years, the author has collected data on 200 below-knee stumps while he was working at the Manitoba Rehabilitation Hospital and at the Eastern Ontario Regional Rehabilitation Centre. These
stumps have been measured while either immature, maturing, or at the stage of maturation.

The types of patients upon which the data were collected is described as follows: The patients were in the following age groups: 23 percent in the 20–39, 32 percent in the 40–59, 36 percent in the 60–79, and 9 percent in the 80-and-over age groups. The age range was between 20 to 87 years. In the group 76 percent were males and 24 percent females. The etiology of amputation was: vascular disease 64 percent, trauma 28 percent, and “other” 8 percent.

Thirteen measurements were taken on the below-knee stumps at each stage of the maturation process. The 13 measurements taken are shown in Table 1 and Figures 1–5. These 13 were decided upon in order to obtain enough measurement data about the stump that could be inter-related to define size and shape in a below-knee socket.

Whenever possible, the stump data were collected on several occasions until the maturation process was considered complete. As the rate of stump change is dependent upon the method of prosthetic management and upon the activity level of the amputee, the rate at which stumps mature varies widely. All the data were collected by the author in order to standardize and offer validity to the measurement technique.
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TABLE 1.—Stump Measurements (Fig. 1-5)

1. Anterior-posterior (A/P): Distance from the relaxed patellar tendon to the popliteal area.

2. Mediolateral (M/L): Widest point at the knee joint in the medio-lateral direction.

3. Hamstrings (Hams): Extreme outer edges of the medial and lateral hamstring tendons at a point just proximal to the insertion of the lateral tendon.

4. Supracondylar (S/C): Distance from a point just above the insertion of the tendinous part of the adductor magnus (adductor tubercle) to the ilio-tibial band laterally (moderate pressure on tissues).

5. Medial condylar height (C/H): A point taken from the middle of the medial knee-joint line to a point just superior to the adductor tubercle. (Allowance for soft tissue is made.)


7. Proximal (prox.): At the patellar-tendon level, exactly at the knee-joint line.

8. Middle (mid.): Measured at the level of the neck of the fibula and the medial tibial flare.

9. Distal (dist.): Approximately 1 in. above the stump end, where a reasonable circ. measurement can be taken.

10. Antero-lateral to mid. posterior (A/L): A point approximately 2-2½ in. below the insertion of the ilio-tibial band on the tibia, which is just below the knee joint (mid-way between crest of tibia and shaft of fibula), to the middle of the posterior aspect of the gastrocnemius (calf).

11. Antero-medial to mid. posterior (A/M): From a point on the antero-medial aspect of the tibia (at the same level and in the same plane as the A/L) to the mid. point of the calf.

12. Medial flare to medial joint line (M/F–MJL): Distance from a point on the medial aspect of the shaft of the tibia where the shaft changes rather abruptly to the medial tibial condyle, proximally to the mid. point of the medial knee-joint line. (Allowance for soft tissue is made at medial flare in No. 12 and No. 13.)

13. Medial flare to lateral joint line (M/F–LJL): From the same point on the medial aspect of the tibia described in No. 12 to the mid. point of the lateral knee-joint line.

The data were then allocated to the categories of stump maturity previously described.

RELATIONSHIPS BETWEEN THE STUMP MEASUREMENTS

Abbreviations of the measurements which are illustrated in Table 1 will be used in this discussion.
FIGURE 3.—CH: Medial condylar height; MF-MJL: Distance from medial flare to medial knee-joint line; L: Length.

FIGURE 4.—MF-LJL: Distance from medial flare to lateral knee-joint line; Circumferal measurements: P—proximal, M—middle, and D—distal.

FIGURE 5.—AL: Antero-lateral to mid-posterior measurement.
Certain dimensions of the stump are more critical than others, and relationships between various measurements were studied. A relationship between the stump M/L and A/P was established. From this relationship seven M/L and A/P brim socket sizes were decided upon. The M/L was related to the S/C (Table 2), C/H, M/F-MJL, and M/F-LJL. These four measurements were added to the initial seven socket brim sizes. The MIL was chosen as a key measurement to relate to the above measurements, as only small change in size occurred at this point; we found that a change in the M/L had an influence upon the measurements related to it.

Both the M/L and A/P measurements were related to the A/L and A/M to determine the A/L and A/M distances in the seven socket sizes.

The circumference stump measurements: The proximal measurement was related to the M/L and A/P. The mid. circ. measurement was related to M/L and A/P and also to the A/L and A/M. The distal measurement was related to the stump length.

Based on analysis of this data, we found that 80 percent of our maturing stump series could be classified into seven socket sizes according to the dimensions shown in Table 3. These sizes were designed assuming the wearing of a three-ply wool stump sock, for which \( \frac{1}{4} \) in. adjustment in socket size was allowed. The percentage of stumps allocated to each socket category were as follows: Size 1—5 percent, 2—16 percent, 3—22 percent, 4—23 percent, 5—15 percent, 6—12 percent, and size 7—7 percent.

**THE SOCKET**

The socket can be described as an open-end, rigid-plastic-laminated, patellar-tendon-bearing (PTB) socket (Fig. 6), which is used in conjunction with the Winnipeg wedge disk-alignment-unit pylon (4) and SACH foot. The range of socket sizes are shown in Table 3.
From experience gained over the last few years, we have found that 75 percent of our maturing below-knee stumps can be fitted without difficulty with a combination of suprapatellar and supracondylar suspension. We have established criteria (to be published) for deciding upon this type of suspension. Therefore, this suspension method is used for the sockets.

**TABLE 3.—Range of Socket Sizes**
(Preferences)

<table>
<thead>
<tr>
<th>Size</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tr>
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<td>71/2</td>
<td>71/2</td>
<td>71/2</td>
<td>71/2</td>
</tr>
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<td>12</td>
<td>123/4</td>
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<td>133/4</td>
<td>133/4</td>
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</tr>
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<td>113/4</td>
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<td>12</td>
<td>123/4</td>
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</tr>
<tr>
<td>Dist.</td>
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<td>103/4</td>
<td>103/4</td>
<td>103/4</td>
<td>103/4</td>
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<td>23/8</td>
<td>23/8</td>
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<td>23/8</td>
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<td>3</td>
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<tr>
<td>MF-LJL</td>
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<td>33/4</td>
<td>4</td>
<td>4</td>
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</tbody>
</table>

**Figure 6.**—Anterior and posterior view of a size 3 maturing prefabricated socket.
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The socket length of $7\frac{1}{2}$ in. was arrived at, as a high percentage (88 percent) of our stump series was in the 7 in.-and-under measurement range. It was decided to limit the socket to this length in order to have a prefabricated socket which could be cosmetically restored without difficulty.

PLASTER MODEL DESIGN

It is interesting to note the method by which the Winnipeg prefabricated sockets were designed (1). The socket sizes were not based upon anthropometric data, but instead a socket which had been fabricated for a mature below-knee stump with a $3\frac{1}{2}$ in. M/L was selected as size 1 to start the series. A plastic laminate shell consisting of two layers of nylon stockinet was made over the plaster model. Another two-layer shell was laminated over this until four shells were obtained. The first three shells were used to make socket molds, and a plaster model was taken from the fourth shell and was shaped to maintain stump contours. This method of laminating one shell over the other and reworking every fourth model was continued until the series was completed. Then, a two-layer semi-flexible polyester shell was fabricated and turned inside-out to obtain a shape to begin design of the other side.

It is interesting how useable these sockets have been when one considers that they initially consisted of 19 sockets, right and left, progressing in size by $\frac{1}{4}$ in. each. The present sockets which are available from the Sanitorium Board of Manitoba consist of the six most common sizes of the original 19 series. The M/L width varies between 3$\frac{3}{4}$ to 4$\frac{3}{8}$ in. with a $\frac{1}{2}$ in.-width change between sizes. The sockets have changed in suspension in that originally they were designed for PTB cuff suspension, but are now equipped with suprapatellar and supracondylar hip suspension. It has been our experience that the present series of Winnipeg prefabricated below-knee sockets are very useful for patients with immature stumps.

Our series of maturing prefabricated sockets were designed from various discarded sockets whose sizes were near the required measurements for the particular socket size being designed. These sockets were once well-fitting ones of stumps at the maturing stage. Originally a right plaster model was designed, and a similar method as used by Foort of a two-layer semi-flexible shell was made and turned inside-out to obtain a starter for the left side. The left model was carefully measured in all aspects and compared with the right model in order to have as similar as possible right and left socket sizes.

The socket sizes shown in Table 3, are the model sizes before plaster relief areas were added. Approximately $\frac{1}{4}$ in. of relief was added to the tibial crest, $\frac{1}{4}$ in. flaring to $\frac{1}{8}$ in. over the head of fibula, and $\frac{7}{8}$ in.
over the prominence of the lateral tibial condyle (insertion of the ilio
tibial tract).

CLINICAL TESTING

For clinical testing, measurement forms are used in order to relate
the stump measurements to the socket sizes. The 13 measurements are
taken of the stump to be fitted and these are related to the 13 socket
measurements. The socket size approximating the closest prosthetic fit
is chosen. Socket liners are added where required and varying sock thick-
nesses worn, to obtain as intimate as possible stump-socket relationship.
To maintain total contact of the distal end of the stump, polyethylene
film is used as a filler.

Clinical testing of these sockets began in January 1973. We are plan-
ing to approach other centers to help us in the testing. Experience
gained will help in future designs of prefabricated below-knee sockets,
indicating what modifications will be necessary to improve them and
what sizes need to be added for certain amputee groups in order to ex-
pand the scope of the prefabricated below-knee socket.

SUMMARY

A series of seven right and seven left prefabricated below-knee sockets
for the maturing stump are described. The method of design and socket
sizes are given.

The 13 measurements taken in the anthropometric study are defined
and their interrelationships for socket design are shown.

Clinical testing of the sockets is in progress.

ACKNOWLEDGMENTS

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