A PRELIMINARY REPORT OF BASIC STUDIES
FROM PROSTHETICS RESEARCH STUDY

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INTRODUCTION

The Seattle Prosthetics Research Study was established under a United States Veterans Administration grant in 1964 to evaluate and develop the application of immediate postsurgical prostheses in amputation surgery as advocated by Berlemont and Weiss (1). Since that time 253 patients have been included in the study. Parts of the technique were also applied to an additional 11 patients with special problems. With experience the original approach has been modified by the Seattle team to include the principles of myodesis and myoplasty, the long posterior myocutaneous flap, meticulous wound closure over a soft drain, the rigid postsurgical compression dressing, and early partial weight bearing on a temporary pylon. An exhaustive clinical review of the Seattle PRS series is now being undertaken for later publication to present the end result in the first 250 patients. An analysis is being made of the factors in the total technique which have been most important in leading to the remarkably good results obtained by the Prosthetics Research Study (2).

A review of clinical factors in the application of the immediate postsurgical prosthesis, however, fails to answer a number of very important questions concerning the principles of the technique. This report describes the methods presently being used to investigate pressure relationships at

* Based on work performed under VA Contract V5261P-438.
the stump-socket interface, skin temperature differences between anterior and posterior skin flaps in the stump, and stump muscle activity as monitored by EMG leads. Preliminary findings are reported and discussed.

METHODS

Basic investigation of this type requires knowledge and skill in bioengineering as well as sophisticated and expensive equipment. To obtain this, the Seattle Prosthetics Research Study became an early participant in the VAPC "instant lab" program. This program is based on the concept that a single bioengineering facility can provide consultation and instrumentation to many clinical research teams on a short term basis for the solution of specific problems at considerable savings both in time and money. Accordingly, the Bioengineering Research Service of the Veterans Administration Prosthetics Center, New York City served as consultant and instrument supplier for the studies reported here.

A multichannel recording unit (Fig. 1) was used for recording stump pressures, forces on the pylon, and EMG signals. Four channels are available on the recording unit for pressure readings and four are available

FIGURE 1.—Specially modified laboratory equipment loaned to Seattle VAH.

FIGURE 2.—Sensotec semiconductor strain gage pressure transducer shown beside paper match.

Edward Peizer, Ph.D., Chief of the Bioengineering Research Service, and Carl Mason, staff engineer, assembled the equipment and trained our staff to operate it.
for EMG readings. One channel records axial load on the pylon and one records moment about the ankle. Pressure is measured from small transducers (Fig. 2) placed on the skin (Fig. 3) prior to the immediate postsurgical prosthesis application. EMG signals are obtained from special surface leads (Fig. 4) applied to the skin over the appropriate muscle groups. An instrumented pylon (Fig. 5) monitors the actual forces involved and indicates the phase of gait for the events measured. Skin temperature is monitored by thermisters placed on the anterior and posterior flaps of the stump immediately following wound closure. The temperatures are recorded from a manual recording unit.

PRELIMINARY FINDINGS

1. The Rigid Dressing

If a rigid plaster dressing is to be applied on an amputation stump immediately following wound closure at surgery, the force applied to that stump after the plaster has become rigid should be quantitated. These determinations are most conveniently made in a seasoned stump. Moreover, one should know what margin of error is present in applying the elastic plaster to the stump.
Table 1 demonstrates the pressures obtained between prosthesis and stump on two patients with seasoned below-knee amputation stumps. Each had a plaster prosthesis of the PRS immediate postsurgical type applied three times. The pressure readings are taken from transducers applied as shown in Figure 6.

As can be noted, all pressures are remarkably low. Even more important is the fact that when the third plaster was applied to patient #1, maximum force was applied to the elastic plaster bandage as it was drawn over the end of the stump, yet the pressure was increased only to 21 mm Hg.
TABLE 1.—Pressures Developed in Temporary Prostheses (Seasoned Stumps)

<table>
<thead>
<tr>
<th>Patient</th>
<th>Cast</th>
<th>Pressure (mm. Hg.) after cast setup</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Proximal</td>
<td>Middle</td>
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<tr>
<td>1</td>
<td>1</td>
<td>34</td>
<td>12</td>
<td>12</td>
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<td>2</td>
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<td>7</td>
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<td>*3</td>
<td>21</td>
<td>11</td>
<td>21</td>
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<tr>
<td>2</td>
<td>1</td>
<td>42</td>
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<td>*3</td>
<td>6</td>
<td>0</td>
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</table>

* Casts made with maximum practicable force applied during the wrapping of the plaster-of-paris bandage.

FIGURE 6.—Prior to casting, three Sensotic gages are placed on a BK stump.

The higher values for the middle and particularly for the proximal transducers can best be explained by their position over bone.
The rigid dressing in its standard application using elastic plaster therefore exerts pressure distally in or below the generally accepted range of internal osmotic pressure considered to be 20-25 mm. Hg. Additionally, variation in the tension applied to the elastic plaster during application within its elastic limits leads to only small pressure variations on the stump.

2. The Rigid Dressing in the Immediate Postoperative Period

If the immediate postsurgical prosthesis exerts "safe" pressure on the seasoned amputation stump, what pressure does it exert on the stump which is developing postoperative edema in the immediate postoperative period?

Two patients have been the subjects of studies on pressure relationships through the early postoperative period. Sterilized pressure transducers were applied to the skin of the stump (Fig. 3) immediately following wound closure and prior to the application of the rigid dressing.

For patient O.E., PRS #229, the relative pressures are shown in Figure 7, and for patient E.H., PRS #219, they are shown in Figure 8. The reference points in these figures are taken as the pressure recorded immediately following the cast application. All subsequent readings are relative to the initial postoperative readings taken as zero. All pressures were recorded with the patient sitting or lying at rest. For each day recordings were taken prior to weight bearing, immediately after weight bearing, and after a 10 to 20 minute rest following weight bearing. The patient began actual ambulation on the second postoperative day.

The data of Figures 7 and 8 reveal a number of interesting facts:

First, the stump edema pressure against the rigid dressing is not uniform in the areas of the pressure transducers.

Second, peak pressures under non-weight-bearing conditions do not rise significantly above 100 mm. Hg or 2 p.s.i.

Third, during the first three postoperative days there is a marked rise in stump pressures which levels off and, at least distally, begins to fall by the fourth day for patient O.E. (Fig. 7) but not for patient E.H. (Fig. 8).

Fourth, in many instances, especially for patient O.E. (Fig. 7), pressure beneath the cast was higher just prior to walking than 10 to 20 minutes after walking and highest just following walking. The point at which the pressure began to fall during the resting period following ambulation was not clear in the records due to patient movement and limb manipulations.

Further studies of this nature are necessary to evaluate the differences between the two patients, but with these preliminary findings in patients whose amputation wounds healed in 2 weeks without complications,
some insight is gained into the nature of immediate postsurgical prostheses. If pressures of this magnitude are typical and if they consistently fall below their pre-exercise levels after weight bearing, then this may well be further support for the concept that partial weight bearing is an important
factor in the postoperative management of these amputees. The rigid
dressing limits the formation of edema therefore promoting wound healing,
and weight bearing further reduces edema allowing better circulation within
the stump.
3. Ambulation in the Rigid Dressing

Once the patient begins to ambulate, the pressures exerted on the stump and those exerted on the pylon must be quantitated and related. Figure 9 demonstrates the relationship between axial load and end bearing in patient E.H., PRS #219, at selected points in his ambulation between the 10th and 21st postoperative days. A cast change was done on the 11th postoperative day.

The general trend shows a maximum end bearing pressure on the stump approaching 127.0 mm. Hg (2.5 p.s.i.) when axial load on the pylon is between 20 and 40 lb. Pressure does not increase with increased
axial load but rather approaches a maximum except in one instance where end pressure rises to 208.3 mm. Hg (4.1 p.s.i.). Undoubtedly it reflects loosening of the stump in the cast at its points of suspension and resultant sinking of the stump farther into the socket.

This study implies that the stump does not sink into the socket and become increasingly end bearing as axial load increases beyond the recommended 20-30 lb. weight bearing on the pylon. The stump remains suspended through the tibial flare, femoral condyles, and thigh as the patient ambulates with partial weight bearing. Thus the healing stump is protected from excessive pressure.

However, in this study the single value showing 208.3 mm. Hg (4.1 p.s.i) end pressure for an axial load of 34.5 lb. is a warning of possible problems and a reason for further studies of this problem. The value was obtained on the 21st postoperative day, 10 days after the first cast change. The next highest end pressure was 129.5 mm. Hg (2.55 p.s.i.) for an axial load of 29.2 lb. on the 17th postoperative day. On the other hand, axial loads at 39.8 and 44 lb. on the 14th postoperative days produced end pressures of only 45.7 mm. Hg (0.9 p.s.i.) and 127.0 mm. Hg (2.5 p.s.i.) respectively. These latter loads were applied to the cast only 3 days after it was changed. Thus, loosening of the cast as the stump shrinks makes excessive weight bearing progressively more traumatic to the stump.

4. Ambulation in the Definitive Prosthesis

The magnitude of the pressure on the seasoned stump when the amputee walks without support is of interest.

Those patients who underwent the immediate postsurgical prosthesis applications documented in Table 1 and described in part one of this section, walked in the temporary prostheses with the pressure transducers inserted between the stump and socket as shown. The pressures are recorded in Table 2. One of these patients walked in his own definitive PTB prosthesis with the pressure transducers in the same positions. Five steps are recorded in Figure 10 with the remarkably high pressure readings noted.

| Table 2.—Maximum Pressures Developed During Walking in Temporary Prosthesis (Seasoned Stumps) |
|---------------------------------|---------------------------------|---------------------------------|
| Patient | Maximum pressure (mm. Hg) during walking |
|         | Proximal | Middle | Distal |
| 1       | 105      | 132    | 75     |
| 2       | 95       | 140    | 50     |

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This comparison between 50 or 75 mm Hg end bearing in the immediate postsurgical prosthesis compared with 825 mm Hg end bearing pressure in a PTB prosthesis further demonstrates the additional support which the temporary plaster socket provides. Extending above the knee as it does, the immediate postsurgical prosthesis carries much of the axial load along the tibial flares, the femoral condyles, and the thigh.

5. Skin Temperature Relationships

The survival of the skin flaps on the stump seems to be dependent primarily upon the circulation to each flap. Anterior flap necrosis was troublesome early in the PRS series. However, as the long posterior myocutaneous flap came to be used routinely, flap necrosis was reduced significantly. In an attempt to reflect the difference in circulation of the two flaps, skin temperature was measured on two patients with below-knee
amputations. One amputation was done using equal flaps (P.S., PRS #203) and one using the long posterior myocutaneous flap (R.N., PRS #224).

Figures 11 and 12 show the relationships of anterior and posterior flap temperatures in these two patients. In Figure 11 values are not available after 48 hours. Values are not available for the first 20 hours postoperatively in Figure 12. Taken together they show a peak temperature during the second and third postoperative days. In the patient with the
equal flaps (Fig. 12) the posterior flap temperature was generally higher although by less than 1 deg. F. In the patient with the long posterior flap (Fig. 11) the converse was true. In both patients, healing was complete within 2 weeks and no wound problems developed.

Further studies of this type have been deferred in the light of failure to find either consistency in our data or support in the literature for using skin temperature as a guide to stump circulation. It is generally accepted that cutaneous temperature readings give no indication of circulatory changes occurring in the underlying muscle. Then, within skin itself the temperature may rise to within a few degrees of the maximum with the
corresponding blood flow being only about one quarter of the maximum. Thus, at higher rates of flow, skin temperature is an insensitive and undependable index of local circulation (3).

6. Muscle Activity in the Prosthesis

The activity of the muscles in below-knee amputation stumps following tension myodesis or myoplasty is felt to be of major importance in the success of the Prosthetics Research Study (4). At present their role in proprioception cannot be demonstrated other than by testimony from the amputees. However, the fact that the stump muscles work in phase with gait is demonstrated in Figures 13 and 14.

EMG leads (Fig. 4) have been applied over the anterior tibial and gastrocnemius muscle groups in each of two patients who had undergone muscle stabilization procedures at surgery. Standard immediate postsurgical prostheses were applied so that the instrumented pylon could be used to signal accurately the phases of gait during ambulation.

![Figure 13. Simultaneous recording from EMG signal and instrumented pylon demonstrating phase relationships.](image-url)
Patient O.E., PRS #229, was 3 months postoperative when the findings shown in Figure 13 were obtained. At the maximum dorsiflexion moment when heel strike has occurred and axial load is increasing, tibialis anterior activity first begins. Gastrocnemius activity begins very soon thereafter and muscle activity in the stump remains high throughout stance phase. Through swing phase the EMG tracings for both muscles show only background activity. Active muscle contraction appears again with heel strike.
Remarkably similar EMG recordings were obtained in Patient D.A., PRS #94 (Fig. 14), who was 3 years postoperative and who had had markedly atrophied calf musculature due to many years of bracing on the involved leg ankle. Although again, clear phasic release of the anterior tibial musculature did not occur in mid-stance, muscle activity was clearly present during ambulation and occurred only during the stance phase of gait.

Further studies in this area will focus on documenting the difference in stump muscle activity between patients who have had stump muscle stabilization and those who have not.

7. Skin temperature is not a satisfactory measure of stump flap circulation in the immediate postoperative period.

8. Stump muscles are active phasically during gait.

The preliminary nature of this report is emphasized and plans for further investigation are discussed.

REFERENCES


