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# BELOW-KNEE PROSTHETICS

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A REPORT OF A SYMPOSIUM SPONSORED BY THE  
COMMITTEE ON PROSTHETICS RESEARCH AND DEVELOPMENT  
OF THE DIVISION OF ENGINEERING  
NATIONAL RESEARCH COUNCIL • NATIONAL ACADEMY OF SCIENCES  
December 1968

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# BELOW-KNEE PROSTHETICS

A Report of a Symposium Sponsored by the  
COMMITTEE ON PROSTHETICS RESEARCH AND DEVELOPMENT  
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of the  
DIVISION OF ENGINEERING  
NATIONAL RESEARCH COUNCIL  
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held at the  
Veterans Administration Prosthetics Center  
New York City      December 16-18, 1968

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## SYMPOSIUM ON BELOW-KNEE PROSTHETICS

### COMMITTEE ON PROSTHETICS RESEARCH AND DEVELOPMENT

December 16 - 18, 1968

#### SUMMARY

A Symposium was held to assess the current status of below-knee prosthetics and make recommendations concerning future research and education programs in the on-going effort to improve current practices. A review of current courses of instruction, current practice in clinical prosthetics, and current research projects was made.

It is the consensus that there now exists a body of knowledge that has been developed over the past few years and which is based on the concepts of the highly successful patellar-tendon-bearing (PTB) prosthesis that permits a significant improvement in present practice, and therefore it is recommended that special postgraduate, or continuing education, courses be made available for practicing clinic teams.

Also, it is the consensus that present research activities in the field of BK prosthetics are generally in the right direction. Increasing emphasis should be placed on the development of a truly refined theory of fitting.





## SYMPOSIUM ON BELOW-KNEE PROSTHETICS

The Symposium was opened by Mr. Anthony Staros who, as Director of the Veterans Administration Prosthetics Center--the site of the meeting--welcomed the participants. As Chairman of the Subcommittee on Design and Development he recounted that the primary objective of the Symposium was to bring together all available information that might be helpful to the Prosthetics Education Program in bringing up to date their courses of instruction in below-knee prosthetics. He added that all research activities in below-knee prosthetics were to be reviewed also, and then turned the meeting over to the Chairman, Mr. James Foort, who followed the Schedule (Appendix A) which had been distributed previously.

A list of participants is included in this report as Appendix B.

## I. ORIENTATION

The Chairman reviewed the history leading to the Symposium noting that the so-called patellar-tendon-bearing prosthesis was developed at the University of California, selecting and synthesizing older ideas and providing rational biomechanical principles, as a result of a Symposium held there in April 1957 (20). Since its introduction in the United States about 1959, the use of the PTB prosthesis (Figs. 1 and 2) has spread throughout the world. Although the original PTB prosthesis has been phenomenally successful (1,9,11,17,19,32,33), a number of centers have, in recent years, introduced modifications in an effort to improve the technique even further. Unfortunately, some of these developments have been presented as though they were completely new types of below-knee prostheses, when in reality they are variations of the basic design.

At the Workshop Panel on Lower-Extremity Prosthetics Fitting held in January 1968, it became apparent that a number of innovations held considerable promise, and the Chairman was requested to organize a Symposium in order to elucidate the pertinent facts concerning improvements in prostheses for below-knee patients. To do this he had

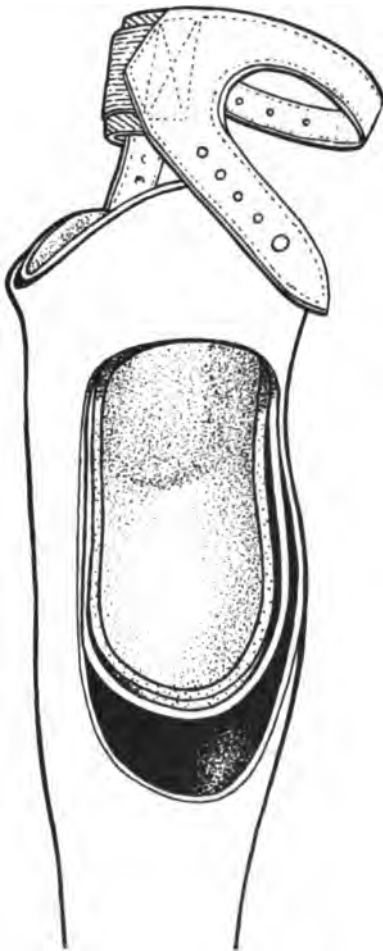


Fig. 1. Cut-away view of original design of the patellar-tendon-bearing socket with soft insert and cuff suspension.

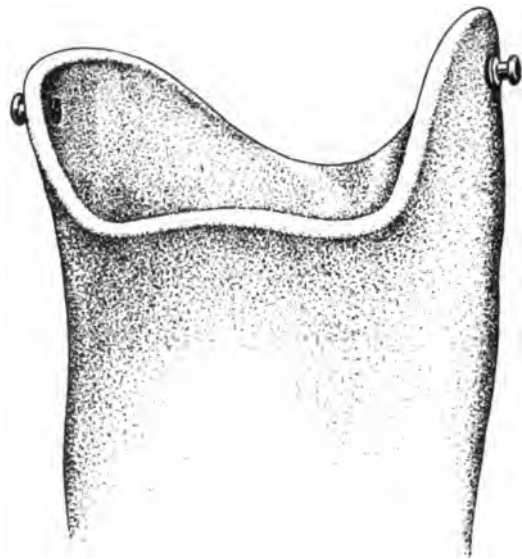


Fig. 2. Posterior view of brim of original PTB socket.

visited virtually all of the research and education centers in the United States and Canada concerned with BK prosthetics, discussed experiences and current projects with the personnel involved, and developed the program as outlined by the agenda. He felt that the Symposium could be beneficial to both the Education Program and the Research Program.

## II. REVIEW OF PRACTICES PRESENTLY TAUGHT IN UNIVERSITY PROGRAMS

### A. University of California, Los Angeles

Mr. Charles Scott, reporting in the absence of Mr. Bray who was ill, noted that the current instruction in below-knee prosthetics was oriented toward "certificate" students, a group which has had little or no previous training, and that five weeks are being devoted to the subject. He went on to report the following:

1. Both the hand-casting technique as described in the manual (29) and the Northwestern suspension-casting technique are taught.
2. Hard sockets with Silastic foam distal ends are taught as well as the Kemblo-backed insert-type of socket.
3. The use of synthetic balata (tubes formed from Polysar\* X-414) for socket fabrication is demonstrated.
4. Modification of the male stump model is carried out in accordance with the BK manual (29).
5. Conventional cuff-suspension method is taught (24,29). Some trials of "PTS" (supracondylar-suprapatellar) (22,23) and supracondylar-wedge methods of suspension (8), as well as trials of the newly developed Hosmer suspension-strap-retainer locator have been made with inconclusive results. A lack of time has prevented the faculty from studying these techniques as closely as they would like.
6. Each student makes and fits four prostheses.

\* Registered Trademark, Polymer Corp. Ltd., Sarnia, Ontario, Canada

**B. New York University**

Mr. Ivan Dillee reported as follows:

**1. Texts used**

- a. "The Patellar-Tendon-Bearing Prosthesis,"  
C. W. Radcliffe and J. Foort (29).
- b. "VAPC Technique for Syme," 1959.
- c. "The Syme and Chopart Prosthesis,"  
H. Blair Hanger.

(NYU is up-dating and reprinting the VAPC manual.)

**d. Supplementary material:**

- (1) Normal Human Locomotion
- (2) BK Alignment Jig--used in lieu  
of chapter in manual.

**2. Types of Courses**

- a. Short-term course taught in the Post-Graduate  
Medical School primarily for prosthetists with  
some experience. (Students are required to have  
two years' experience "in the field," but they  
are often poorly qualified as prosthetist stu-  
dents.)
- b. Degree Program for Prosthetists

**3. Content of Course**

- a. Basic instruction and laboratory exercises cen-  
ter around insert type socket with hand casting.
- b. NU suspension casting (14) demonstrated.
- c. Three sockets and two prostheses are fabricated.

**C. Northwestern University**

Mr. Blair Hanger noted that in recent years one short-term course in BK prosthetics has been offered every other year in August.

He reported that:

1. Four prostheses are made during the course.
  - a. Hard socket with foam end; suspension casting  
of the stump.
  - b. Insert-type socket; hand casting of the stump.
  - c. PTS socket with insert as demonstrated by  
Robert Nitschke.

- d. Supracondylar wedge system with hard socket as demonstrated by Carlton Fillauer (first taught in 1968).

In addition, a lecture-demonstration of the air-cushion socket (31) is given to acquaint the students with its possibilities.

2. Modifications to the male models are made in accordance with principles outlined in the BK manual.

3. In addition to the cuff, PTS (supracondylar-suprapatellar), and supracondylar-wedge methods of suspension, the method developed by Jack Caldwell is taught (4).

4. A lecture-demonstration on the carved-wood socket is included.

5. Included is an orientation session on immediate post-surgical fitting of prostheses.

In the discussion that followed, it was brought out that the major part of the teaching effort in reference to BK prosthetics at the three universities is devoted to the inexperienced students and most of the course content consists of the original methods given in the BK manual (29). Some time was devoted to advantages and disadvantages of various methods that might be used to keep practicing prosthetists up to date, but no concrete proposals were offered at this time, it being recognized that the selection of the most appropriate means must necessarily be related to the particular subject matter being offered.

### III. NEW PRACTICES

#### A. Socket Modification and Suspension Systems

Before calling upon Professor Charles Radcliffe and others to report on the air-cushion socket, the Chairman evoked a discussion in an effort to determine to what extent hard sockets are used in the PTB in reference to sockets with the inserts. It appeared that the hard socket with firm foamed-in-place Silicone rubber ends is the

method of choice in the South, except for the fitting of bony, conical stumps but that this method was not being used as widely in other parts of the country. Mr. Muilenburg reported using mainly hard sockets with Silicone rubber ends as did Mr. Thranhardt. Mr. Fillauer said that approximately 95 per cent of new below-knee amputees now being fitted by him were provided sockets, foamed-in-place Silicone rubber ends, and the supracondylar wedge-suspension system.

Mr. Roy Snelson stated that very few liners were used by his group but that in difficult cases they were finding the air-cushion socket very useful. Mr. Foort related that approximately 200 patients have been fitted at his center over the past five years and the bulk of them are geriatric. They were all fitted with total-contact sockets without liners or foam in the ends. The Northwestern University suspension-casting technique has been used since its introduction. More recently, since introduction of the supracondylar-wedge-type suspension, amputees have been fitted with a high medial extension which clips over the medial femoral condyle. This medial extension is springy rather than rigid, so that entrance into the socket can be effected. Mr. Bert Titus reported that it was general practice at Duke University to provide hard sockets with hard ends and that every socket was x-rayed to insure that total contact was being obtained. Mr. Nitschke reported that most of his patients received the "PTS"-type (supracondylar-suprapatellar) of socket which normally calls for a soft insert. In the immediate postsurgical fitting program in Seattle, Mr. Joseph Zettl said that the standard BK prosthesis has been the PTB with no liner.

#### 1. Air-Cushion Socket (Fig. 3)

Professor Radcliffe distributed copies of the most recent VA manual covering the air-cushion socket (31) and stated that the air-cushion socket has been designed to provide more "endbearing" than the original "total-contact" PTB. After relating experiences gained with the air-cushion socket in the Bay area, and describing

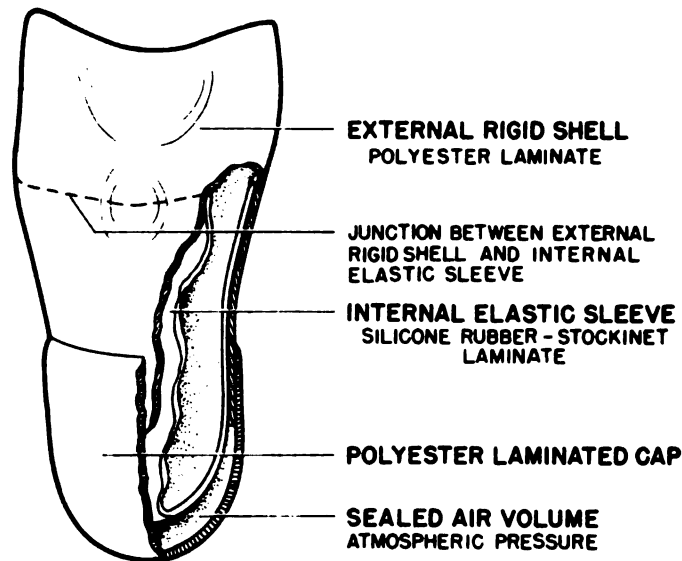


Fig. 3. Cut-away view of the air-cushion socket.

certain key points in the fabricating and fitting procedures, he said that the group at the University of California are convinced that the technique has a rather widespread application and should not be limited to use in special cases for therapeutic value, even though a little more time is required to fabricate it. However, it is not recommended for use when rapid atrophy is anticipated.

Mr. Leigh Wilson described an alternate method that was finding favor in the Bay area for forming the outer shell over the RTV insert using wax as a mold. Prof. Radcliffe called attention to a report from the Orthopaedic Hospital, Copenhagen (Appendix C) and one from the Center for Prosthetics and Orthopaedics in Belgrade (Appendix D) which had been distributed to participants in advance of the Symposium. Both reports dealt with experience with the air-cushion socket and both were quite favorable. Prof. Radcliffe stated that he had received word from Sweden and Italy that experience in those countries with the air-cushion socket had been most favorable also, and deplored the fact that the technique was not being used to any great extent in this country. Mr. Staros

replied that the interim report on fittings being undertaken in the Bay area under the auspices of the VA showed favorable results, that a number of problem cases had been satisfied, but that it was clear that success is quite dependent upon application strictly according to the manual.

Mr. Snelson, with projection slides, reported on five successful problem cases that had been fitted with the air-cushion socket.

Prof. Radcliffe felt that the main difficulty with air-cushion sockets was in the fabrication technique. It was suggested that perhaps a central fabrication facility should be set up so that prosthetists could send their corrected casts to a certified center for fabrication of the socket. The central fabrication scheme could also be applied to the clear vinyl sockets developed by Mr. Snelson.

## 2. PTS-type Socket (Fig. 4)

Mr. Nitschke stated that during the last two years of the 158 BK prostheses he had fitted, 120 (76 per cent) had been of the PTS type, more or less as developed by Mr. Fajal (25,26,27). Distribution by age, and whether "old" or "new" patients, is given in Table 1.

Table 1. Distribution of Cases Fitted with "PTS" Socket by Robert Nitschke.

Age	<u>Unilateral</u>			
	New	Old	Total	
1-20	7	9	16	
20-40	4	12	16	
40-60	11	18	29	
Over 60	26	14	<u>40</u>	101
	<u>Double (All BK)</u>			
1-20	0	0	0	
20-40	0	0	0	
40-60	4	1	5 + 5	
Over 60	2	2	<u>4 + 4</u>	18
	<u>Double (AK and BK)</u>			
1-20	0	1	<u>1</u>	<u>1</u>

120





Fig. 4. The PTS socket.

Of these 120 sockets, three were converted to standard PTB and five were converted to PTB-type with sidebars and thigh lacers. In the PTS, a Kemblo insert with leather liner impregnated with paraffin is generally used and in most cases a wedge is used between the insert and socket to aid suspension. In about half of the cases, a wedge is used on both medial and lateral aspects of the socket. The insert is used primarily to make later adjustments easier. Mr. Nitschke felt that the advantages of the PTS were a reduction in piston action of the stump, the elimination of the cuff-suspension strap, improved cosmetic appearance, good medio-lateral stability at the knee joint, and prevention of hyperextension of the knee, but that anteroposterior motion about the knee joint is restricted somewhat. When complete freedom of the knee joint is required, he fits the conventional PTB prosthesis. He feels that the PTS has definite advantages for patients with short stumps and for geriatric patients. Mr. Nitschke showed motion pictures of a number of cases, and described in detail various steps in fabrication and fitting.

A number of the participants objected to the name "PTS" because it does not adequately describe the socket. Prof. Radcliffe pointed out that PTS had been derived from the initials of the name originally given by Mr. Fajal, prothese-tibiale-supracondylien. It was suggested that a "supracondylar-suprapatellar brim" might be a more functional name.

### 3. Supracondylar-Wedge-Type Socket (Fig. 5)

Mr. Fillauer recalled how in 1967 he had been introduced in Muenster to the concept of achieving suspension by introducing a wedge-shaped object between the stump and socket on the medial side of the socket just above the femoral condyle (16). Upon his return to the United States, he attempted to duplicate the work he had seen in Muenster, and after a number of trials had worked out a successful technique which he had published in the June 1968 issue

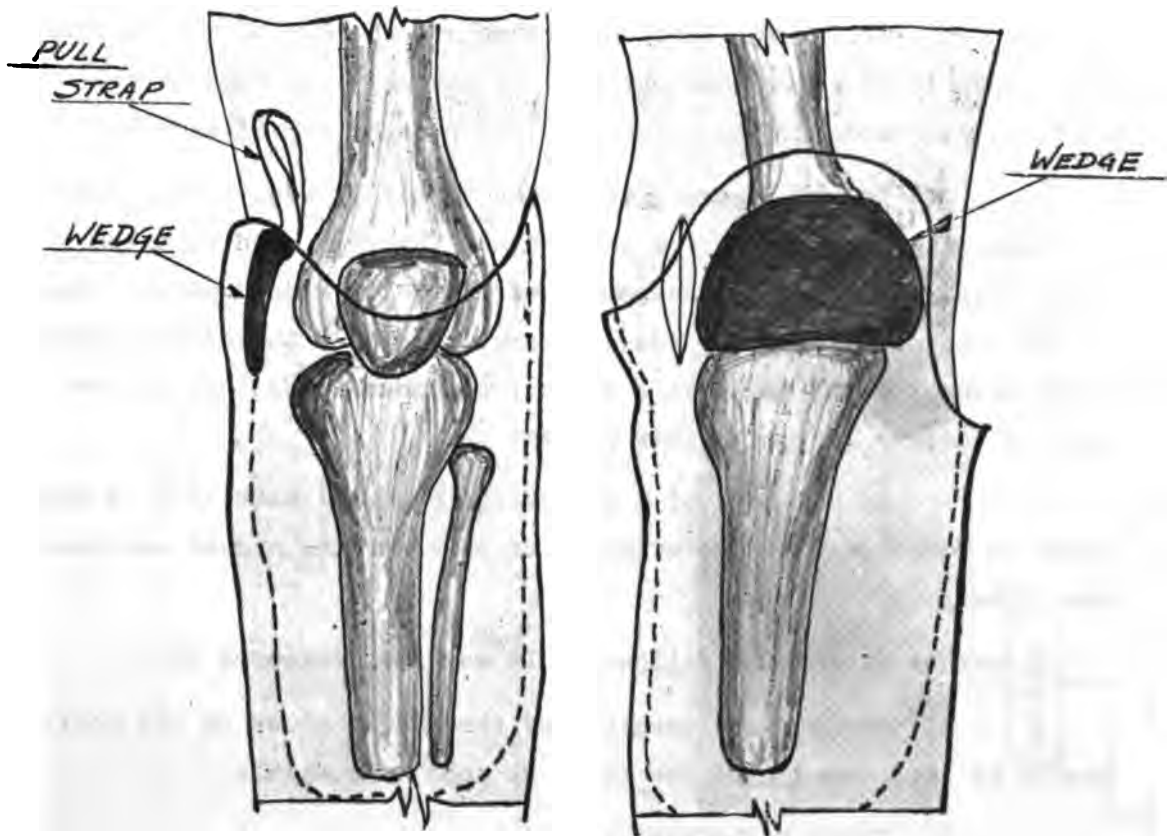


Fig. 5. The supracondylar-wedge suspension method.

of Orthotics and Prosthetics (8). Virtually all "new" amputees seen by Mr. Fillauer are provided with the supracondylar-wedge-type socket. Mr. Fillauer, using projection slides, described fabrication and fitting procedures, noting that development of the male model is the same as described in the manual (29). No liner is used. The higher brim on the medial and lateral aspects impart some stability but not to the same degree as that provided by the PTS type. Three sizes of wedge seem to be sufficient, but there is some argument for adding a fourth size.

Mr. Hanger reported on the experience at Northwestern University when a number of students were taught under the direction of Mr. Fillauer. He felt that the students were fairly successful, but location of the wedge is very critical in achieving a correct fit. NU hopes to continue to offer instruction in this technique in the future.

Mr. Joseph Zettl described a technique he had developed independently of others but which is essentially the same as the supracondylar-wedge system described and used by Mr. Fillauer.

In the general discussion that followed, it was clearly the consensus that all of the innovations that had been reported upon had a valid place in the management of the below-knee amputee. Many of the innovations are not mutually exclusive and, therefore, clinic teams have at their disposal a number of combinations that can be used to satisfy the particular patient.

As a result of a suggestion by Prof. Radcliffe, a chart based on functional characteristics of a below-knee socket was developed (Chart 1).

Further discussion followed. It was the consensus that:

1. The various versions of the PTB as shown on the chart should be introduced into the field as soon as possible.
2. These techniques should be included in the Associate of Arts and Bachelor of Arts and other long-term courses.
3. Some provisions should be made to get the information to practicing prosthetists. Ideally, UCLA, NYU, and NU should offer postgraduate (continuing education) courses, if possible. (Other suggestions including instruction at AOPA regional and national meetings were discussed, but no consensus was established. This approach is limited by the impracticality of providing laboratory practice.)
4. Detailed manuals are needed in addition to the one on the air-cushion socket.

Mrs. Friz invited the participants to consider how the Committee on Prosthetic-Orthotic Education could help. (Since the meeting, CPOE has taken steps to form an ad hoc committee to review publications and other educational material, identify current needs, and develop recommendations for action to meet these needs.)

VARIATIONS of the PATELLAR-TENDON-BEARING (PTB) PROSTHESIS

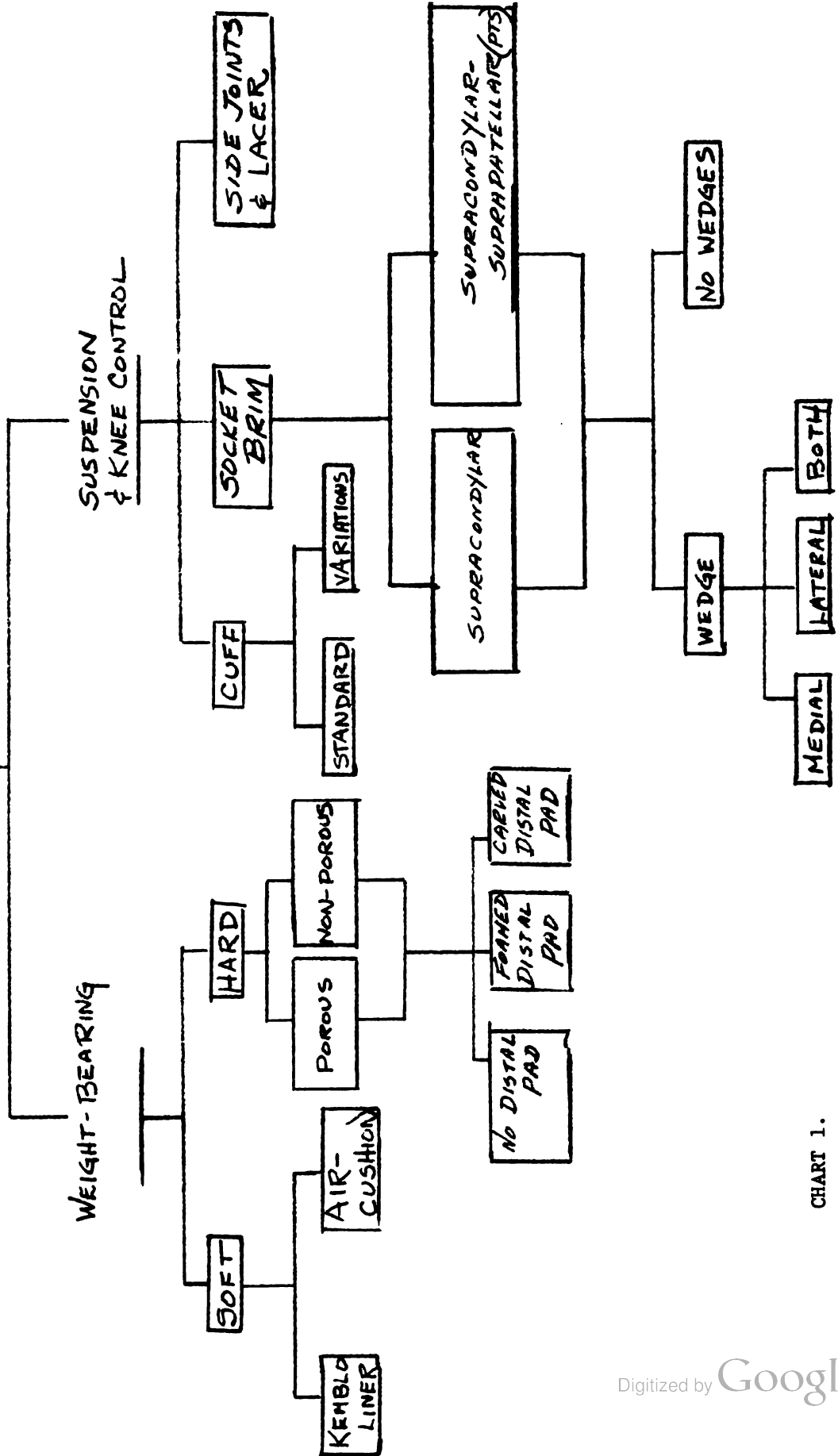


CHART 1.

## B. Socket Materials and Fabrication

### 1. Pneumatic Casting of Sockets using Synthetic Balata (Polysar X-414)

Noting that the Polysar X-414 is a synthetic balata that can be molded at a temperature that is comfortable to the skin yet stable enough at temperatures slightly above normal body temperature to serve as a socket material, Mr. Henry Gardner described a technique that had been developed by VAPC to form a hard but flexible PTB-type socket directly over the stump using a pneumatic pressure sleeve (Fig. 6) (30). Suspension in this design is usually obtained by connecting the medial and lateral "ears" of the socket brim with an elastic strap. This method is feasible because of the flexibility of the socket material. The socket is usually mounted on a pylon. A technique to achieve good cosmetic appearance using a plastic foam, Goodrich "Spongex," was described. The draft manual was currently being revised to incorporate the latest changes. Mr. Gardner reported that trials at VAPC over the past two years had been very successful and that the technique was being used routinely at the VA Brooklyn Hospital to provide immediate postsurgically fitted patients with interim prostheses until they could be fitted by commercial shops.

Mr. A. Bennett Wilson, Jr., reported that under the CPRD Clinical Evaluation Program, six prosthetists had been trained at VAPC, November 6-8, 1968, and that each will report on at least five patients fitted under clinical conditions. At the conclusion of the course all of the prosthetists felt that the technique definitely had merit for fabrication of interim prostheses.

In the discussion that followed it was recommended that the manual be completed as soon as possible and that consideration be given to using the synthetic balata sockets in conjunction with the receptacle system developed at Winnipeg in order to effect even more saving in time. Furthermore, the receptacles may offer the reinforcement that seems to be necessary for some types of patients.

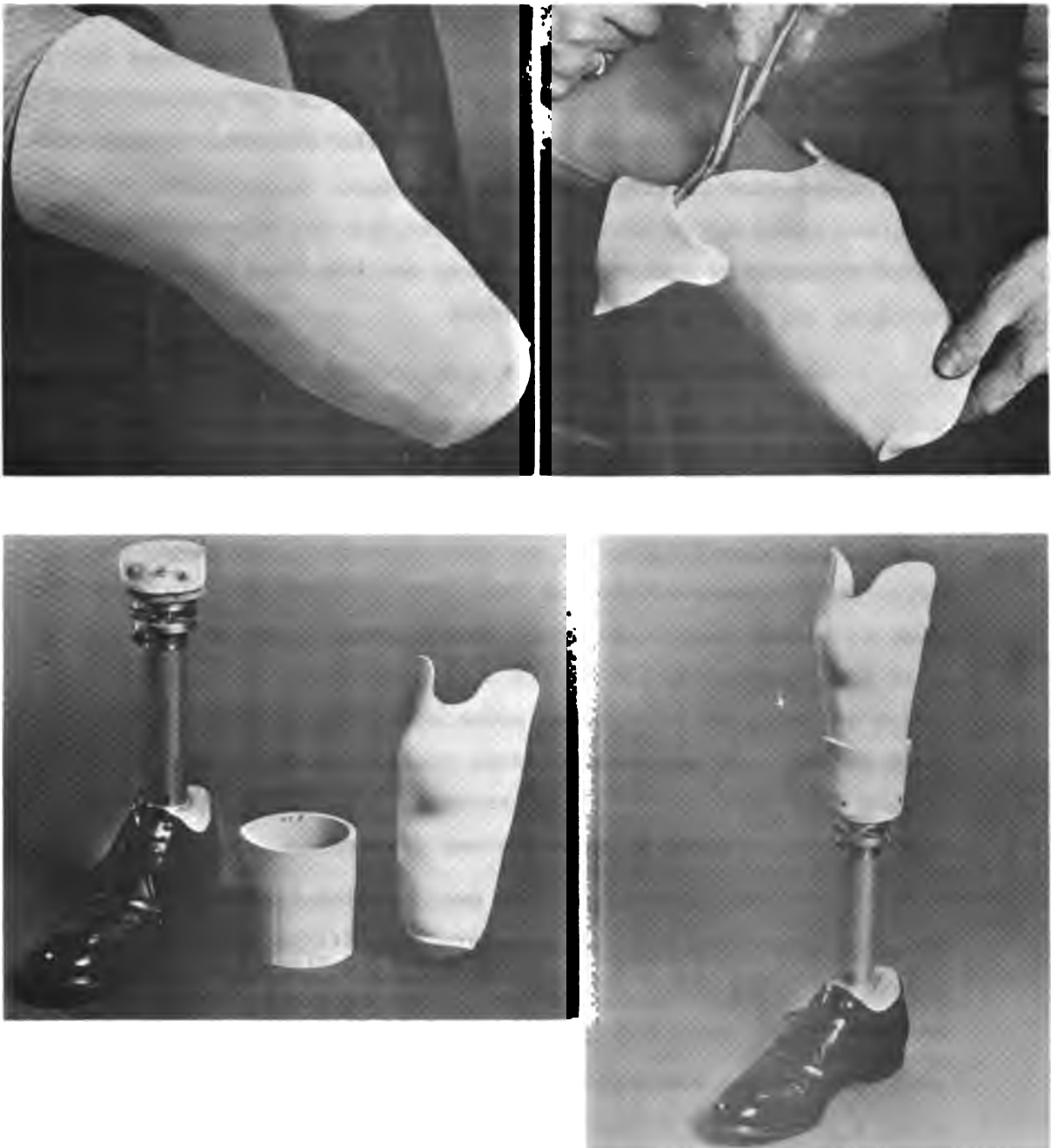


Fig. 6. Some steps in direct forming of a socket using synthetic balata and air pressure.

It was also suggested that, using the standard size information already developed at Winnipeg, synthetic balata sockets for BK patients be made up in a series of standard pre-forms (10). These pre-formed sockets could then be fitted to the patient by heating in the usual manner and shaped to the individual stump using the NU Suspension Casting Technique. Changes in the patellar shelf and other minor adjustments could be carried out subsequently. It was felt that this method will be much quicker than the method demonstrated and proposed by Mr. Gardner.

## 2. Transparent Sockets

Mr. Ronald Lipskin reported on recent developments at NYU concerning transparent sockets and called attention to their technical report "The Development of the NYU Transparent Socket Fabrication Technique" (18). It was the consensus that the transparent socket in this form offered an excellent research tool for further study of socket design, fitting, and alignment. As an example, it would seem quite feasible to fit a PTS-type transparent socket, record relative motion between stump and socket, trim various portions of the proximal section away, record the relative motion, and compare this with the original records. From these comparisons, some very interesting information may develop.

Mr. Lipskin pointed out that the transparent sockets may lend themselves for use in determining stress patterns by techniques involving polarized light and photoelasticity. He was encouraged to continue his investigation in this area.

Mr. Snelson reported that his group was trying to develop a transparent socket that would be inexpensive enough to serve as a check socket or part of a temporary prosthesis. If it were strong enough, it could, of course, be used as part of the permanent prosthesis. Encouraging results were being obtained by using fiberglass and epoxy with essentially the same refractive index. His plan includes the use of a stump sock.



Mr. Snelson also showed a transparent socket made from vinyl sheet formed by drape and pressure-forming over the cast. The socket was beautifully clear but Mr. Snelson reported that the manufacturing process was alien to standard prosthetic procedures, although he had encountered no difficulty in the technique.

It was recommended that all of this work be continued and some thought be given to the development of special stump socks that, when compressed, might give a better idea of the distribution of forces and pressures.

### 3. Porous Laminates

Mr. Clyde M. E. Dolan reviewed the history of porous plastic laminates (6) and cited the pertinent findings of the NYU field study concerning the usefulness of the AMBRL technique for below-knee sockets. The test sockets, when fabricated strictly according to the manual (15,28), provided improved ventilation, were 30 per cent lighter, but still withstood hard wear. Slightly more time is required in fabrication, and keeping the pores clean requires diligence on the part of the patient. In summary, the results of the field tests were positive and it is the feeling of NYU that more patients should be receiving porous sockets than is presently the case. In this the group concurred.

## IV. PROPER APPLICATION OF SACH FOOT

Prof. Radcliffe reported that the Biomechanics Laboratory was working with VA and with manufacturers to modify the shape slightly in order to improve function. It is his belief that two forms of the SACH foot should be available; one for below-knee prostheses, the other for above-knee prostheses.

## V. STUMP-SOCKET RELATIONSHIP

### A. NYU Distal-Contact Regulator

Mr. Thomas Grille described the pneumatic distal-contact regulator (Fig. 7) which has been designed by NYU to control the

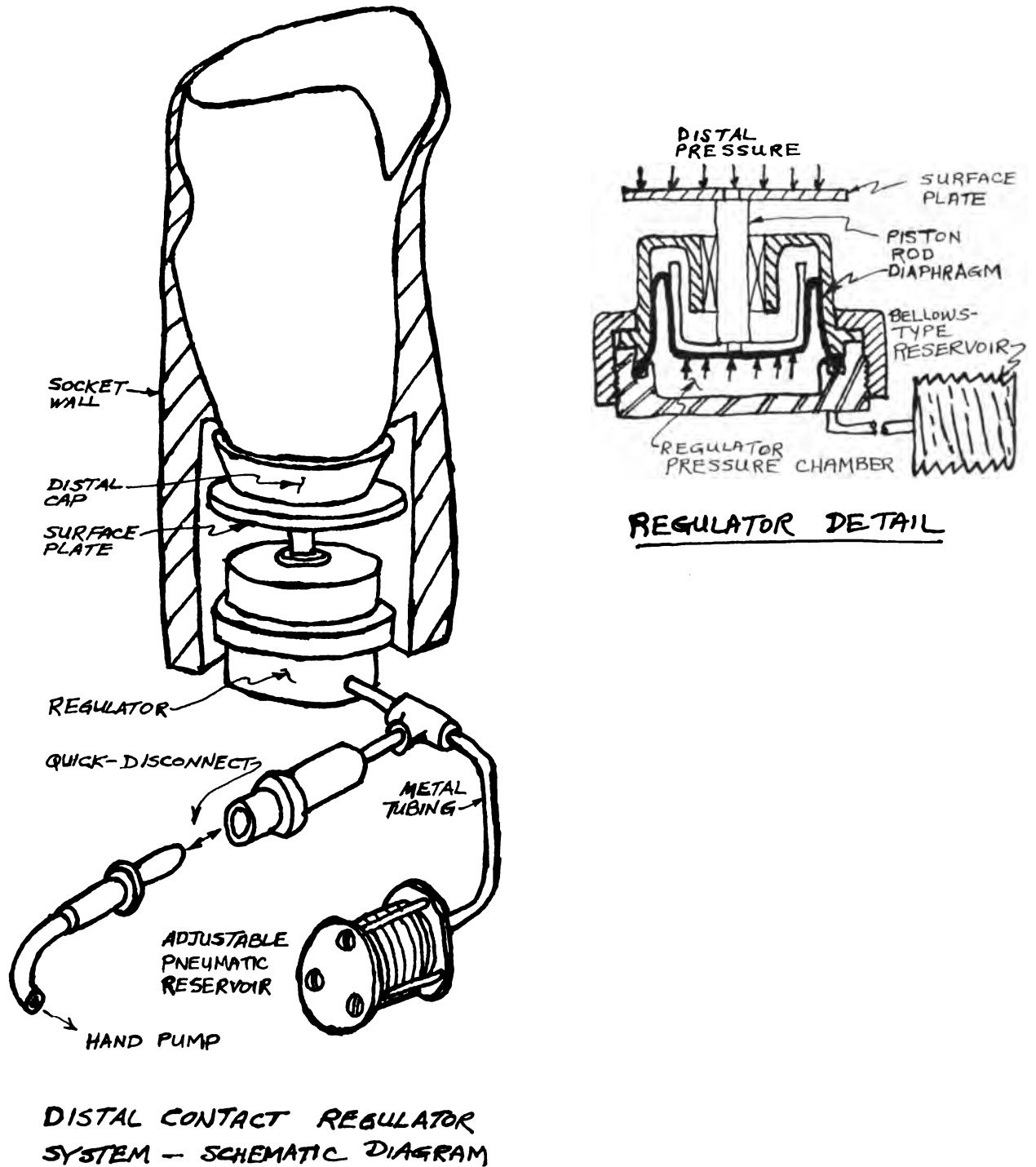


Fig. 7. Distal-contact regulator developed at NYU. Digitized by Google

amount of pressure taken over the end of the stump. The principle, if successful, should apply to both above-knee and below-knee stumps, but current models have been fitted to BK cases.

Two patients had been fitted with the device with generally positive results though it was too early to come to any conclusions. NYU was encouraged to continue the project.

#### B. Veterans Administration Prosthetics Center

Dr. Edward Peizer reviewed the joint project between the Prosthetics Research Study, Seattle, and VAPC in trying to determine the pressures involved in immediate postsurgical fitting procedures (2,3,5). This project will include a study involving the effects alignment changes have on pressure distribution. Pressure data will be correlated with electromyographic data.

#### C. University of Michigan

Mr. Edward Corell reported on progress being made by him at the University of Michigan in developing a method of displaying the pressure distribution patterns using computer techniques (5). Presently he is using five pressure transducers; one at each corner of a square and one in the center. Data are accumulated in the form shown in Figure 8.

D. Mr. David Harden described the development of a double-wall socket with a very flexible inner wall so that adjustment can be made by injecting fluid with a hypodermic-type needle.

## VI. SUMMARY AND RECOMMENDATIONS

### Recommendations

1. There exists a body of knowledge in BK prosthetics that has been developed in recent years that should be made available to practicing prosthetists and other clinicians for use in everyday practice. (See Chart 1, p. 13, and Bibliography, Appendix E.)

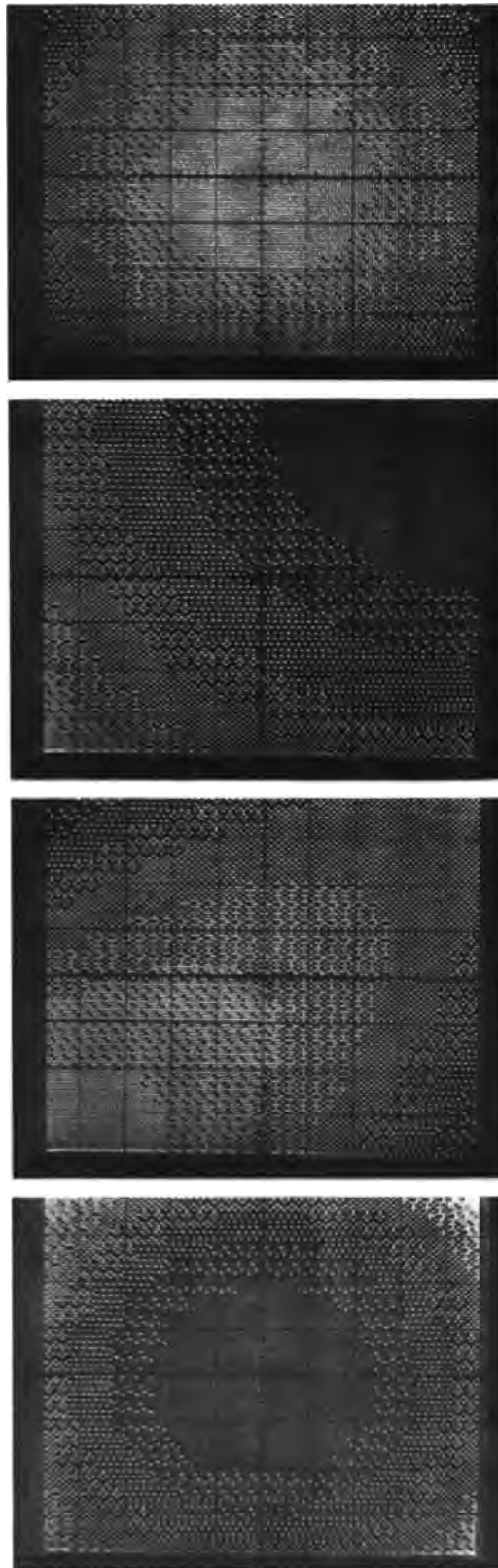


Fig. 8. Typical read-outs for pressure distribution obtained at the University of Michigan.

2. All education programs are urged to include this material in their curricula.

3. Postgraduate-type courses in these latest techniques should be made available to practicing clinic teams.

4. It is recognized that manuals and instructional materials are needed. This points out the need for a central group that would be responsible for the preparation and dissemination of technical information. Material is now developed many times without adequate consideration for its ultimate usefulness. In many cases it has been necessary to use technical reports for classroom instruction.

5. Current research efforts in BK prosthetics should be continued with emphasis on the development of a truly refined theory of fitting.

It is clear that the sockets discussed during the Symposium are satisfactory and represent improvement over previous practices. Most of the work in the last few years in improving the original design, especially in suspension, has been accomplished by practical prosthetists working in the field, and it seems unwise for research centers to devote their time developing techniques for further improvement. There is, however, a lack of knowledge of the basic principles underlying an optimum prosthetic fit. Research centers, therefore, should be encouraged to obtain basic factual information concerning the response of tissue to pressure and shear forces and to more clearly indicate biomechanical requirements through the various phases of walking. Following this, development should include methods by which these principles could be realized in practice, including the use of hydrostatic sockets and other methods of automatic adjustment.

February 14, 1969



S C H E D U L E  
 SYMPOSIUM ON BELOW-KNEE PROSTHETICS  
 PANEL ON LOWER-EXTREMITY PROSTHETICS FITTING  
 SUBCOMMITTEE ON DESIGN AND DEVELOPMENT  
 COMMITTEE ON PROSTHETICS RESEARCH AND DEVELOPMENT  
 NATIONAL ACADEMY OF SCIENCES

Veterans Administration Prosthetics Center  
 252 Seventh Avenue New York City  
 December 16-18, 1968

- I. ORIENTATION *Chairman, James Foort*
- II. REVIEW OF PRACTICES PRESENTLY TAUGHT IN UNIVERSITY PROGRAMS
- |  |                 |
|--|-----------------|
| A. University of California at Los Angeles | Charles Scott   |
| B. New York University                     | Ivan Dillee     |
| C. Northwestern University                 | H. Blair Hanger |
- III. NEW PRACTICES
- |  |   |
|--|---|
| A. Socket Modifications and Suspension Systems |   |
| 1. Air Cushion Socket                          | Charles W. Radcliffe,<br>Roy Snelson, <i>et al.</i>     |
| 2. PTS-type                                    | Robert Nitschke,<br>Samuel E. Hamontree, <i>et al.</i>  |
| 3. Supra Condylar-type                         | Carlton Fillauer,<br>Alvin L. Muilenburg, <i>et al.</i> |
| B. Socket Materials and Fabrication            |   |
| 1. Polysar Socket and Pneumatic Casting        | Henry Gardner   |
| 2. Transparent Sockets                         | Ronald Lipskin<br>Roy Snelson<br>Alvin L. Muilenburg    |
| 3. Porous Laminates                            | Clyde M. E. Dolan                                       |
- IV. PROPER APPLICATION OF SACH FOOT Charles W. Radcliffe
- V. STUMP-SOCKET RELATIONSHIP STUDIES
- |   |                                  |
|---|----------------------------------|
| A. New York University                        | Ronald Lipskin                   |
| B. Veterans Administration Prosthetics Center | Edward Peizer<br>Joseph H. Zettl |
| C. University of Michigan                     | Edward Corell                    |
- VI. SUMMARY AND RECOMMENDATIONS





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## Clinical Study of the Application of the PTB Air-Cushion Socket

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During the period January 1966--September 1968 a clinical study of the application of the PTB air-cushion socket was conducted at the Orthopaedic Hospital, Copenhagen, Denmark.

Manufacturing as well as fitting took place in the Prosthetic/Orthotic Research Department. The casting procedure followed that described by Wilson and Lyquist<sup>2</sup>, and the manufacturing procedures followed, with no significant modifications, the procedures described by Lyquist, Wilson, and Radcliffe<sup>1</sup>.

The preliminary results based on examinations of 24 amputees were presented to the Danish Association of Orthopaedic Surgeons by J. Kjølbye, M.D., in October 1967.

In September 1968 the Prosthetic/Orthotic Research Department published a technical report about the manufacturing and fitting procedures as well as results based on 45 amputees fitted with air-cushion sockets.

The total number of amputees include the 24 amputees mentioned above. The remaining 21 amputees were all checked and evaluated by an orthopaedic surgeon at the time of delivery of the prosthesis and several of them again at later visits. The final extensive medical examination has, however, not yet been completed for this group, but since these amputees have been under close observation by the Research Department it is very unlikely that the results will have changes at the time of the final medical examination.

In the following the figures in ( ) refer to the preliminary results.

Of the 45 (24) amputees in the test series, 4 (2) have been dropped, three of them because they could no longer fulfil the obligation to meet for reexamination at request, and one amputee suffering from a progressive vascular disease became confined to a wheelchair.

Of the thus remaining 41 (22) amputees, 11 (6) are female and 30 (15) male. The average age was 44 (43) years (ages ranging from 7 to 74 years).

Seventeen (9) amputees had been contented wearers of the PTB prosthesis for a minimum of 12 months. When fitted with air-cushion sockets

- 13 (7) amputees obtained better comfort and function,
- 3 (1) amputees found no change in comfort and function,
- 1 (1) amputee complained of stump pains at night, and after 6 months he returned to wearing an ordinary PTB prosthesis.

Seven (6) amputees had previously been fitted with the standard type of PTB prosthesis, but a successful fitting had never been achieved. With the air-cushion socket

- 4 (4) amputees obtained satisfactory comfort and function,
- 1 (1) amputee's condition must be characterized as unchanged, but he is wearing a modified air-cushion socket with soft insert, and
- 2 (1) amputees had to abandon the air-cushion socket. After 8 months one amputee was fitted with a conventional B/K (with thigh corset) as his weight fluctuated due greatly to an ulcerus ventriculi. Both amputees had short stumps (2½ inches) with distal hypersensitivity.

Seven (4) amputees had previously worn prostheses and had complications such as secondary edema distally and ulcerations. When fitted with air-cushion socket

- 6 (3) amputees obtained satisfactory comfort and function.

- 1 (1) amputee was after 4 weeks fitted with a standard PTB prosthesis. Her stump was 2 inches long, and skin transplantations covered the entire stump and the distal part of the thigh.

Four amputees had for 40, 30, 13 and 6 years, respectively, successfully worn a conventional B/K, but when fitted with an air-cushion socket they all preferred that to the conventional prosthesis.

As far as the 35 amputees who had previously worn a prosthesis are concerned, fitting with the air-cushion socket gave the following results:

- in 27 cases, increased comfort and function
- in 4 cases, unchanged condition
- in 3 cases, return to standard PTB prosthesis
- in 1 case the amputee had to be fitted with a conventional prosthesis.

Of the remaining 6 amputees, 5 had not before worn a prosthesis and

- in 2 cases the amputee had edema distally and ulceration which healed when air-cushion socket was applied.
- in 1 case the amputee manages well with air-cushion socket. He has had stump problems which cannot, however, be attributed to the prosthesis.
- in 1 case the amputee, who had no stump problems, is wearing an air-cushion socket with success.
- in 1 case the amputee had to be fitted with a different type of prosthesis because his stump volume was constantly changing and his stump was hypersensitive distally.
- in 1 case the amputee has previously been fitted with an air-cushion socket by a private prosthetist, and she is doing very well.

Of the 41 amputees in the test series, 36 are now wearing the air-cushion socket, whereas 5 amputees had to abandon it.

As earlier mentioned, 22 of the 41 amputees have been through an extensive medical reexamination. The remaining 19 amputees are also to be reexamined, and then a more detailed report on the results and the basic pathology will be published.

#### L i t e r a t u r e

1. Lyquist, E., L. A. Wilson, and C. W. Radcliffe, Air-cushion socket for patellar-tendon-bearing below-knee prosthesis, principles and fabrication procedures. Biomechanics Laboratory, University of California, San Francisco and Berkeley, 1965. (Technical Memorandum).
2. Wilson, L. A., and E. Lyquist, Plaster bandage wrap cast, Prosthetics International, Vol. 3, no. 4-5, 1968.



## EXPERIENCE WITH THE AIR-CUSHION BELOW-KNEE SOCKET IN YUGOSLAVIA

BOSKO ZOTOVIĆ, M.D.\*

The production of air-cushion sockets for below-knee prostheses was introduced into Yugoslavia by the Center for Prosthetics in Belgrade, in January 1966, very shortly after the return of Engineer L. Gavrilović from the States, where he had been taught the technique by Prof. Radcliffe and his group. During his visit to the University of California, Eng. Gavrilović made a number of prostheses. With the help of Prof. Radcliffe's Manual, he began to fit air-cushion sockets in the Center.

Between January 1966 and November 1968, 28 patients have been provided with air-cushion sockets. In addition, patients in other parts of the country, where we have trained the staff, have been fitted with the new type socket.

The technique of work, as well as the applied material with some minor modifications, follows the manual closely. SILASTIC #388, a product of the Dow Corning Co., Midland, Mich., is imported for use in the socket. For the prosthesis itself, a local polyester resin has been used, in standard proportions of rigid and flexible components. The VAPC casting stand, which we have been using for the past several years in all below-knee fitting, is used. Alignment of these prostheses has been carried out in the standard way using the VAPC coupling.

However, in fabrication of the air-cushion socket, certain changes from the initial technique described by Prof. Radcliffe have been undertaken.

1. For stumps with marked sensitivity at the distal end, reduction of the pressure at the bottom of the socket has been achieved by using the plaster-of-Paris mold as it is made, i.e., without modifications.

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2. Corrections of the distal part of the plaster-of-Paris mold have been carried out only for those cases which tolerate distal pressures. In this case, we have followed instructions given in the Manual.

3. When bony prominences as well as the marked oversensitive areas are present, the distal reduction of cast, for about 9 mm., is performed all over, except for areas where the sensitivity and pressures have been noted. In certain cases, at these areas, even the local buildups of the cast, for about 3-4 mm. had to be performed.

These were the only changes made, and these are minor, yet they are significant in providing prostheses that can be used by patients with overly sensitive stumps.

For several years now it has been our policy to trim the anterior, medial and lateral walls at the level of the proximal border of the patella, or even higher, with a slight rounding anteriorly around and above the patella. This practice yields better retention of the stump within the socket and therefore less need for suspension, and shorter stumps can be fitted. At the same time more stability about the knee is obtained, a feature that is necessary for some cases with certain knee disabilities. This higher socket border had been applied to air-cushion sockets.

Stumps as short as 2 1/4 in., measured from the tibial plateau, have been fitted satisfactorily. Not a single patient required a thigh corset with mechanical joints as a suspension means. For the cases with extremely short stumps, suspension was achieved by using a special 3 mm. thick Ortholen cuff attached to the socket by vertical uprights. Such a cuff provides not only suspension but stability about the knee as well.

During fitting and alignment the pressure within the air-chamber is controlled by a manometer attached to the socket, during both the swing and stance phases of ambulation. During the swing phase, the pressure was negative and amounted to 0.2 atmospheres while in the

stance phase its value was increased by 0.07 atm. After the trials, the manometer is detached, the connective tube is sealed with a plastic resin, the coupling device is removed, and the prosthesis is finished in the normal manner.

The patients fitted with these prostheses were of different age groups, their amputations resulted from various causes, and they have undergone regular one-month and three-months follow-up studies. The results were very satisfactory for all of them. There was not any objection on the part of the wearers, and they all were very contented with these prostheses. Not a single patient fitted with the air-cushion socket discarded it or switched to some other type. There have been, however, several cases who have ordered the second prosthesis with an air-cushion socket, and three have ordered a third.

The statements and subjective estimations of the patients correspond, to a great extent, to our findings, as follows:

1. Better and more intimate fit between the stump and the prosthesis.
2. Better positioning of prosthesis during ambulation; better coordination of gait, i.e., better coordination of movements and more improved and easier gait.
3. Better control over the prosthesis has been reported by all wearers.
4. The patients stress the subjective sense of relative elongation of the stump length.
5. The blood circulation within the stump was improved, even where some circulatory changes have been previously diagnosed. The skin quality has been improved to a certain extent, and the skin recovered its normal color. After some time, hair began to grow on stump surfaces where it had vanished due to shear.
6. Muscle function was more obvious while using the air-cushion socket, and muscle strength was improved to a certain extent. This assessment was established on the basis of comparative muscle tests which were performed for all patients.

In several cases, when stump atrophy was present, there were attempts to correct the sockets by making a new Silastic chamber over the cast and mold to make a double air cushion. Unfortunately, this trial, as well as some other attempts at corrections, has failed. The only reasonable method presently known for correcting for stump atrophy is to make a new socket.

After the experimental work was finished and we became familiar with the technique, we organized a Seminar for teaching the other orthopedic enterprises in Yugoslavia, and now the air-cushion socket is being produced in several other places. These institutions report findings parallel to our own.

Last year we demonstrated the use of the air-cushion socket in Hungary and Bulgaria. We are informed that the patients that have been fitted with this type of prosthesis in Hungary and Bulgaria are very satisfied with them. The appraisal of experts in these countries is also very praiseworthy, and it corresponds to our opinion as submitted in this report.

Before closing we would like to point out that we have applied this technique with some modification to below-elbow stumps as well. We have experimented with cases where oversensitivity at the stump end was obvious, or the stump was bulbous, or where bony prominences were present. The patients responded very well to this type of air-cushion socket. They had a feeling of relative elongation of the stump, the positioning of the prosthesis was better, the sense at work was better, and, in their words, they were more manipulative. This was particularly demonstrated in the case of a bilateral below-elbow amputee, where one side was fitted with the air-cushion below-elbow prosthesis, while the other side was fitted with a standard-type of preflected Hepp-Kuhn prosthesis. With this work, Mr. Hector Kay has been acquainted, during his recent stay with us.

In conclusion, we would like to stress that our results with air-cushion sockets have been very good. No contraindications for use

have been found. We would like to point out that this technique requires a solid knowledge and training, and that accuracy and studiousness are necessary for success. Because the accuracy required is greater than that for other types of BK sockets, it is not surprising that some enterprises make a socket which is not adequate. For this reason the clinic team must check out each case most carefully to prevent the unjustified failure of this really good and useful type of below-knee socket.



BIBLIOGRAPHY INCLUDING  
LITERATURE CITED

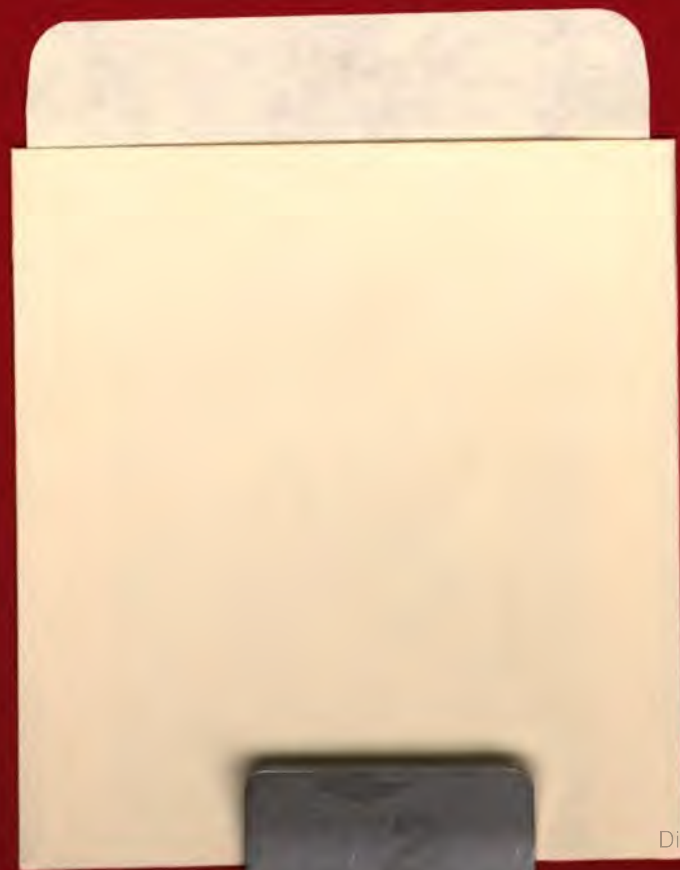
1. Bakalim, Georg, Experiences with the PTB prosthesis, Artif. Limbs, 9:1:14-22, Spring 1965.
2. Burgess, Ernest M., Amputations below the knee, Artif. Limbs, Spring 1969, in press.
3. Burgess, Ernest M., The below-knee amputation, Inter-Clinic Inform. Bull., 8:4:1-22, January 1969.
4. Caldwell, Jack L., Inverted V-strap suspension for PTB prostheses, Artif. Limbs, 9:1:23-26, Spring 1965.
5. Committee on Prosthetics Research and Development, Pressure and force measurement, National Academy of Sciences, Washington, D. C., 1968.
6. Dolan, Clyde M. E., The Army Medical Biomechanical Research Laboratory porous laminate patellar-tendon-bearing prosthesis, Artif. Limbs, 12:1:25-34, Spring 1968.
7. Dunfield, Vaughn, An electronic aid for the alignment of the below-knee pylon prosthesis, Thesis for M.S. degree, University of New Brunswick, September 1967.
8. Fillauer, Carlton, Supracondylar wedge suspension of the P.T.B. prosthesis, Orth. & Pros., 22:2:39-44, June 1968.
9. Foort, James, The patellar-tendon-bearing below-knee prosthesis for below-knee amputees, A review of technique and criteria, Artif. Limbs, 9:1:4-13, Spring 1965.
10. Foort, J., and D. A. Hobson, A pylon prosthesis system for shank (BK) amputees, Prosthetics and Orthotics Research and Development Unit, Manitoba Rehabilitation Hospital, Winnipeg, Report No. 6, November 1965.
11. Goldner, J. Leonard, Frank W. Clippinger, and Bert R. Titus, Use of temporary plaster or plastic pylons preparatory to fitting a permanent above-knee or below-knee prosthesis, Final Report of Project No. 1363 to Vocational Rehabilitation Administration, DHEW, from Duke University, no date given; circa 1967.

12. Hamontree, Sam E., Howard J. Tyo, and Snowdon Smith, Twenty months experience with the "PTS," Orth. & Pros., 22:1:33-39, March 1968.
13. Hampton, Fred, Silicone rubber for distal pads in above-knee and below-knee prostheses, Prosthetics Research Center, Northwestern University, Chicago, 1962.
14. Hampton, Fred, Suspension casting for below-knee, above-knee, and Syme's amputations, Artif. Limbs, 10:2:5-26, Autumn 1966.
15. Hill, James T., Henry Mouhot, and Robert E. Plumb, Manual for preparation of a porous PTB socket with soft distal end, Army Medical Biomechanical Research Laboratory, Walter Reed Army Medical Center, Washington, D. C., Tech. Rep. 6804, May 1968.
16. Kuhn, G. G., S. Burger, R. Schettler, and G. Fajal, Kondylen bettung Münster am unterschenkel stumpf, "KBM prothese," Atlas d'Appareillage Prothétique et Orthopédique, No. 14, 1966, 18F.
17. Lambert, Claude N., Applicability of the patellar-tendon-bearing prosthesis to skeletally immature amputees, Inter-Clinic Inform. Bull., 3:7:7, May 1964.
18. Lipskin, Ronald, and Thomas Grille, The development of the NYU transparent socket fabrication technique, Prosthetics and Orthotics, New York University Post-Graduate Medical School, November 1968.
19. Litt, Bertram D., and LeRoy Wm. Nattress, Jr., Prosthetic services USA--1961, American Orthotics and Prosthetics Association, Washington, D. C., October 1961.
20. Lower-Extremity Amputee Research Project, Minutes of symposium on BK prosthetics, University of California, Berkeley, April 17-20, 1957.
21. Margetis, Peter M., Walter L. Shepard, Robert E. Plumb, and Fred Leonard, A fluid resin technique for the fabrication of check sockets, Orth. & Pros., 22:4:8-27, December 1968.
22. Marschall, Kurt, and Robert Nitschke, Principles of the patellar-tendon-supra-condylar prosthesis, Orthop. and Pros. Appl. J., 21:1:33-38, March 1967.



23. Marschall, Kurt, and Robert Nitschke, The P.T.S. prosthesis (complete enclosure of patella and femoral condyles in below-knee fittings), Orthop. and Pros. Appl. J., 20:2:123-126, June 1966.
24. Murphy, Eugene F., and A. Bennett Wilson, Jr., Anatomical and physiological considerations in below-knee prosthetics, Artif. Limbs, 6:2:4-15, June 1962.
25. Pierquin, L., J. M. Paquin, and G. Fajal, Discussion sur les prothèses tibiales, Atlas d'Appareillage Prothétique et Orthopédique, No. 9, 3 mo. Trimestre, 1965.
26. Pierquin, L., G. Fajal, and J. M. Paquin, Prothèse tibiale a emboîtage Supra-condylien, Atlas d'Appareillage Prothétique et Orthopédique, No. 1, January 1964.
27. Pierquin, L., J. M. Paquin, and G. Fajal, La prothèse tibiale Americaine, patellar-tendon-bearing, Atlas d'Appareillage Prothétique et Orthopédique, No. 8, 2 mo. Trimestre, 1965.
28. Plumb, Robert E., and Fred Leonard, Patella-tendon-bearing below-knee porous socket with soft Silastic distal end, Army Medical Biomechanical Research Laboratory, Walter Reed Army Medical Center, Washington, D. C., Tech. Rep. 6311, June 1963.
29. Radcliffe, C. W., and J. Foort, The patellar-tendon-bearing below-knee prosthesis, Biomechanics Laboratory, University of California, Berkeley and San Francisco, 1961.
30. Veterans Administration Prosthetics Center, Direct forming of below-knee patellar-tendon-bearing sockets with a thermoplastic material, Orth. & Pros., in press.
31. Wilson, L. A., E. Lyquist, and C. W. Radcliffe, Air-cushion socket for patellar-tendon-bearing below-knee prosthesis, Department of Medicine and Surgery, Veterans Administration, Tech. Rep. 55, May 1968.
32. Witteck, Frank A., Evaluation of thirteen below-knee amputees fitted with patellar-tendon-bearing, cuff suspension prostheses, Veterans Administration Prosthetics Center, New York, October 1959.
33. Witteck, Frank A., Some experience with patellar-tendon-bearing below-knee prostheses, Artif. Limbs, 6:2:74-85, June 1962.





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