May 1954

Artificial Limbs

A Review of Current Developments

ADVISORY COMMITTEE on ARTIFICIAL LIMBS

National Academy of Sciences
National Research Council

Artificial Limbs

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MAY 1954

A publication of the Advisory Committee on Artificial Limbs, National Academy of Sciences—National Research Council, issued three times a year, in January, May, and September, in partial fulfillment of Veterans Administration Contract VAm-21223. The opinions expressed by contributors are their own and are not necessarily those of the Advisory Committee on Artificial Limbs.

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ADVISORY COMMITTEE on ARTIFICIAL LIMBS

NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

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Limbs in Limbo

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To **STAND** on his feet and to walk with his legs wherever his heart desires are natural rights guaranteed to man by his own constitution. Heads may plan and hands may build, but only where legs and feet have brought them. Loss of the lower limb is therefore a major catastrophe.

When loss of leg occurs, replacement becomes the primary hope. Ages past, an unknown man hobbled forth from his cave in search of a willow; with one of its limbs adopted as his own, he walked back with majesty. Since then the stage of history has resounded with the staccato echo of countless amputees marching with peg-leg, grit, and gumption.

Rapid perfection of limb construction was to be anticipated after these early ventures had focused human ingenuity upon the problem. To the superlative talent which mankind has shown in the production of machinery both intricate and sturdy, the building of a mechanical leg would appear to offer little difficulty. Why is it, then, that artificial limbs have so generally belonged to the limbo of things undeserving either of unstinted praise or of utter condemnation?

Failure of artificial legs to satisfy our hopes results less from the imperfection of their mechanisms than from the extravagance of our expectations. People who do not expect a glass eye to see or a prosthetic hand to play the piccolo are disappointed when an artificial leg squeaks while dancing the polka. Man has never commanded clear appreciation of his means of locomotion. From time to time he has been ecstatic about the eye and the liver, the heart, the brain, the hand. Legs have been referred to most frequently as symbols of neighboring functions, so lightly have their own merits been regarded.

Why is the performance of the lower extremity so much less spectacular than that of the upper? Independence of the upper limb from obligation to the rest of the body allows it to indulge in ornamentation of movement, so impressive to the eye. The lower limb, sandwiched between the ground and the torso, must ever be responsive to the needs of the body as a whole. It cannot choose to support some parts of the body and not others or to walk with the body through only portions of each step. The intricacy of function of knee and ankle does not

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exhibit itself in capricious movements but excels when it modulates countless disturbing factors so that no tremor mars the stark simplicity of normal locomotion.

No one can rightly expect an artificial limb to take over completely the functions of its predecessor unless it is endowed with an equivalent of muscular and nervous control. Difficult as it is to provide substitutes for bones and joints, such provision is simplicity itself compared with the incorporation within the prosthesis of its own control. Although considerable progress has been made in the field of decelerating mechanisms for lower-extremity prostheses, the leg amputee must still use his own resources when he needs to supply energy or to exercise discretion.

The contribution which the amputee makes to the over-all prosthetic result far exceeds that of acting as a model for exhibiting the achievements of inventors. It is he who must finish creation of the new locomotor mechanism by reshaping the pattern of his muscular activity and establishing alertness to new sensory cues. The success of the artificial leg depends on how thoroughly it becomes a part of the form and the function of the amputee after he has blended its metal, wood, and plastic with his muscle and perception. It is only appropriate that the new mechanism, having superseded the natural limb, should contribute to amputee gait that special accent which identifies the supernatural walk.

The complexity of human motion makes it inevitable that fundamental improvement in leg prostheses must come slowly, since it is based on factors so numerous that no one individual can comprehend them all. In addition to the profession of engineering, there is needed the cooperation of the physician, the physicist, the physiologist, the physiotherapist, the prosthetist, and the psychologist—to list them in alphabetical order—so that the patient may get the total care he deserves.

The problems which need attention are of different degrees of complexity and must be approached by different methods. Choice of materials, details of construction, and provisions for repair require less consideration of the over-all characteristics expected in the rehabilitated amputee than do problems of fit and socket shape. More general considerations must be weighed in projects concerned with alignment, basic design of mechanisms, and evaluation of performance. For these there should be a conscious choice of a realizable objective, the attainment of which requires integration of man and machine into a functional unit.

All of these are practical problems amenable to increasingly useful solutions year by year, provided we do not surrender to the impatience of those who must have the answer to the question of the century today and of the millennium tomorrow. It is necessary to preserve clear vision of long-term objectives, although some members of every team find the environment more familiar when details arise.

Had trial-and-error and serendipity been able to produce truly satisfactory lower limbs, we would not still be waiting for such. It was left for the National Academy of Sciences—National Research Council to initiate the development of artificial limbs on a modern basis by creating the Committee on Prosthetic Devices and, later, its successor, the Advisory Committee on Artificial Limbs. By carefully balancing the fundamental and the practical in their program, these Committees have laid a firm basis for some progress today, much more tomorrow.

This is the key to the future in lower-extremity prosthetics. Used wisely, it will allow us eventually to rescue the limb problem from limbo and to provide the amputee of the future with a fitting legacy.

The Objectives of the Lower-Extremity Prosthetics Program

HOWARD D. EBERHART, M.S.[1]

MAN depends upon his legs to support the body and to move it from place to place as occasion warrants. Since mobility is nearly indispensable to most human activities, the loss of part or all of a leg—through accident, war, or disease—imposes serious limitations and has always made a replacement of some sort more or less of a necessity. Accordingly, artificial legs of one kind or another have been made and used since the most ancient times. As a result of the long-continued effort, leg prostheses have undergone progressive, if slow, development through the centuries, so that many lower-extremity amputees have in the past been successfully restored to something resembling a normal life. With the advent of industrial development, and of improved tools and materials with which to work, the nineteenth century marked the appearance of many new lower-extremity devices and of new techniques in the medical treatment of amputations.

Impetus provided by World Wars I and II gave rise to rapid advancement in all branches of technology and thus made possible a concerted attack on the problem of supplying the best possible artificial limbs. The term "lower-extremity prosthetics" has now come to mean the practice of rehabilitation of the leg amputee by providing him with an artificial limb that will restore lost functions to the greatest possible degree. But more than just the artificial leg is involved. The amputee himself is a most important part of the end-product, and amputees, like other people, are individuals with widely differing characteristics and abilities. Of course surgical procedures should be designed to secure a painless stump and to retain maximum function, and it would seem that the artificial leg, when properly fitted, should duplicate as closely as possible the normal activity of the lost part. Moreover, physical conditioning and gait training are both important phases of the whole rehabilitation process.

This concept of lower-extremity prosthetics has developed during the years since the start in 1945 of the program of the Advisory Committee on Artificial Limbs, National Research Council. Initially, the primary objective was to develop improved devices, it being considered as obvious that, if a better prosthetic knee or ankle or foot could be devised, the amputee would benefit. Attempts to produce such items, however, made necessary the determination of functional requirements and thus immediately revealed the lack of necessary fundamental information. Basic research into the complicated phenomenon we call "locomotion" was therefore carried on simultaneously with the development of devices.[2] These investigations indicated a need for the application of basic mechanical principles to fitting and alignment of artificial legs. A three-

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[2] A more logical and systematic approach, had there been sufficient time, might have been to postpone device development until the results of the basic work became available. But the urgency of amputee demands at the end of World War II made such an approach less desirable than the one adopted.

pronged approach, all parts of which are complex and interrelated in various ways, has thus evolved. Basically, the three objectives are:

1. To extend knowledge of the amputee, of lost and remaining functions affecting locomotion, and to collect information on the best possible medical treatment.
2. To improve fitting techniques and practices, including training, so that existing devices might be used with greater comfort and function.
3. To develop improved lower-extremity devices.

Relative emphasis on these three phases is shown in Figure 1. Implied in such a program is the dissemination of information and techniques to those who serve the amputee. Many of the accomplishments to date are recorded, and fully documented with the report literature, in Klopsteg and Wilson's *Human Limbs and Their Substitutes* (McGraw-Hill, in press). In addition, various seminars and short courses for surgeons and prosthetists have been conducted throughout the program.

FUNDAMENTAL STUDIES

Detailed and comprehensive study of normal human locomotion is the basic key to improvement in all phases of the lower-extremity problem. Walking is to all appearances so natural and simple a process that it is difficult to conceive of its complexity. A knowledge of the behavior and the contribution of each anatomical part in providing the many services required of legs in normal use is essential to determine the functions that have been lost through amputation and the functions that still remain. The surgeon needs such information in order to provide the best amputation stump with maximum remaining function. The prosthetist must understand the limitations and potentialities of the amputee-prosthesis combination for optimum fitting, alignment, and adjustment. The designer needs detailed information on angles, displacements, velocities, accelerations, forces, energy requirements, and functions in order to improve existing devices and to develop new ones. And finally, the amputee himself has problems that require a fundamental approach. Causes and treatment of phantom or other pain, circulatory difficulties resulting from amputation, skin tolerance to pressure in areas never intended for such use, as well as the better understanding of the psychological problems of the amputee are examples of important areas of investigation.

The objectives of the program of fundamental studies of the lower extremity may be summarized as:

1. To study the phenomenon of locomotion in a sample of normal individuals and to analyze the results for use by the surgeon, the designer, and the prosthetist.
2. To develop design criteria for new or improved devices and as a basis for evaluating existing devices.
3. To develop an understanding of the compensatory mechanism of the human body and its ability to adapt itself to overcome functional deficiencies of its parts.
4. To provide a frame of reference for evaluating the degree of success obtained in replacing lost functions by means of an artificial leg.
5. To obtain information on the cause and possible

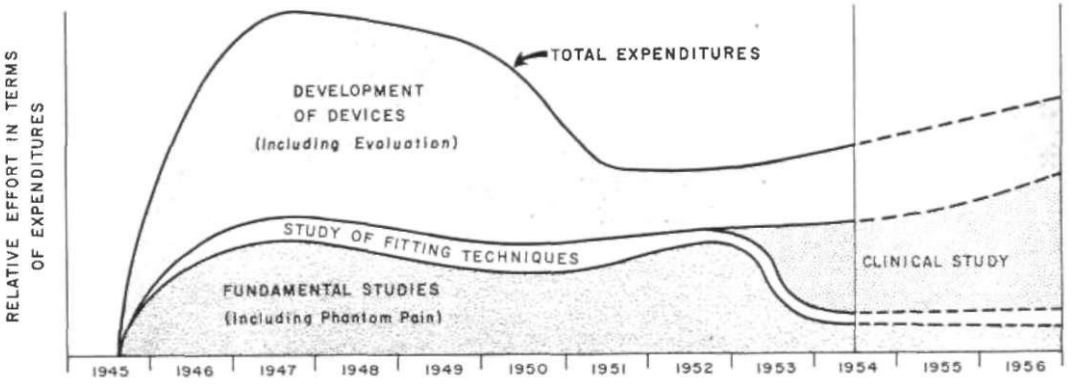

Fig. 1. Trends in the lower-extremity prosthetics program, 1945-54, projected through 1956

treatment of phantom pain and other medical problems of the amputee.[3]

DEVELOPMENT OF TECHNIQUES OF FITTING AND ALIGNMENT

It appears obvious that, no matter to what degree an artificial leg is perfected mechanically, its effectiveness will depend upon the comfort afforded the wearer. Comfort is a function of the fit and alignment of the prosthesis.

Although the artificial-limb industry has, through the years, developed reasonably successful techniques for fitting and aligning artificial legs, the results have been obtained mostly by trial-and-error methods; seldom have basic mechanical and anatomical principles been employed. It was found, for instance, that even among the most successful prosthetists there existed little agreement as to what constituted a satisfactory fit. For these reasons it appeared necessary to include in the lower-extremity program a project to develop fitting and alignment techniques based on sound scientific principles and to include, if necessary, the development of auxiliary tools and a study of materials and of methods of suspension.

The study was launched with the following objectives in mind:

1. To learn from the artificial-limb industry the procedures used in fitting and alignment of artificial legs.
2. To work with the industry in applying fundamental principles to the problem of fit and alignment and to formulate the guiding principles involved.
3. To develop mechanical aids to improve fit and alignment and to serve as tools to simplify shop operations.
4. To investigate and evaluate types of suspension as well as materials and methods used in socket fabrication.
5. To develop simplified methods of evaluating the amputee-limb combination—to be used as a check by the prosthetist, the surgeon, and the physiotherapist.
6. To improve methods of training the lower-extremity amputee in order to get better functional and more effective use of his prosthesis.

Out of this study have come such developments as the introduction of the above-knee suction socket (page 29) and the University of California adjustable legs and alignment duplication jig (page 23). The study of fitting and alignment continues at the University of California, Berkeley Campus.

DEVELOPMENT OF PROSTHETIC DEVICES

New and improved devices have always been a major objective of the ACAL program. Great effort has been expended in this direction, often without the necessary or valid criteria. Although engineering designs can be made to accomplish nearly any specified function, the end result of any given design may be unsatisfactory if the specifications were unrealistic. The device may be too complicated, too heavy, uneconomical for the improvements obtained—or it may actually interfere with some service functions though improving others. Since the beginning of the ACAL research program, a number of outstanding industrial firms have engaged in development of devices. As a result of these activities, a great deal has been learned about what is possible—and about what *not* to do. Together with the fundamental studies, a body of knowledge has been developed to provide a realistic approach to design criteria. A number of devices based on this information are now in the development stage; they show promise for the future.

Criteria for improved knee joints for above-knee amputees have undergone great changes as fundamental knowledge of locomotion has increased and as various knees, alleged to be improved ones, have been tested on amputees. Similarly, dependence of knee performance on ankle function, fit and alignment, training, and total coordination is becoming better understood. In the light of present knowledge, it seems clear that "super-devices" are not apt to be the solution to improved artificial legs and that considerations of natural appearance, minimum energy consumption, and simplicity of mechanism for maintenance and economy will in the end be the controlling factors. Of course no device should be made available for general distribution until it has been checked thoroughly for function, strength, maintenance requirements, life expectancy, and adaptability to different types of amputees. A complete testing program has there-

[3] It should be noted that the work on phantom pain is applicable to both upper- and lower-extremity amputations.

fore been established under the direction of New York University to ensure the adequacy of each device approved under the program.

Present objectives for the development of prosthetic devices may be stated as:

1. To invent new mechanisms, improve and adapt existing mechanisms, and apply new materials so as to add functions, or to improve presently provided functions of prostheses, seeking in the end lu provide better devices to meet the needs of every amputee type.

2. To perfect those functions involved in level walking, with the best possible solution Lor oilier services such as sitting down, walking on slopes and stairs, elc.

3. To adapt devices that take advantage of remaining functions in the amputee's stump.

4. To increase stability during the weight-bearing phase but to reduce the energy requirement during transition as well as during the entire cycle of walking.

CLINICAL STUDY

Throughout the program, amputees have been fitted with experimental prostheses in order to conduct studies, trials, and tests of the equipment. Techniques and practices involved in fitting amputees are so varied, however, that some orderly means of investigating these areas became necessary. Accordingly, in 1952 a program of clinical studies was established under the project at the University of California, Berkeley, in space at the Artificial Limb Shop of the U. S. Naval Hospital at Oakland, California. Here an orderly approach can be made to a review and formulation of best practice in lower-extremity prescription, fabrication, fitting and alignment, and training in the use of the prosthesis. Complete documentation of each step in the process, as applied to a variety of amputee types, under the supervision of an advisory panel and with the cooperation of members of the limb industry in the San Francisco Bay-Area, will serve to close the gap between fundamental work in the laboratory and practice in the field. Besides this, it will serve to supply source material for the information of the various professions involved in physical rehabilitation of the amputee as well as to define areas where more information or new devices are required.

In addition to establishing what is the best prosthetic practice, the objective of the clinical study is to develop, for distribution to each member of the rehabilitation team, including the amputee, information such as:

1. Medical data for use by the surgeon in connection with amputee problems.

2. Criteria for use in proper prescription of a prosthesis.

.1. Principle* and practices of fabrication, fitting, and alignment of a prosthesis.

4. Suggested means of evaluating prosthesis and amputee. Including gait analysis, performance checks, and achievement tests for use by the prosthetist, the surgeon, and the physical therapist.

5. Suggested curriculum for training the amputee in the use of his prosthesis.

6. A comprehensive list of specific prosthetic appliances and devices, with descriptions of their individual characteristics and functions, for use in preparing prescriptions.

7. Suggested curriculum for training the prosthetist, the surgeon, and other members of the clinic team in lower-extremity prosthetics.

8. Data useful to the research and development laboratories in continuing their studies.

FUTURE PROGRAM

The investigation and development involved in a lower-extremity prosthetics program are complicated and time-consuming. And since it appears impossible to reach the ultimate goal of replacement of all functions that have been lost, the task must be considered as never-ending. For the immediate future it is contemplated that development of devices, the clinical study, fitting and alignment studies, and fundamental research will continue. The relative emphasis on each phase is projected on Figure 1 through 1956.

As progress is reflected in the results of the clinical study, some means must be developed for effectively transmitting this information to orthopedic clinic teams throughout the nation. Whether this is to be accomplished]priori ically al a central location, or whether through field teams on a continuing basis, will depend to a large extent upon the results obtained in the clinical study during the coming year. Whatever method evolves, every effort will be made to ensure that any useful information is disseminated to the field as quickly and efficiently as possible.

Contributions of the Lower-Extremity Prosthetics Program

EDMOND M. WAGNER, M.E.[1]

WHEN, in 1945, the National Research Council launched its program for improvement of artificial legs, the original concept was that the major portion of the work would in all probability consist simply of devising mechanically improved artificial knees, ankles, and feet and of applying new materials to existing designs. But it soon became apparent that, if any appreciable success were to be had, the scope of the work would have to be broadened considerably[7]. For new items that were designed failed Lo satisfy the amputee, and there were insufficient fundamental data on which to base improvements. Such information as was available on the mechanics of the lower extremity was either incomplete or else not presented in such form as to be useful to designers.

The character of the fit was shortly found to be a matter of paramount importance in determining the success or failure of a given device. But fitting itself was based largely on the personal experience of individual fitters, and there were in existence no formalized standards or rules for guidance in obtaining proper fit. Moreover, the results of testing of devices were too often based on the impressions of only a few amputees and casual observers, either or both generally not qualified to express a competent opinion. There was not even general agreement on some of the principles involved in the surgery of amputations. Before any real progress could be made, information had to be secured in all these fields and coordinated with data from others.

The task of obtaining the required information was assigned by the National Academy of Sciences to a number of subcontractors. At the outset, basic research on problems concerned in lower extremities, including studies on surgery, pain *(9,25),* and fitting *(18),* was placed with the University of California at Berkeley *(22).* To assist designers and fitters, and to provide a record of the devices and techniques being used in the limb industry, a review of prior art was carried out at Northwestern University *(15),* and the Surgeon General of the Army sent to Europe a commission *(26)* to study and report on the prosthetics art as practiced in various other countries. Solutions attempted in the past for many problems in leg design are cataloged and described in the Northwestern report *(15)* and in the report of the European commission *(26).*

Development of devices was undertaken by Goodyear Tire and Rubber Company *(10);* Vickers, Inc. *(20),* Detroit; C. C. Bradley and Son *(2);* Catranis, Inc. *(4);* Adel Precision Products (/); A. J. Hosmer Corporation *(11);* Northrop Aircraft *(14);* the U.S. Naval Hospital at Oakland, California *(21);* National Research and Manufacturing Company *(12);* the Aero-Medical Laboratory of the U.S. Air Force, Wright-Patterson Air Force Base; the Army Prosthetics Research Laboratory, Walter Reed Army Medical Center; and the University of California at Berkeley *(22).* Later in the program, the Denver Research Institute *(6)* of the University of Denver carried out an investigation of below-knee prostheses, some additional basic data have been supplied by New York University *(13)* and by the Prosthetic Testing and Development Laboratory of the Veterans Administration in New York City, and another commission *(23)* was sent to Europe to observe

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progress abroad after 1945. Testing and evaluation of devices has been developed and carried out at New York University *(13),* and the Orthopedic Appliance and Limb Manufacturers Association has cooperated in general program guidance.

DEVELOPMENT OF BASIC DATA

Because prior to 1945 little study had been conducted on the characteristics of human locomotion, because of the complexity of the problem, and because of its highly specialized nature, it was necessary first to devise special equipment for collecting information which, ultimately, would lead to determination of the mechanical and physiological changes occurring during various activities of the lower extremity. A number of pieces of unusual apparatus, such as force plates, a glass walkway (Figs. 1 and 2), and special photographic equipment were designed *(7,22),* and from the data collected using this equipment it was possible to determine such factors as the forces and moments in human and artificial legs and the roles played by major muscle groups under a series of conditions. From such findings it has been possible to describe fully the phenomenon of human locomotion and thus to establish a set of realistic criteria for the design and evaluation of artificial-leg components. Aside from applicability to the field of prosthetics, the data collected are useful also to designers of leg braces and to

Fig. 1, The University of California glass walkway. With this device, motion pictures taken from a single camera yield sufficient information to determine relative motions of various segments of the body during level walking. Subject shown here is wearing an above-knee experimental leg.

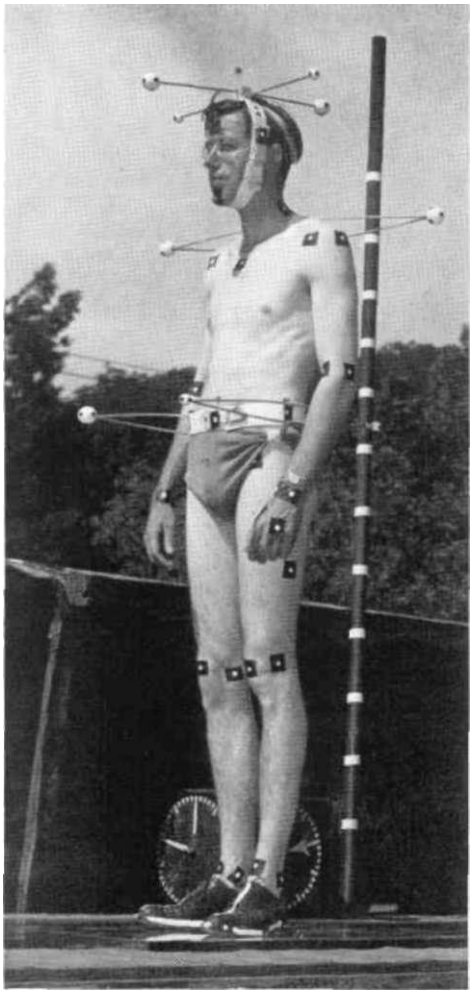

Fig. 2. Normal subject prepared for participation in studies using the University of California glass walkway. Some targets are mounted on levers to amplify motions otherwise of small magnitude.

the medical profession in the treatment of pathological gait *{19).*

The major portion of this work was performed at the University of California, Berkeley, and many of the results have been documented in reports and in the journal literature. Of the many reports issued, most, such as those of Cunningham (5), of Bresler and Berry (J) and of Radcliffe *(17),* generally cover a single phase of the subject.

CREATION OF DESIGN OBJECTIVES

From study of the basic data, and from careful review of current practices, it has been possible to set up a listing of design objectives for leg prostheses, it being understood that above all the prosthesis must satisfy the amputee. Arranged in generally decreasing order of importance, these requirements are as follows:

1. Security from [all.
2. Minimum consumption of energy in normal walking
3. Appearance of the walking pattern to compare favorably with that of a normal person.
   a. Smooth swing phase, including deceleration of the prosthesis at the end of extension, control of heel rise at the end of flexion, and deceleration of the prosthesis just prior to heel contact.
   b. Smooth stancephase, includingattainmentof full extension without final snapping action.
   c. Ability to change gait to maintain smooth, normal-appearing gait.
4. Ability to extend the leg under load at any time.
5. Proper phasing of the locking action, if used, with all portions of the stance and swing phases.
6. Performance of incidental operations—such as going up and down stairs and ramps, turning, and sitting down—with reasonable ease and smoothness.

A listing of the features desired of leg prostheses at three functional levels (Table 1) has finally evolved.

IMPROVEMENT or FITTING AND ALIGNMENT

As a result of the early attempts to improve existing knee-brake devices, it was found that fitting and alignment were together often more of a determining factor in amputee acceptance than was the performance of the device itself. In the two trips to Europe *(23, 26),* various techniques and several mechanical aids for obtaining greater uniformity in fitting were observed. These techniques and devices have been analyzed, and from the resulting knowledge, together with information from the basic studies, improved methods of fitting and aligning above- and below-knee legs have been formulated. All of these observations have been published in a report of the University of California at Berkeley *(18).*

In order to make these principles of fitting and alignment easier to apply, an adjustable leg (page 23) for above- and below-knee prostheses, with provisions for individual adjustment of major elements, was designed by the project at Berkeley and turned over to the limb industry. This leg, once adjusted, can be worn by an amputee for periods of a

Table 1

DESIRABLE FEATURES OF LEG PROSTHESES[a]

Class of leg	Component			
	Foot	Ankle	Shank	Knee[b]
Standard	1. Toe break so set as not to interfere with amputee's gait. Range: 30 deg. Stiffness: 2.5 in.-lb. per deg. 2. Shock absorption at heel contact 3. Proper shape of foot to fit shoe	1. Plantar-flexion stiffness: 10–15 in.-lb. per deg. Range: 10–20 deg. 2. Dorsiflexion stiffness: 60–150 in.-lb. per deg. Range: 2.5–10 deg.	1. Shape similar to normal leg 2. Pleasing color and cosmetic appearance	1. Satisfactory range of motion, min. 110 deg. 2. Predetermined constant knee friction in swing phase 3. Stability in stance phase independent of added mechanism
Improved	1. Toe break 2. Shock absorption 3. Proper shape	1. Plantar flexion 2. Dorsiflexion 3. Transverse rotation with independent adjustment. Range: ±15 deg. Stiffness: 1–6 in.-lb. per deg. Location: any level below knee 4. Lateral-motion range: ±10 deg. Stiffness: 4–8 in.-lb. per deg.	1. Proper shape 2. Cosmetic appearance 3. Sufficient space for installation of knee-friction device	1. Range of motion: 120 deg. min. 2. Predetermined variable friction in swing phase 3. Stability in stance phase independent of added mechanism 4. Involuntary control, yielding-type knee brake. Resisting moment: 750–2500 in.-lb.
Maximum function	1. Toe break 2. Shock absorption 3. Proper shape	1. Plantar flexion 2. Dorsiflexion 3. Transverse rotation 4. Lateral motion 5. Toe pickup 6. Ankle extensor for push-off	1. Proper shape 2. Cosmetic appearance 3. Space for knee-friction device 4. Additional inner space required for mechanisms 5. Cosmetic covering	1. Range of motion: 120 deg. min. 2. Predetermined variable friction in swing phase as a function of angular velocity for cadence control 3. Stability in stance phase independent of added mechanism 4. Yielding-type knee brake 5. Voluntary control, positive-action knee brake, with provision for initial knee flexion. Resisting moment: 1500–5000 in.-lb. 6. Anatomical knee motion

[a] All components of the leg prosthesis must have sufficient strength to meet structural and durability requirements. Proper alignment is required to derive maximum benefit of the leg prosthesis. All components affecting alignment must be capable of adjustment during assembly. The socket or other method of attachment used must support the weight of the amputee comfortably and suspend the leg satisfactorily during the swing phase.

[b] The column "Knee" must be interpreted according to whether the prosthesis is for above or below knee. It applies almost in its entirety to very short below-knee stumps.

few days to determine if the fitting is satisfactory. To transfer to the permanent prosthesis the measurements thus determined by the adjustable leg, there has been designed a fixture which holds the elements of the prosthesis in position while they are being assembled with the predetermined alignment. With these two devices, which are now available commercially, fittings become quite exact. The ease with which minor adjustments can be made in the adjustable leg makes it possible to try variations in fitting which, previously, were avoided because of the time and expense involved. Moreover, the adjustable leg has the psychological advantage of demonstrating to the amputee that the fit of the device he is obtaining is the optimum for him.

METHODS OF SUSPENSION

A major factor involved in fitting of both above- and below-knee legs is the socket. On the first trip to Europe *(26)*, a number of exceptionally well-fitted suction sockets (page 29) were observed in Germany. This type of suspension had been tried previously in the United States *(16)* and in England with poor results. The successful cases seen in Germany

in 1946, however, prompted another trial of the technique in the United States. A thorough study of the shape of the socket and other features involved in fitting of suction sockets was undertaken at the University of California at Berkeley *(8,24)*. As a result of the successful conclusion of this work, the suction socket has since been widely applied by the United States limb industry and has been accepted by the Veterans Administration as an improved method of fitting prostheses for above-knee amputees where there are no contraindications. The knowledge gained in perfecting the technique of suction-socket fitting and in determining the optimum shape of the suction socket has contributed to improvement in the fitting of other sockets. Development work is now proceeding on suction sockets for below-knee amputees.

In addition to the work on suction sockets, a "soft" socket for below-knee amputees, consisting of a thin, resilient pad under a conventional leather or plastic socket lining in a plastic or wooden socket, has reached the testing stage at New York University.

SCHOOLS FOR PROSTHETISTS AND SURGEONS

Since the suction socket was as much a technique as a device, it was determined that, if the suction socket was to be as successful in general practice as it had been in the development period under the supervision of the University of California, the technique had to be taught to limbfitters throughout the United States. Accordingly, plans were laid for a series of schools to be held in various cities in the United States. A course of instruction was laid out, and under the auspices of the Veterans Administration, with the assistance of the Orthopedic Appliance and Limb Manufacturers Association, a series of schools was held throughout the country. The Veterans Administration, by requiring that fitters and surgeons have certificates from one of these schools before suction sockets could be provided beneficiaries, ensured that the best practices were provided. Establishment of these schools was an important advance, for it provided a mechanism for bringing to the commercial limb industry and medical profession the new techniques and ideas developed. Their success has led to expansion of the principles of the clinic-team approach for handling both upper- and lower-extremity cases.

In connection with the suction-socket schools, manuals were issued on how to fit suction sockets. They constituted the first attempt to present, in a manner that would be useful to the limbfitter, data developed in the program. Their success has led to the issuance of manuals on other subjects.

AMPUTATION SURGERY

In the early investigations, it became apparent that relative difficulty of fitting rather than surgical considerations often dictated the site of amputation. This circumstance led to a study of the sites of election and to a consideration of whether some changes might not be advisable. Studies have since clearly shown that the longer the stump the more function and control can be obtained—a matter that has not always been fully appreciated. In the above-knee amputee, the increased length of stump is particularly important, since it is one of the governing factors in obtaining stability of the prosthesis in abduction. In the above-knee amputation, it has also been found advantageous to tie the muscles together across the bottom of the stump or otherwise to attach muscles to the bone to aid in obtaining stability in abduction. These new concepts are leading to a revision of amputation practices. There will, no doubt, be other such advances in amputation surgery as more is learned about body mechanics.

PAIN STUDIES

Pain, both phantom and real, has always been a troublesome problem in amputee management. In order to obtain a clearer understanding of and possible solutions to the pain syndrome, a project was instituted at the University of California. Although practical applications of methods to alleviate pain and eliminate phantom pain have been meager to date, the mechanism of pain radiation has been elucidated, and the results *(9,25)* form the basis for future work in this field.

NEW DEVICES

One of the most important parts of the lower-extremity program is the development of new devices. Consequently, device development has been one of the major efforts. In the early stages of the program especially, there was an urgent demand from new Service-connected amputees for improved devices. At the time, the data from the basic studies at the University of California were not available. But because of the urgent demand, a program for invention and development of devices was undertaken simultaneously with the program for developing basic data. While most of these devices were unsuccessful, the time, money, and effort expended developing them were not entirely wasted. For in trying these devices, much needed information was developed, and the need for long-range research on several items of a basic nature was pointed out. As the data were collected at the University of California, devices were produced incorporating features which seemed desirable.

A great deal of effort was expended in attempting to perfect a knee lock for above-knee amputees. But most of these designs were abandoned for one reason or another after a few models had been made and tried on amputees. The particular difficulty in obtaining smooth and reliable action in a knee lock was found to reside in the method of control. In addition to knee locks, considerable effort has been expended on coordinated motion between the knee and ankle, toe pickup, transverse rotation in the leg, and control of the swing phase. Numerous devices incorporating such features have been made. Both mechanical and hydraulic devices, with varying degrees of complexity, have been tried.

Of all the knee locks tried to date, only two, the Stewart-Vickers (Fig. 3) and the Henschke-Mauch (Fig. 4), appear to have reached the

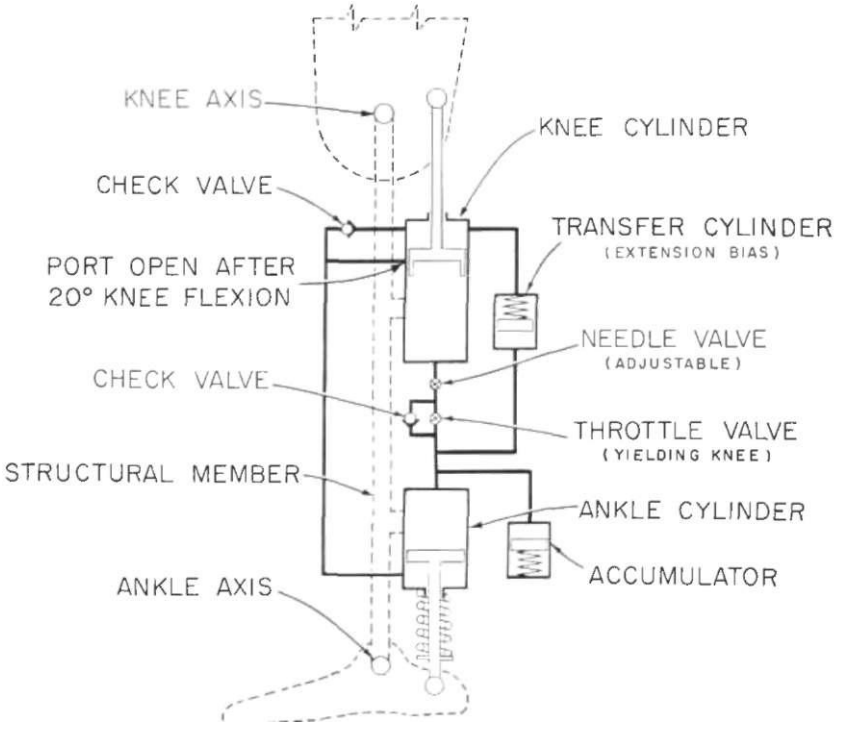

Fig. 3. Schematic diagram of the Stewart-Vickers hydraulic leg incorporating knee lock, swing-phase control, and coordinated motion between ankle, shank, and thigh.

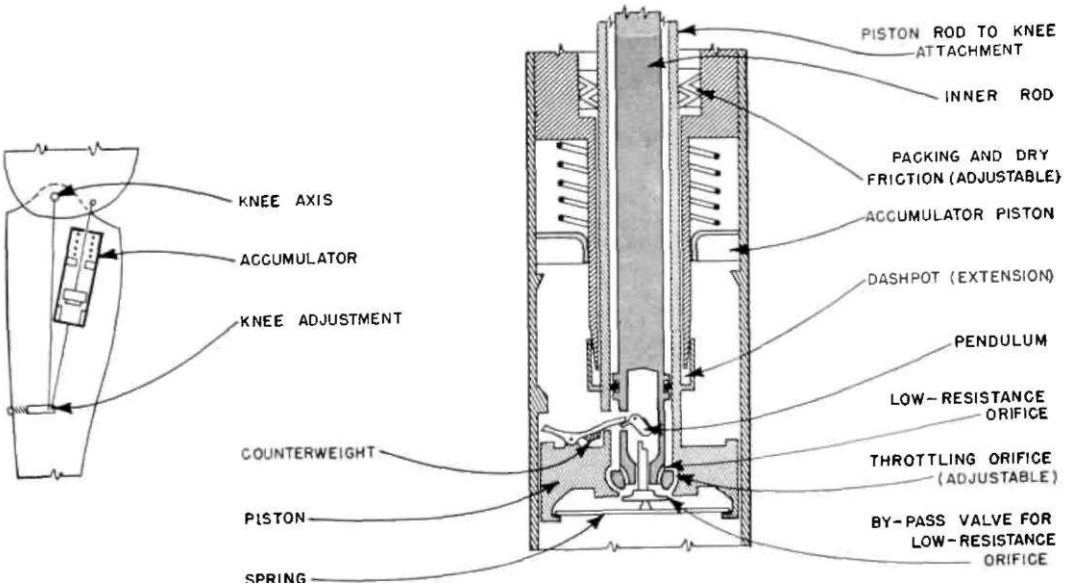

Fig. **4.** Schematic diagram of the Henschke-Mauch hydraulic leg incorporating knee lock and swing-phase control.

point of having commercial possibilities. More recently, however, there have been indications that proper swing-phase control, coupled with alignment stability or limited stability over the first few degrees of flexion, are all that the average above-knee amputee may need. The more or less elaborate knee locks might therefore be indicated for special cases, for older persons, or for those who prefer "the best" and can afford it. Both Stewart and Henschke-Mauch have swing-phase control devices incorporated in their designs, and both have under test legs in which only the swing phase is controlled.

Another lower-extremity device now under test is the University of California four-bar-linkage or polycentric knee (Fig. 5). The four-bar-linkage knee is not a new idea, but the UC version has been so designed that the toggle action existing in prior designs to provide extreme stability as the knee approaches full extension has been eliminated. Instead, it depends for its stability on alignment in fitting. It has the advantage, like many other four-bar linkages, of providing at the start of flexion a pivot point about 6 in. above the actual knee joint—a feature which provides a very favorable mechanical advantage for the amputee to start the leg to flex.

In the UC leg the swing phase is controlled by a radial-vane type of damping device in which hydraulic fluid passes from one side of the vane to the other through suitable needle valves. Hence this device is responsive to gait change and limits excessive heel rise as cadence is increased.

The limbshop at the U.S. Naval Hospital, Oakland, California, has developed and had accepted by ACAL a complete above-knee leg featuring a very simple mechanical device for controlling the swing phase in connection with a more or less conventional knee bolt (Fig. 6). This type of swing-phase control is not nearly so responsive to gait change as are the hydraulic units, but it marks a definite advance in the design of artificial knees. Also featured in the Navy leg are a plastic shank and the so-called "Navy functional ankle." The latter (Fig. 7) uses a rubber block with different degrees of hardness at front and rear to provide for plantar flexion and dorsifiexion and at the same time to permit some rotation about the vertical axis of the leg. It is anticipated that the Navy above-knee leg will be available commercially early this summer.

To summarize the work done on new devices for lower extremities, there is now available a large store of information on devices

which have been tried and found lacking in one respect or another. With what is now known about performance desired in above- and below-knee legs, it is possible that a review of past developments, coupled with some changes based on present knowledge, may lead to the development of more acceptable leg prostheses. At this time, however, only the Navy functional ankle and the swing-phase control have been accepted as completed devices. Others appear very close to acceptance.

TESTING AND EVALUATION

Throughout the early stages, the development of new devices in the lower-extremity program was retarded by the lack of techniques and organization for objective testing and evaluation. Until the data on the mechanics of walking had been developed, it was almost impossible to set up means for objective evaluation because no satisfactory standards of comparison were available. In addition to this lack of standards, it became apparent early in the program that some means had to be established for testing, under a controlled set of conditions, the devices which appeared ready for production. A testing laboratory at New York University was therefore set up. With its entry into the program, there was obtained a much better evaluation of the desirability of the devices proposed and a much better idea of their mechanical performance *(13)*. It was soon found that most of the devices submitted had minor mechanical shortcomings, and as a result many devices which two or three years ago appeared almost ready for release are only now approaching that point. The field-testing procedure has avoided premature release of several supposedly completed items and has indicated the need for more information on several basic points. It has thus proven to be a very valuable step in the development program, and the information gained in

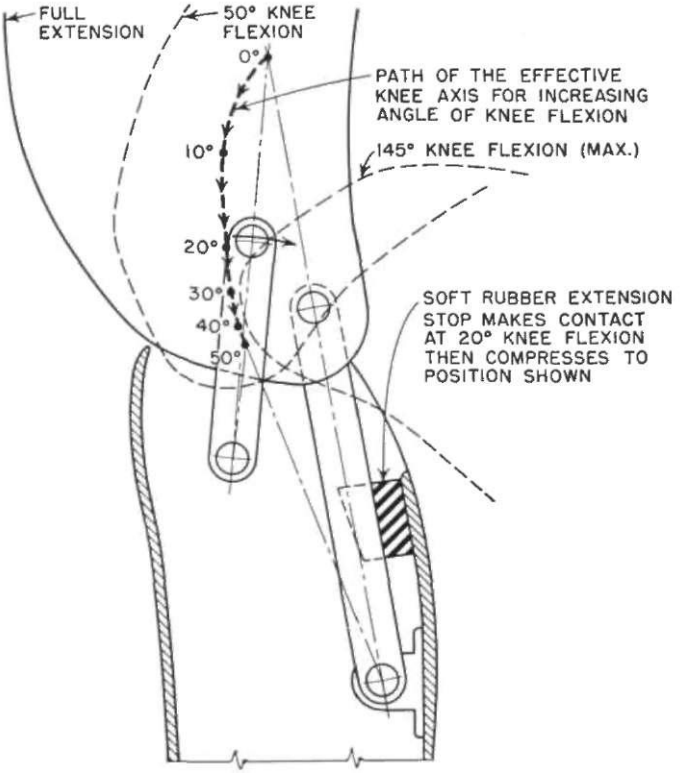

Fig. 5. Schematic diagram of the University of California four-bar-linkage (polycentric) knee showing change in center of rotation of shank as knee is flexed.

the field tests has fully justified the time and cost of field-testing.

CLINICAL PROGRAM

When the program for development of new devices had reached a certain stage, it became apparent that, if there could be instituted a clinical program to try devices on various amputees under as nearly identical conditions as possible, progress would be much more rapid. Information was also needed to confirm conclusions about the suitability of certain devices for various sites of amputations and for various physical and mental characteristics of the amputee and to determine new types of devices which might be needed under certain sets of conditions. Among others, such questions as the need for, or suitability of, a knee lock, or whether limited stability coupled with swing-phase control would be better, needed investigation and decision.

A clinical study was therefore set up under the direction of the University of California at the U.S. Naval Hospital, Oakland, with certain facilities provided by the Surgeon General of the Navy. It is expected that, by providing a complete staff of surgeons, prosthetists, physiotherapists, engineers, and research

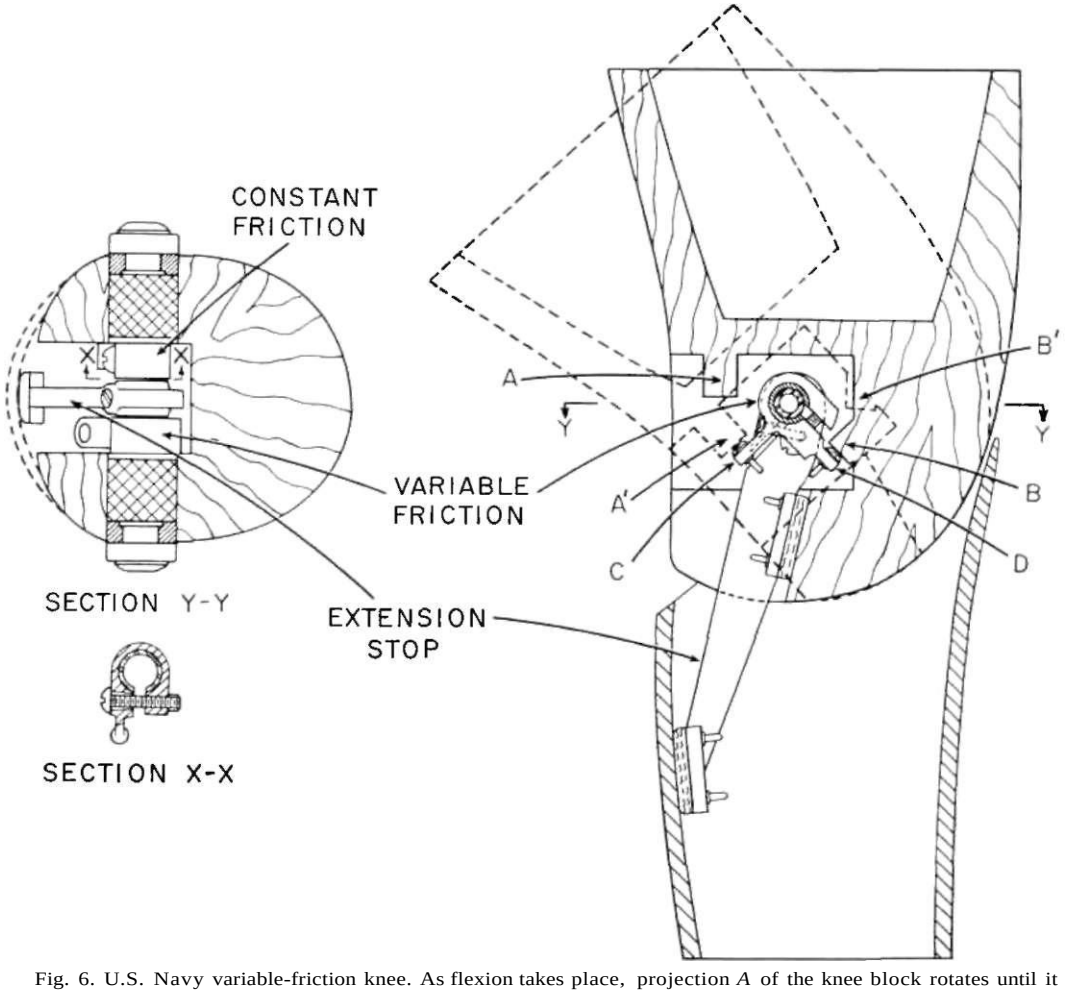

Fig. 6. U.S. Navy variable-friction knee. As flexion takes place, projection *A* of the knee block rotates until it contacts lever arm C, which induces additional friction about the knee bolt to limit heel rise. As extension occurs, projection *B'* rotates to contact lever arm *D*, which induces additional friction to decelerate the shank (terminal deceleration).

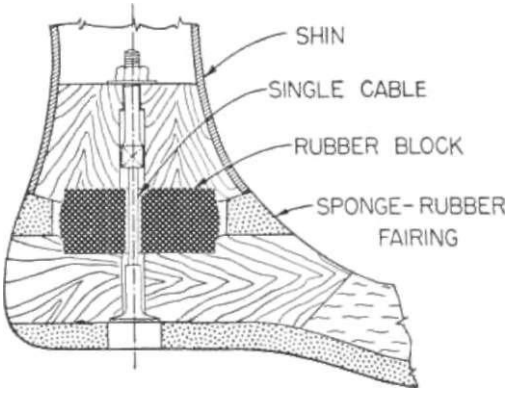

Fig. 7. U.S. Navy functional ankle. Single cable extends through rubber block of different degrees of stiffness at front and back.

workers, with the opportunity for controlled fitting and follow-up of patients, rapid progress will be made in improving fitting and alignment techniques, in surgical procedures, and in the development of improved devices.

DEVELOPMENT PROGRAM

Since the establishment of the lower-extremity clinic, a development group, staffed with people skilled in lower-extremity prosthetic art, including representatives from the industry, has been established. This group has headquarters at the U.S. Naval Hospital at Oakland, California, in close proximity to the clinic. It is expected that they will complete the development of some of the devices partially completed in the past and develop new devices, possibly combining or utilizing some of the ideas and data resulting from development work on these new devices. It is expected that this group will bring the program for new devices somewhere near its required level within the next two years.

CONCLUSION

Because the improvement of leg prostheses has required research and investigation in many fields, and because of the broad scope of much of the work, its full usefulness will not be realized until some time in the future. Time and study are required to analyze the data and to apply the results of such analyses. Nevertheless, the basic data developed under the ACAL program have already been useful, not only in the design of above- and below-knee prostheses but also in the design of leg braces, and they have proved extremely helpful in the diagnosis of pathological gait. Among the developments of more or less immediate practical applicability are the new techniques introduced for fitting and aligning above- and below-knee prostheses. Devices to facilitate adjustments in fitting so that optimum results can be attained quickly have been developed and introduced to the industry, as has also the equipment for transferring the dimensions determined for the prosthesis.

As a result of efforts of ACAL, the suction socket for the above-knee amputee has come into general use in the United States. In addition, the principles developed in the suction-socket program have helped to improve techniques used with other types of sockets, thus contributing generally to the well-being of the leg amputee. Experience gained in the suction-socket program has led either directly or indirectly to the development of the clinic-team concept which is proving so useful in the management of amputees of all types.

Certain changes in the surgical procedures of amputation have been suggested, especially in regard to the so-called "sites of election" and to stabilization of the above-knee stump in adduction. Study of the nature and propagation of pain in stumps has yielded results which should be the basis for future advances in treatment and prevention of pain arising from amputation.

Outgrowths of the lower-extremity clinical study may be expected to confirm, apply, and develop further the principles of fitting and alignment, to advance further the use of the suction socket, to improve the fitting of conventional above- and below-knee sockets and the "soft" socket for below-knee amputations, and to develop prostheses for other types of amputations. With the above-knee clinic established, the work in surgery, prescription, fitting, and training of the amputee is likely to advance even more rapidly than has been the case in the past.

The development of devices with increased function, reliable enough and with benefit enough to the amputee to justify the increased complexity and cost, has proven difficult.

Many devices have been built, tested, and found wanting in one detail or another mechanically or else have proven too costly to be practical at the present time. Although thus far only two devices, the Navy variable-friction knee and the Navy functional ankle, have been accepted by ACAL and made ready for distribution, several experimental ones appear to be almost ready for general use. The groundwork in the field of lower-extremity prosthetics has been laid. By 1956 we should see the appearance of many more, and more practical, accomplishments resulting from the preceding eight years of pioneering work.

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Mechanical Aids for Alignment of Lower-Extremity Prostheses

CHARLES W. RADCLIFFE, M.S.[1]

IF A prosthetic device is to give optimum service to the amputee, it must always be properly fitted, regardless of its mechanical excellence. This is especially true in the case of the lower extremity, where the prosthesis must function continually and where poor fit or alignment will lead quickly to rejection of the device by the wearer. Among prosthetists there seems to be general agreement that by far the most important factors in the success of any artificial leg relate to fit and alignment on the subject. Fit and alignment are usually considered together, since they are mutually interdependent.

Over the years many different mechanical devices to aid in fitting and alignment of lower-extremity prostheses have been developed to help in the application of one or another particular set of alignment principles in use by individual titters. Others of these devices are more general in application and are adaptable for use by any prosthetist regardless of the particular alignment principles he advocates. In every case, however, an attempt has been made to improve the fitting and alignment technique by adopting one definite set of principles and using a mechanical device to aid in the application of those principles.

HISTORICAL BACKGROUND

In 1919 Franz Schede *(2)* wrote *Theoretische Grundlagen fiir den Bau von Kunstbeinen,* a work generally considered to be one of the first important contributions in the field of prosthetic devices. In this volume Professor Schede established for the alignment of lower-extremity prostheses a set of principles based on application of known laws of mechanics. He was particularly concerned with alignment of the joints in a lower-extremity prosthesis so as to provide sufficient stability during the stance phase. As a result of the interest in his work, there was developed the so-called "plumb-line" method of alignment, a method which, essentially, assumes that the prosthesis carries weight along a vertical plumb line, the elements of the prosthesis then being arranged using this line as a reference. Still in general use throughout Europe and the United States, this system involves the problem of determining the location of the plumb line in the socket so that it can be extended down to the foot and used as a reference. For this purpose, many mechanical devices have been used.

THE PITTING STOOL

One of the oldest devices to aid in the fitting of lower-extremity sockets is the common fitting stool (Fig. 1). This device was well known as early as 1915 and is still in general use. When it is used to aid in establishing a "weight line," wedges are employed to tilt the socket block until the desired orientation is achieved. The hydraulic fitting stool of Habermann (Fig. 2)

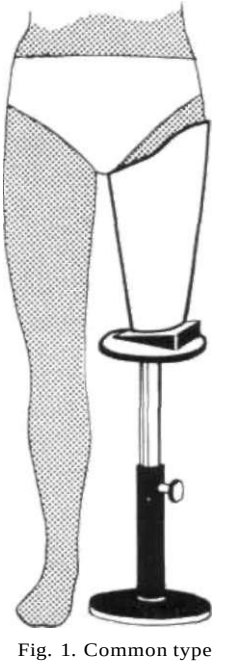

Fig. 1. Common type of fitting stool in use as early as 1915.

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is a recent refinement. It requires that the location of one point on the weight line be assumed, usually at the socket brim, and that the plumb line be drawn vertically downward from this point.

Pivot-Point Balancing Devices

In an attempt to eliminate the necessity for the assumption of one point on the weight line of the socket, various modifications of the standard fitting stool have been tried *(3,4).* Figure 3 is a schematic diagram of a titling stool which uses a fixed ball as the lower contact point. The point of contact of the ball locates one point on the plumb line, which is then extended upward through the socket.

In a further refinement of this technique, introduced into this country in 1947, the plumb line is located at the intersection of two vertical planes (Fig. 4). The lower edge of each plane is determined by use of a triangular block giving a line contact along the bottom of the socket. *4*

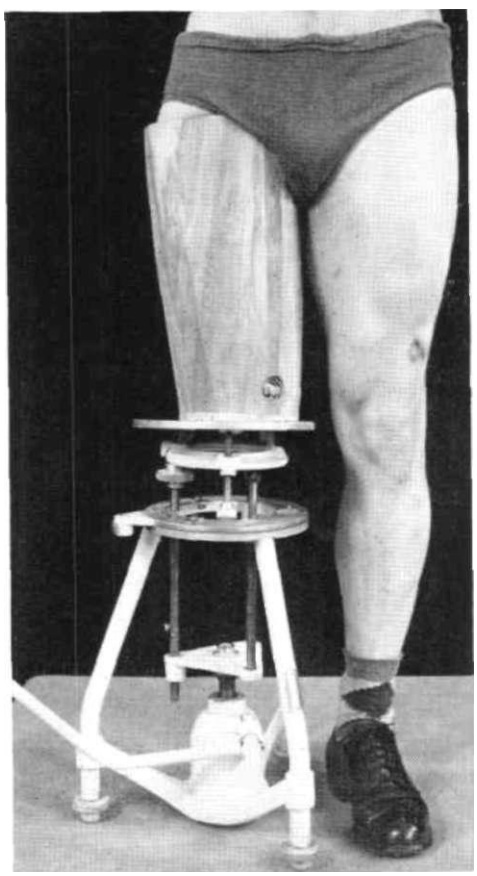

Fig. 2. Modern titling stool w ith hydraulic height adjustment. Manufactured in Germany by Habermann.

Another pivot-point balancing device (Fig. 5) locates a similar point near the top of the socket block by supporting the socket in a clamp which pivots aboul a fore-and-aft axis and allows the pivot point to be moved medially or laterally as desired. Weight is transmitted to the floor through a connecting pylon.

Vise-Type Fitting Stand

Another school of thought in the alignment of the above-knee socket believes that establishment of a plumb line is not as important as is establishment of the proper inclination of the socket in space. In the vise-type fitting stand (Fig. 6) of Habermann (/), the socket can be adjusted in inclination to any position desired. ()nce the proper inclination and height have been established, the socket is clamped rigidly in space, and the amputee "marks time" in the socket. If necessary, changes are made until the amputee is able to bear weight comfortably and to use his stump efficiently in the control of body movements. After an arbitrary plumb line has been assumed, the optimum socket orientation is incorporated into the final prosthesis.

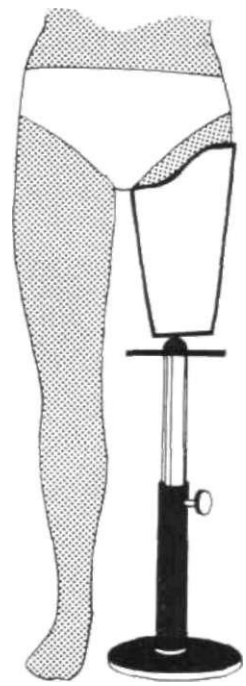

Fig. 3 Point-balance fitting stool with a fixed ball as the supporting point

All of these mechanical aids have helped in the so-called "static alignment" of the prosthesis, a condition which determines the stability of the artificial limb in the stance phase. The "dynamic" factors, which affect the swing phase of the prosthesis, and which account for the differences between the static

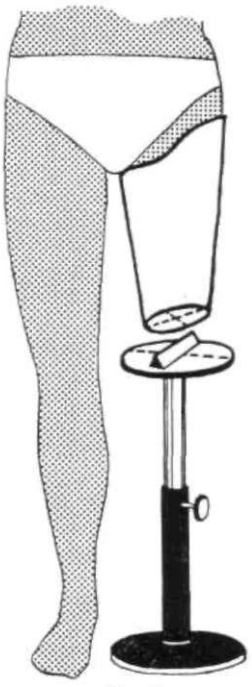

Fig. 4

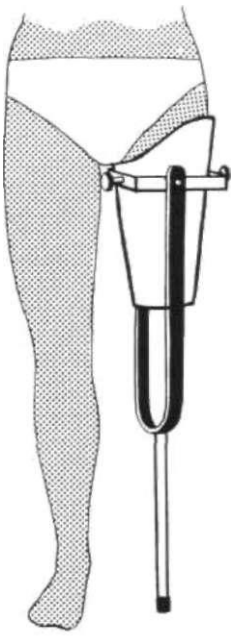

Fig. 5

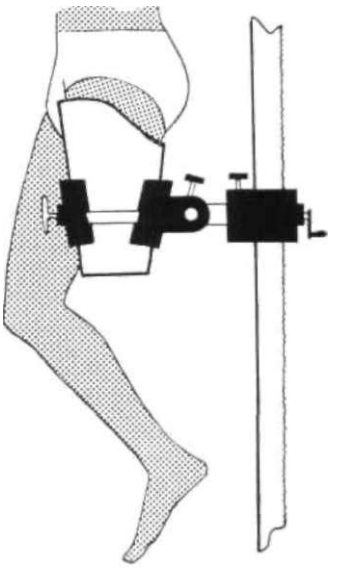

Fig. 6

Fig. 4. Line-balance fitting stool with triangular block as a support.

Fig. 5. Pylon-type fitting stand with support at a point near the top brim of the socket.

Fig. 6. Vise-type fitting stand.

and dynamic conditions in the stance phase, are adjusted as necessary after the amputee is walking on the rough leg.

SCHNEIDER'S "GEHMASCHINE"

Hans Schneider *(6)* of Nuremberg, Germany, has long advocated the use of an adjustable leg or "walking machine." Essentially, his method is to allow the amputee to walk on a trial prosthesis (Fig. 7), changes being made empirically until the alignment is considered satisfactory. Then, as the optimum alignment is being duplicated in the final prosthesis, various measurements are read from the adjustable leg and a measuring stand (Fig. 8). It is claimed that from these measurements the fit and alignment can be duplicated in additional prostheses ordered later.

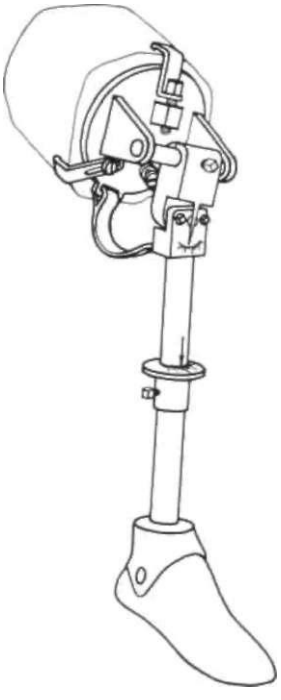

Fig. 7. Schneider's "Gehmaschine."

THE UNIVERSITY OF CALIFORNIA ABOVE-KNEE ADJUSTABLE LEG

A study of methods for alignment of the above-knee suction-socket prosthesis was started at the University of California, Prosthetic Devices Research Project, in the autumn of 1946. As one of the first phases of investigation, two adjustable prostheses were designed and constructed. These experimental devices (Figs. 9 and 10) allowed adjustment of a large number of variables, and data were collected having to do with the effect of a change in one of the many alignment variables upon the behavior of the prosthesis (5). It soon became apparent that devices of this nature were not only useful as research instruments but that they might also have some practical use as limbshop tools. Accordingly, there was designed and constructed for limbshop purposes a series of models of a simplified device incorporating only those adjustments found most important, as determined using the research devices.

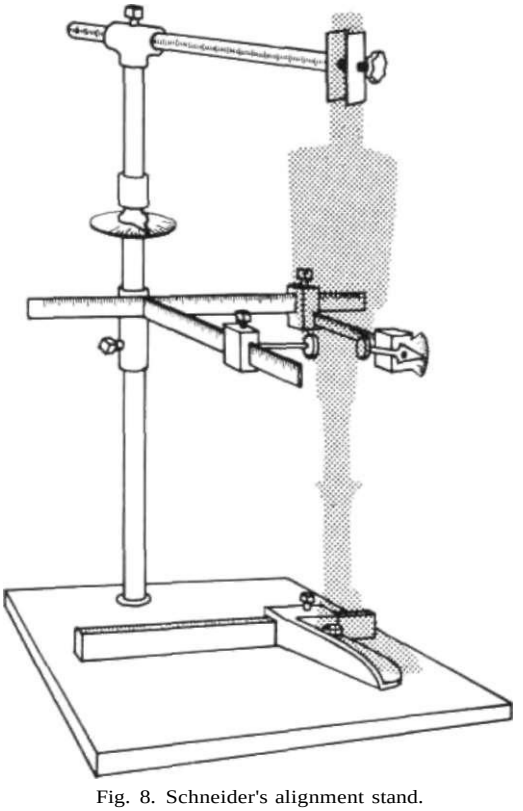

Fig. 8. Schneider's alignment stand.

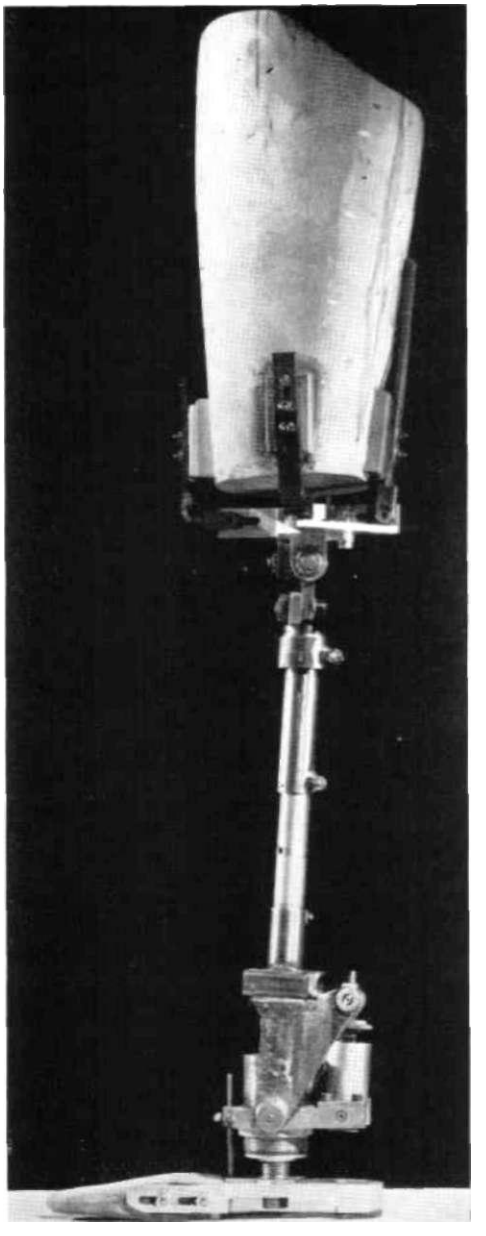

Fig. 9. Experimental adjustable above-knee leg used for research at the University of California.

The initial effort was to develop a device for alignment of the above-knee suction-socket

prosthesis. Out of (his work came the above-knee adjustable leg shown in Figure 11. Several units of this design were used in the experimental program at the University of California and were given shop trials in the San Francisco Bay Area. They were found very useful in the alignment of above-knee prostheses in the shops and, in addition, were widely used for demonstration of alignment principles. But use of the above-knee adjustable leg was then limited because of the difficulty in transferring the optimum relationships from the adjustable trial prosthesis lo the final setup.

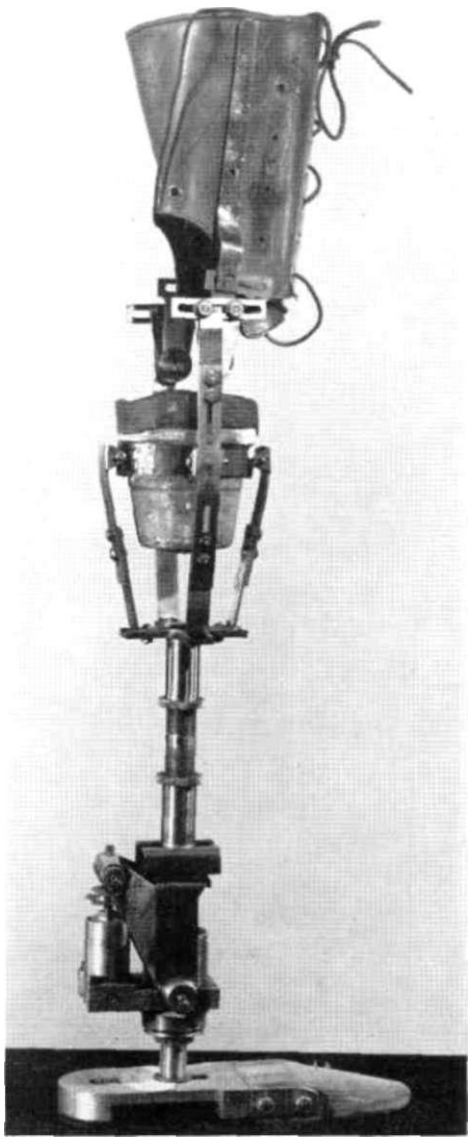

Fig. 10. Experimental adjustable below-knee leg (University of California).

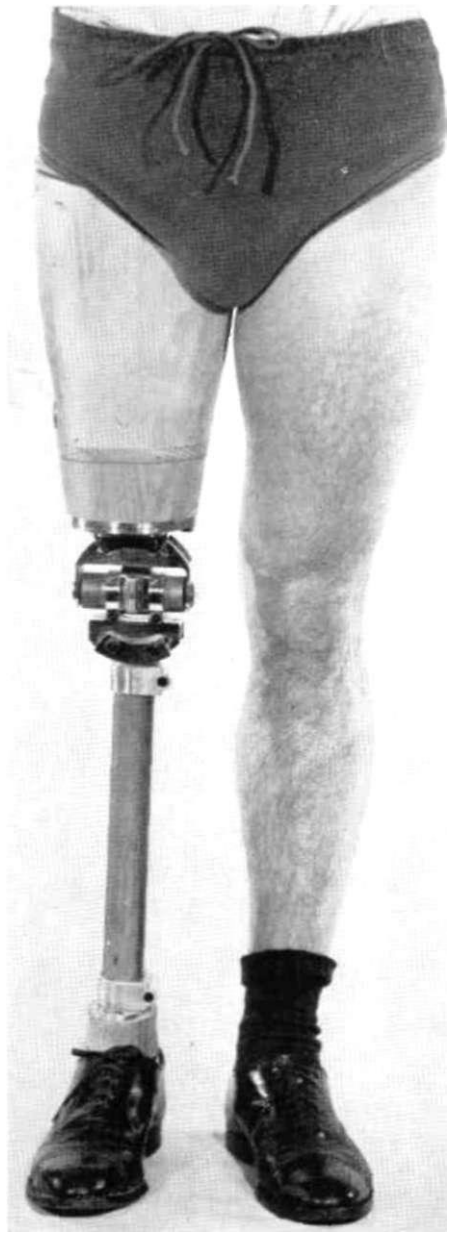

Fig. 11. The UC adjustable leg.

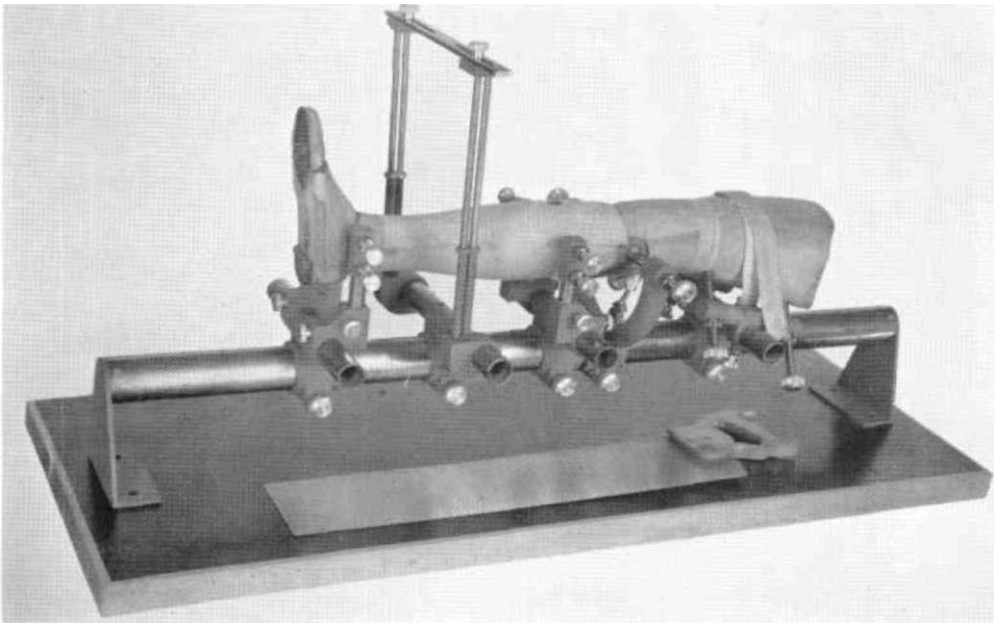

Fig. 12. The alignment duplication jig.

THE UC ALIGNMENT DUPLICATION JIG

To fill this need, the designers produced the Alignment Duplication Jig (Fig. 12), which is essentially a rather specialized set of clamps and an associated saw guide to maintain the socket, knee axis, ankle axis, and foot in a fixed position, thus permitting the temporary adjustable knee to be removed and replaced with wood, plastic, or metal structural members and joints. Three models of the alignment duplication jig were constructed and loaned, along with models of the above-knee adjustable leg, to the representatives of the Orthopedic Appliance and Limb Manufacturers Association who were then serving as the Technical Advisory Committee to the Lower-Extremity Technical Committee of ACAL. The representatives of the limb industry were unanimous in their conclusion that use of these devices offered considerable advantage to the prosthetist for alignment of all above-knee suction-socket prostheses.

On the basis of the experience gained, the above-knee adjustable leg was redesigned, as shown in Figure 13, and drawings for both the adjustable leg and the duplication jig were made available to the artificial-limb industry. Devices similar to those shown in Figures 12 and 13 are now being manufactured[2] and can be purchased by limbshops.

THE UC COMBINATION ADJUSTABLE LEG

Because of the acceptance of the above-knee adjustable leg during its trial period of limbshop use, the Technical Advisory Committee of OALMA recommended that a similar unit be developed for alignment of below-knee prostheses. As a result, the combination above-knee/below-knee adjustable leg (Fig. 14) was designed and constructed at the University of California. Its use as a below-knee alignment device is indicated in Figure 15. The principal advantage of this unit over previous designs is that no tools are required in making adjustments.

USE OF THE ADJUSTABLE LEG AND ALIGNMENT DUPLICATION JIG

The basic difference in the use of the University of California alignment devices, as compared with Schneider's apparatus, lies in the manner of duplication of the optimum

[2] By the Plastic Fibre Limb Company, Minneapolis, Minnesota.

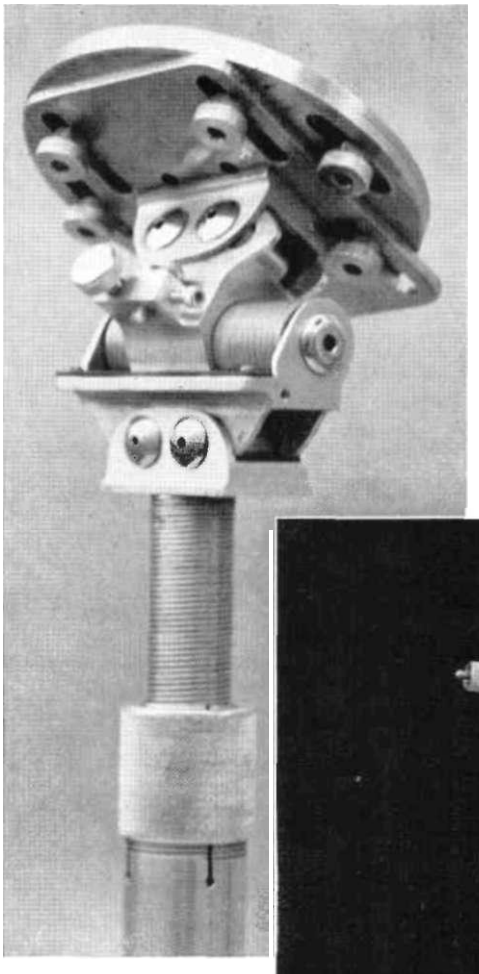

Fig. **13.** Revised design of the adjustable leg as released to the artificial-limb indust rv.

alignment. The adjustable leg is used in much the same manner as is Schneider's device. A set of guiding principles for filling and alignment has been established, and the adjustable leg is used as a means of applying these principles to the conditions existing with a particular amputee. But the devices serve as shop tools only, and any set of priniciples can be applied by the prosthetist.

In the use of the alignment duplication jig, the jassumption is made that the optimum alignment will be influenced considerably by the fit of the socket. Since subsequent sockets for a particular amputee are not apt lo be exactly alike, it is considered unnecessary to try to duplicate in all later prostheses the alignment of the first. Each socket is considered as a separate alignment prob-

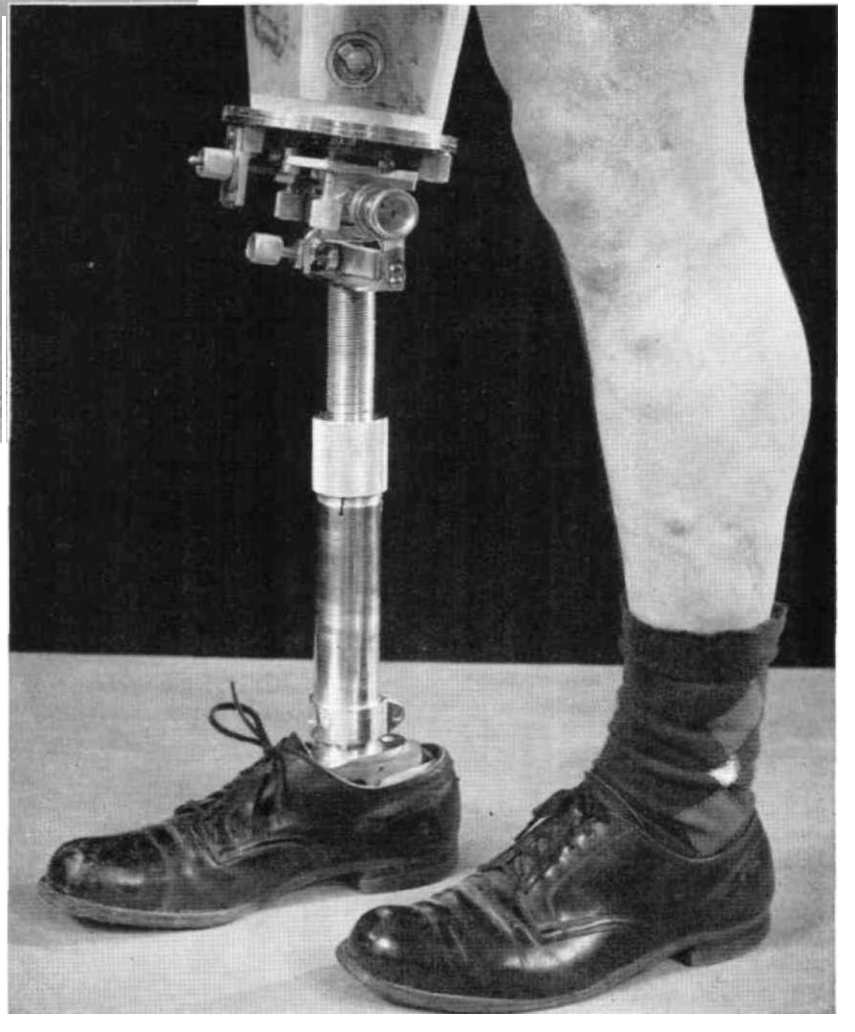

Fig. **14.** Combination above-knee/below-knee adjustable leg in use as a trial above-knee prosthesis

lem, and the alignment duplication jig helps in the construction of the final prosthesis rather than as a measuring instrument.

In the prior art of lower-extremity limb-fitting, there has naturally been the tendency to stop making adjustments as soon as the prosthesis is just "good enough," especially so when a further change would mean breaking a glued connection or resetting a joint. The principal advantage of the UC alignment equipment is that, since all adjustments in the trial prosthesis are easily and quickly made, the prosthetist can make very small changes until both he and the amputee are satisfied that the best job has been done. The alignment of a leg prosthesis is especially critical in the swing phase and during the periods of transition from stance to swing. Very small changes in alignment can have very noticeable effects upon the performance of the prosthesis at these times. Since small adjustments can be made accurately using the adjustable leg, the prosthetist is able to obtain optimum performance where that is difficult, if not impossible, to achieve by trial-and-error methods. Besides this, the adjustable leg has found considerable use as an educational aid in teaching prosthetists the fundamentals of

Fig. 15. Combination above-knee/below-knee adjustable leg in use as a trial below-knee prosthesis.

limb **alignment in suction-socket schools and in demonstration of alignment principles before groups of orthopedic surgeons, physical therapists, and others.**

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Status of the Above-Knee Suction Socket in the United States

CHESTER C. HADDAN[1] AND ATHA THOMAS, M.D.[2]

1 HE above-knee suction socket constitutes a means of attaching an artificial leg to the stump of an amputee without necessity for the conventional pelvic band, a metal hip joint, or other types of suspension harness (Fig. 1). The leg is held on by the slight vacuum created in the socket each time the leg is lifted from the ground, the pressure usually being controlled by a valve installed in the lower portion of the socket. Accurate functional fit of the socket, as distinguished from the conventional "plug" fit, permits the creation of negative pressure, gives a wider range of muscular control of the leg, and provides comfort while walking or sitting. Because the conventional belt and hinge joint are eliminated, the suction socket gives the above-knee amputee more freedom and less interference with clothing. The leg feels more like an integral part of the body, a feature which tends to decrease the sensation of dead weight and to improve sense of position. Reduced piston action of the stump in the socket results in greater toe clearance during walking. No stump sock is necessary. Any adductor roll is corrected. And finally, active use of the stump muscles causes them to develop instead of becoming atrophied.[3]

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[2] Professor of Orthopedic Surgery, University of Colorado School of Medicine, Denver; member, Lower-Extremity Technical Committee, ACAL, NRC.

[3] For a complete discussion of the prescription, fabrication, fitting, alignment, and use of the above-knee suction-socket prosthesis, reference may be had to Bechtol (J), to Eberhart and McKennon (5), and to the so-called "suclion-socket brochure" of the University of California ***(19).***

EARLY HISTORY

The earliest known reference to the suction socket is in the form of a patent issued by the United States, February 10, 1863, to Dubois D. Parmelee *(12)* of New York City. Subsequent patents have been issued to George Beacock and Terence Sparham *(2)* of Brockville, Ontario, Canada, in 1885; to Justin K. Toles *(16)* of Stockton, California, in 1911; and to Ernest Walter Underwood *(17)* of Birmingham, England, in 1926. The fundamental principles of the Beacock and Sparham suction socket differed but little from those of the Parmelee method. Toles' description was basically the same but with the addition of a rubber tube and bag lining which could be inflated by air to assist in holding the socket on. The socket described by Under-

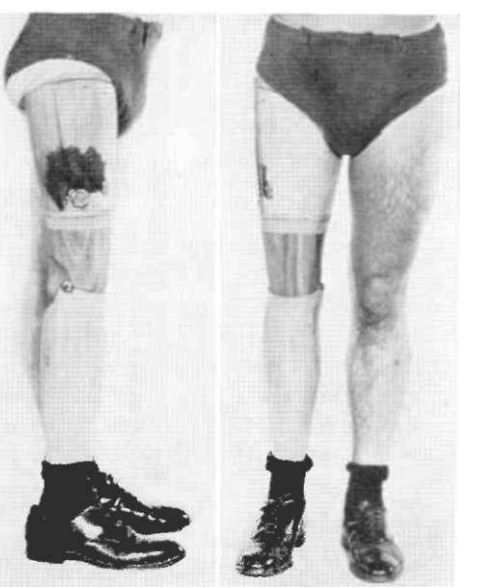


Fig. 1. Typical above-knee suction-socket leg before application of the usual rawhide finish.

wood had smooth helical grooves, which he claimed ventilated the stump as well as assisted in holding the socket in place.

A search of the literature on above-knee suction sockets has revealed only a few articles prior to the last few years. In 1925 Muirhead Little *(9)* of England reported favorably on 11 amputees fitted with the suction socket after the design of Blatchford *(9),* made of metal, and containing a smooth helical groove of a little more than one turn around the circumference of the socket. Some 30 cases were reported as fitted at Roehampton, England, following World War I using a metal socket with a helical groove as described by Blatchford *(9).* It is not known whether these 30 cases included the 11 reported by Muirhead Little, but it is considered doubtful since during this period several different groups were using the suction socket in England. Use of the suction socket has been practically dormant in England since that time, although it has been revived in recent years.

Pfau *(13)* of Berlin says the suction socket has been known in Germany for 30 years but that it was not popularized until Oesterle, in Ulm, started his work in the early '30s. Felix *(6),* a surgeon of Diisseldorf, reported on above-knee sockets in 1941. He stated that the suction socket had been used in Germany to some extent since World War I but that it was not popularized until a satisfactory suction-socket valve had been developed in 1932. After this accomplishment, numerous selected cases were successfully fitted in Germany.

As a result of the apparent reported success with artificial limbs in Germany, early in 1946 the Surgeon General of the United States Army sent to Europe a "Commission on Amputations and Prostheses" to observe foreign practice. One principal item of interest was the successful use in Germany of suction sockets for above-knee prostheses. Because of the favorable report *(21)* issued by the commission, the Advisory Committee on Artificial Limbs instituted, as one activity of its general plan of providing information on the best possible prostheses, a program to determine the possibilities and limitations of the suction-socket type of suspension for the above-knee leg.

CLINICAL RESEARCH IN THE UNITED STATES

After extensive trials and studies in their own laboratory, workers at the University of California, Berkeley, prepared instructional material and started a nation-wide program to determine the feasibility of use of the above-knee suction-socket technique under field conditions in the United States. By September 1947, 52 subjects had been fitted in 10 widely separated localities by local prosthetists in their own shops with materials and devices normally employed but making use of supplementary information and supervision by University personnel.

The success of this program led the Advisory Committee on Artificial Limbs, in October 1947, to recommend to the Veterans Administration the use of the suction-socket technique for above-knee amputees, its use being limited for the time being to further field tests within the VA under the direction of qualified surgeons. The recommendation was accepted and, from December 1947 through January 1949, 20 schools, each of one week duration, were held throughout the country to provide 250 orthopedic surgeons and 200 prosthetists with sufficient knowledge of the fabrication and application of the suction socket to introduce it on an experimental basis.

By October 1949 comprehensive records had been made of over 500 cases, and ACAL felt that sufficient experience had been gained in the use of the suction socket to warrant its general application. Accordingly, a recommendation was made to the Veterans Administration, and the above-knee suction socket has since been in use routinely. The Orthopedic Appliance and Limb Manufacturers Association and the Veterans Administration, in a cooperative effort, have sponsored suction-socket schools from time to time to permit surgeons and limbfitters to gain sufficient knowledge in this field to qualify them to prescribe and fit the suction socket.

SURVEYS or AMPUTEE ACCEPTANCE

The enthusiasm with which the suction-socket above-knee leg has been accepted in the United States is indicated by the results of a number of surveys. Among them are the surveys of selected groups made by Thorndike

and Eberhart *(15)*, by Mazet, McMaster, and Flutter *(10)*, and by Canty and Asbelle *(4)*. Results of three surveys, two by the Orthopedic Appliance and Limb Manufacturers Association, are shown in Table 1. The earliest data are from a University of California report *(18)* of April 1948. The 52 cases reported at that time had been carefully screened, selected, and fitted under the supervision of representatives of the Advisory Committee on Artificial Limbs. The results were carefully recorded. At the termination of this initial experimental program on April 15, 1948, of the 52 subjects fitted, 40 had been wearing their suction-socket legs routinely for 4 to 20 months. All were satisfied and had no intention of returning to the type of prosthesis worn previously. Six of the subjects, owing to improper fittings, nervous disorders, or lack of cooperation, were still alternating between the suction-socket leg and their previous legs. Six had been dropped from the program and were considered as failures.

In February 1949, the Orthopedic Appliance and Limb Manufacturers Association, in an effort to determine the extent of acceptance of the suction-socket leg in the United States, mailed questionnaires to approximately 200 limbshops. Of these, 159 shops reported. Eighty of those reporting had made no suction sockets at all; 79 shops had at that time fitted 1262 men, women, and children, with an amazingly small number of complete failures. A comparatively small group of 46 were converted to pelvic-belt-controlled legs, but many of these continued to use the suction-socket shape and some the suction valve, thus retaining many of the advantages of the suction-socket leg. The 1954 survey, also conducted by OALMA, with 72 firms reporting on 5882 cases, indicates similar conclusions. The 1954 OALMA questionnaire includes those firms reporting as few as three cases fitted and those reporting as many as 500 cases or more.

Table 1

AMPUTEE ACCEPTANCE OF THE ABOVE-KNEE SUCTION SOCKET

Year	1948[a]	1949[b]	1954[c]
Limbshops reporting	10	79	72
Total cases fitted	52	1262	5882
Men	52	1047	4616
Women	—	170	912
Children	—	45	354
Gritti-Stokes	—	112	250
Fitted with auxiliary supports	—	149	1539
Converted to conventional prosthesis	—	46	461
Complete failures	6 (11.5%)	56 (4.4%)	301 (5.1%)

[a] Data from the University of California (*18*).
[b] Data from OALMA's national survey on suction sockets, 1949; reported in *The OALMA Journal* (*11*).
[c] Data from OALMA's 1954 national survey on suction sockets.

Many of the limbshops reporting in both the 1949 and the 1954 OALMA questionnaires indicate that they have adopted the suction-socket method of fitting (that is, ischial bearing) as standard practice even though the amputee cannot actually wear the suction socket as such. Auxiliary supports, such as the Silesian bandage (Fig. 2), are used almost routinely by some limbshops. One of the most widely known and reputable shops in the United States reports the use of auxiliary supports on 300 out of 322 cases fitted. Another reports auxiliary supports applied in 300 out of 373 cases fitted. Another highly successful shop, in fitting 181 cases (of which 91 were children), used auxiliary supports on 90 cases. It is interesting to note that the firms reporting the largest number of cases also report the largest percentage of cases fitted with auxiliary supports.

The surveys indicate that over 96 percent of all suction sockets fitted since the introduction of the program were fitted to stumps over 3 in. long. In the one shop that reported 90 children fitted, not a single one was fitted with a stump shorter than 3 in. It is to be noted that most of those fitted with the stump shorter than 3 in. were women; and some reported that, although they did not believe the fitting of a stump shorter than 3 in. to be practical, they were almost forced at least to attempt it because of pregnancy, a condition which precludes wearing the conventional pelvic belt.

It may therefore be assumed that, except in very rare instances, generally it is impractical to prescribe the suction socket for stumps less than 3 in. long. A further observation is that of the large number of apparently quite successful cases of Gritti-Stokes amputations fitted, no failures whatever being reported in the case of amputation at this level.

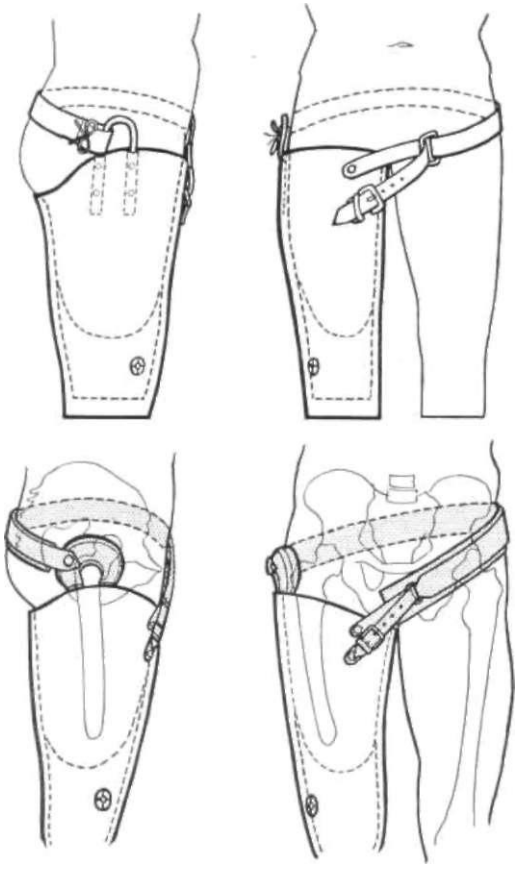


Fig. 2. Two forms of the Silesian bandage commonly used as an auxiliary support for the suction-socket leg, both in the United States and in Europe, particularly in Germany, where, according to Pfau, Hepp, and others ***(13),*** it is used almost routinely.

Another interesting feature brought out is that, while in 13 percent of the cases reported edema was present in the early stages of fitting, in only two cases did the edema persist and become a contributing cause of failure of the suction-socket leg. It is obvious from these data that, while edema may be common, it need not be considered a serious problem.

An effort was made to determine the number of bilateral above-knee amputees fitted successfully with suction sockets, but reliable data were not obtained on this question. From the information received in the survey, however, it is believed that the number will probably be about 100, the percentage of failures being approximately the same as in the case of unilaterals.

The overwhelming reason given for failure in the use of the suction socket comes under personality factors. An effort has been made in the surveys to obtain reliable data as to the definite reasons for failure. Personality factors are found to be predominant, with physical factors next in line, the condition of the stump third, and social and economic considerations fourth in importance. Thus tabulated, the causes of failure look about like this:

1. *Personality Factors*
- Unfavorable temperament
- Poor cooperation
- Inability to adjust
- Discouragement
- Lack of interest
- Low order of intelligence
- Insecurity

2. General Physical Factors
- Skin trouble
- Age
- Change in weight
- Circulatory difficulties
- Inability to bear weight on ischium
- Buerger's disease
- Ovenveight
- Perspiration
- Allergy
- General weakness
- Loose abduction
- Unsocial noises

3. *Slump Characteristics*
- Inadequate length
- Bone spurs
- Interfering scars
- Undue length

4. *Social and Economic Considerations*
- Insufficient time for proper fitting
- Excessive distance from shop
- Undue sales influence
- Employer disapproval
- Occupational requirement

Another question asked the reporting firms was: "What percentage of above-knee amputees could, in your opinion, be fitted with a suction socket?". While the answers to this question range from a low of 30 percent of all amputees to as high as 100 percent, the average is 73 percent, a figure thought, in the opinion of the authors, to represent a realistic approach.

Another question, asked because of the unusual amount of interest in children and the older age group on the part of the Committee on Artificial Limbs, was: "Is the socket suitable for amputees under five and over

seventy?". Almost without exception the suction socket was said not to be suitable for the very young or the very old.

Again, the question was asked: "When is the suction socket a practical approach to prosthetic fitting?". The following list of conditions, in the order of frequency with which they were mentioned, indicates the thinking prevalent among the reporting firms on this particular question:

Right personality factors and willingness to cooperate
Healthy, unscarred stump over 3 in. long
Under 65 years of age
New amputees not conditioned to suspenders or pelvic control
Easy access to facility
Good muscular reaction
Patient's enthusiasm
Good circulation
Good balance and coordination
Available training and therapy
Reasonable occupational demands

FACTORS IN SUCTION-SOCKET TECHNIQUE

Accumulated experience with fitting the suction-socket above-knee prosthesis over a period of seven years has clearly demonstrated its many advantages and its desirability over the conventional belt- or shoulder-suspended leg. On the other hand, the experience of the authors during the same period has convinced them that the suction socket is not suited for all above-knee amputees. This belief has been confirmed further by reports of survey studies previously conducted by others and by the results of the surveys reported here. In our opinion, there is considerable question as to the validity of the statement made by some to the effect that the suction socket can be used profitably by any thigh amputee who can wear the conventional type of prosthesis successfully. Experience has shown that there are certain amputees who cannot wear a suction-socket prosthesis successfully. If failures are to be avoided, all cases should be studied and screened carefully before a suction socket is prescribed.

The factors to be considered are divided roughly into two groups, each often affecting the other—those relating to characteristics of the prosthesis itself, and those relating to the characteristics of the amputee. Chief among the mechanical considerations of the leg are alignment and socket shape. Factors relating to the amputee are the general physical and mental condition, the condition of the stump, and the condition of the opposite extremity.

FACTORS RELATING TO THE ARTIFICIAL LEG

Alignment

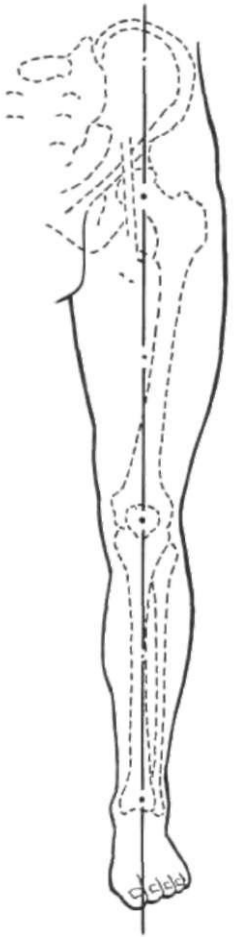
With the suction-socket leg, which is controlled entirely by the stump muscles, alignment becomes much more critical than in the case of the pelvic-band suspension and therefore must be correct for proper control and comfort. If alignment is incorrect, there is a definite whip or rotation of the prosthesis during the swing phase. The problem of alignment has not yet been solved completely, and opinions differ a little as to what constitutes the ideal alignment of the prosthesis. Theoretically, it is desirable to incorporate as much adduction of the stump within the socket as is possible mechanically, since to do so tends to suppress body sway and to place the iliotibial band (or that portion of it which may remain intact) under tension.

In the normal, the centers of hip, knee, and ankle joints coincide in the frontal plane with the mechanical axis of the lower extremity as a whole (Fig. 3). After amputation through the femur and fitting with a prosthesis, however, the body weight is no longer borne through the center of the hip joint but on the ischial tuberosity, which lies medial to the center of the hip joint. This would indicate, then, that the mechanical axis of the well-aligned above-knee prosthesis would more nearly coincide with a vertical line extending from the ischial tuberosity through the centers of the knee and ankle joints (Figs. 4 and 5).

In the sagittal plane, the weight line in the normal person is a vertical line drawn through the centers of the shoulder, hip, knee, and ankle joints (Fig. 6, left). After amputation and fitting of a prosthesis, however, this vertical weight line must be shifted forward in order to obtain alignment stability (Fig. 7).

If the amputee is young and agile, with no stump deformities and with strong and well-developed muscles in the back of the stump, the dimension *b* in Figure 7 may be reduced to zero. On the other hand, in the presence of flexion contracture in the stump, or weak

musculature, this dimension may have to be increased to give sufficient stability. But to do so may result in the sacrifice of a normal gait and cause a tiring and awkward one. Similarly, postural abnormalities (Fig. 6, center and right) can make proper alignment very difficult to achieve.



Fig, 3. Normal alignment in the frontal plane, showing how centers of hip, knee, and ankle joints coincide with the mechanical axis of the lower extremity as a whole. From Thomas and Haddan ***(14).***

Such deviations in the weight line have upon postural stability and body alignment a biomechanical effect that is obvious. To complicate matters further, the amputee is deprived of a number of those sensory cues upon which every normal human being depends for the autonomous control of posture and motion. These include touch and pressure sensations from the soles of the feet and the never-ending bombardment of proprioceptive impulses that emanate from sensory receptors in the muscles, tendons, and joints of the weight-bearing limbs and sweep upward to the cerebellum. In the aggregate, these physiological and biomechanical deviations from normal appear formidible. Yet with proper fitting and alignment of his prosthesis, and with adequate training in the proper gait and posture, the average amputee can compensate for them to an amazing degree.

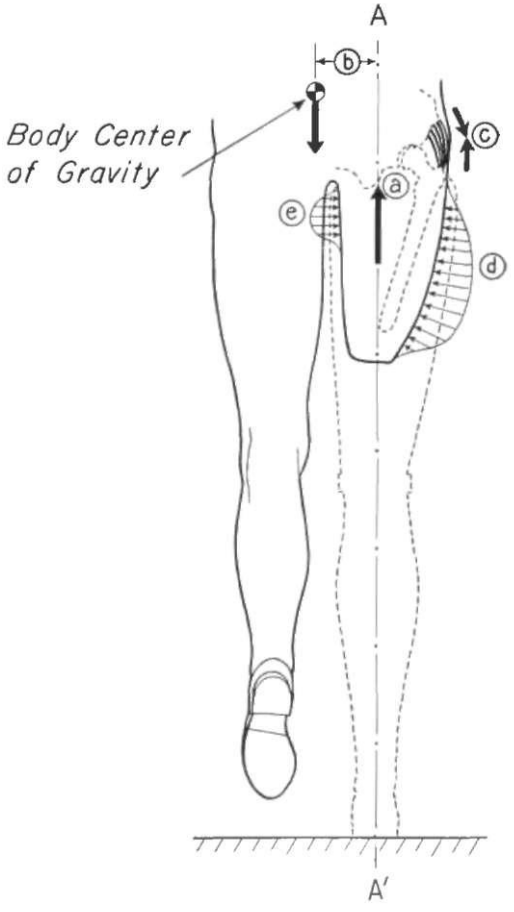


Fig. 4. Forces acting on the stump and pelvis of an above-knee amputee during the stance phase. In the well-aligned prosthesis, the heel of the foot and the center of the knee should fall approximately on a vertical line (A-A') through the point of contact of the ischium (a). The tendency of the pelvis to rotate downward on the normal side owing to the body weight can be reduced by keeping the dimension **(6)** as small as possible. This is accomplished by an upward force through the ischium (a). Lateral rotation of the pelvis and sidesway in the shoulders and torso can both be minimized if the force in the abductor muscles (c) is sufficient to balance the body weight by lever action about the ischial seat *(a).* The stump must be anchored firmly and comfortably by pressure along the entire lateral side *(d).* Failure to do this results in discomfort at the crotch (e). From Haddan («).

Socket Shape

Exactly what constitutes the most successful socket shape has not yet been fully determined owing to the many variables involved in the use of this technique. Several successful designs have been fully described in the literature *(3,5,18,19).* In these designs, weight-bearing occurs chiefly about the top posterior portion

of the socket, particularly in the region of the ischial tuberosity, with a lesser amount on the gluteal muscle. The addition of a well-defined ischial seat reduces piston action of the stump in the socket to a minimum and allows for a looser fit at the top of the socket. Incorrect shape, size, or location of the ischial seat leads to definite discomfort and frequent loss of suction, particularly when the wearer is sitting. In some very muscular stumps, the ischial seat may be reduced in size and in some cases removed entirely. Such amputees bear weight on their well-developed muscles, with the load distributed around the top portion of the socket. The socket is shaped the same except for the reduction or removal of the ischial seat.

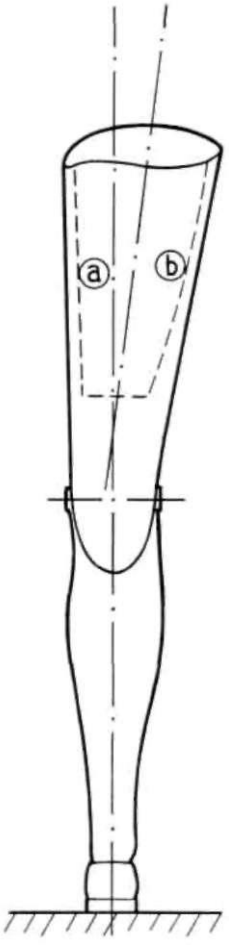


Fig. 5. Posterior view of the above-knee prosthesis showing position of the socket in relation to the rest of the leg. The medial line (a) should be approximately vertical. The lateral line (6) is sloped downward and inward. From Haddan *(8)*.

FACTORS RELATING TO THE AMPUTEE

General Physical and Mental Factors

A complete history and physical examination is the first step in determining the desirability of fitting the suction socket. Age is an important consideration, and as a rule elderly amputees are poor candidates for the suction socket. But old age *per se* is not a contraindication. Amputees over 70 years of age have been fitted successfully. As already noted, the suction-socket prosthesis is activated almost entirely by the muscles of the stump, and for this reason it requires considerably more effort and muscular skill to learn to use it. If, therefore, the elderly amputee is, as is so often the case, debilitated and feeble, with muscles weak and flabby and with poor coordination and balance, he is a poor candidate for the suction socket. On the other hand, if he is strong, alert, and agile (that is, if he "appears younger than he is"), and if the stump is in proper condition and of adequate length, there is no reason why the elderly amputee cannot use a suction socket successfully.

Experience has indicated that children as young as seven years can be fitted successfully *(1)*. The problem of lengthening and replacement as growth proceeds is no different from that with the conventional prosthesis.

Before a suction socket is prescribed, every effort should be made to determine the psychological make-up of the amputee. All reports indicate that most failures have been due to

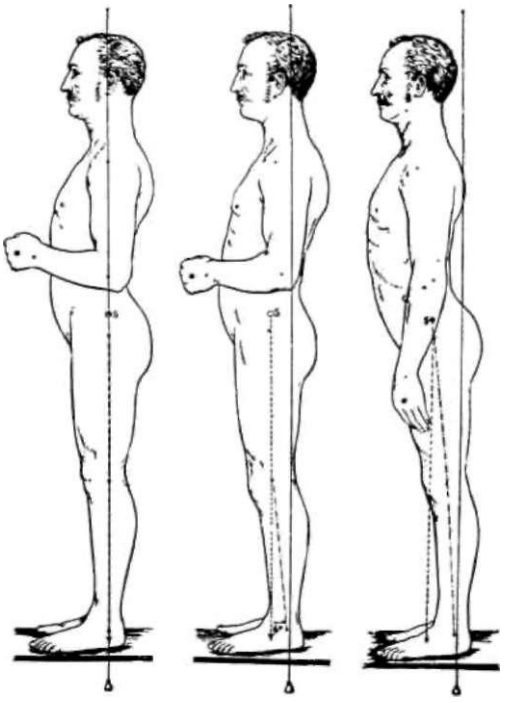


Fig. 6. Normal posture and two postural deviations which must be compensated for in fitting and aligning the prosthesis. Left, normal; center, slight deviation from normal presenting few difficulties in prosthetic fitting; right, extreme postural abnormality which, unless corrected by postural exercises, would present almost insurmountable alignment problems. From Gocht (7).

psychological or emotional difficulties. Learning to wear and use a suction-socket prosthesis requires cooperation, effort, patience, and perseverance. If the amputee is impatient, resentful, undependable, easily discouraged, unreasonable, or otherwise emotionally unstable, he most likely will be uncooperative and is apt to be a poor subject for the suction socket. Many failures can be attributed to the fact that the amputee is either unwilling or unable to devote the necessary time and effort to obtain a satisfactory fitting. As experience has been gained by the prosthetists, and with the additional aid of the recently developed alignment devices (page 23), the time required for construction and fitting has been considerably lessened in recent years. The interesting observation has been made that, when an amputee has to purchase his limb himself, he is likely to be much more cooperative than if he is given one by some agency.

Slump Considerations

Length. Stump length is not so important a consideration as might be thought. Contour, muscle tone, and mobility are important determining factors in deciding whether or not a short stump can be fitted. Naturally, the longer the stump the better is the muscular control and the easier is the fitting and training problem. But stumps as short as 3 in. (measured from the crotch) have been fitted successfully. Usually the shorter stumps require the addition of an auxiliary suspension belt (such as the Silesian belts shown in Figure 2) in order to stabilize the socket on the stump.

End-bearing supracondylar and Gritti-Stokes amputation stumps can be fitted successfully with the suction socket, although in such cases the mechanical knee joint usually has to be placed at a level slightly below that of the opposite knee.

Stump Contour. With the conventional socket, a conical-shaped stump has always been considered desirable. Such is not the case with the suction socket. A stump'of more cylindrical shape, with only slightly tapering sides and a fairly broad end, seems to maintain better suction and friction than does the conical or pointed stump. Most undesirable is a long, redundant, flabby mass of skin and fat extending beyond the bone end. Such a mass of tissue not only offers fitting problems but is prone to become edematous and swollen, thus making it difficult to don the leg or to remove the stump from the socket. In such cases, surgical revision is advisable before a suction socket is prescribed.

Excessive subcutaneous fat or extreme flabbiness of stump muscles frequently results in marked changes in the contour of the stump after the suction socket has been worn for a while. Repeated modification of the socket thus becomes necessary. With excessive subcutaneous fat, the stump may shrink considerably after wearing the socket, necessitating the insertion of leather liners or even the making of a new socket. Muscles that are atrophied and flabby and of poor tone will develop and increase in size with the use of the suction socket, necessitating enlargement of the socket.

Muscle Control and Strength. Good muscular control and mobility of the stump are essential for successful use of the suction socket. Fixed deformities due to muscle contracture are very common in amputations above the knee, particularly in the older age group, and they not only present very serious fitting and alignment problems but also handicap the amputee in walking. Flexion and abduction deformities are the usual ones, and the shorter the stump, with resulting greater muscle imbalance, the more likely are they to occur. Once they do occur they are very difficult to correct. It is imperative, therefore, that every effort be made postoperatively to prevent such deformities. Studies in alignment conducted at the University of California *(20)* indicate that the most efficient gait with the suction-socket prosthesis is obtained by fitting the socket with the stump in adduction and slight flexion (Fig. 7). Severe flexion-abduction deformity of the stump makes such alignment very difficult, if not impossible, without producing marked tilting of the pelvis and excessive pressure on the stump.

The adductor and hamstring muscles are important not only in controlling the limb but also in preventing flexion-abduction deformity by overcoming muscle imbalance. The shorter the stump, the less power remains in these muscles and the greater the tendency to

deformity. It is well known that, in order for muscles to function at maximum efficiency, they must have a fixed insertion. In amputations through the thigh, the major muscles are sectioned well above their insertions, and all too often these muscles are allowed to retract upward, no attempt being made to fix their cut ends to fascia or over the end of the bone. Failure thus to fix the free ends seriously impairs muscle function in controlling the stump. In considering an amputee for a suction socket, the stump should be carefully examined to determine how well the thigh muscles are functioning and whether there are any fixed deformities. If any are present, active and passive exercises should be carried out to correct them as much as possible before the socket is fitted.

Scars. Deep linear scars near the socket brim may interfere with maintenance of suction. Tender, adherent scars in the weight-bearing area beneath the ischial tuberosity and over the buttocks may cause pain sufficient to prevent the wearing of a suction socket. Deep, folded, adherent, or puckered scars over the end of the stump, which so often cause difficulty with the conventional socket, rarely offer any problem with the suction socket. In fact, it has been observed repeatedly how often these scars smooth out and become more pliable after a suction socket has been worn for some time.

Ulceration and Infection. Open ulcers, draining sinuses, and active deep infection of the soft tissues of the stump, as well as active osteomyelitis, are definite contraindications to the use of the suction socket. With adequate surgery and use of antimicrobial drugs, these conditions can usually be eradicated readily.

Bony Spurs. Although in many thigh stumps bony spurs develop at the end of the femur, they rarely offer any difficulty in the fitting or wearing of a suction-socket prosthesis. Occasionally, however, a large spur will develop on the lateral side of the bone in a stump with a fixed abduction, thus producing painful pressure against the side of the socket. Relieving the socket at point of pressure, realigning the socket, or surgical removal of the spur usually solves such a problem.

Skin Disturbances. Skin sensitivity, irritation, and infections are not uncommon in amputation stumps, and there appears to be considerable variation in the skin's resistance to pressure, friction, and irritation among individual amputees. Some are constantly troubled, while others have no difficulty. Dermatological complications are cited as a fairly common cause of failure in the use of the suction socket. Usually they can be prevented by proper hygienic care of the stump and good fitting, or else they can be relieved by dermatologic treatment. Skin allergy and contact dermatitis, of rare occurrence with the suction socket, usually can be controlled readily. The troublesome adductor roll, with recurring "pressure boils" (suppurative hydroadenitis and folliculitis), so commonly encountered with the use of the conventional socket, rarely if ever occurs with the well-fitted suction socket. In fact, when such a condition exists with a conventional socket, and the socket is converted to a suction one, usually the roll and

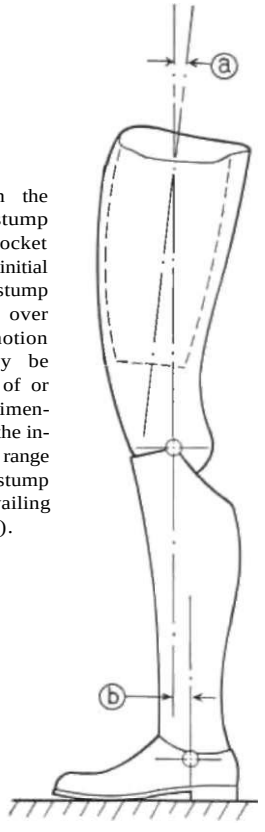


Fig. 7. Alignment in the sagittal plane. The stump should be oriented in the socket with several degrees of initial flexion *(a)* to allow the stump to control knee stability over the widest range of hip motion possible. The ankle may be positioned either in front of or behind the knee. The dimension (i) will depend upon the individual amputee, his age, range of motion in the stump, stump musculature, and prevailing terrain. From Haddan(#).

cysts rapidly disappear. This is one of the great advantages of the suction socket.

Perspiration. One troublesome problem occurs in individuals who perspire excessively and who also have a high bacterial count in their perspiration. Irritation or skin friction in such a situation leads to suppurative hydroadenitis and furunculosis. Excessive perspiration is not uncommon when the suction socket is first worn, but it usually subsides after varying lengths of time. In alleviating these superficial skin infections, x-ray treatment is often of value. Autogenous vaccines have also been used with some success. Before any suction socket is discarded as a failure, every possible effort should be exerted to treat and eradicate such troublesome skin conditions. Some of them can be anticipated from previous history and careful examination and can be eliminated by proper treatment before the socket is fitted.

Condition of Ike Opposite Extremity

During the experimental program, and in the early suction-socket schools, abnormalities and disabilities in the opposite extremity were considered as constituting an important factor—and even as a probable contraindication—in determining the suitability of the amputee for a suction socket. Subsequent experience has shown that abnormalities in the opposite extremity, while still to be considered, are not necessarily contraindicative. Amputees with disabilities so great as to require permanent bracing of the opposite limb have been fitted successfully with suction sockets; many persons with below-knee amputations on one side are wearing above-knee suction-socket prostheses with ease and comfort on the other. In fact, in such cases the suction-socket leg appears to have several advantages over the conventional above-knee leg. Survey studies also reveal that some bilateral above-knee amputees have been successfully fitted with suction-socket prostheses. But of course it is apparent that all such cases must be selected only after a very thorough analysis of individual problems.

Peripheral vascular disease which has necessitated amputation is in itself no contraindication to use of a suction socket, provided the opposite limb is not too seriously affected by the disease.

CONCLUSIONS

On the basis of the surveys reported upon, it appears quite definite that the suction-socket prosthesis has many advantages over the conventional belt- or shoulder-suspended leg. Approximately 75 percent of all above-knee amputees can be fitted successfully with the suction socket. Chief causes of failure, listed in decreasing order of importance, are psychological difficulties, general physical factors, stump abnormalities, and social and economic factors. Teamwork between physician, prosthetist, therapist, and amputee is an essential requirement in the successful fitting and wearing of the suction-socket prosthesis. Meticulous attention to fitting and alignment techniques is important, as is also adequate training.

Research studies in gait and principles of alignment, and the development of new alignment devices and duplicating jigs, have been of great value in reducing the time involved in construction and fitting by eliminating, to a great extent, trial-and-error methods. Although many limb manufacturers in this country still do not appreciate the advantages of the suction-socket above-knee limb and make no attempt to fit it, the wide acceptance of the above-knee suction-socket prosthesis in the United States today indicates that it can no longer be considered an experimental device, its use limited to a few selected amputees. Use of the above-knee suction socket is now so prevalent that it can be safely stated—and fairly stated—that the majority of above-knee amputees can successfully be fitted with the suction-socket prosthesis.

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Digest of Major Activities of the Artificial Limb Program

Human Limbs and Their Substitutes

Klopsteg and Wilson's *Human Limbs and Their Substitutes,* in preparation under the aegis of ACAL since 1948, will be available in bookstores by late summer. Two thirds of the page proof had been returned to the publisher, McGraw-Hill Book Company, by March 15, leaving one third still to be proofed and indexed.

This 800-page collaboration—prepared by some 30 specialists including surgeons, physiologists, prosthetists, therapists, chemists, engineers, psychologists, and so on—describes medical and engineering studies of the human arm and leg and application of the results to the design and fitting of artificial limbs and the care and training of amputees. Containing 450 illustrations, and tho'roughly documented, it covers all the aspects of amputee care, from surgery and pain problems through psychological adjustment to fitting and training, and describes methods and mechanisms growing out of systematic research toward improved artificial limbs.

Divided into sections according to the various professions involved—medicine, engineering, prosthetics, and therapy—*Human Limbs* is intended as a reference work and source book that should be of interest to everyone involved in any aspect of amputee rehabilitation. In addition, it should offer the best available guidance for designers working toward the further development of artificial limbs. The five parts of the volume are as follows:

PART I

MEDICAL PROBLEMS or THE AMPUTEE

PART II

THE UPPER LIMB AND ITS SUBSTITUTES

PART III

THE LOWER LIMB AND ITS SUBSTITUTES

PART IV

ADJUSTMENT OF THE LIMB TO THE AMPUTEE

PART V

TRAINING AND EVALUATION

European Tour by Dr. Craig L. Taylor

After postponing his sabbatical leave for several years because of the pressure of research activities, Dr. Craig L. Taylor, Professor of Engineering and Biophysics at the University of California at Los Angeles, member of ACAL and chairman of the Upper-Extremity Technical Committee, has finally turned over his various responsibilities to others for six months while he investigates European and Near Eastern developments in artificial-limb research and other biomechanical studies.

Dr. and Mrs. Taylor sailed for France aboard the French liner *Liberie* March 6 and have selected Paris as their first base of operations. Their proposed itinerary includes England, Italy, Spain, Portugal, Austria, Lichtenstein, Israel, Greece, Turkey, Germany, and the Scandinavian countries.

The Taylors' return is scheduled for the latter part of August, a few weeks prior to the Scientific Assembly of the Orthopedic Appliance and Limb Manufacturers Association in Atlantic City, September 26—30, where Dr. Taylor will give the first formal report on his findings.

Field Study of the Navy Below-Knee Leg

Having been reported upon favorably after the service-testing of 10 units by New York University, the Navy below-knee leg, consisting of a "soft" socket, plastic shank, and Navy functional ankle, now moves into field-testing in approximately 10 cities throughout the country. The first trials will take place in Chicago in May under the direction of the local Veterans Administration Orthopedic Clinic Team headed by Dr. Clinton Compere. After an intensive two-day instructional course conducted locally by personnel from the Oakland Naval Hospital Limb Shop, prosthetists in Chicago familiar with the use of polyester

resins will fit the experimental prostheses in their own shops.

The Navy publication, *Construction, Fitting and Alignment Manual for the U.S. Navy Soft Socket Below Knee Prosthesis,* prepared under the direction of Captain Thomas J. Canty, (MC, USN), will be used as a guide for prescription, fabrication, and fitting. Personnel from the Oakland Naval Hospital Limb Shop will remain on hand to render any assistance that may be necessary in the initial phases. The data required in evaluating the prosthesis and the technique of fitting will be collected by a Field Representative of the NYU Prosthetic Devices Study.

As experience is gained in Chicago, projects will be initiated during the summer and fall in other cities yet to be determined.

Lower-Extremity Research and Development Panel

At a meeting of the Lower-Extremity Research and Development Panel, held February 7 and 8 at the U.S. Naval Hospital, Oakland, California, the entire lower-extremity program was thoroughly reviewed, with special emphasis on the Clinical Study now in operation at the Prosthetic Devices Research Project, University of California.

Upper-Extremity Research and Development Panel

At a similar meeting of the Upper-Extremity Research and Development Panel, held February 10, 11, and 12 at the University of California at Los Angeles, all upper-extremity projects were considered, with special emphasis on the Field Study.

At the request of Chairman Taylor, Mr. Chester C. Haddan will be chairman *pro tern* until Dr. Taylor returns from his sabbatical leave.

Upper-Extremity Armamentarium Boards

Members of Prosthetics Clinic Teams, returning to their homes after attending the Upper-Extremity Training Course at the University of California, Los Angeles, have found a display of the armamentarium almost indispensable in their clinic operation. Accordingly, the Veterans Administration is making an armamentarium board available to each of its clinics, fabrication of the boards being carried out in the New York Regional Office limbshop. The VA has offered to lend boards on a necessarily limited basis to private clinics operating in areas in which the VA boards are located.

Some private clinics will no doubt desire armamentarium displays of their own, and it is understood that one of the leading artificial-limb manufacturers will, in the very near future, offer the VA-designed boards for sale to private clinics.

Prosthetics Training Center (University of California at Los Angeles)

The eighth session of the Upper-Extremity Prosthetics Course, with 12 prosthetists, 8 therapists, and 14 physicians in attendance, most from the Southeast, was completed April 2. The ninth session was begun on April 12 with an enrollment of 12 complete clinic teams, mostly from Los Angeles and San Diego. After the tenth session, which will be held between May 24 and July 2, the instructional staff will prepare a revision of the now-outdated *Manual of Upper-Extremity Prosthetics.* It is anticipated that at least two sessions of the training course will be offered to clinic teams during the coming fiscal year much on the same basis as in the past.

ACAL Annual Exposition of Progress

In Washington on April 7 the Advisory Committee on Artificial Limbs, with the assistance of several orthopedic surgeons, various specialists in physical medicine, and a dozen volunteer amputees, staged the annual demonstration of progress in prosthetic devices before a special session of the Committee on Veterans' Affairs of the United States House of Representatives, the Committee which initiated the enabling legislation (Public Law 729, 80th Congress) for continuance of the artificial-limb research and development program. On hand were a number of members of Congress; delegates from the Veterans Administration; representatives of the Department of Health, Education, and Welfare; members of the diplomatic corps; and various other persons interested in amputee rehabilitation.

The Caucus Room of the Old House Office Building, scene of the event, was lined with informative exhibits prepared by the Armed Services and the Veterans Administration. The public was invited.

In opening the meeting, the Honorable Edith Nourse Rogers (R., Mass.), Chairman of the House Committee on Veterans' Affairs, cited the "great progress made in the development of prostheses" since the beginning of the Artificial Limb Program and extended her personal thanks "to all those men of science and engineering who have dedicated their lives to the improvement of artificial limbs and who have, in many cases, given up other and more promising opportunities in order to continue the work for the benefit of our amputees."

Before presenting the several clinic teams and their respective amputee demonstrators, Brig. Gen. F. S. Strong, Jr., Executive Director of ACAL, took occasion to point out that, "although the program of systematic research for improved artificial limbs has required the expenditure of nearly a million dollars annually year after year since the program was started, it is absolutely necessary to have these funds if real success is to be achieved in this challenging field." He said also that "it is gratifying to know that the problem has been fully appreciated and that consequently the Congress has seen fit to provide for continued support." General Strong thanked the Committee on Veterans' Affairs for having initiated "a statute that looks to the continuance of the work now so well under way."

First of the physicians to appear was Dr. Everett Gordon, orthopedic surgeon and consultant to the Veterans Administration, Washington. Together with the additional members of his prosthetics clinic team, Nelson McFarlane (administrative officer), Charles Buffalino (physical therapist), and Raymond A. Beales (prosthetist with the J. E. Hanger Company), he presented results with certain difficult amputee cases which, heretofore, could not have been fitted successfully. Other principals in the presentation included Dr. Allen S. Russek, Director of the Prosthetic Service for New York University—Bellevue Medical Center; Dr. Roy Hoover, orthopedic surgeon and consultant to the Woodrow Wilson Rehabilitation Center, Fishersville, Virginia; and Dr. Eugene Record, orthopedic surgeon and consultant to the Veterans Administration, Boston, Massachusetts.

Presenting devices now in the experimental stage were Lt. Col. Maurice J. Fletcher (MSC, USA), Director of the Army Prosthetics Research Laboratory, Walter Reed Army Medical Center, and Dr. Sidney Fishman, Director of the Prosthetic Devices Study, New York University College of Engineering.

Amputees participating in the demonstrations were as follows: from the Washington area, George Barthel, Capt. Albert P. Clark (USA), John C. Gale, Charles Mattingly, and Dr. Robert C. Winfield, from the New York area, Edward V. Beamon, Herbert Kramer, Allen McCague, and Robert Sutcliffe; from the Boston area, Dr. Robert Dowst, Alverie Paradis, and Leonard Vanderlinde, Jr.

As he concluded the presentation, General Strong said that all of the devices shown, most of them stemming directly from the Government-sponsored research program, are either already in commercial production or else are very close to actual commercial manufacture. The international significance of the Artificial Limb Program was reflected by the presence in the audience of many representatives from the free nations of the world.

NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

The National Academy of Sciences—National Research Council is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare.

The Academy itself was established in 1863 under a Congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the Federal Government in scientific matters. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency.

The National Research Council was established by the Academy in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the Academy in service to the nation, to society, and to science at home and abroad. Members of the National Research Council receive their appointments from the President of the Academy. They include representatives nominated by the major scientific and technical societies, representatives of the Federal Government designated by the President of the United States, and a number of members-at-large. In addition, several thousand scientists and engineers take part in the activities of the Research Council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the Academy and its Research Council thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the Government, and to further the general interests of science.