Modern research in lower-extremity prosthetics in the United States started with the bioengineering studies performed at the University of California immediately after World War II. Many developments have followed: improved clinical care of lower-extremity amputees, significant economic benefits especially in terms of durability of artificial limbs, and increased convenience and function for patients are the prime products (26).

Concentration on improved socket designs and more adequate functional knee mechanisms has characterized the last 20 years. In the same time span, some additions have been made to the amount of fundamental information, but only lately have more laboratories become interested in developing bioengineering capabilities to add to the developers' data resources.

The introduction of immediate and early fitting has changed many concepts of lower-extremity rehabilitation. It has also affected the prosthetic designs being employed. Modular systems are now becoming part of the tools of the prosthetist. Improvements in materials for socket fabrication are also being made available. The concept of prefabricated sockets is being explored. Some thought is also being given to control of knee and possibly foot-ankle functions using EMG and other remote sources. Surgeons have taken a renewed interest in amputations, as part of a reconstructive procedure and are employing research resources for improvement in surgical practices and in the control and weight-bearing capabilities of amputation stumps.
Lewis and Staros: Research in LE Prosthetics

Yet much more needs to be done. Improved foot-ankle mechanisms are still badly needed. Simple prosthetic systems for the geriatric amputee should be sought. Improved methods of training amputees and in evaluating their fit and their use of prostheses need to be developed. Attention must also be paid to improving the management of research and development programs, essential ingredients of which are the evaluations and testing to assist developers and to assure the clinical usefulness of research and development products.

FUNDAMENTAL STUDIES

Locomotion

Developments in lower-extremity prosthetics have been primarily based on the pioneering fundamental research work of the University of California started just after the end of World War II. The data on kinematics and kinetics of normal walking have been repeatedly used over ensuing years for the development of improved artificial limbs for the lower-extremity amputee (5). Subsequently, energy studies at the University of California (8), at the Veterans Administration Prosthetics Center, and in other laboratories have added to information available about the biodynamics of locomotion.

The early University of California studies were performed using young adults, of special significance at the time in relation to the needs of the war disabled. Lately, because of the increasing numbers of geriatric amputees, the VA Prosthetics Center has performed similar studies on locomotion of older people. Force plate data already accumulated indicate significant differences in the patterns of loading during level walking between older normal subjects and younger people (15). A slightly different kind of gait seems characteristic (Fig. 1). But how the differences relate to criteria for the design of prostheses for the geriatric amputee is not as yet clear.

Kinematic and kinetic studies are also being performed to extract better measurements of performance during locomotion. With the use of accelerometers, normals and amputees are being studied to determine if there are “summary” indicators of efficient performance. Energy consumption is used to gage efficiency. It is expected that this type of research can lead to simplified systems and devices to provide quick read-outs in evaluation of amputee performance in a clinic, without resorting to extraodinarily detailed and yet subjective performance analyses.

Bioengineering Laboratory Facilities

Perhaps of major significance has been the increasing worldwide interest in development of bioengineering or biomechanical laboratory capability to support prosthetics research and development. The Uni-
versity of California-Biomechanics Laboratory, the Veterans Administration Prosthetics Center, Case-Western Reserve, Moss Rehabilitation Center, and other groups in the United States have various laboratory capabilities. Similar facilities have been developed at the Biomechanical Research and Development Unit at Roehampton and at the University of Strathclyde in Glasgow. Other groups in Poland and Yugoslavia have started to develop such facilities.
Lewis and Staros: Research in LE Prosthetics

Kinematic studies using photographic methods or television systems and kinetic measurements with force plates and instrumented pylons (Fig. 2) constitute the basic program of a laboratory with a mission in lower-extremity prosthetics research. In addition, barographs will help give a reasonably good display of pressure distributions between foot and ground or between shoe and ground (14). Pressure gages of the type described by Peizer (13), EMG equipment to measure muscle activity, accelerometers, treadmills, energy-consumption measuring devices, and the like are all very essential in the bioengineering laboratory.

But most of all, data recording equipment and preferably data processing equipment to eliminate the time-consuming efforts in data reduction are indicated. Modern data processing systems will also permit the accumulation and analysis of data on an expanded number of variables, permitting more correlations and thus greater capability for researching a greater portion of man-machine systems.

Special devices are built occasionally to suit a particular study, but essentially the equipment described above (in very general terms) is used in accumulating data of significance in the development of improved techniques and devices for lower-extremity artificial limbs.

**Figure 2.—Instrumented pylon.**  
**Figure 3.—Pressure transducers.**

**Surgery**

The wider scale use of myoplastic techniques in lower-extremity amputations has probably improved stump capability for load bearing. Socket designs which vary from traditional principles regarding avoidance of stump end-bearing or "total surface-bearing" are now being
developed, to relieve proximal constriction and in the above-knee case, to reduce dependency on the ischium.

Surgical research to increase the end-bearing capability of stumps is being performed by Swanson (25) who uses a synthetic material over the cut end of the bone in attempts to increase the end-bearing capability of stumps. Further, Esslinger (6) continues with his work to determine the feasibility of direct skeletal attachment.

Socket and Rigid Dressing Fittings

Intensive studies of the socket-stump interface have recently been started. Reliable and accurate yet adequately minute pressure transducers (Fig. 3) have been made available which permit study of socket fit by quantifying the interface relationship in terms of pressure readings. These can be particularly helpful in assessing socket design incorporating increased distal bearing.

The instrumentation has been particularly important in research on the rigid dressing used in immediate postsurgical prostheses. Schrock et al. (19) report pressure studies performed on several cases in the Seattle, Washington, area: Although the data are not conclusive, indications have been provided on the value of the rigid dressing in limiting the formation of edema and consequently promoting wound healing.

In the studies in Seattle, Schrock and his co-workers also employed EMG outputs to investigate muscle activity as well as skin temperatures in the period just after immediate postsurgical fitting. These and like studies are aimed at researching immediate postsurgical fitting to evaluate the relative roles of surgery, the rigid dressing, and the postsurgical treatment, especially early weight bearing and locomotion.

Voluntary Control Systems

The intensive work on control of external power for upper-extremity prostheses has stimulated some researchers to consider voluntary control of certain lower-extremity functions (16). EMG sources, from stumps prepared by myoplastic techniques or even from the other lower-extremity (Fig. 4) or control signals from pressure switches as well as other systems, are being considered in research studies of sites for operation of knee and foot-ankle mechanisms, designed not for powered functions but for motion control, a function demanding reasonably low power magnitudes.

DEVELOPMENTS

The Development and Refinement of Techniques and Processes for Fitting and Alignment

Data from fundamental studies on locomotion and from clinical experiences have been used to develop a number of designs introduced
over the years for use by the prosthetist in fitting and alignment. The *quadrilateral above-knee socket*, based on analyses of the required load-bearing and control functions of the limb socket, was an early contribution which has often been combined with the suction suspension system, a German development.

Later changes were made in above-knee socket design to give the amputee other advantages. *Total-contact* fittings which combined the necessarily high forces on some specific load-tolerant stump tissues with low uniform pressure on all other tissues produce better prosthesis control, better sensory cues, improved comfort, and reduced proximal constriction (27). Casting processes were developed because the prosthetist could not easily produce total-contact sockets by carving in wood; replicas of the stump were used in designing the critical biomechanical relationships, and plastic laminates were introduced for lower-extremity sockets of all levels. *Alignment devices* were introduced as a result of efforts by the University of California. Geometry could be thus adjusted in a biomechanical fitting.

*The hip-disarticulation and Syme prostheses* (7, 31), based on the Canadian principles, were introduced and yielded improved function, stability, cosmesis, and durability.
Finally, the employment of some rational principles in fitting below-knee stumps resulted from intensive studies by the University of California and others. The patellar-tendon-bearing or PTB socket, which incidentally is poorly named, is a total-contact socket based on strategic design of the interface, placing loads for control and support on appropriate stump tissues. The system also was based on use of a stump replica and plastic lamination of the socket. Whether the socket contained a liner or not or whether the socket contained the cuff suspension as described in the first manual did not affect the basic principles.

No matter what suspension is used, the principle that has become known as the “PTB” is the same. Figure 5, from reference 3, makes quite clear that many of the latest BK socket designs are merely adaptations of the original PTB.

Recent clinical research has improved on these original lower-extremity socket developments:

I. Variations in Suspension of Below-Knee Prostheses (3)

There are now designs of the “PTB” socket which either (a) bring its brim above the condyles medially and laterally for knee stabilization in the frontal plane as well as to provide suspension or (b) provide suspension and both supracondylar and suprapatellar stabilization against knee-extension moments by a high brim medially, laterally, and anteriorly. Whether wedges or flexible materials are used for the socket brim to provide the suspensory function makes little difference
in terms of the socket weight-bearing and control properties defined by the "PTB" concept.

II. The Below-Knee Air-Cushion Socket (10, 32)

The Below-Knee Air-Cushion Socket, a recent development of the University of California, employs a flexible sleeve in the lower part of the socket to increase the amount of distal loading of the stump. Proximal contours of the socket are similar to the original "PTB" concept. The air-cushion socket, therefore, represents another relatively minor modification to give the prosthetist a design alternative for fitting cases for whom this type of load distribution might be advantageous. Similarly the elimination of liners and the use of foamed-in-place distal pads are minor modifications of the original concept of "PTB."

III. Porous Sockets

Porous sockets involve some modification of the socket lamination procedure (17). Again the basic principles of socket design are not affected. Provided in this socket is improved air circulation around the stump, sometimes of great advantage in hot, humid environments.

IV. New Materials

New materials have been introduced. The use of a thermoplastic synthetic (Fig. 6) which can be formed directly on the stump has simplified procedures and thus speeded up the "PTB" socket fabrication process, enabling more rapid fitting especially of temporary sockets (30). This procedure eliminates the need for the plaster-of-paris intermediate steps and thus reduces process time. Moreover, the thermoplastic so far used is quite supple or leather-like, without the hygienic disadvantages of leather. This property also may make this material
Bulletin of Prosthetics Research—Spring 1970

advantageous for various types of below-knee suspensions involving high brims, in which the flexibility of the material can facilitate “clamping” over the condyles.

V. Prefabricated Sockets

Prefabricated sockets both for the above-knee and below-knee levels are now being developed especially using materials which might have some slight adjustability such as the thermoplastics. The concept involves prefabricating above-knee and below-knee socket blanks based on established quadrilateral and “PTB” shapes and in a number of sizes and tapers so that a fitting laboratory with a reasonable inventory of such items could select one which can be adjusted slightly for fitting to any client. Total contact can be achieved by foaming-in-place the distal socket contours.

This approach certainly useful for temporary prostheses will produce economies for all concerned. The introduction of immediate postsurgical fitting and early fitting (1, 2) has stimulated the development of rapid fitting processes. The use of prefabricated sockets could certainly be integrated with immediate and early fitting programs. Moreover these programs of immediate postoperative and early fitting have stimulated the concept of modular design in prostheses, possibly with prefabricated sockets available for incorporation as one module. When integrated with the modular prosthetics structure discussed below, prosthetic fitting might become a simple assembly process but still based on custom fitting of an adjustable socket, careful alignment adjustments, and selection and incorporation of the appropriate functional components.

THE DESIGN AND DEVELOPMENT OF IMPROVED DEVICES AND NEW CONCEPTS OF APPLIANCE CONSTRUCTION

Hydraulic and Pneumatic (Fluid-Controlled Prosthetic Knees)

These are knee systems using the velocity-dependent resistances to fluid flow to provide cadence responsiveness, or higher resistance at higher walking speeds, and smoother function (21). Some of these knees use programmed resistances in which designed resistance variations are provided as a function of knee angle. One unit provides a very valuable stance-control feature.

The Mauch Laboratories of Dayton, Ohio, has for many years been interested in control of prosthetic knee function, during both swing and stance. In fact, development of hydraulic knee-control systems by Mr. Mauch and Dr. Henschke began in Germany during the mid-1940's. The design of a pendulum-controlled hydraulic stance-phase unit with nonadjustable hydraulic swing-phase control was completed
in 1947. In 1953, two systems were constructed which permitted outside adjustability of the hydraulic swing-phase resistance. Tests of these two systems proved the need for swing-phase adjustability to satisfy the majority of amputees. Also in 1953, Mauch completed design of a system with only adjustable swing-phase control yet compatible with the stance-phase control system. The 1953 swing-phase unit was the prototype of the present “Hydraulik” Swing-Control System formerly designated Model “B” and in its latest configuration, the Model “S.” Two swing-phase (“B”) systems were built in 1955 and tested and evaluated. At that time, it was decided that the time had come for more extensive clinical trials of the swing-phase unit. The swing- and stance-phase control systems still required additional developmental efforts. A limited field study of the swing-phase system was followed by a nationwide clinical study (28). The swing-phase unit (Model “B”) became commercially available in 1965.

An intensive series of laboratory and clinical tests performed by New York University with a small number of swing and stance systems (Model “A”) culminated in a recommendation that the U.S. Veterans Administration (the sponsoring agency) conduct a nationwide evaluation of the device (12). Accordingly a VA clinical evaluation study was authorized in October 1966. Thirty-three male veterans with service-connected amputations above the knee were selected and fitted with new prostheses incorporating the test system. The system was well received by the majority of amputees and all of the professional personnel involved in the study (9). A number of design changes were made in the unit and the wooden setup as a consequence of the study. The production model, now designated as the Model S-N-S (Swing-N-Stance) (Fig. 7), is now commercially available and accepted by the U.S. Veterans Administration for routine issue.

Both Model “S” and Model S-N-S offer the user programmed, adjustable control of the flexion and extension portions of swing phase. Flexion and extension resistances are independently adjustable permitting a broad spectrum of resistance possibilities.

The Model S-N-S offers two additional types of control in addition to being able to control the swing phase (11). By far the most valuable contribution to prosthetic knee control developed to date is the stance-phase control provided by this system. A very high (although adjustable to the user’s need) level of resistance to flexion is provided to prevent inadvertent collapse of the knee during stance. This stance-phase resistance aids in step-over-step stair descent, ramp ascent and descent, as well as control on uneven terrain and in the event of toe stubbing. Late in stance phase this high level resistance to flexion is automatically disengaged to facilitate the start of swing phase. Should the amputee desire he may manually engage a hydraulic lock to prevent
knee flexion. Experience indicates that all amputees being fitted with the Mauch S-N-S must receive training in order to derive maximum benefit from the system.

The "Hermes" system, manufactured by Dupaco, Inc. of Arcadia, California, is a small lightweight hydraulic system for above-knee and hip-disarticulation prostheses. Using the Mauch principle, the piston successively covers fluid-escape ports in the cylinder wall and thus maintains the desired higher resistances near the ends of the stroke. For simplicity though, all parts governing flow during motion in one direction lead into a single passage with an independently adjustable needle valve thus permitting separate control of flexion and extension resistances. The control unit is provided in a slightly modified wooden
Lewis and Staros: Research in LE Prosthetics

setup, although it can be installed in most existing prostheses by means of a special installation kit also made by the Dupaco Company. The “Hermes” system was evaluated by the Veterans Administration and is currently available to veterans (29).

The Biomechanics Laboratory at the University of California, Berkeley and San Francisco, has been one of the most active contributors to the improvement of prosthetics technology since the United States prosthetics research program began after World War II. The UC-BL Pneumatic Swing Control mechanism is one of their latest developments to reach the stage of clinical evaluation (18). The knee mechanism simulates for the above-knee or hip-disarticulation amputee the effects of normal quadriceps and hamstring muscle action during swing phase. No particular advantages during stance phase are provided by the system.

The pneumatic cylinder is a small, lightweight unit which is installed in a knee/shank setup composed of a special wooden knee block and with an aluminum shank/pylon unit and rigid polyurethane foam cover or a wooden shank of more conventional design. When used with the pylon shank, a SACH foot must be used. When the wooden shank is used, any prosthetic foot may be fitted. “The functional element is a piston/cylinder unit that works in a manner similar to that of an automobile shock absorber or a pneumatic door closer. Flexion of the prosthetic knee causes the bellcrank pivot located at the rear of the knee to move distally in the shank and forces the piston into the cylinder” (18). The pressure difference formed on the different sides of the piston creates the resistances which simulate the quadriceps-hamstring control patterns. To provide good performance for the wide variety of amputees, separate, adjustable bypass and leak-rate controls are provided to adjust overall flexion/extension resistance and the ratio between flexion and extension resistances.

Lately, variations on the UC-BL design, but employing the same principles, have been developed by Blatchford in England and Hosmer in the United States. These designs are now being tested for clinical applicability.

Other Prosthetic Knee Systems

A number of mechanical friction prosthetic knees have been developed to provide improved swing-phase and stance-phase controls. The Northwestern University Disk Friction System, for example, used a number of friction elements to pattern the resistance as a function of knee angle, with more friction at the termini of the swing phase (22). With more resistance provided at the extremes of knee flexion and extension than during mid-stance, some semblance of cadence responsiveness can be provided. For example, with the tendency to get higher
heel rise at higher cadences, more resistance would be introduced at the larger angle of knee flexion produced.

Commercial manufacturers of knee mechanisms have introduced a number of units primarily designed to provide an increase in mechanical resistance during weight bearing. Units such as the Varigait "Deluxe," the Teufel "Secura," the Otto Bock "Safety," and the Blatchford "Stabilized" knees provide by varying means some extra stability, primarily to assist an amputee in recovering control of his prosthesis at varying knee flexion angles (Fig. 8).
Lewis and Staros: Research in LE Prosthetics

Research and development groups primarily in North America have offered polycentric systems in which the instantaneous axis of knee rotation is strategically programmed in the kinematic design to provide knee stability (24). Care has been taken by the designers to avoid having the knee so stable that it would not “break” when the amputee wished to initiate knee flexion for swing phase. Although a bit bulkier than other types of prosthetic knees, these units would provide the needed stability for most geriatric amputees who have minimal need for swing-phase control. Several designs are now being readied for limited production of prototypes (Fig. 9).

A major problem over the years has been the unavailability of good prosthetic knee systems for amputations at or through the knee. Fitting of prostheses for through-knee amputations or true knee disarticulations is difficult due to space limitations for an appropriate knee mechanism. Various attempts have been made to have side joints incorporate friction materials, but these have been unsuccessful because the amputee with the long above-knee stump requires a high amount
of swing-phase resistance such as produced by hydraulic mechanisms. Some encouraging developments have occurred in using fluid-controlled systems for amputations through or just above the condyles (Fig. 10). A limited number of such designs have been used successfully in these cases (4). However, the problem of prosthesis design for through-knee amputations has not yet been adequately attacked. The University of California-Biomechanics Laboratory is presently developing a design employing a slanted socket attachment plate which would permit incorporation of a fluid-control system behind the knee. Lyquist in Denmark is developing a system to permit control of knee motion about a kinematically displaced knee center. Both designs have a great deal of merit and may constitute significant steps forward in solving the problem for this level of amputation.

Torque Absorbers

Very simple torque absorbers to be mounted in the shank of lower-extremity prostheses have been worked on in a number of laboratories. Attempts to provide controlled resistance to rotation in the transverse plane were stimulated by the desire to reduce the transference of torsional loads to the stump-socket interface. A design recently developed by the VA Prosthetics Center employed laminated bearings used in helicopter rotors. Some difficulty was had with the VAPC unit with material failures from the high bending moments in the anterior-posterior plane. The University of California-Biomechanics Laboratory redesigned the VAPC unit offering a prototype of a system to overcome the problems had with the VAPC design. Hopefully, experimental units will be available shortly.

Foot-Ankle Mechanisms

Several commercially developed foot-ankle systems, particularly those made by Trautman in the United States and Teufel and Bock in Germany, have controlled resistances to motion in all three planes. These systems provide controlled plantar flexion and dorsiflexion as well as inversion-eversion and transverse rotation. These units present functional features of value to many amputees.

The SACH foot, primarily designed as a simple, durable device for controlled motion in the anterior-posterior plane, has caused some clinical problems in recent years due to a shape that evolved in the mass production of prefabricated units. Very recently the University of California-Biomechanics Laboratory and the VA Prosthetics Center standardized new shapes to overcome the problems of poor fit of foot to shoe which in turn significantly affected the foot's function (Fig. 11).

Development of a hydraulically controlled ankle system is rapidly progressing to the stage where controlled field testing will be under-
taken. Work on developing a hydraulic ankle offering only plantar-flexion and dorsiflexion control began in the late 1950's with U. S. Patent #2843853 issued to Mr. Hans A. Mauch in July 1958. As development continued, emphasis was first placed on a hydraulic ankle providing plantar-flexion and dorsiflexion control with optional nonhydraulic inversion-eversion foot control (based on a 1949 patent granted to Henschke and Mauch on a Turnable Foot mechanism) and also optional nonhydraulic control of transverse rotation.

From these early concepts the current design has evolved. It offers the following features:

1. Hydraulically controlled plantar-flexion dorsiflexion ankle action of 30 deg. with toe-slap damping. Maximum dorsiflexion is 11 deg. and maximum plantar flexion is 19 deg.

2. Variable self-adaptive dorsiflexion stop activated by the relationship of the shank to a vertical orientation.

3. Automatic spring-controlled neutral foot position, activated at toe-off. Foot angle is adjustable manually, if desired.

4. Inversion-eversion (lateral motion) control, by mechanical means, which provides a firm base of support through a range of 10 deg.

5. A mechanical transverse rotation mechanism combined with the upper shank attachment rod in which rotation of the prosthetic shank is induced by the rotation of the pelvis when a forward step of the sound leg causes a slight plantar flexion of the prosthetic foot. The mechanical work produced by the rotating pelvis is used to produce a slight push-off effect. Low spring force restores the normal foot-shank relationship after toe-off of the prosthetic foot. All of the preceding are
incorporated in a small unit which increases the total weight of the prosthesis by a mere 3 oz. (Fig. 12).

**Modular “Skeletal” Prostheses**

Modular prostheses or prosthetic systems using a basic structure which can be adapted or adjusted to suit a particular amputee’s special functional and geometrical needs are being developed based on several design approaches, primarily at Winnipeg in Canada, by Blatchford in England, and at the VA Prosthetics Center in the United States. Several designs all using a skeletal structure but representing some variation in concept are now becoming available for evaluation.

Previous mention has been given to the concept of a prefabricated socket as one element or module in such a prosthetic system. The rest of the prosthesis consists essentially of the metal, skeletal structure permitting the incorporation of different foot-ankle modules and for the above-knee cases, different knee-control modules. Blatchford’s design uses the same basic structure for both the below-knee and above-knee prostheses. The Winnipeg and VAPC designs employ separate below-knee and above-knee systems.

With the introduction of immediate postsurgical and early fitting of prostheses, metal structures became quite common as part of temporary prostheses. These metal prostheses or pylons lacked cosmetic features although they provided for the very essential alignment adjustability. The above-knee pylon did not have functional adjustability at the knee since most of the cases being fitted required either some simple knee lock or at most, an adjustable but constant mechanical friction system with or without an extension bias.

One present approach (at VAPC) has been to build on these temporary limb designs by establishing skeletal prosthetic systems which can be used from the time of immediate or early fitting through and including the definitive prosthesis or used for all kinds of fittings. Thus alignment and functional adjustabilities were both incorporated (23). Alignment adjustability can also be included as a permanent part of the definitive prosthesis if desired so that as an amputee’s capability changes, even on the so-called definitive limb, alignment adjustment can still be made without a major overhaul (20).

With the introduction of a number of fluid-controlled systems for prosthetic knees, it also became apparent that metal structures which could incorporate precise and dimensionally stable locations for the bushings for the fluid systems were essential. Wood was inadequate. Secondly, it was necessary to standardize the dimensions of these fluid-

---

*Distinct from a crustacean design, in which load transmission is through the outer walls of the limb, the skeletal design uses a central column as in the normal extremity.*
control systems so that one metal structure could be used for each and every one of them. As a result of these considerations, the present VAPC system for the above-knee design incorporates a stepped or variable mechanical friction which can be disengaged, a knee lock which also can be disengaged or removed completely, an extension bias which can be removed, and facility for the incorporation of any of a number of fluid-controlled prosthetic knees (Fig. 13). Later development efforts will be directed toward incorporation of additional modules such as friction stabilized knees, polycentric systems, and mechanisms for the through-knee amputee.

Cosmetic treatment of the skeletal systems continues to be a problem. Vinyl foams have been used reasonably successfully on the below-knee limb (28). The foam and polyurethane finish provides a reasonably good and durable appearance as well as a soft feel not present in existing wood-laminate crustacean limbs (Fig. 14). Prefabricating of cosmetic covers for the below-knee limb is quite difficult; dimension and shape standards would be complicated because of amputee-to-amputee variability in stump attitude in the frontal plane. However, custom covers can be formed either by means of the vinyl foam system or by forming a plaster replica of the opposite extremity, making a thin and flexible plastic laminate mold which when turned inside out can be
used as a mold for a foam-in-place cover for the artificial limb.

The above-knee cosmesis problem is somewhat different; prefabricated cosmetic covers can be designed to encompass the entire limb from foot through to socket. It would be preferable to have a single cover designed in such a manner that it offers no restriction to the motion controls provided for the foot-ankle and the knee.

**FUTURE DEVELOPMENTS**

A great deal of effort has been devoted to development of sophisticated fluid-controlled and mechanical systems for prosthetic knee function. Many of the units which have already been developed can be integrated into recently conceived modular systems for lower-extremity prosthesis design and construction. There is need to continue the development of these modular devices and to consider specific problems primarily presented by geriatric amputees. Employment of polycentric knee mechanisms would be advantageous in terms of stability, simplicity, and durability. There is need to consider the employment of EMG and other remote methods of control of prosthetic knee function. Moreover, there is specific need for the development of knee-control systems, preferably employing fluid control, for the very long above-knee stump.

In general, component development might well focus on improved foot-ankle systems including designs which relate to increased knee stability. The eventual introduction of the Mauch ankle is patiently anticipated. However, there is need for modular design, especially size adjustability in foot-ankle mechanisms. A basic foot should be designed which would permit length adjustment as well as the incorporation of different kinds of foot-ankle controls, including hydraulic ones. All should be compatible with the lower-extremity modular systems now being readied for clinical use.

The employment of newer materials for the socket would simplify its construction. Thermoplastics will have their place; standards will be developed for prefabricated socket blanks which can be inventoried on a laboratory shelf. Preferably these blanks should be of a material or design which permits some degree of volume adjustability. Also they might be reinvented for reuse when the limits of their adjustability have been exceeded. Such blanks could then constitute another element in the modular system of prosthetics which will be promulgated throughout the world (Fig. 15).

There is need for improved procedures for training amputees, to simplify the process and to make it more acceptable and rewarding to the patient, permitting the patient to gain in the shortest possible time the full advantages of the prosthetic design prescribed for him. There is also a need for improved prosthesis inspection procedures to determine
whether indeed a clinic team has provided the best possible prostheses for their patients. Such checkout procedure should also be simple, but all-inclusive, probably based on instrumentation yet to be developed by one of our laboratories.

As the prosthetics researchers take the above steps their surgeon colleagues should further stimulate as well as undertake research and development to improve the load-bearing capabilities of stumps. Eventually, more and more effort should be devoted to the possibilities of direct skeletal attachment. Any fundamental research undertaken should probably support these hoped-for improvements in lower-extremity prostheses.

Accompanying such a development program is a very necessary program of testing and evaluation. Facilities will need to be available not only for laboratory testing of hardware but to develop standards as new hardware becomes available and then to use such standards to see that manufacturers comply, for we all will depend on prefabrication more and more. At the same time, improved clinical evaluation programs should be developed not only to validate the usefulness of new devices and techniques but to help point up the problems inherent in the introduction of new items for patients. Such clinical programs will necessarily point up requirements for the very important educational
and informational programs where all products of research and development should be focused preparatory to wide-scale employment.

The reconstructive process, which begins even before amputation, is a satisfying clinical experience which should be under the supervision of an interested surgeon. The process requires the assistance and support of the other professions—in physical medicine and prosthetics. But to this team must be made available the tools of modern practice and the products of our research and development laboratories to make reconstruction more expeditious, more productive, more rewarding, and most of all, more stimulating.

REFERENCES


204


22. Staros, A. and E. Peizer: Northwestern University Intermittent Mechanical Friction System (Disk-Type), Artificial Limbs, 9 (1) :45-52, Spring 1965.


