HIGHLIGHTS OF OTHER VA RESEARCH PROGRAMS

PROSTHETICS

Edited by

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Committee on Prosthetics Research and Development
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For progress during this report period see "Summary of Activities of the Committee on Prosthetics Research and Development for the Period June 1, 1970, to December 31, 1970," appearing elsewhere in this issue of the Bulletin.

Committee on Prosthetic-Orthotic Education
National Academy of Sciences-National Research Council
Washington, D.C.
Herbert E. Pedersen, M.D.

Subcommittee on Orthotics

A recently reported (2, 3) study conducted by the Subcommittee on Orthotics showed that, among orthopedic surgeons in this country, the lumbosacral corset is the most commonly prescribed external support for low back pain. Next in preference are the Chairback (Knight) and Williams braces. A cast is used least frequently. Dr. Jacquelin Perry, who reported the study, noted a definite relationship between the etiology of low back pain and the type of support chosen. The major goal in prescribing low back support is to restrict lumbosacral motion.

Results of the study related to *selection* of the support are based on responses from 3,140 members of the American Academy of Orthopaedic Surgeons; those related to *function* of the support, on responses from 2,192 members.

The Subcommittee on Orthotics decided at its meeting in Chicago, October 21, 1970, to compile a mailing list of clinicians involved in prescription of orthoses. It was noted that orthotic devices were not prescribed in a centralized place, as are prostheses in amputee clinics, with the result that this group of clinicians is more difficult to reach. With direct mailing, it is hoped that dissemination of educational and informational materials can be expedited. The certified orthotists in the country will be solicited to help in this endeavor.

Subcommittee on Publications and Educational Materials Information Retrieval System

An information retrieval system for prosthetics and orthotics, a current project of the Subcommittee on Publications and Educational Materials, was one of the subjects discussed at a meeting of the Subcommittee held in Miami, December 3, 1970.

For some time, the Committee on Prosthetic Orthotic Education has been interested in the possibility and desirability of developing an information retrieval system in prosthetics and orthotics. Within the last year, it was learned that the Subcommittee on Orthopedic Information Services of the Committee on the Skeletal System, National Research Council, was working with the National Library of Medicine to establish a computer-controlled system for the retrieval of data on orthopedic literature. Subsequently, arrangements were agreed upon with the latter National Research Council Subcommittee to include prosthetic and orthotic terms in the microthesaurus being prepared for orthopedic subjects. An *ad hoc* committee is now scanning published prosthetic and orthotic literature available at the National Library of Medicine, for the purpose of selecting appropriate terms. Other groups, including the Veterans Administration Prosthetics Center, the R&D Division of the Prosthetic and Sensory Aids Service, and the Winnipeg Prosthetics and Orthotics Research and Development Unit, are developing information retrieval systems for technical literature usually not found in the National Library of Medicine.

In view of the information explosion in the fields of prosthetics and orthotics, as in other scientific fields, the availability of information retrieval systems constitutes a tremendous advantage to researchers, clinicians, and educators. It means that workers may quickly review current publications in specified areas, and may also obtain printouts of published articles on selective subjects without extensive and time-consuming searches that are now unavoidable in any meaningful study.

Members of the *ad hoc* committee are Warren Springer, Chairman, Dr. Newton C. McCollough, Joseph M. Cestaro, and Basil Peters and Charlotte L. Cranmore, CPOE staff.

Subcommittee on Special Educational Projects in Prosthetics and Orthotics Survey—Graduates of Degree Programs in Prosthetics and Orthotics (4)

The first graduates of a prosthetics and orthotics degree program in the United States were two students who received their baccalaureate degrees from New York University in 1965. By the end of the school year in 1969, 84 students had been graduated from various degree programs —25 with a bachelor of science degree in prosthetics and/or orthotics; 29 with an associate in arts degree in prosthetics and orthotics; and 30 with an associate in arts degree in prosthetics.

Of the 65 who responded to a recent survey [see Ref. (4), also reprinted elsewhere in this issue of the Bulletin] conducted by the Subcommittee on Special Educational Projects in Prosthetics and Orthotics, CPOE, 53 were gainfully employed in the fields of prosthetics and orthotics and eight were continuing their education at an advanced level in these fields.

Of the 53 graduates working in the fields of prosthetics and/or orthotics, 42 were working in a commercial facility, seven in a hospital, two in a university research program, one in a medical school, and one in a military service.

The median salary for those with a baccalaureate degree was $12,000; for those with an associate in arts degree, $9,000. Four with B.S. degrees who held executive or administrative positions reported salaries of over $15,000. The ratio of those working exclusively in the field of prosthetics to those working exclusively in orthotics was 3.6 to 1.

Sixty-one of the 65 respondents (94 percent) plan to stay in prosthetics and/or orthotics. Several expressed the opinion that their educational background and experience prepared them for more active participation in the clinics they attended, but that some clinicians were not aware of the potential contribution of prosthetists and orthotists.

The results of the survey of graduates of prosthetic and orthotic degree programs were reported at the meeting of the Subcommittee on Special Educational Projects in Prosthetics and Orthotics at Miami Beach, December 4, 1970. A finding of the survey that related to the ill-defined role of the prosthetist in an amputee clinic situation led to a discussion of the current status and structure of amputee clinics and their effectiveness in delivery of prosthetic services. It was pointed out that changes in delivery of health care and services would inevitably have an impact on amputee clinics and that it was time to take a new look at the conduct and status of these clinics in the United States. For this purpose, an *ad hoc* group was appointed by the Chairman. Other subjects discussed at the meeting for possible future action included plans for accreditation of prosthetic and orthotic educational programs and more effective methods of recruiting students to the fields of prosthetics and orthotics.

Publications

Journal Publications

1. Davies, E. J., B. R. Fritz, and F. W. Clippinger, "Amputees and Their Prostheses," *Artificial Limbs,* 14:19–48, Autumn 1970.
2. Perry, J., "The Use of External Support in the Treatment of Low Back Pain," *Artificial Limbs,* 14:49–57, Autumn 1970.
3. Perry, J., "The Use of External Support in the Treatment of Low Back Pain. Report of the Subcommittee on Orthotics of the Committee on Prosthetic-Orthotic Education, National Research Council," *Journal of Bone and Joint Surgery,* 52-A:1440–1442, October 1970.
4. Perry, J. W., and B. R. Friz, "Graduates of Degree Programs in Prosthetics and Orthotics," *Orthotics and Prosthetics,* 24:10–20, December 1970.

Publications Issued

5. *Newsletter . . . Amputee Clinics*—three issues.
6. "Educational Programs for Prosthetists and Orthotists," a report of a workshop held at Ponte Vedra Beach, Florida, June 15–17, 1970.

Mauch Laboratories, Inc., Dayton, Ohio 45439
Hans A. Mauch

R&D activities during the report period continued on a somewhat reduced scale because of the production of the S-N-S system which involves part of the shop personnel. In spite of this diversion of effort, substantial progress has been made in the development of the Hydraulic Ankle Control Unit. All the remaining functional problems have been solved and all the noises seem to have been eliminated including a rather problematical one at toe off. In addition, significant progress has been made in the development of the Voluntarily Actuated Swing and Stance Control Unit. The design of the prototype unit was completed and all the shop drawings are ready for parts manufacturing. Two machinists, hired in December 1970 for the increasing production work load, will release R&D capacity in the shop.

A number of S–N–S systems from the first production run are now coming back from the field after approximately 1 year of use by very active wearers. Typically these units are returned because of a small amount of air in the system or because of somewhat reduced maximum swing-phase resistances, both due to wear by abraded particles. In order to reduce abrasion and to lengthen the first wear period, hard-anodizing of the inside wall of the main cylinder is being considered.

A second finding from the field concerns the eccentric inserts or bushings used on the piston rod bolt for enabling the prosthetist to vary the knee alignment at maximum extension of a finished prosthesis by ±3 deg. In a few cases it was found that these eccentric inserts worked them-

selves out of the aluminum bushings inside the knee block. It was decided to use shorter glass fibers (⅛ versus ¼ in.) as a filler in the molded nylon eccentric inserts, thus producing a more uniform distribution of these glass fibers and higher rigidity of the eccentric insert against cold creep.

Generally the modified setups for the S–N–S system performed very well: The reduced side play of the knee block made possible by a blunter taper at the end of the knee bolt, combined with reduced radial tolerances of all three bolts, has eliminated the noises encountered initially.

No further significant findings were revealed by analyzing the first units returned from the field for minor repairs or updating, though service experience will be monitored carefully on a continuing basis. The S–N–S system stands up very well in practical use and the demand for both VA and civilian amputees is increasing steadily.

In view of the upcoming next production run a number of design and production improvements have been incorporated in the system and setup in order to reduce cost.

In carrying out further amputee tests with the Hydraulic Ankle Control Unit numerous modifications were introduced in the existing control bushing and ankle bolt, often in an improvised manner which made the durability of these parts doubtful. It was therefore decided to manufacture replacements for these parts and make them for the first time of hardened steel.

Tests were resumed after these changes and the following results were obtained:

a. The control bushing functioned as expected and to the satisfaction of the test amputee in all walking activities including standing, walking, stair descent, and ramp descent. No yielding or other instabilities were present at or just after dorsiflexion stop during standing.

b. A number of rather annoying noises initially occurred during every step in walking. Since there was reason for the assumption that these noises were caused at the interfaces between the hydraulic unit proper and the attachment elements for it within the shank, these elements were tentatively modified to investigate the assumption. Subsequent tests confirmed that all the noises except one at toe off were eliminated by these modifications. The tentative design changes were then given their permanent configuration which involved a certain amount of redesign work.

The one remaining noise on toe off could not be eliminated for quite some time in spite of extensive tests. It was finally decided to add more grooves on the surface of the control bushing and bolt in an attempt to eliminate cavitation by reducing the areas which separate under oil dur-

ing load reversals. In order to do this it became necessary to redesign the control bushing in such a way that the oil access recess on its surface became square shaped. This made it possible to apply a system of circumferential and longitudinal grooves which intersect at right angles (for manufacturing ease) and still come very close to this recess without producing leaks. The grooves were made approximately .030 in. wide leaving a land of .020 in. width between them. Almost the entire outside surfaces of the control bushing and bolt were covered with these grooves except for an area on the top side of these two parts which is under heavy load in walking over the leg and where no pronounced load reversal takes place.

The unit thus modified was tested by hand and in actual walking by the amputee, with marked success. The main noises are eliminated and the remaining noises are so insignificant that the amputee is now willing to wear the unit routinely. However, before this starts an effort will be made to reduce or eliminate the remaining noises.

In designing the prototype Voluntarily Actuated Swing and Stance Knee Control Unit, it was possible to reduce the knee bolt-cylinder bolt distance for this unit from the 8⅜ in. of the S–N–S system to 7½ in., which is more in keeping with established standards. The space thus obtained at the bottom of the unit can also be utilized for the installation of an elastic member which may enable the amputee to walk in a more natural fashion, by locking the unit fully on heel contact, but still allowing him to produce an elastically limited knee flexion by pushing his stump forward and by compressing the elastic member at the bottom of the hydraulic unit. The leg will straighten out again shortly before the end of the stance phase when the dorsiflexion stop prevents further forward motion of the shank. In this way the shock absorbing gait of a natural leg would be duplicated for the first time in a prosthesis.

New York University, New York
Leon Bennett

A program concerned with stress analysis of amputation stumps has been initiated. The study will seek answers to the following questions:

1. Does a zone of high stress exist in that flesh proximal to the brim of prosthetic sockets?
2. If so, can the local stress be reduced by such means as gradually reducing socket stiffness as the brim is approached?
3. Does the initial fit (constraint) influence the stress level at or near the socket brim?
4. Does the existence of a cyst influence the stress level in the immediate neighborhood of the cyst?

The means employed in this study will be largely analytical, with special emphasis on variational techniques as applied to the theory of

elasticity. Early results indicate that a linear load applied to a thick slab of flesh, as by a knife edge, will create considerable stresses 1 in. radially from the point of application. The thickness of soft tissue from skin to firm bone also influences the stress distribution and magnitude.

Northwestern University, Chicago, Ill.
Robert G. Thompson, M.D., Dudley S. Childress, Ph. D., and Edward C. Grahn

It is clear that improved prostheses for amputees develop most quickly when there is close interaction between the prosthetic developers and the amputees. It also seems evident that the amputee and prosthesis need to be viewed as a total system and not merely as individual components. Therefore, while it is obvious that a development laboratory must work on individual components (e.g., sockets, limb components, etc.) and individual techniques it seems clear that this individual development should be guided so that it is kept in the proper relation to the development of the total system (man-prosthesis). This approach as well as rapid service is being used at Northwestern.

A guiding principle for the Laboratory is that the systems which are developed should be self-contained and self-suspending. The cosmetic aspect is stressed but not at the expense of function. A modular concept is emphasized to facilitate simple repair or exchange of components.

Upper-extremity development work has centered on the design of self-suspending sockets for wrist-disarticulation, below-elbow, and above-elbow amputees. Success has been obtained with self-suspension at all these levels. It is felt that self-suspension is required in order to maximize the effectiveness of external power and neuromuscular control.

Design work has continued on improved neuromuscular control systems so that upper-extremity amputees may control their prostheses without external harnessing.

Commercially available electric hands and the VAPC elbow have been used with the systems now under development. An electric-powered hook is necessary for these systems and preliminary work has begun on such a unit. A wrist rotator, also under development, may later prove to be a necessary adjunct to the systems, particularly for the bilateral amputee.

Success with self-suspension of the above-elbow prosthesis using an atmospheric-pressure suspension approach has prompted the investigation of the same method for above-knee prostheses. Two above-knee sockets of this type have already been fitted and an accelerated evaluation of this socket through other facilities of the Northwestern Prosthetic-Orthotic Center is anticipated.

Experience with upper-extremity amputees fitted immediately or soon after surgery indicates that this is a method of management which can be very beneficial to the amputee. It is therefore believed that this management procedure should be widely publicized so that it can be more generally used.

Encouraging results have been obtained through the application of electric power to hand orthoses, so development work is continuing.

University of California at Los Angeles
Biotechnology Laboratory
John Lyman, Ph. D.

Current work in the Biotechnology Laboratory has covered the following areas: 1. The continued development of a prototype model of an electropneumatic actuator for a prosthesis, 2. The integration of a transducer control harness to an experimental arm model, and 3. Experimental studies on the application of an aiding control subsystem to prosthesis control. An interim report which describes in detail the work accomplished and the experimental results is now in preparation and will be published at the end of March 1971.

A brief summary of the progress to date in each of the areas of work is given as follows:

1. Electropneumatic Actuator

The electropneumatic actuator consists of a double-acting pneumatic actuator which is piloted by a stepper motor. A motor-driven worm gear adjusts a 4-way pilot valve which drives a double-acting pneumatic cylinder. Current work in the Biotechnology Laboratory is focused on streamlining the actuator and overcoming the technical problems of achieving a smooth and stable closed-loop control. At present the complete control system is operational; the actuator is installed to provide for elbow flexion-extension movement in a bench model simulating an artificial arm. Preliminary evaluation indicates excellent capability in holding the position of the elbow. Disturbance of the holding position of the actuator produces a counter torque which tends to return the elbow to the "lock" position in a smooth, cosmetically desirable manner. Two problems will necessitate mechanical modification of the existing actuator. Instability occurs in response to high-speed operation or large disturbances, and a control delay is caused by a deadband in the 4-way valve. Solutions to these problems appear to be attenuation of the mechanical feedback and a new valve design.

Planned pursuit of the development task aims at providing a working electropneumatic actuator model which will yield specifications for a prosthesis actuator.

2. Transducer Control Harness

A prosthesis harness which contains three control transducers has been developed at the Biotechnology Laboratory in past years. Current efforts are directed to testing the operation of the "transducerized" harness in the control of a three degree-of-freedom bench model which simulates an arm prosthesis. On his right shoulder the subject wears a plastic

shell. The shell is held on by a figure-eight harness in a configuration similar to a prosthesis harness. The subject also wears a strap across his chest and a belt around his abdomen; a strap connects his right shoulder to the belt at the center of his back. Strain gages fixed on the harness straps make up the transducers. A control logic circuit has been developed which provides for two-directional control of the drive for each axis. The circuit provides for proportional rate control in both directions. A small pull force on the strap generates a positive control signal. A larger force generates a negative control signal.

Experiments with the control harness are currently in progress. In these experiments subjects perform a set of block moving and arrangement tasks. Preliminary results have indicated that the approach is feasible. Subjects were able to exercise proportional control and produce fine movements in the arm. As the approach has proved feasible, it is planned to initiate work in technical streamlining of the control harness. This will involve the selection of strain gages and the optimization of the harness configuration for prosthesis support and control.

3. Aiding in Prosthesis Control

Research efforts of the Biotechnology Laboratory on the development of patient aiding systems to assist in prosthesis control action have led to the development of an adaptive aiding concept. The concept utilizes machine-learning principles and is principally based on a doctoral dissertation by Amos Freedy. Current efforts are directed toward the evaluation of applications of adaptive aiding to prosthesis control. Experiments are being conducted in the application of the aiding system to assist subjects in the control of an externally powered bench model of an artificial arm while using the control harness which was developed in the Laboratory. In these experiments two groups of subjects are being compared. One group performs a task while the adaptive aiding system is connected to the control loop; the other controls the arm without the aiding system. Preliminary results emphasize a distinct improvement of level of performance for subjects with the aiding system. The results of the preliminary experiments will be given in the coming interim report. Continued experiments to obtain formal identification of the effect of aiding capabilities may improve performance. The results of the experiments would provide guidance for the further streamlining of the adaptation of the adaptive aiding concept to control of artificial limbs.

University of California at San Francisco and Berkeley
Biomechanics Laboratory
Charles W. Radcliffe, Howard D. Eberhart, and James M. Morris, M.D.

Redesign of the pneumatic damper and the linkage to alleviate structural problems in the UC–BL Four-Bar Linkage Knee for above-knee prostheses has been completed. Complete drawings of the re-

designed device will be prepared early in 1971 with the intention of progressing to preproduction testing of approximately 10 units.

One prototype of the UC–BL Six-Bar Linkage Knee for above-knee and through-knee prostheses has been completed and subjected to limited amputee trials. Performance of the device was very encouraging. It exhibited greater knee stability and less polycentric action than the UC–BL Four-Bar Linkage Knee. Modifications of the design have been made, and plans for production of a second prototype early in 1971 are underway. The new unit is expected to be considerably smaller and to perform more like the Four-Bar Linkage Knee than the first prototype.

The computerized digital data-acquisition system to be used for fundamental studies of human locomotion was ordered in mid-1970 and delivered late in November 1970. It is being installed, along with the old treadmill and floor walkway, in new laboratory space on the Berkeley campus. Actual use of the new system is expected to start early in 1971, with emphasis on two related objectives: one, to continue development of a unified body of normative material on human locomotion, and the other, to proceed with the development of clinical techniques and devices for applying these norms to the evaluation of pathological gait.

Preliminary fittings of the laboratory model of the Four-Mode Artificial Arm were made in September 1970, using proportional, open-loop control of prosthesis motion, which is pneumatically powered. The method of control proved to be smooth and easy to learn. Position feedback was added to increase stiffness of the system. Testing of this method has begun and comparison of open-loop and closed-loop control will continue. Potentiometers have been added to the prosthesis to make possible precise measurements of control effectiveness. The new data-acquisition system, mentioned above, will be used to gather and digitize the data.

Digital computer programs, written to allow the simulation of the dynamics of swing-phase control systems, are currently being used to study the motion of single-center and four-bar polycentric knee mechanisms. The performance of the pneumatic controller at various cadences has received particular attention.

Studies of the physiological and therapeutic effects of the Royalite jacket on 12 normal subjects have indicated that the vital capacity is decreased by approximately 10 percent. Increased intra-abdominal pressure generated as a consequence of wearing this spinal brace does cause some mild restriction of venous return from the lower extremities in the sitting and stooping positions. However, with normal walking and standing there is minimal, if any, effect on venous return. Braces made on the Royalite pattern but fabricated from more resilient materials are being made in an effort to improve the comfort and acceptance of the appliance.

VA Hospital, Seattle, Wash.
Ernest M. Burgess, M.D., and Joseph H. Zettl

For progress during this report period, see "Prosthetics Research Study Progress Report, July 1, 1969–December 31, 1970," appearing elsewhere in this issue of the Bulletin.

VA Hospital, San Francisco, Calif.
Wesley L. Moore, M.D., and Albert D. Hall, M.D.

During the 6-month interval ending December 31, 1970, seven amputations with immediate postoperative prostheses were performed. Skin blood flows at the site of amputation were measured using Xenon-133. There was only one failure of primary healing. This occurred in a patient who had a skin blood flow measurement of 0.55 cc/100 gm. of tissue/min. The other six patients had blood flows well in excess of this figure. These data continue to correlate well with initial observations concerning the value of Xenon-133 as an accurate technique for evaluating the adequacy of skin blood flow at the proposed level of amputation.

During this period, two knee-disarticulation amputations were performed in patients with ischemia too high to permit a short below-knee amputation. These operations were done in preference to the supracondylar location for amputation. Both patients came through the immediate fitting procedure extremely well. Their ability to ambulate compared well with the below-knee amputation inasmuch as the type of prosthesis used for the knee disarticulation was identical with the immediate fitting procedure for the below-knee amputation. These patients have gone on to permanent prostheses and show a definite advantage over above-knee amputation with regard to their ability to ambulate.

The initial phases of testing of capacitance plethysmography as a means of measuring total extremity blood flow have been completed. The initial plethysmograph cuffs were the size that have been used only on arms. At the present time larger cuffs and calibration devices are being constructed to permit application of these measurements to the lower extremity.

Currently in preparation is a scientific exhibit documenting the advantages, technique, and results of the immediate postoperative prosthetic program. It is planned to have this exhibit ready for initial showing at the American College of Surgeons meeting in October 1971. Applications for showing this exhibit at other meetings including the American Medical Association will also be made.

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Since the last report, collection and organization of the data from the 427 patients receiving 559 low-extremity amputations because

of ischemia have gone forward. The work on this is being performed by Dr. Gilbert W. Beebe and his team of the National Academy of Sciences-National Research Council Follow-Up Agency. Dr. Ronald B. Kihn has been consulting with that team and preparing two reports. One of these will appear in the surgical literature, and the other will be published by the VA Prosthetic and Sensory Aids Service. Two findings of interest have emerged as compared with the 1964 survey in 14 VA hospitals, namely, that due to our interest in these patients the mortality in the hospital has dropped from 22 percent to 11 percent, more patients were walking with a limb at time of hospital discharge, but the overall mortality at 2 years approaches 40 percent.

Cambridge Hospital
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Richard Warren, M.D.

The objectives of the project were outlined in the last report. By the end of 1970, 27 lower-extremity amputations had been treated by the collaborative team, 24 of them in ischemic limbs. Rehabilitation success has been obtained in 15. There were three healing failures. The first year of the experience has taught cautions pertaining to the administration of a project undertaken on a consultative basis. Maintenance of communications between the responsible clinical group and the Boston Interhospital Amputation Study (BIAS) Group is the most difficult problem, and a breakdown in this area was responsible for two of the healing failures. During the year, the project staff saw an estimated 5 percent of all major amputations done in the lower extremity in the Boston area. Hopefully this percentage will increase markedly during the next year.

The Johns Hopkins University
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Woodrow Seamone and G. Schmeisser, M.D.

During the latter half of 1970, the work at Johns Hopkins was concentrated on the fabrication of additional external power pack units for upper-extremity prostheses and the fitting of these units to amputees for evaluation. These power packs interface with conventional upper-extremity prosthetic components and provide for proportional control of the terminal device or elbow. External power is controlled by a single-site myoelectric sensor built into the socket of the prosthesis, transmitted through a Bowden cable to replace body power. Four amputees have been fitted during calendar year 1970.

Unit #1—This unit was fitted to a wrist-disarticulation amputee in February 1970. The motor, electronic control unit, and battery pack are worn on the waist. The EMG sensor is built into the stump socket in a

floating arrangement. Proportional opening of the terminal device is controlled by varying the EMG signal in the desired manner. The unit was evaluated in three phases.

During the break-in phase, which lasted for several weeks, the amputee wore the prosthesis for graduated periods while performing increasingly demanding manual skills. Design features which caused wire breakage and other mechanical and functional problems were identified and corrected. By practicing various manipulations the amputee attempted to develop maximum dexterity.

In the comparison phase, various physical and functional measurements were made comparing the new prosthesis to the amputee's preexisting body-powered prosthesis. These include the span, force, velocity, and fine control characteristics of the terminal device grasp, the range of terminal device placement, the bi-manual work envelope, and grasp-placement coordination as well as stability, weight, comfort, and speed of application. Test activities were recorded on movie film for review and further analysis.

In the final phase, arrangements were made for the amputee to wear the new appliance as his primary prosthesis for all of his activities for several months in order to reveal undiscovered problems and to determine mechanical endurance and ultimate amputee preference.

After wearing the unit for 1 year, the amputee reported the following: For delicate work the body-powered (BP) prosthesis is superior to externally-powered (EP) due to 1. shoulder muscle feedback, 2. the capability of setting shoulders for steady force, 3. lack of lag, and 4. higher speed. Due to the time lag and lower velocity, he was inclined to use his EP prosthesis primarily in a bang-bang mode, neglecting its potentialities for proportional control. He disliked battery and motor bulk and weight, especially at the end of the day. EP is useful in special situations where shoulder motion is undesirable or difficult, e.g., 1. reading in bed, 2. lubricating under an automobile. Lack of compression force on the end of the amputation stump is a definite advantage with EP. A snugger socket fit is an advantage with the EP unit. He has had no sensor site skin sensitivity problems despite a known high sensitivity to nickel, used in the metal rivets in his lower limb prosthetic socket and in his wrist watch. The net result of all factors is that he likes to have his EP for special uses and for relief from his BP, especially in hot weather. The average EP use is now 2 to 3 days per week.

Unit #2—This unit was fitted to an above-elbow amputee in August 1970. One year prior to this time he had been fitted with a BP above-elbow prosthesis with internal locking elbow, above-elbow figure-eight harness, dual control quick-disconnect wrist, VO hook, and APRL hand. He developed moderate facility with this equipment but never used the hand. The EP unit is located in the elbow space and controls either the ter-

minal device (VO function) or elbow flexion, using a routine external locking strap to the shoulder saddle in order to select terminal device versus elbow function. The battery for this system is located on the belt. The single-site EMG sensor is mounted in the stump socket over the biceps muscle.

This amputee uses the EP prosthesis exclusively full time, all the time. Except for some strap buckle adjustments and problems with the quick-disconnect wrist unit, both of which are unrelated to the powered system, there have been no problems or adjustments of the EP system. Preliminary results of this evaluation have pointed up many of the potential advantages of this powered system including its ease of control, lack of noise, and a wider work envelope range.

Unit #3—This system was fitted to a right, mid-below-elbow amputee during October 1970. He had 1 year's prior experience with a BP below-elbow prosthesis. He wears his EP system most of the time, except when he does not have time to put on this tightly fitted socket which was selected to aid him in playing piano. He believes a socket fitting equivalently tight in a BP model would be very uncomfortable, due to the end pressure required in a BP system to react against the Bowden cable forces.

This amputee had a very weak EMG signal when he was first fitted. After the first week of wear, his signal improved by a factor of 2–3, necessitating a readjustment in electronic system gain. His EMG output has remained constant at this high level since that time. This amputee is a piano student. He has been able to continue his piano lessons and is developing a good facility for the control of his EMG signal while playing the piano.

Unit #4—This unit is fitted to an above-elbow amputee who had only 2 months' experience with his BP prosthesis prior to being fitted with the EP unit. His power unit and battery pack are worn on the waist with a Bowden cable transmitting power to control elbow flexion and terminal device of a conventional above-elbow prosthesis. As of the end of December 1970, he had worn the unit less than 1 month but extremely pleased with the functioning of the unit. He wears his EP unit preferentially and exclusively except for short periods in the evening when he wears no limb at all.

Evaluation will be continued with these four amputees and, in addition, four more amputees will evaluate EP prostheses during 1971 in order to provide quantitative data on system performance over a wide range of potential applications.

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Studies were initiated and/or continued on several projects dealing

with the development of refined fitting procedures for lower-extremity prosthetics.

1. The development of an *above-the-knee suction prosthesis* which is easily applied, light in weight, and requires only minimal proximal suspension. This experimental prosthesis is based on the principle of a two-part socket: the inner one being soft and pliable and non-attached to the main prosthesis. This functional prosthesis has been used in patients of advanced age or those afflicted with other physical impairments. Recent investigations have been geared toward the development of an adjustable socket which will accommodate stump atrophy. The original design has been modified to allow adjustment of the proximal 2 in. of outer socket. With this modification, suction suspension may be maintained for longer periods of time for the new amputee, eliminating the need for frequent socket replacement.

2. The development of improved *suspension mechanisms for below-the-knee prostheses* using built-in soft supracondylar wedges. The wedge is placed proximal to the adductor tubercle. The soft rubber wedge is shaped to each individual's requirement; it is glued to the socket and covered with leather. Compressibility of the wedge allows the patient to don the prosthesis with ease. Considerable experience has been accumulated in this area with over 200 patients. Present efforts are being devoted to the development of similar mechanisms applicable to "difficult" short and flabby stumps where additional suspension systems may be necessary. This prosthesis will eliminate the constricting effect of the conventional supracondylar PTB strap, as well as the often cumbersome and unreliable removable hard wedge. It will benefit, however, from the suspension principles of the PTS design.

3. The development of a cosmetic and *functional Syme prosthesis* in an effort to eliminate some of the traditionally undesirable features of this prosthesis. This prosthesis was initially developed in 1964. This expandable inner-wall windowless prosthesis provides the maximal advantage when used for the *modified* Syme amputation with narrowed distal end. Avoidance of the removable window of the traditional Syme prosthesis, therefore, strengthens its structural design and improves the unsightly appearance of the Canadian Syme prosthesis. Studies are being conducted at the present time to investigate the use of expandable materials that will maintain desirable compression of the stump tissues during the various periods of atrophy and girth changes inevitably experienced by stumps stabilized in presently available prostheses.

Studies conducted in the three areas described above have included the *mapping of pressure distribution* in an attempt to utilize best the available areas for maximum efficiency and comfort. In an effort to redesign Syme and below-knee prostheses, pressure studies are being conducted to determine the major weight-bearing areas. Those areas

generally considered to support the majority of the load, such as the patellar tendon, the medial tibial flare, and the distal end, are being studied by considering these areas in the entirety (1–3 sq. in.) rather than by attempting to map pressure distribution by means of ¼ in. dia. transducers. This technique is expected to provide information that will allow changes in the weight-bearing characteristics of the socket.

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At McGuire Veterans Administration Hospital an intramural project has just been started to study the possibilities of applying upper-extremity braces prior to or immediately following surgery. The reasons for such brace experimentation are to speed up the process of brace construction and application, to provide flexibility in accomplishing specific surgical goals, to reduce hospital stay, and to improve the results obtained from patients who require operations such as tendon transfers, nerve repairs, and other more complex reconstructive operations in the upper extremity.

To date, braces have been simple metal braces without felt padding so that the braces could be autoclaved at surgery and applied directly over the dressing. Within 2 weeks following this surgery sutures are usually removed and the dressing reduced to a small size, so the brace can then be padded with felt and applied directly to the skin. So far this method has eliminated the casting step and has made care of the wound much easier.

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This project, initiated November 2, 1970, is concerned primarily with improvement of material for lower-extremity prostheses. The work is being performed by an interdisciplinary team including engineers, physicians, and prosthetists. In this initial report period, the primary efforts include a comprehensive critique of the literature, materials data review, structural analysis, and preliminary design. It is essential to retain as much of the developed technology in the disciplines of prosthetics and orthotics as possible, i.e., use the commercially available fixtures and components. It is understood, however, that some changes and revision of procedures may be necessary.

A summary of specific tasks is:

1. *Literature Review.* A comprehensive literature review has been completed. Using all of the readily available locomotion data, the kinesiology of normal walking is being summarized in a set of illustra-

tions having consistent scales and units. These data can be used for synthesis of new designs or for analysis of existing designs.

2. *Materials Review.* Both generic and specific data were collected on available commercial materials for new composite designs. Generic data are necessary for choosing a class of materials for particular designs. Specific data pertain to subsets of materials within a class which can be used in new composites which have desirable physical, mechanical, and chemical properties.

3. *Lower Extremity Prosthetic Standards.* Existing lower-extremity designs were summarized in a table to study possible systems standardization.

4. *Structural Analysis.* In general, existing lower-extremity prostheses are not significantly structurally deficient; however, suitable structural integrity can be achieved with lighter, composite-material designs.

5. *Anatomical Knee.* A 4-bar linkage has been designed in modular concept to provide an analog for the anatomical knee. This concept should be useful in orthotic bracing as well as in prostheses.

6. *Flexible Hip-Disarticulation Socket.* Procedures are being reviewed for designing a hip-disarticulation socket which is light in weight with increased strength, and with flexure characteristics deliberately differing in A–P and M–L planes.

7. *Uniform Pressure Socket.* Two design concepts have been completed which will provide for uniform pressure distributions which vary during the walking cycle and which provide for adjustment to accommodate for changes in stump size.

8. *Variable Gait.* A variable gait mechanism is being developed which employs the position of a weight in the lower shank as the means of adjustment.

9. *Knee Cosmesis.* High elongation, low-modulus, castable materials are being assessed to serve as a cover for the knee to improve cosmesis and decrease clothing wear.

10. *Cosmetic Shape.* Procedures are being investigated for rapid and inexpensive replication of the existing leg of a unilateral amputee by inversion molding and foam casting. Problems being studied included mold stability and compatibility with existing procedures.

11. *Cosmetic Coatings.* Casting, spray, and dip procedures for producing waterproof covers having skin texture and appearance are being investigated.

It is planned that a hip-disarticulation prosthesis will be fabricated for a selected patient which will incorporate the lighter, uniform pressure socket with variable flexure properties, variable gait, cast cosmetic shape, and knee cover, as described above.

Other aspects of materials and structures being investigated include the following:

12. *Leave-In Alignment.* Suitable materials are being considered for

a low-cost, leave-in, permanently adjustable alignment device.

13. *Thigh Cosmesis.* The possibility of casting an air bag for thigh cosmesis on the Canadian hip prosthesis is being investigated.

14. *Goniometric Compensator.* A simple low-cost wafer system for rotation about the vertical axis of the limb has been designed in modular concept. Stability, fabrication methods, and materials compatibility are being studied. The compensator will be about 1 in. thick and can be employed in existing designs.

15. *Powered Knee Extension.* A design is being investigated whereby orthotic knee braces could be placed asymmetrically on an above-knee artificial limb. The brace would then serve simultaneously as a joint and a spring. The spring action results from the torsion of the brace bars with flexion of the knee.

SENSORY AIDS

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Fabrication of Obstacle Detectors for the Blind

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During the period 7/1/70–12/31/70, a series of modifications were made to the cane, as recommended at an evaluation meeting at Hines, Ill. VA Hospital on September 3, 1970.

The meeting was attended principally by mobility trainers who were working with the cane.

The general attitude toward the cane seemed to be cautiously optimistic. All found the forward channel to be either currently useful or potentially useful if its range were moved forward 2 ft., and one group (Hines) found the lower channel to be useful in its present form. It was generally considered that a laser cane, even with only a forward channel, would be a significant improvement over a simple mechanical cane, and that the usefulness of the other two channels would vary with the individual, the geographical location and patterns of travel, and the extent to which mechanical, electronic, and inherent optical problems (primarily in the lower channel) could be corrected.

On the basis of experience to date it was decided to make the following modifications to all 10 canes to improve their functioning: