# HIGHLIGHTS OF OTHER VA RESEARCH PROGRAMS

## PROSTHETICS

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For progress during this report period, see "Annual Summary Report, Activities for Year Ended June 30, 1972, Committee on Prosthetics Research and Development" appearing elsewhere in this issue of the Bulletin.

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For progress during this report period, see "Annual Report, Committee on Prosthetic-Orthotic Education, Fiscal Year 1972" appearing elsewhere in this issue of the Bulletin.

Because of the organizational changes described in the above report, the CPOE report will no longer appear separately, but instead will be combined with the CPRD report starting with the next issue of the Bulletin.

**Research and Development in the Field of Artificial Limbs**
**Mauch Laboratories, Inc.**
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For progress during this report period, see "Abstract of Summary Report on Research and Development in the Field of Artificial Limbs" appearing elsewhere in this issue of the Bulletin.

**Stump Stress Analysis**
**New York University**
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**Bronx, New York 10453**
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For progress during this report period, see "Transferring Load to Flesh: Part IV. Flesh Reaction to Contact Curvature" appearing elsewhere in this issue of the Bulletin.

**Prosthetic Research**
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Design of electronic components for the VA/NU myoelectric system for below-elbow amputees was completed. Production versions of this system in hybrid form should be available in 1972.

The laboratory assisted with the fitting of two bilateral upper-limb amputees. This experience led to several interesting developments: 1. A rugged and simple glenohumeral joint, which provides glenohumeral flexion-extension and abduction, was developed for the interscapulothoracic amputee. The joint is called an *orthogonal cylinder glenohumeral joint* because its construction consists of cylinders which are orthogonal to each other. The holding ability of the joint is good, and this does not diminish with time or with usage. 2. The Sierra wrist-flexion unit was modified so that the locking and unlocking latch could be placed on the lateral side. The two patients who were fitted both found the lateral location of this latch to be preferable to the medial location. 3. The VAPC elbow was adapted to the Otto Bock endoskeletal system. The endoskeletal system seems very beneficial for the interscapulothoracic amputee, since the prosthesis can be made relatively light with this type of construction.

Work has continued on above-elbow hybrid systems and with above-elbow self-suspending sockets.

A graduate student has been engaged in a preliminary study of myoelectric activity of muscles associated with the hip and knee. The object is to find superficial muscles whose natural activity can be used for control of a passive artificial knee joint.

**Fundamental and Applied Research Related to the Design and Development of Upper-Extremity Externally Powered Prostheses**

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Current work in the Biotechnology Laboratory is directed toward the production of a prototype operational externally powered prosthesis system. The system will incorporate an adaptive control technique and is centered around the UVP prosthesis (University of California–Veterans Administration Prosthesis). Work in the reported period covered the following items:

*a. Adaptive Aiding Technique*

Continuing work in the area of adaptive aiding for upper-limb prosthesis control has concentrated on preparing a general facility for developing and evaluating aiding techniques. While the physical elements of the man-computer control system are being prepared, the adaptive aiding algorithms previously used with a three-degree-of-freedom manipulator are being modified and programed for use with the UVP in clinical experiments and evaluations.

The previous adaptive aiding system used absolute position information to predict the next stopping point of the manipulator. An aiding system for use with the UVP must use different input information since, due to variations in the natural position of the patient's shoulder region, absolute position will not be known. Additionally, the new system is designed to control the path of motion between stopping points. These improvements are currently being implemented.

*b. Variable Transformer Skin Motion Transducer (VTSMT) Control System*

A method of controlling orthotic/prosthetic devices by means of skin motion transducers is being developed for tests with the prototype system. The transducer consists of a variable transformer with a moving

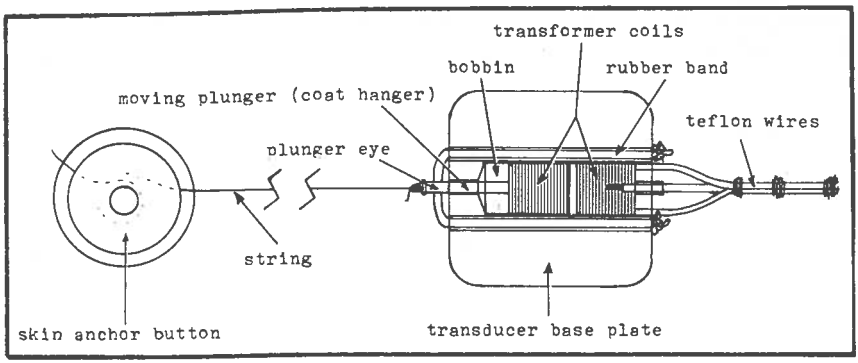


FIGURE 1.—Transducer base plate and skin anchor button.

plunger linked by a string to a skin anchor button (Fig. 1). The transducer base plate (1¾ in. long x 1¾ in. wide x ½ in. above skin surface, Fig. 2) and the skin anchor button (Fig. 3) are adhered to the skin by

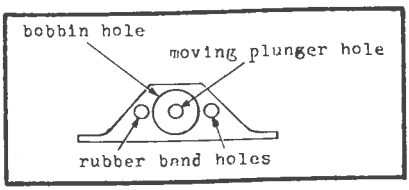


FIGURE 2.—Rear view of transducer base plate.

means of double-sided iliostomy bag adherent tape and can be left in place for as long as 2 weeks.

In operation, movement of the distance between the transducer base plate and skin anchor button moves the plunger in and out, thereby

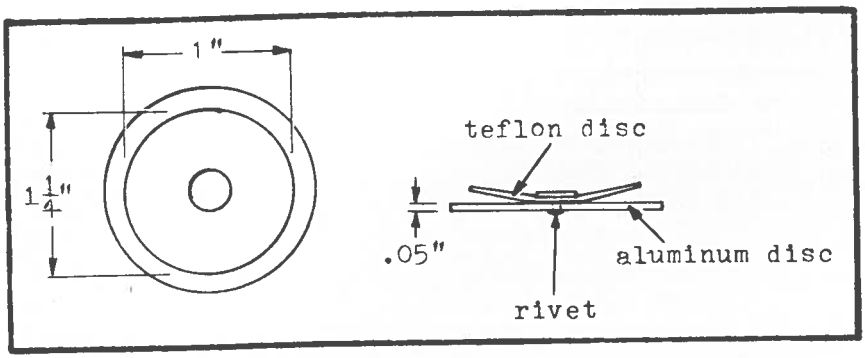


FIGURE 3.—Skin anchor button. This button is similar to the skin motion button originally developed by Seamone at the Johns Hopkins Applied Physics Laboratory (private communication).

varying the voltage induced into the secondary winding of the transformer. This secondary voltage is rectified and processed in electronic circuits to produce the function shown in Figure 4. In addition, level detectors with hysteresis are provided for each transducer. They can be set so as to provide TTL-compatible switching signals at any desired plunger position.

A three-VTSMT-control system and a computer-aided externally powered prosthesis are in the process of being experimentally evaluated on a unilateral above-elbow amputee. Elbow flexion-extension, wrist rotation, and hand prehension are to be controlled by the skin motion transducers, which will be mounted somewhere on the body trunk. Computer control of the prosthesis/orthosis will occur automatically when a predetermined confidence level concerning the next desired movement is achieved by the computer. Override will be effected by moving any one of the three VTSMT plungers from the fully inserted position, thereby causing a Schmitt trigger to reset the manual/computer switching circuits.

*c. Mechanical Modification of the UVP Arm*

Some mechanical modifications were done to the UVP arm. In the past, two 2/56-in. screws with a 180-deg. angle between them were attaching the gear onto the elbow shaft, which was driven by a worm gear. It was found that every time a load was put on the arm, the screws would loosen, and backlash occurred. Also, it was found that a clutch and two static stops were built on the same shaft to limit the arm's motion (these were in addition to two microswitches and shaved teeth

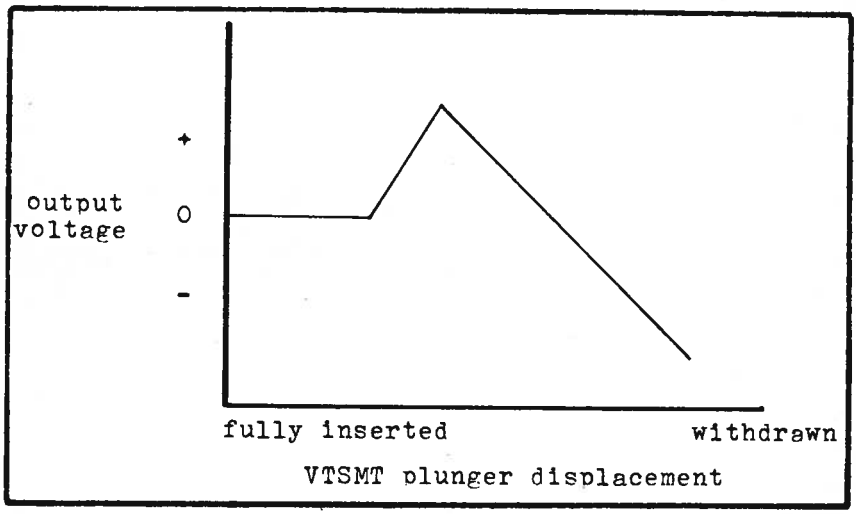


FIGURE 4.—Nonlinear bipolar control function for use with skin motion transducers.

on the gear that automatically disengage from the worm gear when it gets to the end of the motion). Since it appears that the arm would be well protected with the two microswitches and the shaved teeth on the gear, it was decided to remove the clutch and two static stops. To prevent loosening, two "Loctite" 8/32-in. screws with a 90-deg. angle between them replaced the 2/56-in. screws.

**Design of Prosthetic and Orthotic Devices and Biomechanical Studies of Locomotion**
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Twenty production prototypes of the four-bar-linkage polycentric knee unit with pneumatic swing-phase control were delivered by A. J. Hosmer Corporation. Amputee testing in the San Francisco Bay area and at VAPC, N.Y.C., will begin after completion of the development of a suitable cosmetic cover for the shank pylon.

The development of an axial torque absorber, which permits rotation of the socket about the long axis of the leg, has been completed. Three months of amputee testing indicated the need for minor design changes. These changes have been incorporated in five new units now ready for additional amputee testing.

Design of a six-bar-linkage knee unit suitable for supracondylar and knee-disarticulation amputees has been a major activity of the design group in this period. The kinematic arrangement has been optimized to provide functional characteristics similar to the four-bar unit for above-knee amputees. Drawings for a compact unit, which incorporates the same pneumatic swing control used in the four-bar design, are now being prepared.

The new prosthetics-orthotics laboratory, located in the Clinics Building at the San Francisco Medical Center, has been completed and is now being made ready for an increased activity in clinical prosthetics and orthotics.

**Immediate Postoperative Prostheses Research Study**
**Prosthetics Research Study**
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In addition to ongoing programs, primarily in clinical research, PRS has entered into a new field of investigation, that of bioengineering.

Many centers throughout the Western world are contributing to our knowledge in biomedical engineering. No attempt will be made to duplicate or substantiate information coming out of many extensive studies. PRS has the opportunity, however, to apply basic bioengineering methodology in certain areas in which the patient load, experience, and accumulated information can be meaningful. Attempts will be made to determine amputation level based on the measurement of several physiological parameters not previously coordinated. These will include discrete and improved measurements of skin temperature, impedance plethysmography, and refined Doppler ultrasound techniques developed by Dr. Bok Lee (Castle Point, N.Y., VA Hospital). A careful coordination of these measurements, together with the clinical determinants of level previously developed at PRS and including the usual vascular workup of these patients, may further refine the stated goal of routinely obtaining low amputation levels in peripheral vascular disease.

The protocol for this work will consist of the normal surgical workup and a bioengineering study of each patient. The results of the bioengineering workup will not be disclosed prior to the amputation initially, so that the presently utilized available medical information can later be coordinated with the biological measurement techniques. Thus, a "double-blind" technique will be used initially in these experiments. The goal of this type of work is to generate a list of parameters and their norms for each level of amputation, so that a simple equipment station can promptly, and without great expense, more accurately guide successful amputation level. This study will also involve a callback of a significant number of amputees for pulsatile bioengineering blood flow studies, both on the amputated and unoperated sides.

The new Bioengineering Research unit will also study the area of prosthetic sensory control systems. Attempts will be made to extend and complement the work of Dr. P. Rabischong (Montpellier, France) and Dr. Frank Clippinger and his colleagues at Duke University, on neuronal stimulation in the upper extremity for use in the lower extremities. The hopeful outcome of this work may be a more dynamic lower-limb prosthesis, with both proprioceptive feedback and stability of prosthetic control. Radial-frequency-stimulator implants of both the Medtronic and Avery design will be used to act as nerve stimulators, together with equipment proposed to be developed at PRS. As one of eight nationwide centers for the clinical evaluation of the Medtronic neuromuscular-assist device, for use in CVA patients with specific types of equinovarus gait deformity, it is planned to have 10 implants of the peroneal nerve stimulator type over the next few months.

In cooperation with Dr. George Van Cochran (St. Luke's Hospital, New York City), implanting self-contained battery-powered bone stimu-

lators for use in the study of electro-osteogenesis techniques will be done.

Functional limb-use evaluation on amputees with peripheral vascular disease will be conducted. The PRS system of management has now been standardized in the geriatric patient with ischemia long enough to allow an in-depth objective review of functional rehabilitation. In addition to the accepted measures for rehabilitation, analysis of gait using the heel-switch techniques developed by Dr. J. Perry (Rancho Los Amigos Hospital, California) will be performed.

Research continues in amputation surgical techniques. Additional knee disarticulations using the PRS low-transcondylar technique have been carried out. The two-stage Syme amputation for diabetic forefoot gangrene (Dr. W. Wagner, Rancho Los Amigos Hospital) is being evaluated. Technical improvements in muscle stabilization, particularly at the above-knee level, are continuing. Refinements in the immediate postsurgical prosthetic systems are under trial.

PRS has a continuing education program underway, directed particularly at Veterans Administration personnel and at the vascular surgical profession in general, whose members encounter the majority of civilians in this country who require major amputation.

In the area of prosthetics research, PRS is engaged in prosthetic socket designs and interface innovations in the below-knee prosthesis.

The Seattle Veterans Administration Hospital formally opened its newly completed Prosthetic Treatment Center on April 7, 1972. The region covered by the Center includes Washington, Oregon, Alaska, Idaho, and areas of Montana. In conjunction with this Center, the Seattle VA Hospital has established an Amputee Service of 10 beds, with future expansion planned when bed space becomes available, to admit those patients requiring hospitalization.

**Below-Knee Amputation for Vascular Insufficiency with Immediate Postoperative Fitting of Prosthesis**

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**San Francisco, California 94121**
**Wesley L. Moore, M.D., and Albert D. Hall, M.D.**

For progress during this report period, see "Below the Knee Amputation for Ischemic Gangrene, Comparative Results of Conventional Operation and Immediate Postoperative Fitting Technique" appearing elsewhere in this issue of the Bulletin.

## Interdisciplinary Development and Evaluation of Externally Powered Upper-Limb Prosthesis

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During the first half of 1972, the work at Johns Hopkins was primarily aimed at clinical fittings of four additional externally powered prosthetic and orthotic systems, as well as continued evaluation of eight systems which had previously been fitted (BPR 10–17, pp. 33–37).

The system under development at Johns Hopkins is basically an electrically driven cable puller (EXPACS). These EXPACS have been attached to a conventional prosthesis with minimal modifications over a wide range of amputation levels. Each EXPAC consists of a motor and an electronic control module which are packaged as a single unit. Details of their design and basic operating characteristics have been described in earlier issues of the Bulletin of Prosthetics Research.

The control signal sensor and battery pack are packaged as separate units. The EXPACS are arranged in two basically different equipment configurations: an above-elbow (A) configuration, and a below-elbow (B) configuration. In Type A, which is appropriate for amputations through or preferably proximal to the elbow joint, the motor is located within the prosthesis. In Type B, which is appropriate for amputations through or distal to the elbow joint, the motor is located outside the prosthesis, e.g., on the patient's belt. However, Type B can be used for amputations at any level or to power braces. Both configurations have been used to power more than one joint. The primary control input for the power unit is received either by a single-site myoelectric sensor or by a skin-displacement sensor.

### *Evaluation Progress*

Test amputees, representing an assortment of occupations and ages and with a full range of amputation levels, were selected to determine system versatility and reliability as well as other factors related to user acceptance. All amputees were fitted with functional, conventional, body-powered (BP) prostheses to facilitate comparison with the externally powered (EP) prostheses. All amputees were interviewed and examined periodically.

A summary of the evaluation results with the first eight amputees was presented in the BPR 10–17 Spring 1972 issue of the Bulletin of Prosthetics Research (pp. 33–37).

The new cases fitted during the reporting period include the following:

*Powered Elbow Brace.* This individual who was fitted has a congenital anomaly of his cervical spine, which has resulted in paralysis of the muscles of his shoulders and elbows. He cannot lift his forearms against the force of gravity. However, he has good function in the hands and wrists. He is an office executive who works at a desk, and he must stand in order to move objects from his drawer to the desk top. An articulated elbow brace powered by a Type-B belt-mounted EXPAC controlled by a myoelectric sensor over the atrophied biceps provides him with synthetic biceps muscle function.

A photograph of the brace arrangement is shown in Figure 5. The unit operated functionally, but the patient considered the brace heavy and bulky. Modifications have been made which significantly reduce the weight and bulk, and evaluation tests are about to begin.

*Shoulder-Disarticulation Prosthesis.* The system shown in Figure 6 was fitted to a man who is a rodeo rider and landscape-gardening manager. He has an acquired shoulder-disarticulation amputation. This prosthesis uses a Type-A EXPAC unit to provide terminal device function and elbow flexion. Proportional control of the motor is by a skin-motion sensor using an adhesive button attached to the skin. Elevating the shoulder controls the elbow lock by a cable connected to the trousers with a suspender clip. Although this man originally requested suspension by the cervical collar shown here, he has found that his prosthesis flops about when galloping on horseback. He has returned it for the addition of a cross-chest strap. He reports that all electrical components function satisfactorily but he has not had the appliance long enough for a meaningful evaluation.

FIGURE 5

FIGURE 6

*Below-Elbow Prosthesis.* This prosthesis was fitted to a high-voltage electrician and is shown in Figure 7. This man sustained a mid-forearm below-elbow amputation secondary to an electrical burn which produced severe scarring about his opposite shoulder. For this reason the socket must be self-suspending. The prosthesis is powered with a Type-B belt-mounted EXPAC. The prosthesis is shown here without its cosmetic cover. He usually prefers to wear a hook. Unlike all of our other amputees, he has not been fitted with a body-powered prosthesis for functional comparison. In his case, it was believed that the fragile skin on his opposite shoulder would not tolerate additional harnessing. Although he has been fitted with the powered prosthesis only within the last few weeks, he has expressed delight with his prosthesis and is wearing it full time.

*Bilateral Powered Prosthesis.* This prosthesis was developed to evaluate the use of external power for the bilateral case. The completed prosthesis is shown in Figure 8.

The volunteer for this case is a college student with a bilateral congenital shoulder-disarticulation amputation. After some test sessions with this patient to determine adequate control modes, the following system was evolved:

In this double prosthesis, a single Type-A EXPAC unit has been connected to provide both terminal-device function and elbow flexion on both sides as well as wrist rotation on one side. Force is transmitted to the opposite side by a cable running from the motor around a free pulley concealed just below the shoulder joint. This pulley is attached to a secondary cable which runs to the opposite side. By routing the cables in front of the rotational axes of the elbow joints and obliquely

FIGURE 7

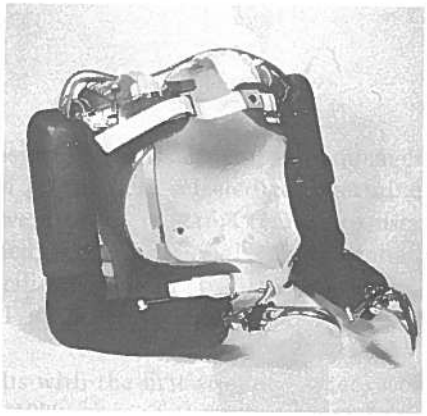

FIGURE 8

across the wrist joints, torque is applied to these joints when the motor is activated.

The control system entails a single proportional control and a set of selector switches. The myoelectric signals on this patient's trunk are of poor quality and are not used for this system. She can move the tip of her left scapula vertically only slightly, but nonetheless with greater range and precision than anything else about the shoulders. Hence, this is the motion harnessed for proportional control of the motor. This is done by running the control thread across the tip of the shoulder from the displacement transducer, which is attached on the posterior aspect of the prosthesis, to the button located on the front of the prosthesis. By this orientation, valuable control-thread excursion is gained with vertical movement of the shoulder. Other small, non-proportional voluntary motions of this and of the right shoulder are used to trip the microselector switches assigned to specific joints. These switches control logic circuits which unlock the individual joints to be moved. An electronic mechanism then automatically relocks each joint, after an adequate time interval has elapsed to permit bringing the joint into the desired position. In addition, there is a selector switch to coordinate the left elbow and wrist in a synchronized plate-to-mouth feeding sequence. As with all other joint motions, the rate and force are controlled by the same vertical motion of the left shoulder.

Although this appliance has been completed only recently and the amputee is now just starting functional evaluation, her ability to operate all components on command in the test sessions proves that a single motor can be arranged to power more than one joint in the contralateral as well as in the ipsilateral limb.

### *Future Plans*

Evaluation testing will be continued on these four new patients as well as followup on the eight original patients. Engineering and development will be continued on the basic EXPAC design. Studies during the coming year will address the use of the skin motion sensor more fully and will include further design and miniaturization of the electric elbow lock. Four patients will be fitted during fiscal year 1973, three amputees and one orthotic case, to further evaluate special features of this system. Drawings and specifications for the basic EXPAC system have been forwarded to the VA Prosthetics Center in New York for submittal to industry to manufacture a limited number for further evaluation.

## Development of Refined Fitting Procedures for Lower-Extremity Prosthesis

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The previously described experimental below-knee prosthesis (1), designed to spontaneously accommodate stump changes and maintain uniform pressure distributions throughout the stump, was subjected to further clinical testing. This Taslon-lined prosthesis demonstrated rapid decrease of swelling in old as well as recent amputation stumps. Problems with fraying of the Taslon material, which militated against satisfactory and prolonged use of the prostheses, were partially resolved by RTV rubber impregnation.

Through the use of a socket of modular design, investigations were carried out toward making possible the interchangeability of the Taslon material required by the wearing, fraying, and weakness of the material. Cosmetic covers were fabricated for the experimental prosthesis.

Investigations have also continued with the use of compressible inner soft wedges to serve as suspension mechanisms for PTS prostheses. Results obtained have been most gratifying and the technique of fabrication of the wedges standardized. Similarly, investigations have continued with the windowless cosmetic Syme's prosthesis that eliminates the unsightly removable windows of the conventional Syme's prosthesis. Considerable progress has been made in the development of functional braces for the treatment of fractures of the tibia, femur, and forearm. Fractures at all levels and types have been studied, and Orthoplast cosmetic and functional braces have been studied and developed. Indications for the use of these braces and the technique of fabrication have been recorded.

### REFERENCE

1. Sarmiento, Augusto, M.D., et al.: Development of Refined Fitting Procedures for Lower-Extremity Prostheses. Bull. Prosthetics Res., BPR 10–16:112–129, Fall 1971.

## Immediate Postoperative Application of Upper-Extremity Orthoses

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Development has recently been directed strongly toward the plight of the patient with rheumatoid arthritis.

The three orthoses illustrated depict some early models designed to accomplish specific goals in the rheumatoid hand.

This project agrees with Dr. Swanson, who has emphasized that there is need for dynamic braces in rheumatoid arthritis. Retaining motion wherever possible seems to be very important in assisting with "preventive maintenance" of joint integrity. Simple positioning splints contribute to muscle and joint wasting. Attempts are being made to achieve "positioning" (i.e., protection of ligaments and tendon integrity) and to allow motion at the same time.

The following presents three cases of rheumatoid arthritis and the braces developed for them:

*Finger Separation Splint*

Primary Application: Rheumatoid arthritis
Secondary Application: Central nervous system disease with spasticity
Goals: 1. Maintain a separation between the fingers.
2. Positioning.
Discussion: This orthosis was designed for patients who had severe adduction of their fingers as a result of rheumatoid arthritis or central nervous system diseases, such as a stroke, where it was not only important to maintain position, but also to maintain a separation between the fingers, as the patient it was applied to had severe fungal infections in the web spaces. After experimentation with many types of orthoses, the one illustrated is the final design and has been the only one generally accepted by the patients which accomplished the goals and still allowed some finger flexion and extension (Fig. 9 and 10).

*Dynamic Orthosis for Wrist and Metacarpal-Phalangeal Joint Control (Developmental)*

Primary Application: Rheumatoid arthritis
Secondary Application: None

FIGURE 9

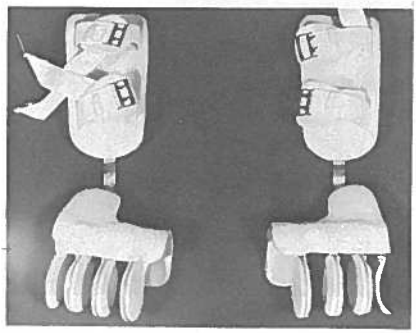

FIGURE 10

Goals: 1. Position the *wrist* in slight ulnar deviation while allowing full flexion and extension of the wrist.
2. Position the metacarpal-phalangeal joints of the *fingers* in neutral or slight radial deviation.

Discussion: A spring-and-lever arrangement can be added about the metacarpal-phalangeal joint hinge to provide varying strengths of metacarpal-phalangeal joint extension assist. Also, it was found that the hinge rotation gave more precise control of the metacarpal-phalangeal joints.

The hinge at the wrist may be excluded from the prescription if the surgeon would prefer a solid bar for positioning.

The illustration demonstrates a patient with ulnar drift who has been satisfactorily positioned in the orthosis (Fig. 11). His wrist flexion and extension have been preserved by the hinge joint. The palm piece is split, a feature which can be incorporated into the orthosis where indicated to allow for swelling of the hand.

*Dynamic Orthosis for Wrist and Metacarpal-Phalangeal Joint Control (Developmental)*

Primary Application: Rheumatoid arthritis

Secondary Application: Radial nerve paralysis (the prescription would have to be modified for thumb-extension assist); wrist flexion contractures and metacarpal-phalangeal joint flexion contractures

Goals: 1. Passive-assistive extension of the wrist in a neutral plane or

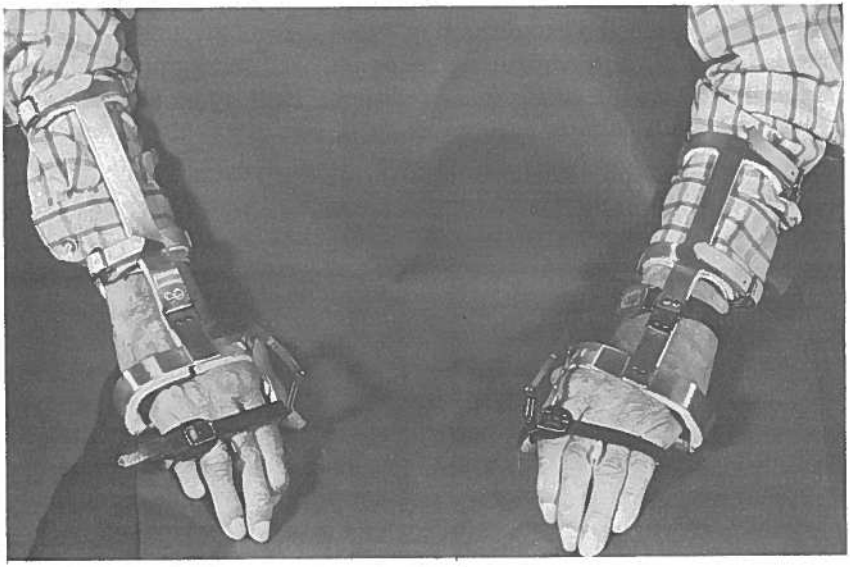

FIGURE 11

in ulnar deviation (as in this case, where slight ulnar deviation was chosen for the rheumatoid arthritic).

2. Metacarpal-phalangeal joint extension (with radial deviation as chosen for this rheumatoid arthritic).

Discussion: This orthosis is illustrated to demonstrate the application of the Jaeco hinge and lever to the wrist for passive assist of wrist extension. With this hinge it is possible to hold the wrist in some ulnar deviation during flexion and extension. Ulnar deviation of the wrist is helpful in prevention of metacarpal-phalangeal joint ulnar drift (Fig. 12 and 13).

**The Improvement of Assistance Systems Through Research, Design, Clinical Testing, and Team Evaluation**

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During the period January 1, 1972, to July 1, 1972, the research program at Texas A&M University started a clinical evaluation of the lightweight, modular, endoskeletal hip-disarticulation prosthesis that was described in the BPR 10–17 Spring 1972 issue of the Bulletin of Prosthetics Research (p. 245), and formulated plans for continuing and expanding the research program into the area of mobility aids for the physically disabled.

The patient evaluation of the prosthesis has produced a series of

FIGURE 12

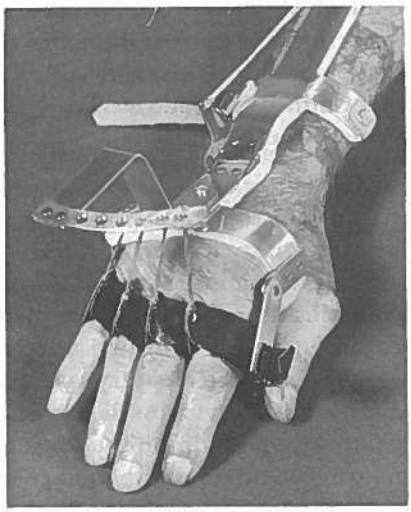

FIGURE 13

comments concerning the improved comfort of the girdle due to its variable flexure properties and the significantly reduced effort that is required to cause the leg to swing-through during ambulation. Also, as a result of the patient testing, a series of minor design modifications were identified to increase the range of motion at the hip. An alignment device was developed that is now an integral part of the unit. This unit consists of a spherical linkage with a range of motion of 8 deg. from the vertical and a locking mechanism to hold the unit at any position in this range.

These improvements have been accomplished, and the prosthesis is currently being evaluated for a period of 3 months by an amputee. Based on the results of this evaluation, the design will be finalized. However, the development of a refined endoskeletal safety knee and a power-assisted hip joint is planned.

In addition to modifying the hip-disarticulation prosthesis, detailed plans for future research in the area of prosthetics and mobility aids were completed, and efforts to collect the resources that are necessary to conduct the projects were initiated. These projects include: 1. The development of a phonic control system that responds to words and can be used to operate aids such as an electric wheelchair and ultimately an automobile. It should be noted that this work will be based on previous experience that Texas A&M University research has acquired in developing a phonic controller that responds to changes in the pitch of the voice. 2. Analysis and development of improved control systems for use by the amputee and the SCI patient in driving.

**Control of an Artificial Upper Limb in Three Degrees of Freedom**

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The design of the digital logic and of the related electronic analog circuitry for controlling three degrees of freedom of an upper-limb prosthesis via toe actuation has been improved and completed, in terms of microelectronic hardware. This design has aimed at coordinating four most sensitive and responsive toe movements for the purpose of controlling elbow flexion, wrist rotation, and grasp by appropriate logic design. The logic circuitry was designed to have further capabilities of eliminating some most likely errors in actuation by the user of the prosthesis, and to minimize the mental effort of the user when actuating the controller. Hence, the most sensitive and responsive toe movements were allocated to the most sensitive of the three degrees of freedom to be controlled, namely to the grasp action. The actual construction of the

above circuitry using integrated logic chips and analog components has been performed. This circuitry has been assembled on two 5-in. by 4-in. printed circuit boards, noting that in production models all the circuitry may be condensed into a couple of microelectronic chips, which are still much smaller but far more expensive than the present construction. The interface of the logic and analog circuitry with d.c.-stepper-motor drives has been designed; these stepper motors have attractive speed-versus-torque characteristics, high hold-torque, and excellent weight-to-torque ratio. Research into improving the grasp sensitivity of the present controller has been continued, and studies on incorporating myoelectric actuation in the controller in order to extend the number of its degrees of freedom have been started.

See the article "Control of an Artificial Upper Limb in Three Degrees of Freedom" appearing elsewhere in this issue of the Bulletin.