VETERANS ADMINISTRATION PROSTHETICS CENTER RESEARCH REPORT

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The following presents progress during a 6-month period on a number of research, development, and evaluation projects performed by the VA Prosthetics Center:

I. LOWER-LIMB PROSTHETICS
   A. Basic Studies
      None
   B. Development (Techniques)
      1. Machine Forming of Plastic Sockets
      2. Transverse Rotation in Lower-Limb Prostheses
      3. Insert Socket Fitting Concepts
      4. VA Endoskeletal Structures
      5. Development of Lightweight Advanced Composite Multiplex Structures
   C. Evaluation
      None

II. UPPER-LIMB PROSTHETICS
   A. Basic Studies
      None
   B. Development (Components)
      VAPC Harmonic-Drive Hook

III. LOWER-LIMB ORTHOTICS
   A. Basic Studies
      None
   B. Development
      None
   C. Evaluation
      Walking Device for Paraplegics

IV. UPPER-LIMB ORTHOTICS
   A. Basic Studies
      None

B. Development
None
C. Evaluation
Electric Hand Orthoses

V. SPINAL ORTHOTICS
A. Development
1. Hospital-Type Environmental Controller
2. VAPC Home-Type Environmental Controller

VI. MISCELLANEOUS AIDS
A. Development
1. VAPC Pneumatic Control for Powered Wheelchairs, Model II
2. VAPC Pneumatic Control for Powered Wheelchairs, Model III
B. Evaluation
1. Optimizing Powered Wheelchair Performance
2. Sonotrol Environmental Control
3. Automatic Dialing Telephone
4. E-Z Hold Telephone Clip
5. Overly-Bressler Stand-Up Wheelchair
6. Expandable-Adjustable Crutch
7. Astropedic Chair
8. Mercy Lift
9. Hess Rotary Bed
10. Specially Adapted Vans for Wheelchair Users

VII. TESTING
A. Standards Development
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2. Endoskeletal/Modular Systems
B. Compliance Testing
1. Upper-Limb Components Compliance Tests Conducted
2. Stump Socks
C. Evaluation
Langan Below-Knee Joint

I. LOWER-LIMB PROSTHETICS

A. Basic Studies

None

B. Development (Techniques)

1. *Machine Forming of Plastic Sockets.* Since the installation of a vacuum-forming machine for plastics in March 1972 (BPR 10–18, pp.

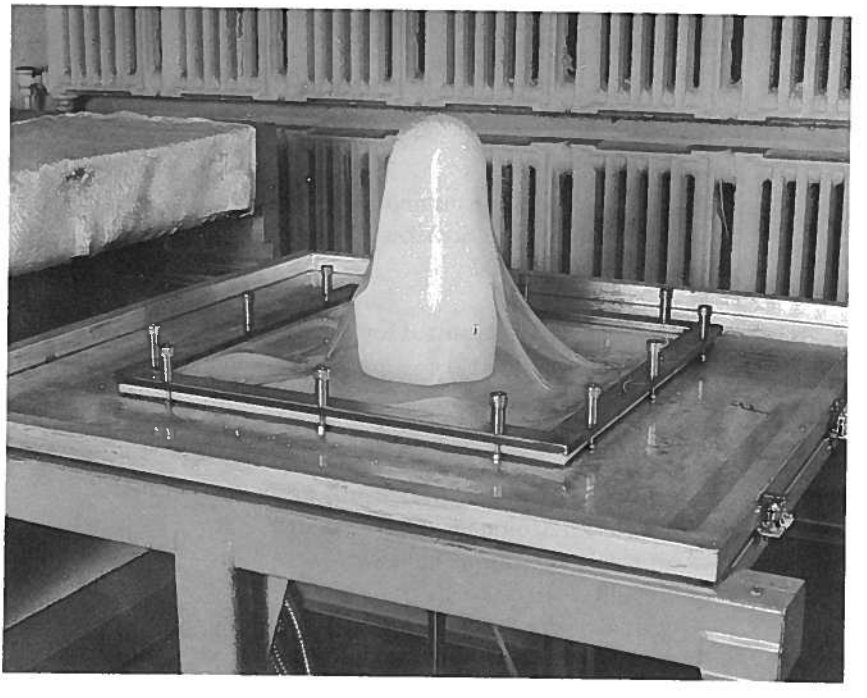

FIGURE 1.—Fabricating plastic socket by vacuum-forming process.

224–226), it has been used to gain familiarity and experience with this type of equipment and with the vacuum-forming process.

Forming characteristics of several materials are now being studied for making prosthetic sockets for below-knee and above-knee limbs. Sockets have been made with polyethylene, Lexan, Acrylonitrile Butadeine Styrene (ABS), and polypropylene. Present experience with vacuum forming points to the potential superiority of prosthetic sockets made of polyethylene. The material is inexpensive, easy to form (Fig. 1), can be bonded into an appliance (Fig. 2), and exhibits all of the structural characteristics required for prosthetic socket use.

2. *Transverse Rotation for Lower-Limb Prostheses.* Two transverse-rotation systems are currently being tested at VAPC—the elastomeric reflex joint submitted by Lord Corp. of Erie, Pennsylvania, and the Weber-Watkins rotator made by Weber and Watkins Co. of Ohio.

The Lord elastomeric system (Fig. 3 and 4) is a relatively thin, wafer-type torque control weighing 0.93 lb. (.422 kg.). The joint body measures 3 in. (7.62 cm.) in diameter and is approximately 1.25 in. (3.18 cm.) in height. The points of attachment are two flange posts which accommodate tubing of 1.250 in. (3.18 cm.) i.d. Resistance to rotation is con-

FIGURE 2.—Finished above-knee socket produced by vacuum-forming procedure.

trolled by resistance to shearing forces applied to three rubber cylinders. Variation in resistance is provided by sets of rubber cylinders of different durometers. Motion is provided in one direction only, with the maximum range of motion set at 7.0 deg. (.122 rad.).

The Weber and Watkins rotator (Fig. 5) consists of a vertical assembly of two thrust bearings that are joined together by a common shaft internally and a section of rubber tubing externally. The unit, weighing 1.09 lb. (.494 kg.), is 3.535 in. (8.98 cm.) high and 2.250 in. (5.72 cm.) in diameter. The unit is attached by means of two flange post fittings sized

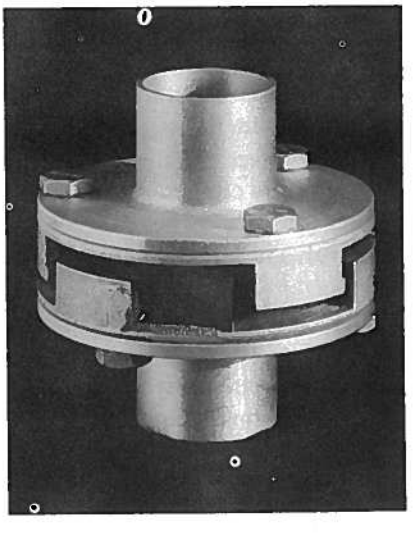

FIGURE 3.—Elastomeric reflex joint produced by the Lord Corp.

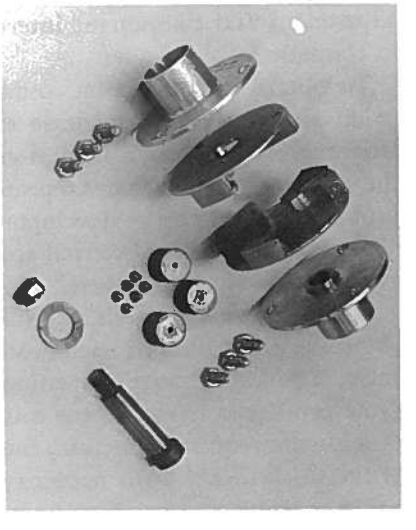

FIGURE 4.—Elastomeric reflex joint component parts.

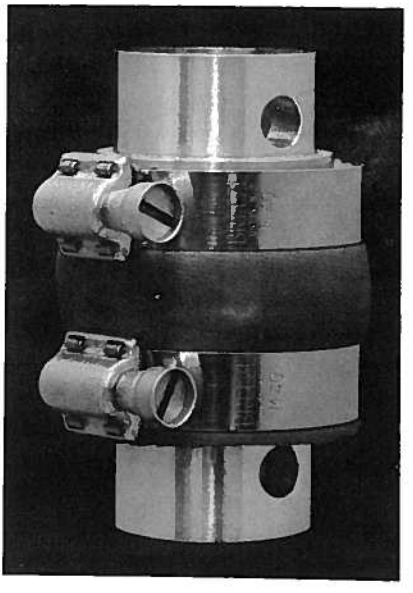

FIGURE 5.—The Weber and Watkins rotation system.

for 1.50-in. (3.81 cm.) i.d. tubing. Motion is available in two directions without mechanical blocking: approximately 6 deg. (.105 rad.) of rotation takes place per ft.-lb. of torque. Very little angular deflection occurs under torques in excess of 6 ft.-lb. (.830 kg.-m.).

3. *Insert Socket Fitting Concepts.* The Veterans Administration has long been involved in the design and application of modular and endoskeletal prostheses. While these devices provide advantages in alignment adjustment and component interchangeability, they present a problem in cosmetic finishing.

To obtain the maximum cosmetic advantage, the cosmetic cover for pylon structures should encase the *entire* limb, including the socket. Donning or removing a suction-socket limb, however, requires access to the valve which necessitates repeated removal of the cosmetic cover. This problem has led to the development of socket-fitting techniques which eliminate the need for external access to the valve in both the below-knee and the above-knee prosthesis.

For the Syme prosthesis, the insert socket liner provides a method of obtaining the effects of suction-socket suspension without the use of a valve. The VAPC medial-opening and the Canadian posterior-opening Syme prostheses have become quite popular. Although both prostheses provide the required function, they tend to be heavy and bulky because of the thick socket walls necessary to withstand the high stresses at the ankle opening.

The recent development of a thin-walled non-opening Syme socket was found to be superior in strength to the open-walled type. The first

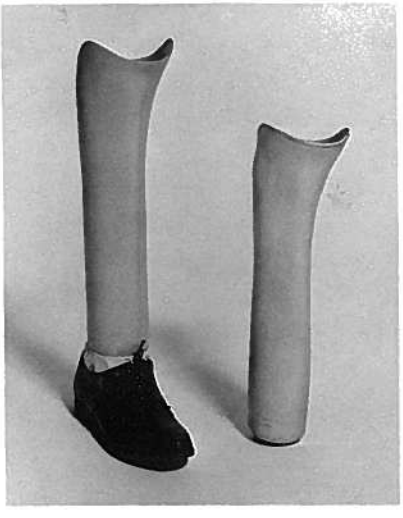

FIGURE 6.—Syme prosthesis with removable liner.

models were fabricated with an inner liner of soft material, in the small diameter of the socket above the ankle section, to permit the passage of the bulbous stump end into the socket. However, the built-in liner increased the weight of the appliance and caused difficulties in socket modification, in replacement of liners, and in fabrication. The closed-socket liner overcomes these difficulties by fabricating the socket shell over the removable liner (Fig. 6).

For the below-knee socket, the liner is fabricated of a combination of P.V.C. ("Cordo") and Pelite or Plastazote (BPR 10–18, pp. 182–188). These liners, removable from the socket, are held tightly to the stump by means of an air-expulsion (suction) valve located in the distal socket (Fig. 7). The patient gains access into the liner in the same manner used to gain entrance into the above-knee suction socket. Since the liner is flexible and has a reasonable degree of elasticity, it remains in full contact with the stump for longer periods of time while the stump undergoes minor volumetric changes. The outer liner surface is contoured to "key" into the rigid socket shell, locking the liner in place (Fig. 8). The rigid socket is deeper than the liner, thus providing an air chamber beneath the liner in the socket. The liner end is free to expand and contract with stump-volume changes. A valve is also used in the outer socket wall opening into the chamber beneath the liner. The resistance settings of the two valves are adjusted to maintain a negative pressure in the air chamber beneath the liner, producing a mild air cushion and supplementary suspension. The external valve is easily depressed through the foam cover to release the liner from the socket.

For the above-knee socket, the liner is fabricated in the same manner as the below-knee socket, except that the liner walls are heavier. The

FIGURE 7.—Location of suction valve at distal end of socket.

FIGURE 8.—Insert liner locked into place inside rigid socket shell.

liner may be supported distally by the rigid socket. When the liner is in contact with the rigid socket, an opening is made in the socket wall for access to the valve. If air cushioning is required, a second valve is installed in the space below the liner, in the same manner as that used for the below-knee socket. In both methods, the outer surface of the liner is "keyed" into the socket walls for retention.

4. *VA Endoskeletal Structures.* A limited clinical application study is under way to evaluate the utility of the Multiplex above-knee endoskeletal prosthesis. Its aim is to determine fabrication and fitting requirements and to identify the structural adequacy of the system. Fifty systems have been manufactured for this evaluation program.

At present, 12 VA artificial-limb contractors are participating in the program. Kits containing the mechanical components and the fluid-control systems, along with instructions, are sent to each contractor as prescriptions are made.

Due to the system's capability to accommodate various mechanical and fluid knee controls, few restrictions are placed upon the prescription of a Multiplex endostructure. For purposes of minimizing the variables in this study, unilateral above-knee amputees, otherwise physically and mentally sound, are being selected as pilot wearers. Feedback information will be recorded by the Prosthetic Representative in each area and forwarded to VAPC where the data will be studied. Shown in Figure 9 is the endoskeletal system and the socket with an attachment ring for the

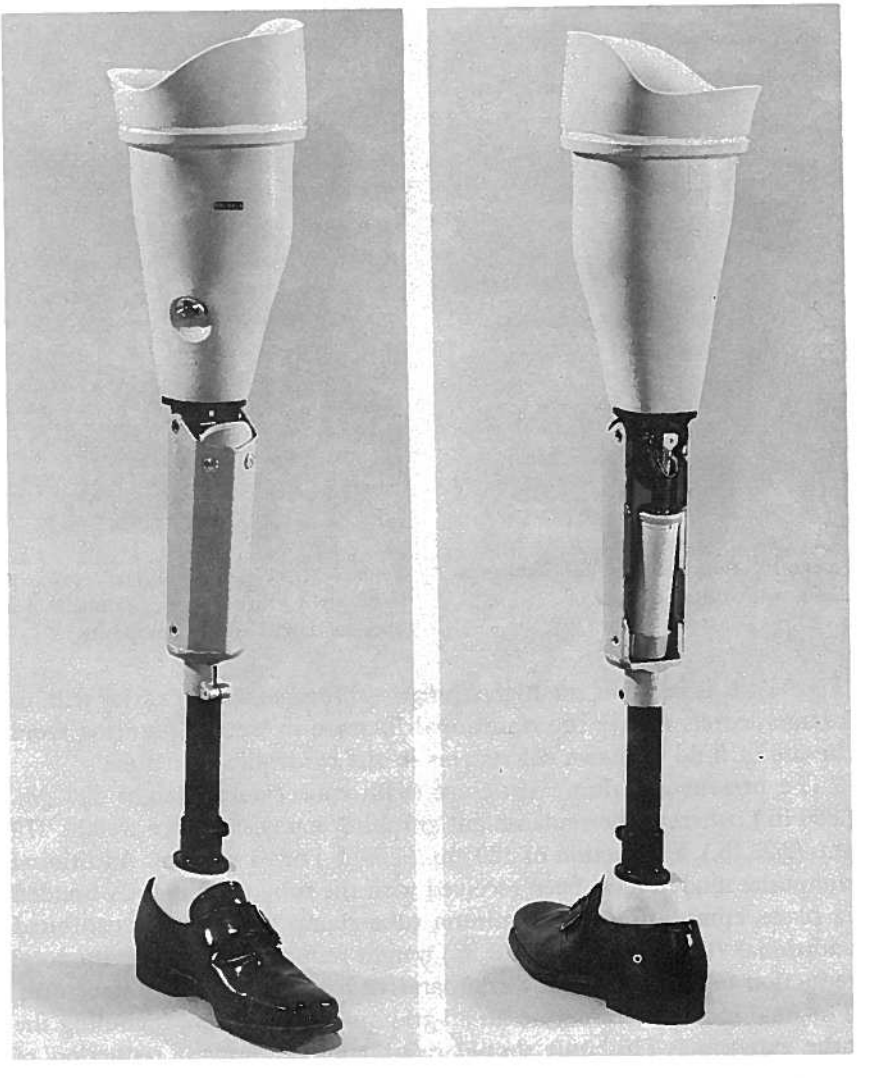

FIGURE 9.—Front and rear views of endoskeletal prosthesis showing socket with attachment ring for cosmetic cover.

cosmetic cover. Figure 10 shows the completed limb with a cosmetic cover.

5. *Development of Lightweight Advanced Composite Multiplex Structures.* The Veterans Administration has an agreement with Northrop Corporation's Aircraft Division in Hawthorne, California, for the purchase of several models of the Multiplex structure fabricated of the graphite-fiber-reinforced epoxy materials used in their aerospace work

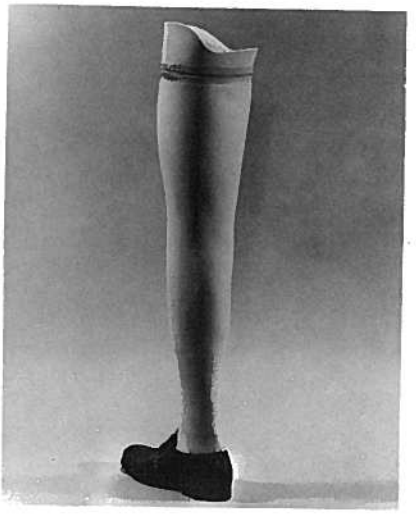

FIGURE 10.—Completed endoskeletal prosthesis with cosmetic cover.

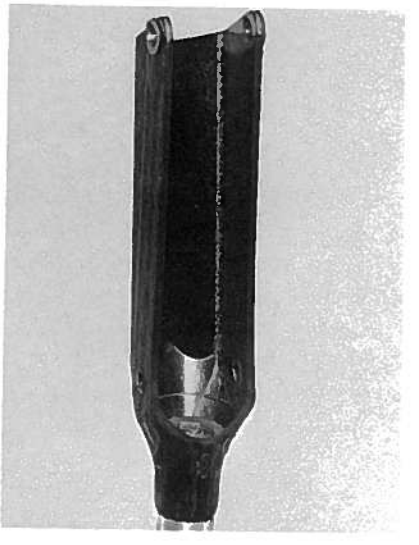

FIGURE 11.—The "Multiplex" yoke, a lightweight unitized structure made of a fiber-reinforced epoxy composite.

(Fig. 11). It is felt that the high strength stiffness-to-weight ratios will, to a large degree, negate the traditional increase in weight resulting from the use of fluid knee-control systems in the Multiplex structure.

The present aluminum structure (with tube clamp) weighs 390 gm. (.860 lb.), whereas the replacement graphite/epoxy structure weighs 270 gm. (.595 lb.), a reduction of 120 gm. (.265 lb.) or 31 percent. Additional composite models have been received with the tube permanently bonded in place, eliminating the aluminum tube clamp. These units exhibited additional 70–80 gm. (.154–.176 lb.) weight reductions bringing the total reduction to 50 percent on a comparative basis with present structures. The final models will feature an all-graphite construction, including the tube extension. This unit should exhibit a total weight reduction of approximately 70 percent over the present metal structure (including the shank tube).

Evaluation and testing of the composite structures are now underway to determine their structural adequacy and clinical applicability.

C. Evaluation

None

II. UPPER-LIMB PROSTHETICS

A. Basic Studies

None

B. Development (Components)

1. *VAPC Harmonic-Drive Hook.* Our previous experiences in applying the harmonic-drive concept in the development of prosthetic devices has suggested the possibility of other applications to take advantage of the special characteristics of this device. The VAPC Electric Elbow is a prime example of the use of the harmonic drive, in which full advantage is taken of its potential for light weight, efficient speed-reduction ratios, small size, and high adaptability for compact packaging due to its hollow configuration. An effort was made to combine the most desirable physical and functional characteristics of this concept in the development of a prosthetic hook utilizing harmonic drive (Fig. 12).

The unit manufactured by United Shoe Machinery Corp., features a double plastic harmonic-drive gear reducer and a three-load wave generator consisting of a sun-planetary speed reducer, similar to that in the VAPC elbow (BPR 10–18, pp. 10–24). In this design, the hook fingers are prevented from applying too much force by sensing the output load mechanically and by actuating a microswitch to limit the power fed to the motor, thereby limiting the output torque. A mechanical overload,

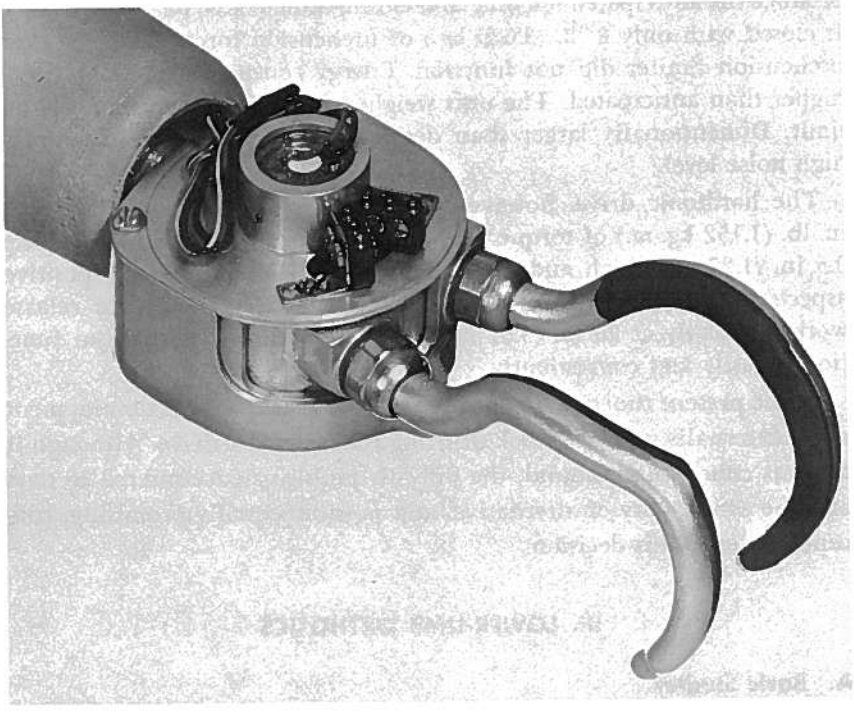

FIGURE 12.—VAPC (USM Corp.) harmonic-drive hook.

also provided within the same assembly, permits the hook fingers to be driven open by external forces exceeding 20 lb. (9.07 kg.).

The compact double harmonic-drive planetary reducer provides a speed reduction of approximately 16 to 1 between the shaft and the planetary rollers. The first stage of the harmonic drive engages a flexible 226-tooth *rigid* spline, providing a reduction ratio of approximately 75 to 1. The second set of 140 teeth on the *flexible* spline engages 143 teeth on the rigid spline which connects to the overload release mechanism providing a further reduction ratio of approximately 47 to 1. The speed-reduction ratio of the entire system is 2075 to 1.

The unit was intended to provide full opening-to-closing time of under 1 second, and to consume less than 500 ma. when controlled by a pulsed solid-state circuit and when powered by six self-contained, rapid-charge 450-mah. NiCad batteries. Electrically limited prehension of 12 lb. (5.44 kg.) at the fingertips was expected, and the fingers were to release automatically if they applied more than 20 lb. (9.07 kg.) force. The entire system was to weigh 6.3 oz. (175 gm.) without batteries and 10.5 oz. (298 gm.) with batteries.

Actual performance of the unit was significantly *below* these optimal standards. Closing time was almost 2 seconds, and the hook did not produce the anticipated opening and closing range of 60 deg. (1.047 rad.). It closed with only 8 lb. (3.629 kg.) of prehension force. The electrical prehension limiter did not function. Energy consumed was four times higher than anticipated. The unit weighed more than twice the desired limit. Dimensionally larger than desired, it also had an unpleasantly high noise level.

The harmonic drive, however, was capable of generating over 100 in.-lb. (1.152 kg.-m.) of torque, and it only occupied a disk-shaped space 0.5 in. (1.27 cm.) high and 2.0 in. (5.08 cm.) in diameter (two positive aspects of this design). In addition, the mechanical override release worked reliably at 20 lb. (9.07 kg.), and the resetting mechanism functioned easily and conveniently.

At the present time, we do not intend to continue further development of an externally powered hook utilizing the harmonic drive. Although it appears conceptually sound, the difficult problems encountered to date and the availability of alternative, and possibly equally promising, concepts underlie this decision.

III. LOWER-LIMB ORTHOTICS

A. Basic Studies

None

B. Development

None

C. Evaluation

Walking Device for Paraplegics. In the previous issue of this Bulletin (BPR 10–18, pp. 233–234), we reported initiation of a new project to design and develop an externally powered ambulation system for paraplegics and others with similar functional losses. In the course of this program we have had occasion to review the thoughts and work of others interested in this field. At the same time, two other devices designed for similar purposes have come to our attention.

One of the first attempts to design a power-assisted walking device for paraplegics was the work of Dr. W. T. Liberson when he was at VAH, Hines, Illinois. Dr. Liberson employed motor-driven hip joints controlled by switches under the heel of the patient in an otherwise conventional pair of bilateral long-leg braces. Lifting the heel of one foot drove the hip joint of the brace on that side in the direction of hip flexion, advancing the foot, enabling the patient to place his body weight on that foot by pushing off with his forearm crutches. Repeating the process with the other foot enabled him to advance the other leg.

The earliest systematic and clinically useful work in developing devices for crutchless ambulation is the product of the Ontario Crippled Children's Centre (OCCC) in Toronto, Canada, where Mr. Wallace M. Motloch has developed and highly refined the OCCC Parapodium (Fig. 13). Intended for use by children, this appliance is fundamentally a standing frame which supports the patient at the level of the hips, knees, and foot/ankle joints, enabling him to attain an upright position with minimum muscular effort. Biomechanically efficient alignment of the lower-limb joints is achieved by fine adjustment of a system of restraints and clamps. The device permits the patient to sit down by unlocking hip- and knee-joint hinges. The most significant feature of this device is that it enables children to ambulate with, and in some cases without, crutches.

In an effort to determine whether this concept could also be utilized by adult patients, Mr. Johannes W. Prast, President of Prast Research Associates, Inc., Grand Island, New York, in collaboration with Mr. Motloch, designed and fabricated a Parapodium for an adult paraplegic. The principal problem anticipated in this work was that of providing sufficient anterior-posterior stability. The ratio of the height of the patient's center of gravity from the floor to the anterior-posterior dimension of the base of support in a 6-ft. 2-in. (1.88 m.) tall adult is far higher than among children. This problem was resolved by making necessary design changes as shown in Figure 14. The adult device has greater

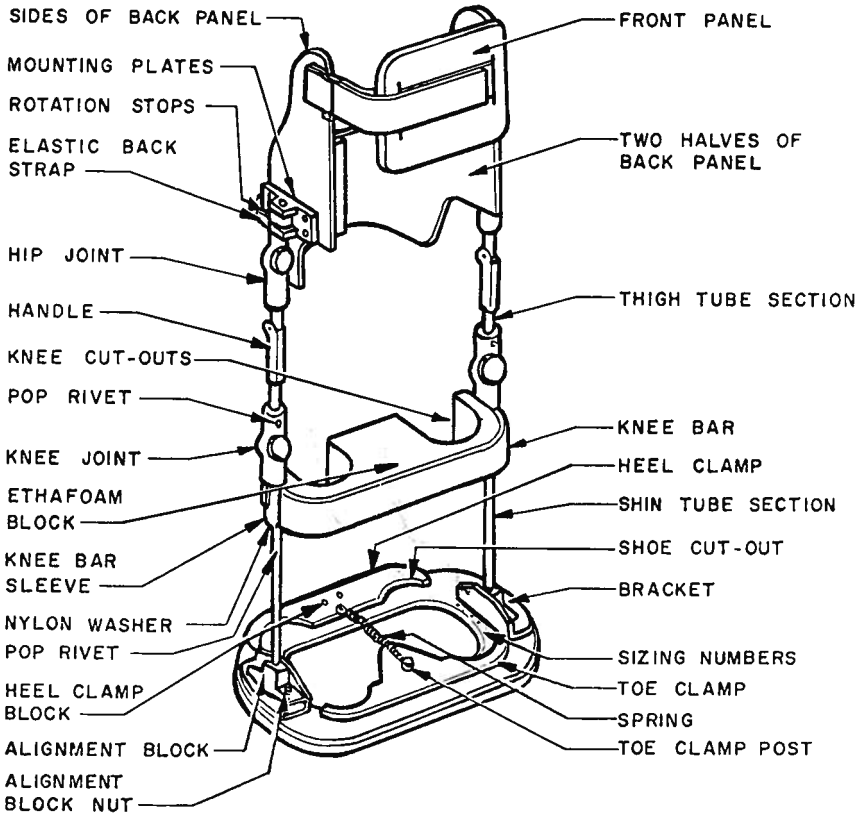

FIGURE 13.—Schematic showing structure of Parapodium developed at Ontario Crippled Children's Centre in Toronto, Canada.

structural rigidity, heavier hip and knee locks, and variations in the padding around the pelvic area. The device is also equipped with pivoting caster wheels enabling the patient to "walk" by pivoting his body around a longitudinal axis. Work continues to further improve the design of this device to enable a patient to climb stairs.

The Ortazur Pneumatic Suit, an adaptation of a pilot's antiblackout "g" suit, has also been developed for use by paraplegic patients by the Aerazur Constructions Aeronautiques, 58 Boulevard Gallieni, 92 Issy-les-Moulinequx, France. Designed for both children and adults, the appliance consists essentially of rubberized trousers or overalls with compartments for containing air under pressure (Fig. 15). When the suit is inflated, sufficient rigidity is achieved to prevent collapse of the hip and knee joints enabling the patient to stand upright and to walk with

FIGURE 14.—Parapodium modified for an adult paraplegic.

forearm crutches. In the present configuration, inflation may be accomplished in several ways: with a large-volume, compressed-air bottle; with small-capacity, one-time, compressed-air cartridges; and with a small electric air-compressor.

We have equipped four VA patients with these suits for evaluation purposes. One patient has a spinal-cord lesion at the level of the 6th thoracic vertebra (Fig. 16). While it is too early to report significant

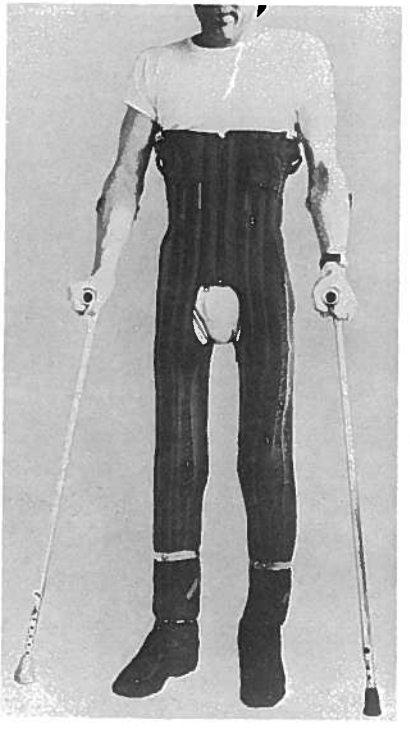

FIGURE 15.—The Ortazur Pneumatic Suit, Model B.

results of this evaluation, initial fitting procedures were fairly simple, and all of the patients were able to stand and ambulate in parallel bars or with forearm crutches.

Conceptually, the Ortazur suit is a pneumatic analog of the conventional system normally supplied these patients—bilateral long-leg braces and forearm crutches. It is, however, lighter and, by reason of its pressurization, prevents blackout when patients stand up after being in a recumbent or sitting position for long periods. The course of this evaluation program will bring out the relative utility of these several methods of inflating and deflating the suit, procedures which must be accomplished each time the patient stands and sits, and the optimal utilization in or out of the hospital.

VAPC is pursuing its work to develop a powered paraplegic ambulation system intended to enable patients to walk, step-over-step, with one or two forearm crutches, under the control of a biofeedback system.

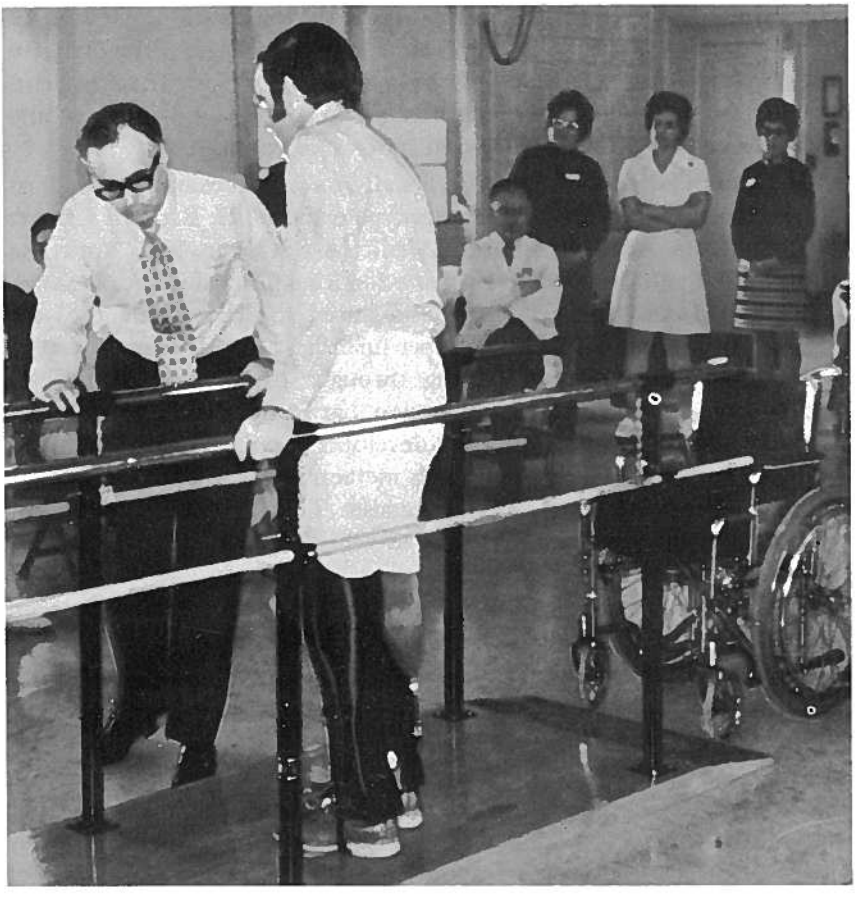

FIGURE 16.—VA patient demonstrating Ortazur Pneumatic Suit.

IV. UPPER-LIMB ORTHOTICS

A. Basic Studies

None

B. Development

None

C. Evaluation

Electric Hand Orthoses. Restoring a measure of useful function in the paralyzed hand is an extremely difficult problem. Functional hand deficits secondary to spinal-cord lesions at C 3–4, C 5–6, and C 6–7 levels are

often accompanied by other complicating factors, such as deformity, limited range of motion, and/or contracture. Nevertheless, the orthotist and for that matter the developer of orthotic devices for these patients face similar problems: the correction or prevention of deformity and restoration of function regardless, in general, of etiology.

The state of the art today rests heavily on the development and refinement of the well-known opponens-type orthoses. H. Richard Lehneis of the Institute of Rehabilitation Medicine (IRM) in New York and Thorkild Engen of the Texas Institute for Rehabilitation and Research (TIRR) in Texas have extensively advanced the development of the opponens-type orthosis. Each developer furnishes a family of easily adaptable modular components, ranging through the basic opponens-type orthosis consisting of thumb abduction bar, palmar bar, wrist strap, dorsal bar, and opponens bar. Each developer supplies this basic unit in modified form for wrist control, with metacarpophalangeal hyperextension stops, and with finger-extension assists. They also supply this basic unit in finger-driven prehension-type as well as wrist-driven prehension-type orthoses.

However, where wrist power is not available it is necessary to depend on external power. One of the earliest applications of external power was the McKibben "muscle," essentially a gas actuator, which functioned rather efficiently but required the use of a refillable gas cylinder (Fig. 17).

Two electrically driven hand orthoses are now available. One is the Hosmer hand orthosis which is operated by means of a switch (Fig. 18). The other is the Viennatone myoelectric hand orthosis controlled by myoelectric signals from the trapezius which are detected by means of electrodes mounted in a harness (Fig. 19).

Several models of both the Hosmer and the Viennatone electric hand orthoses are being evaluated in VAH Castle Point and VAH Bronx, N.Y. Some early indications are that these devices are somewhat more difficult to fit initially than the wrist-driven types, but that, once fitted, they have

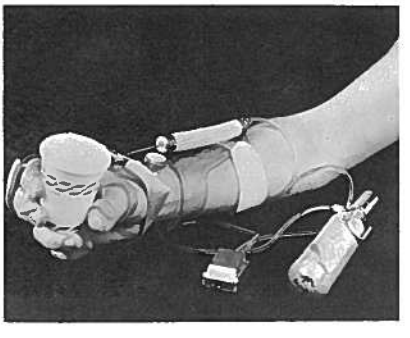

FIGURE 17.—Gas-actuated McKibben "muscle" wrist orthosis.

FIGURE 18.—Switch-controlled Hosmer hand orthosis.

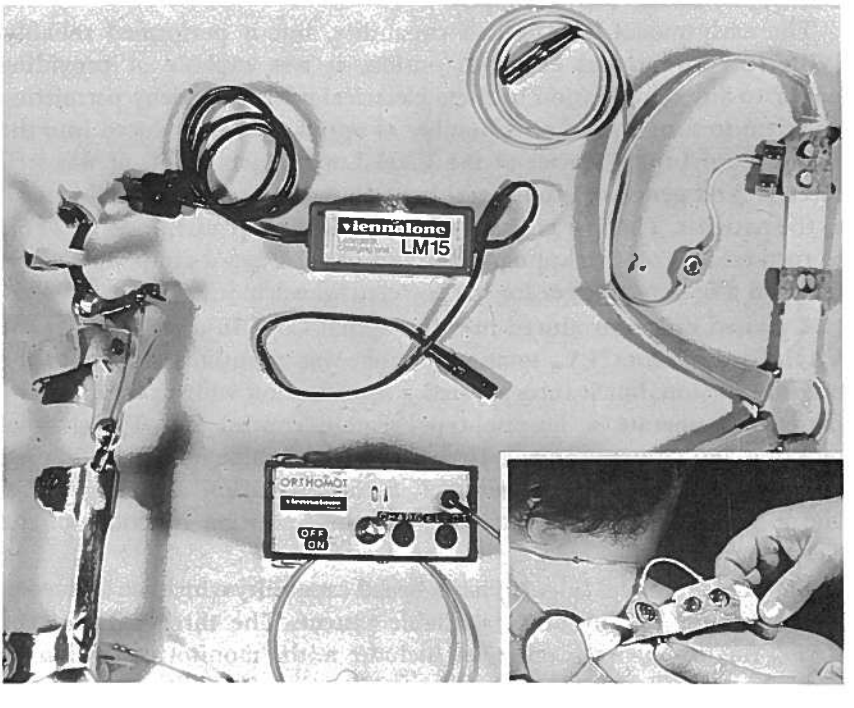

FIGURE 19.—Viennatone myoelectrically controlled hand orthosis and component parts, with insert showing myoelectric electrodes located in harness.

definite advantages. The evaluation program is intended to specify the relative merits of electrical hand orthoses over muscle-power types and to discriminate the prescription indications and utility of switch control versus myoelectric control for powered orthoses.

V. SPINAL ORTHOTICS

A. Development

1. *Hospital-Type Environmental Controller.* Severely paralyzed patients, who suffer from spinal-cord injuries, multiple sclerosis, muscular dystrophy, and similar disabilities, are typically unable to operate or control common electrical appliances. In the hospital setting, these patients are unable to signal the nurses' station for help because they cannot operate the conventional call switch. They require assistance in order to operate lights, radios, or television sets, or to adjust the positions of their electric beds.

To provide these patients with equipment that would permit them to control electrical appliances and to give them some measure of direct control over their immediate environment, the first VAPC Environmental Controller was developed.

The early model had limited capability, but it performed reliably. With 10 conventional electrical outlets, it was capable of providing power to any combination of these electrical outlets, thereby permitting a patient to turn on and off a number of appliances. Introduced into the Spinal Cord Injury Service at the VAH Long Beach, Calif., it was well received and generated considerable enthusiasm among the staff as well as the patients. The first patient, a 20-year-old, C–4 quadriplegic, was able to turn on and off five appliances—a radio, a TV set, a lamp, an electric fan, and a battery charger for his powered wheelchair.

A revised unit, introduced into the Spinal Cord Injury Service at the VAH Castle Point, N.Y., some time later, was essentially similar to the original version, but it incorporated a modification which permitted the patient to operate a hospital-type remote control for TV channel selection and volume control. However, both of these models still failed to provide two essential services: 1. a nurse's station signaling device and 2. the capability of controlling the three-position functions of the electric bed.

The current model (Fig. 20) has a broad capability which we believe to be unmatched by any other available system. The three parts of the VAPC Environmental Controller include: a. the monitoring section, b. the actuator, and c. the power and control section. The actuator (Fig. 21) contains two air switches and two pushbutton switches. Pushbuttons may be operated by patients with sufficient arm function or by hospital at-

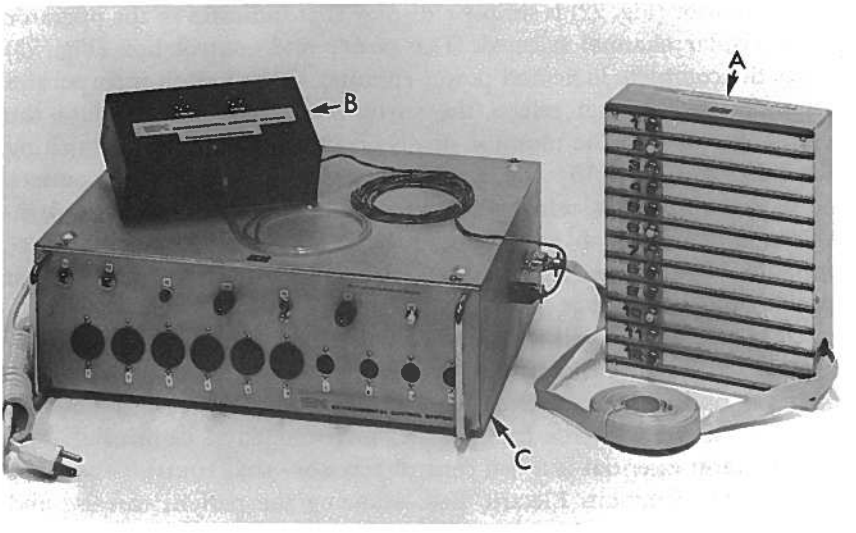

FIGURE 20.—VAPC environmental control system: A. monitoring section, B. actuator, C. power and control section.

tendants. One button selects the channels on the controller, while the second button activates the selected channels. The *severely* disabled patient operates the Controller by sucking on the air tube to select channels and by blowing into the air tube to activate the selected channels.

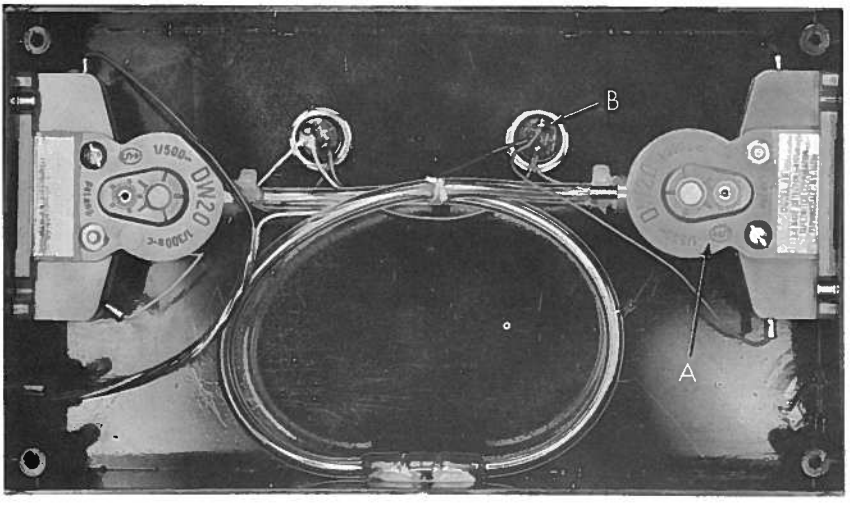

FIGURE 21.—Inside view of VAPC environmental control actuator section: A. pneumatic switch, B. pushbutton switch.

The monitor (Fig. 22) is simply a display that indicates to the operator the particular channel selected. The power and control box (Fig. 23) houses the complete logic and power circuitry. This section incorporates a stepping switch that selects the various channels and displays the selected channel on the monitor. It also contains a number of latching relays that transmit 110-v. a.c. power to the grounded electrical outlets, and several all-purpose relays which provide low-voltage power or switching capability, both on a momentary basis. Three types of outlets are available: 110-v. a.c. grounded outlets, as noted above; a second type that provides the low-voltage power; and a third type that performs as a switch. These outlets will accommodate all electrical appliances that are encountered in the hospital environment.

Several optional accessories (Fig. 24) have been developed and are available for use with the basic VAPC Environmental Controller. Perhaps the most essential is a bed-control accessory that controls the three phases of the Simmons Electric Bed, allowing the patient to raise and lower his head, feet, and/or the entire bed and mattress.

Another accessory, the remote power module, is physically located

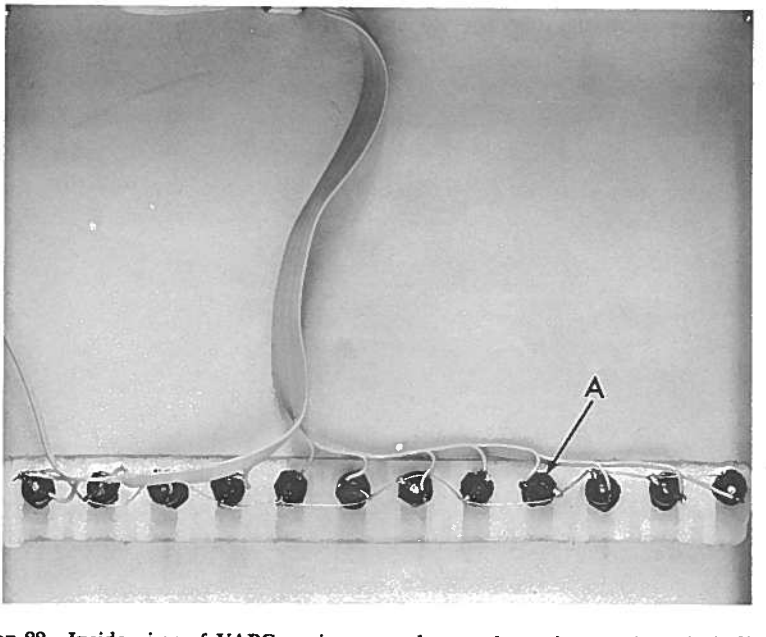

FIGURE 22.—Inside view of VAPC environmental control monitor section: A. indicator lamp.

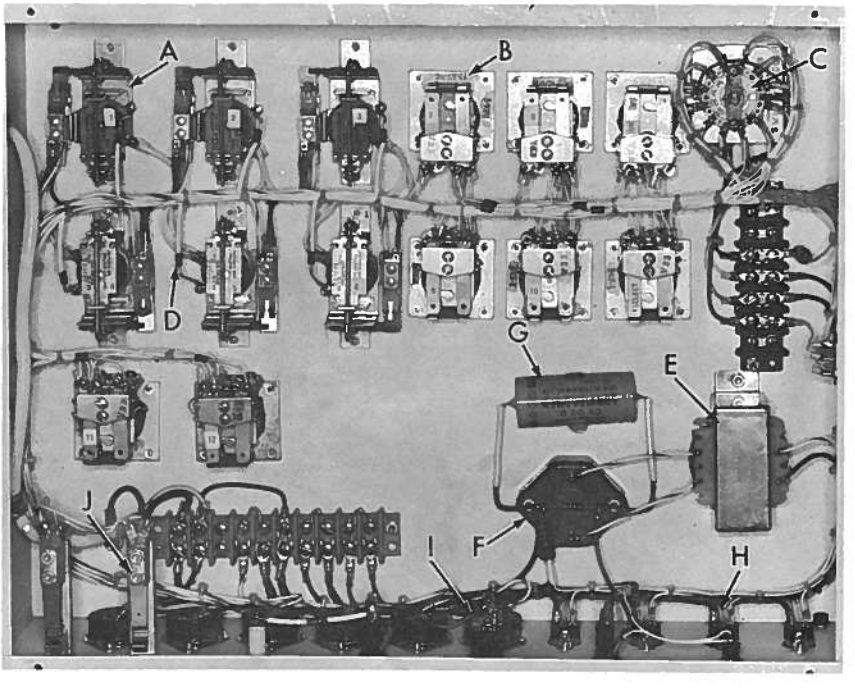

FIGURE 23.—Inside view of VAPC environmental control power and control section: A. latching relay, B. all-purpose relay, C. stepping relay, D. diode, E. transformer, F. full wave rectifier, G. capacitator, H. low voltage outlet, I. 110-v. a.c. outlet, J. shorting jack.

away from the power and control section, and near the controlled appliance. In this situation, low-voltage control wires connect the power module to the Environmental Controller, preventing electrical or fire hazards. A typical application for this remote power unit is control of a window-type air conditioner.

Another optional accessory is an emergency alarm device which generates a visible and audible signal. Strategically located outside of the patient's room, the alarm can attract the attention of hospital personnel.

A total of 10 Environmental Controllers were in use in five VA Hospital Spinal Cord Injury Services by early 1973. The three experimental models were still in use, and seven late-model, commercially manufactured units had also been installed. Of these seven units, two were at VAH Castle Point, N.Y., two at the VAH Bronx, N.Y., two at the VAH Miami, Fla., and one at the VAH East Orange, N.J. Patients using these late models can call the nurses' station, control the three phases of

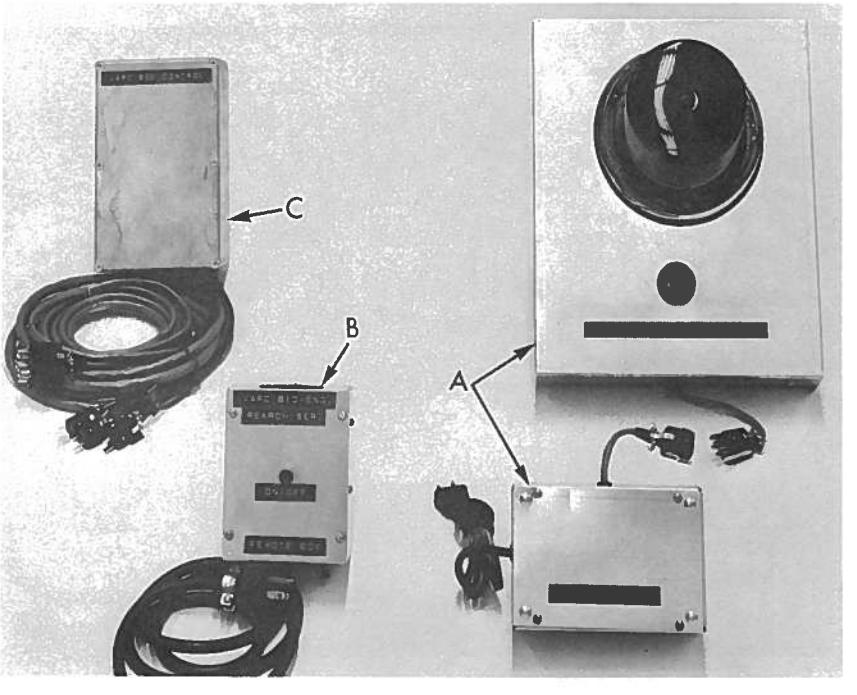

FIGURE 24.—Accessories for VAPC environmental control system: A. VAPC patient alarm, B. remote power box, C. electric bed control.

electric-bed operation, operate a conventional radio, turn the TV on and off, and select channels. Those patients with critical disabilities have been fitted with the VAPC Patient Alarm Device accessory.

Some of these patients are late-night TV watchers and have been provided with a small bed lamp. When a patient concludes his TV viewing, he turns off the television set, reclines the head of his bed, turns off the night lamp, and is then able to go to sleep. With the VAPC Environmental Controller, he can perform all of these tasks without assistance.

2. *VAPC Home-Type Environmental Controller.* Earlier this year, a new "Hospital-Based Home-Care Program" was initiated in the Spinal Cord Injury Services at the VA Hospitals Castle Point and the Bronx, New York. In this program, selected patients are sent home and are visited regularly by a medical team for required care. The team may visit any one patient, two or three times per week. Included are several high-level-lesion spinal cord injury patients.

Patients participating in this program were initially furnished the hospital-type environmental controls which were installed in their homes. Experience to date shows that the needs of the patient at home are generally quite different from his needs in the hospital. For example, if the patient is left alone during the day, it may be necessary for him to communicate with individuals in other rooms or outside the home. In the event of an emergency, such as a fire or sudden illness, it would be absolutely necessary for him to have access to, as well as control of, a telephone. There is an understandable desire to communicate with members of the family and friends. This not only creates a need for a telephone, but also a need for more capacity in the basic environmental controller.

Also to be considered are such other needs and appliances, such as an intercom system, electric door lock, electromechanical door and window openers, or possibly a front door surveillance and operating system. An additional requirement for the home model is that other members of the family should not be prohibited from operating ordinary household appliances in the conventional manner.

Several months ago, we introduced into the home a special type of environmental controller (Fig. 25). This unit, providing 12 channels, is different from the hospital unit in that it is capable of remotely controlling devices, such as alarms, located two or three rooms away. The

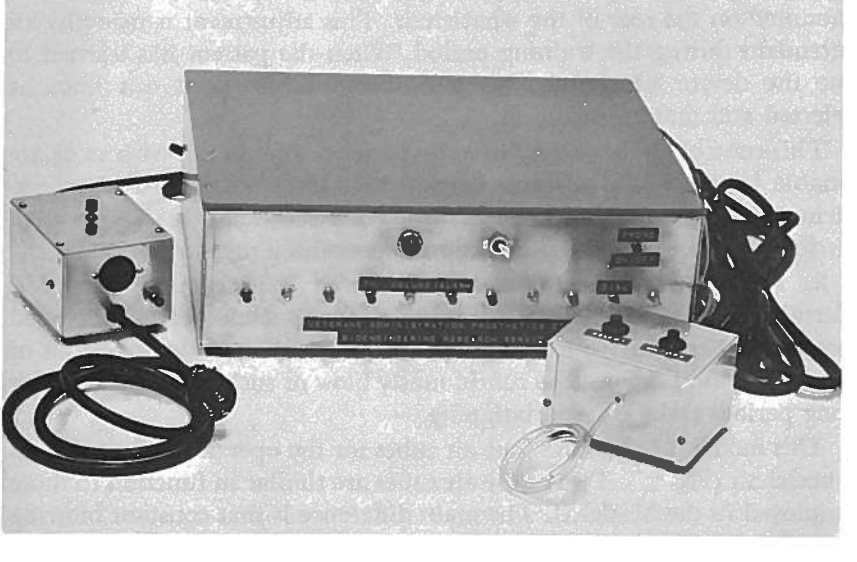

FIGURE 25.—Original VAPC home environmental control.

patient is able to turn on this alarm at will and a member of the household in the remote location is able to turn it off. This device is available with the basic hospital unit—i.e., lamps, radio, TV set, electric bed. In addition, this controller enables a patient to operate a dial telephone by means of a new dialing device.

VI. MISCELLANEOUS AIDS

A. Development

1. *VAPC Pneumatic Control for Powered Wheelchairs, Model II.* In clinical evaluation for 1 year, this pneumatic system enables a patient to operate the wheelchair by blowing into or sucking air from two tubes mounted on a bracket in front of his mouth (Fig. 26). Constant blowing into either of these tubes causes one of the motors to spin in one direction, and constant sucking reverses the direction of spin. Blowing or sucking air from both tubes operates both motors in the directions indicated. If the patient fails to blow or suck into the tubes the motors will not turn.

If the patient desires to turn to the right, he blows into the right tube. If he wants to turn to the left, he blows into the left tube. In order to move forward, he blows into both tubes simultaneously. Control by blowing or sucking is effected by a sealed or a closed-ended air-switch chamber, so that actuation of the motorized wheelchair does not interfere with normal breathing.

Chair speed is selected by turning a dial on top of the control unit mounted on the rear of the wheelchair. This adjustment is made by an attendant during the training period. When the patient has learned to use the device adequately, his most comfortable speed can then be selected and maintained.

This control has been employed by patients who do not wish to or are unable to use a chin control. Certain high-level spinal-cord-injury patients who have suffered a recent injury are subject to blackouts when sitting up in a wheelchair; this control provides a measure of safety.

2. *VAPC Pneumatic Control for Powered Wheelchairs, Model III.* Certain patients have expressed a desire for a pneumatically controlled powered wheelchair which could be easily operated for long periods of time. They find the need to continuously blow or suck on an air tube for long periods awkward and fatiguing.

This model incorporates four air tubes for the operation of a powered wheelchair (Fig. 27). Two of the air tubes are similar in function to those employed in the Model II. The main difference is that constant blowing into the air tubes is not necessary to maintain wheelchair motion in the forward mode.

FIGURE 26.—VAPC pneumatic control for powered wheelchairs, Model II.

A light puff of air into either of these tubes causes the motor to spin in one direction until another puff of air is injected into the air tube. The second puff stops the motor and sequential puffing into the tube turns the motor on and off, but always in the forward mode. To propel the chair in a forward direction, it is necessary to blow into both tubes controlling the motors. Sucking on these air tubes (as in Model II) reverses the motor direction. However, constant sucking on the tube is necessary to maintain motor spin in the reverse direction as a safety factor. If the patient

FIGURE 27.—VAPC pneumatic control for powered wheelchairs, Model III.

ceases to such of the tubes, the chair stops or returns to the forward mode.

A third tube permits the patient to vary the speed of the wheelchair. Blowing into this tube increases wheelchair speed. When blowing into the tube ceases, the chair maintains the selected speed. Sucking on this air tube causes the chair to reduce speed. When sucking on the air tube ceases, the chair maintains the selected speed. The speed adjustment setting may be effected by the patient while the chair is either moving or stationary.

The fourth tube controls a main power switch. When the patient is in his chair, he turns the power on by a puff of air into this fourth tube. If, at any time, the chair malfunctions during motion, the patient can turn the power off by blowing into this tube.

Model III, which incorporates four tubes in the present design, is simply an outgrowth of Model II. The patient clearly uses the motor controls most of the time. The speed-control tube is used occasionally and the main power tube is used quite infrequently. Several units of Model III are being furnished to patients in the SCI Services of VA Hospitals to evaluate their utility in comparison with Model II.

B. Evaluation

1. *Optimizing Powered Wheelchair Performance.* The previous edition of this Bulletin (BPR 10–18, pp. 236–238) described several motors which were being evaluated for use on powered wheelchairs. These included units manufactured by Applied Motors of Rockford, Ill., Ohio Magnetics of Maple Heights, Ohio, Inland Motor Corp. of Radford, Va., and Photocircuits Division of Kollmorgen Corp. of Glen Cove, N.Y.

All of these motors performed reliably, but with varying degrees of efficiency. The Inland motors were the smallest and consumed the least amount of battery energy, but performance was poor. It is planned to continue to evaluate these motors for use in an adequately portable powered-wheelchair configuration.

The motors available from Ohio Magnetics and Applied Motors were both excellent performers. Patients expressed considerable satisfaction with both units and power consumption was minimal. We are not, however, pursuing an evaluation of these motors at this time. While cost is low and performance and reliability are high, wheelchair manufacturers object to the size and weight of these units, claiming that patients required powered wheelchairs that are both foldable and portable. This requirement precludes the use of these types of motors.

The most successful motor packages evaluated so far are the so-called "pancake" motors available from the Photocircuits Division (Fig. 28). These printed-circuit motors have been excellent performers and permit the chair to be folded, thus meeting the "requirements" for commercial consideration. The motors can be powered by d.c. voltages up to 48 v. The assembly is being evaluated at 24 v. and at 12 v.

Responses by the patients have been excellent; the motors are quiet and draw minimal power from the batteries for a given speed and for ramp-climbing. The manufacturers have recently delivered a proportional-control system. In our opinion, this prototype appears to be superior to any other conventional powered wheelchair. It is planned to place 15 units in selected clinics for broader evaluation.

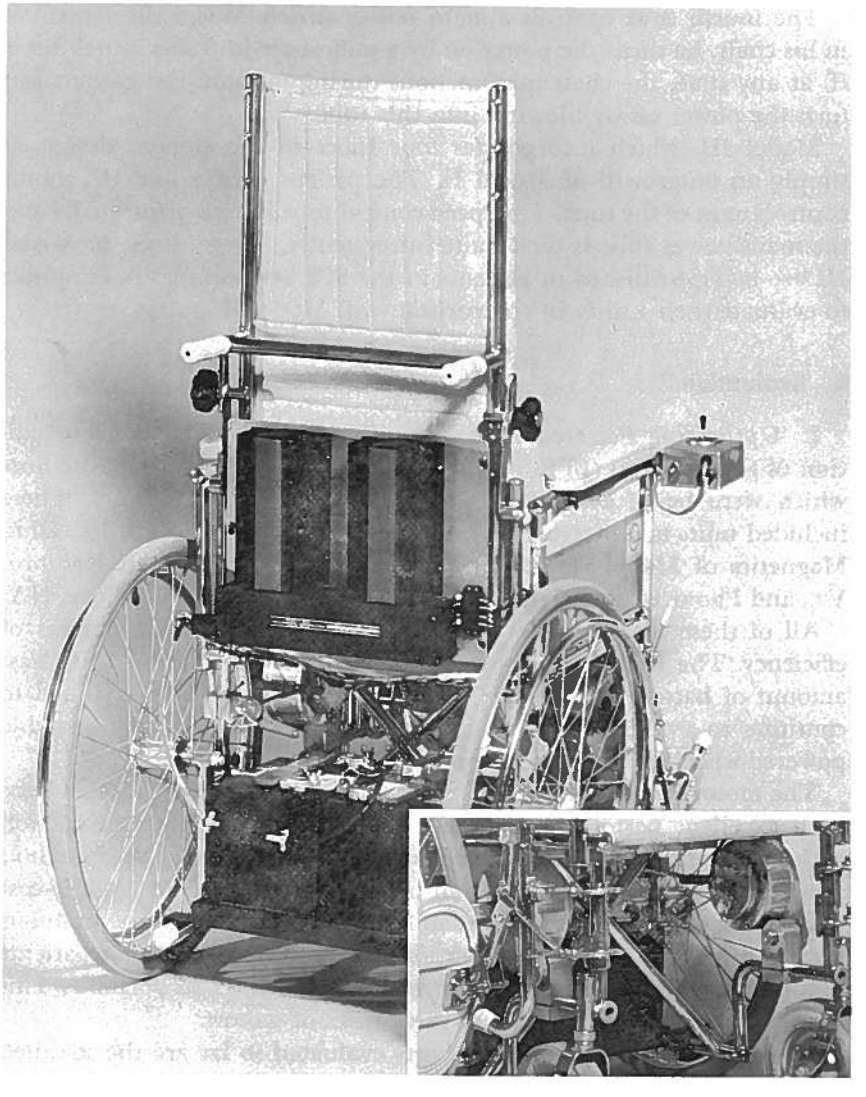

FIGURE 28.—Powered wheelchair with printed-circuit "pancake" motors.

2. *Sonotrol Environmental Control.* Purchased from Bio-Med Technology, Rochester, N.Y., this control system is similar in design and operation to the Sonotrol Wheelchair Control (BPR 10–17, pp. 223–226). A microphone, sensitive to puffs of air, activates the unit. However, the microphone is also sensitive to shock or impact (Fig. 29). Ten channels, each rated at 120 v. a.c. are used to provide electric power to any appliance connected to them. The control system is an on/off switching system.

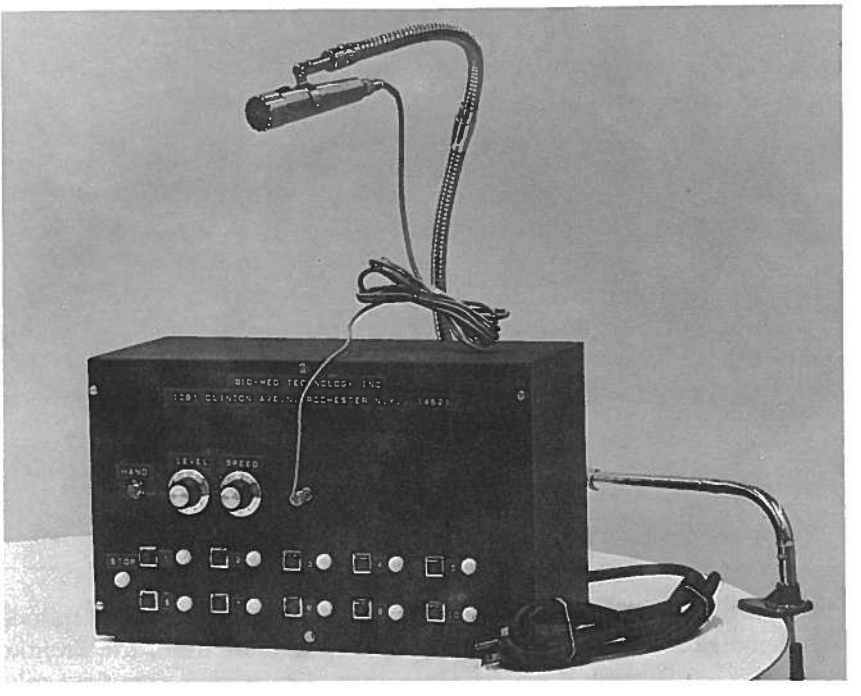

FIGURE 29.—Sonotrol environmental control system.

Channels 1–5 and channels 6–10 function on two different types of operational logic. The initial puff of air into the microphone causes an automatic sequencing for channel selection. The sensitivity to breath response and sequencing rate are each adjustable. The second puff of air into the microphone causes the sequencing to stop, and the selected channel then provides 120 v. a.c. to the connected electrical appliance. The third puff effects a different response from the two sets of channels. Channels one through five turn off power to the appliances, and the sequencing operation commences again. Channels six through 10 continue to provide power to the appliance, but the sequencing operation commences again. Channels six through 10 can be turned off by passing through an additional cycle and repeating the above operation.

Any combination of channels six through 10 may be turned on or off on a continuous basis, but the remaining channels can be activated only on an intermittent basis. The rationale for the function of the first five channels is not clear to us. The Sonotrol was evaluated at the VAH Castle Point Spinal Cord Injury Service where it exhibited limited capability. Several patients attempted to use the device, but it offered little useful function. No further evaluation is planned.

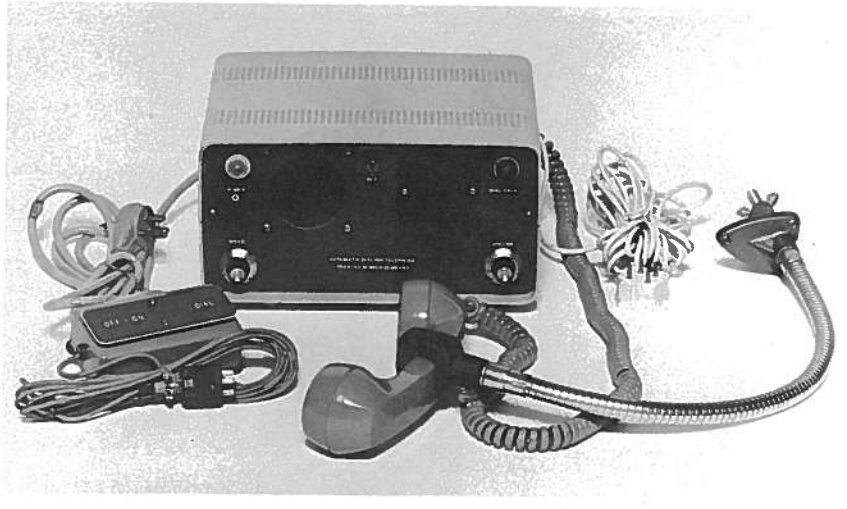

FIGURE 30.—Automatic dialing telephone manufactured by Prentke Romich Co.

3. *Automatic Dialing Telephone.* This automatic dialing telephone was designed and manufactured by, and is available from, the Prentke Romich Company of Wooster, Ohio (Fig. 30). It is a complete telephone in which dialing is accomplished electronically rather than mechanically, as in the conventional dialing telephone. Intended for use by quadriplegics and other severely disabled people at home or at work, the mechanical activity of lifting the receiver is accomplished electronically by touching one section of a rocking-lever switch assembly. Dialed numbers appear on a digital display when the opposite side of the rocking-lever switch assembly is pushed. The lever is released when the desired number appears on the display, and the number is dialed. Dialing can be achieved with minimal body motion. Accessories included are a loudspeaker and gooseneck tubing, which holds the receiver in a suitable position relative to the patient's head.

This unit is currently undergoing evaluation at the ADL department of the Castle Point VA Hospital, as well as in several patients homes. The device has been modified for pneumatic operation by the VAPC Environmental Control system to expand the evaluation of this item. Early results indicate that this device is an important adjunct to the home environment of a physically disabled individual.

4. *E-Z Hold Telephone Clip.* This device, submitted for evaluation by Wolfe Enterprises of Long Beach, California, is designed to permit quadriplegics and other disabled individuals to use a telephone without assistance (Fig. 31). It incorporates a clip which, when attached to a telephone receiver, permits a patient to pick up the receiver. The

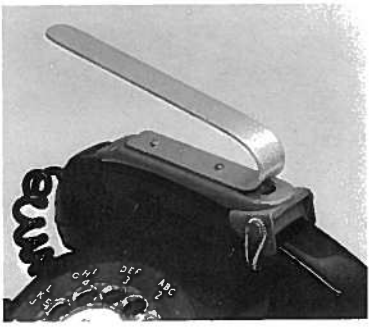

FIGURE 31.—E-Z Hold telephone clip.

extension of the clip is also claimed to be of assistance in dialing a push-button model telephone. This dervice is currently undergoing evaluation by an out-patient who uses a telephone in his occupation.

5. *Overly-Bressler Stand-Up Wheelchair.* The Scientific and Medical Equipment Division of Overly Manufacturing Company, Greensburg, Pennsylvania, submitted for evaluation one unit of the Overly-Bressler Stand-Up Wheelchair. The device is a manually operated wheelchair (Fig. 32), equipped in such a manner as to lift its occupant to a nearly vertical position (Fig. 33). It is designed to be used by paraplegics, and others with neuromuscular disorders, to extend the range of their capabilities by permitting them to stand erect without assistance. In the standing mode, the chair is not mobile; it is not meant to be moved with the patient in the partially erect position.

This unique wheelchair has a frame made of welded tubular steel and a supporting structure (seat and back) of five rolling Latex-foam bolsters. A spring-loaded mechanism, housed within the tubular steel side members, raises the chair and the occupant to a nearly upright position (approximately 80 deg. (1.396 rad.) from the horizontal). The spring mechanism is adjustable to accommodate persons of different weights and physical conditions. A system of snap locks permits the chair to be disassembled for portability. The steel framework is brightly color-coated (green, blue, orange, and sand), with seat and back bolsters covered with removable polyester cotton covers in vivid yellow, green, or tan.

To stand unaided, the wheelchair occupant: 1. locks the wheel brakes; 2. swings the foot rests down to the floor; 3. secures a knee bolster, to prevent his lower limbs from flexing when in the standing position; and 4. secures an abdominal bolster, to prevent him from toppling forward. Then the patient pulls backward on the two knob-headed levers, each mounted on a side member; this releases compressed helical springs which elevate the chair frame. The patient must lean *well* forward to displace the body's center of gravity forward.

FIGURE 32.—Overly-Bressler Stand-Up Wheelchair.

The stored energy in the spring system elevates the chair frame, a movement that can be stopped or controlled by ceasing to pull backwards on the two lock levers.

To return to the seated position, the subject must pull backward on the lock levers and lean backward, displacing the body's center of gravity backward. This recompresses the springs, lowers the frame and patient to the seated position, and stores energy for use in elevating the frame.

Since this unit is both a wheelchair and a standing device, it was evaluated by checking its wheelchair functions against the tentative VA Standards for Wheelchairs, Self-Propelled, Folding Multi-Purpose, dated May 1966. Its standing function was evaluated in relation to the manufacturer's claims for the device. Special consideration was given to safety, ease of operation, maneuverability, reliability, increased range of useful motion, and patient acceptance. To complement the bioengineering evaluation, a clinical evaluation was conducted by the staff of the Spinal Cord Injury Service, VAH Castle Point, N.Y. The laboratory tests were first conducted on the initially submitted unit.

FIGURE 33.—Subject standing in Overly-Bressler Stand-Up Wheelchair.

The Overly-Bressler Stand-Up Wheelchair has generated much patient interest, indicating that there is a need for a wheelchair that can easily and conveniently serve as a standing device. Perhaps some degree of mobility in the standing mode is also indicated. It is not clear, however, from our laboratory and from our clinical experiences, as to what type of patient can best benefit from the Overly-Bressler Stand-Up Wheelchair. It seems to be for paraplegics with low-enough lesions to allow good trunk stability. The wheelchair features of this device apparently would not meet their complete daily wheelchair needs. It might serve as a complementary device that permits mobility within a particular environment, such as a home, office, or work situation, or serve as an intermittently used standing device for physiological and/or psychological benefits.

6. *Expandable-Adjustable Crutch.* Unlimited Development, Inc., of Winter Park, Florida, submitted for evaluation two pairs of their Expandable-Adjustable Crutches, complete with carrying cases (Fig. 34). When not in use, these adjustable axillary-type aluminum crutches can be easily and conveniently "retracted" to a portable 23½ in. package by simply releasing several spring-loaded detent pins.

The Expandable-Adjustable crutches were evaluated against existing

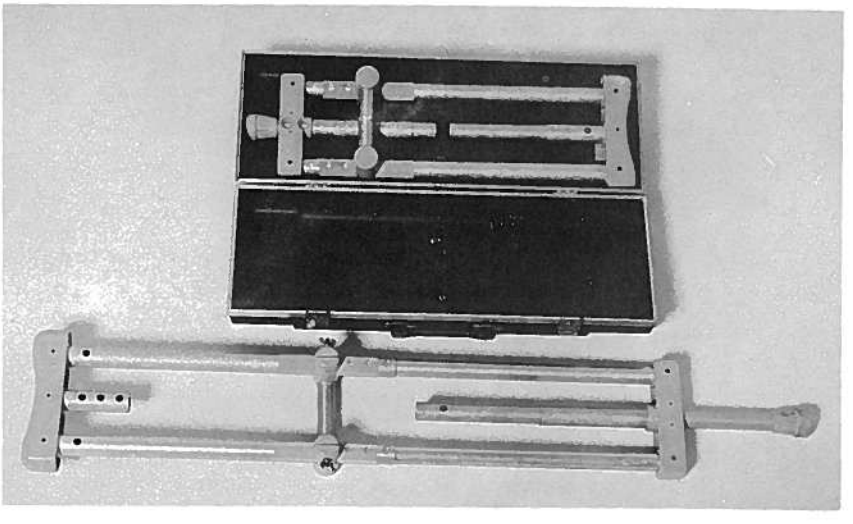

FIGURE 34.—Expandable-Adjustable Crutches with carrying case.

VA Specifications for Crutch, Axillary Type, Aluminum, Adjustable, No. 7777 320a, dated February 28, 1961. In addition, bioengineering analyses were conducted in the laboratory, complemented by a clinical evaluation in the Rehabilitation Medicine Service at the VAH Bronx, N.Y.

The unique Expandable-Adjustable Crutches do comply with the functional requirements as specified in current VA Standards. They are sturdy and are capable of length adjustments that meet the needs of most adult male VA beneficiaries.

A device of this type may be useful for unilateral leg amputees who, perhaps while traveling, might have occasion to move around their hotel rooms without their prostheses. It is difficult to see other applications. We have recommended that the crutches be modified to eliminate certain specific limitations. A properly modified version may be useful to some patients.

7. *Astropedic Chair.* The Astropedic Chair (Fig. 35) is a unique, multi-purpose device submitted for evaluation by Astropedic Enterprises, Inc., Ozark, Alabama. It is essentially a rocker and a recliner. With three adjustable cushions and one fixed cushion, the manufacturers state that it is possible to completely support the body in any position. They further assert that it provides a method of gravity-assisted blood circulation through the "back shoulder stand position."

Our evaluation of subjects with different disabilities indicates that the Astropedic Chair cannot be used successfully by many wheelchair

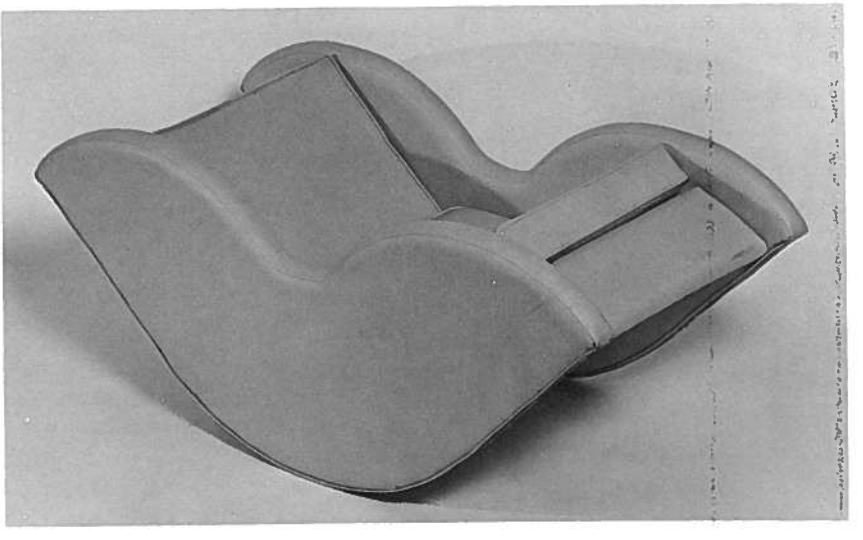

FIGURE 35.—Astropedic rocker and recliner chair.

subjects, primarily due to an inability to get in and out of the chair unassisted, and to an inability to accomplish the chair's rocking function.

In general, we found the Astropedic Chair to have novelty and possible therapeutic value for the non-disabled person. Disabled persons may encounter difficulty in transferring in and out of this device, and in its operation.

8. *Mercy Lift.* Mercy Lift, Inc., of Lake Wales, Florida, has submitted for evaluation an electrically operated patient lift for use with spinal-cord-injured patients (Fig. 36). The lift, a large superstructure designed to be rolled over a hospital bed, features two lifting devices. The patient's feet and head can be lifted either together or separately. A center lifting hoist raises a patient into a sitting position and places him into a wheelchair or straight-backed chair. Use of this device permits one person to turn patients, change linens, elevate foot or head, give bed pan care, and transfer the patient to a chair. It also acts to restrain patients, and it can be used to pick up a patient who has fallen on the floor. This device is currently being clinically evaluated at the VAH Castle Point, N. Y

9. *Hess Rotary Bed.* This bed is a turning frame manufactured by Walter Hess, Dubendorf, Switzerland (Fig. 37). It is being evaluated for use by Spinal Cord Injury Centers in the United States. In addition to providing a safe means for one person to turn a patient from the prone to the supine position or vice versa, the patient's head or feet

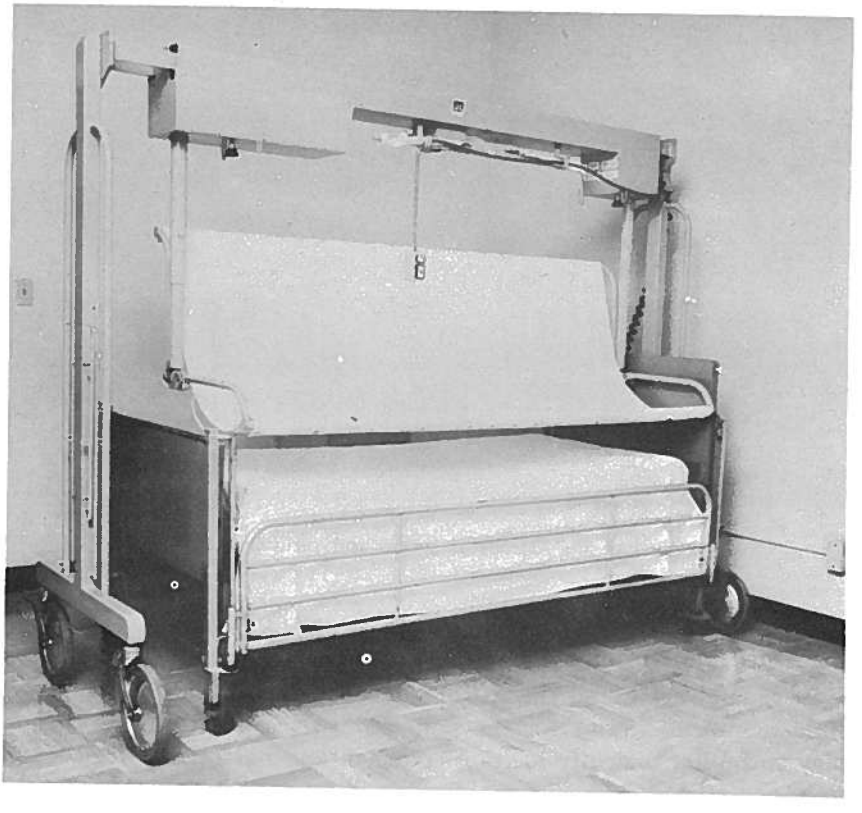

FIGURE 36.—Mercy Lift, electrically operated patient lift.

can be raised independently. Provision is also made for both cervical and lumbar traction.

10. *Specially Adapted Vans for Wheelchair Users.* Most paraplegic veterans who drive have sufficient upper-limb strength and range of motion to permit them to operate sedan-type motor vehicles.

The general procedure, with individual variations, consists of approaching the automobile on the driver's side in a hand-propelled wheelchair, opening the driver's door, transferring in a lateral and forward direction into the driver's seat or, in some cases, into the passenger's seat and then shifting laterally into the driver's seat. Once positioned in the driver's seat, they are capable of reaching out through the open door, on either the passenger's side or the driver's side, of collapsing the wheelchair by upward movement against the bottom of the seat of the chair, and then pulling the chair into the rear passenger compartment behind the front seat.

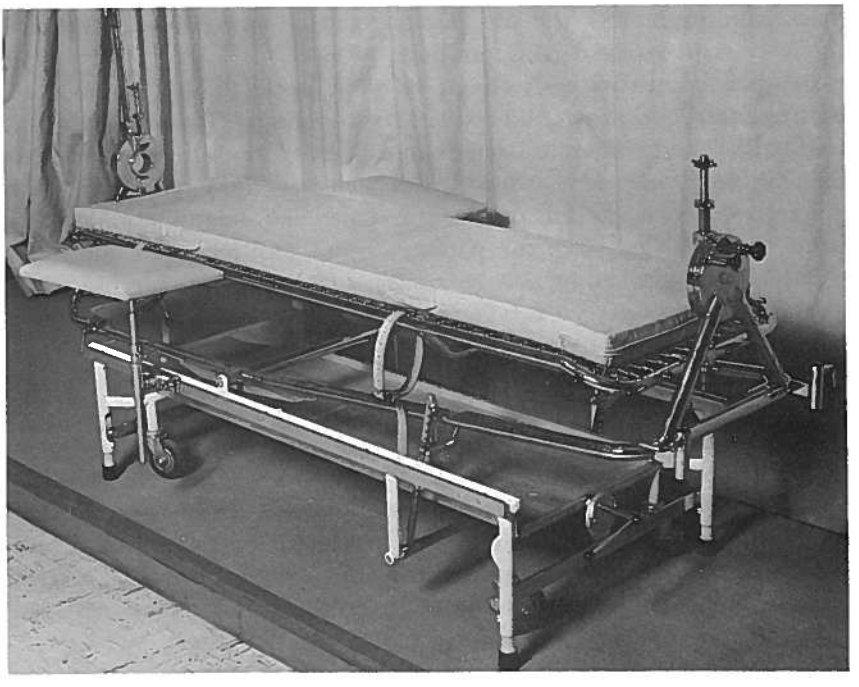

FIGURE 37.—Hess Rotary Bed.

These patients have no functional *need* for a van in the sense that they are capable of entering, exiting, and operating standard sedan vehicles with modifications such as hand controls and seat adjustments. They may *desire* a van for its cargo space, multiple passenger capacity, and/or the current vogue of van use. Vans for these patients require several major modifications: Removal of the driver's seat; installation of hand controls; an elevator system to permit the patient to enter and exit the vehicle, whose floor bed is higher than the conventional sedan; a tie-down system for stabilizing the wheelchair in the operator's position during operation of the vehicle; a redundant control system enabling the patient to open the van doors, to operate the elevator lift from outside the van, and permit him to store the lift and close the doors from within the van.

The assumed mode of operation for these patients is to approach the van from the curb side, if it is a side-loader, or from the rear if it is a rear-loader; operate the control system to open the doors; bring the elevator to curb or street level; manually propel the wheelchair into position on the elevator; actuate the elevator-ascent control; enter the van by manually propelling the chair off the elevator and into the

driver's position; lock the lift in place and close the doors; and lock the wheelchair in the driving position.

Paraplegic patients with absent or weak upper limbs due to other than primary etiology, and partial quadriplegics whose upper-limb residuals are too limited in strength and range of motion to permit them to operate a manually propelled wheelchair, may use electrically powered wheelchairs. This precludes independent operation of standard sedan-type vehicles, since the patient cannot position the chair inside the sedan even though he may be capable of exiting and entering.

These patients have a functional *need* for one of the two available types of vans:

a. Those whose residual upper-limb functions enable them to operate an automobile with hand controls may require an otherwise-conventional van equipped with hand controls and the previously cited entry/exit modifications.

b. Those individuals whose residual functions do not permit them to operate conventional hand controls may need the specially equipped Scott Van which features a unique control system enabling the patient to operate the van with one hand with very small forces and very small hand/arm motions.

To clarify prescription indications and to determine the general utility of vans for spinal-cord-injured patients, the VAPC is evaluating three different vans:

Scott Van (Fig. 38, 39)
Helper Lift Van (Fig. 40)
Motorette Van (Fig. 41)

For purposes of this evaluation, the patients are being selected who fulfill the following requirements:

1. legally eligible veterans
2. normal use of an electric wheelchair (to establish the need for the elevator mechanism of these vans)
3. licensed to drive a vehicle prior to injury
4. capable of effectively manipulating standard hand controls.

Depending on its availability, the van can also be used in general treatment services to train or retrain other types of patients.

VII. TESTING

A. Standards Development

1. *SACH Feet.* In a continuing effort to improve the functional specifications for SACH feet, several comments received from the field are being studied. Although machine test data show that all the samples of SACH feet have similar heel and toe deflection values, patients have commented on differences in the performance of each foot.

FIGURE 38.—Outside view of Scott Van.

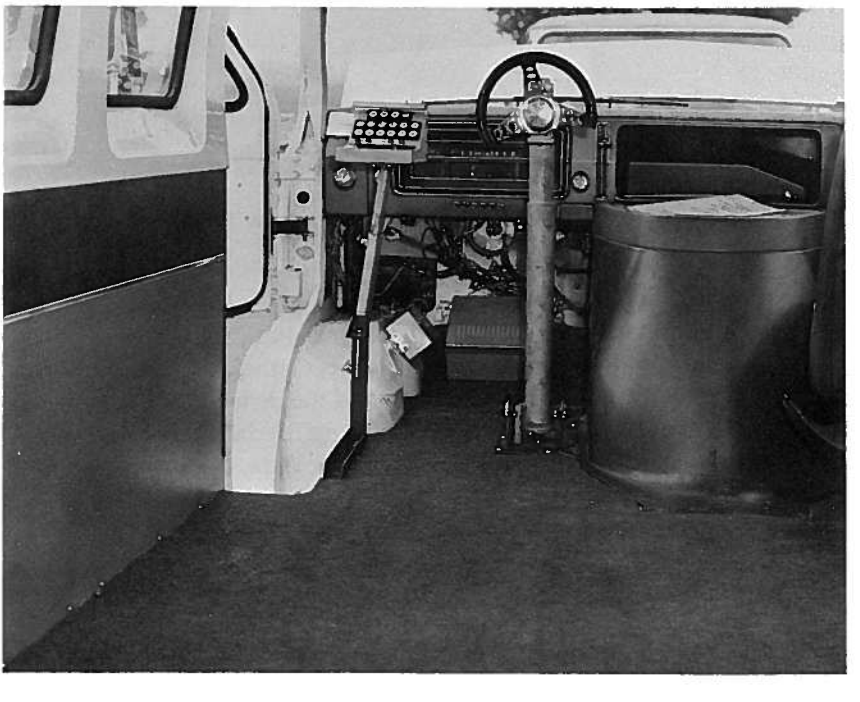

FIGURE 39.—Inside view of Scott Van.

FIGURE 40.—Wheelchair elevator to provide access to the Helper Lift Van.

We are currently reviewing the specifications with a view toward revising the standards. Revisions made to date indicate that both high-profile and low-profile SACH feet which meet other requirements will be acceptable. We are recording the heel and toe deflections for purposes of gathering more information, but not to qualify feet according to the previously published specifications. Using these data, the prosthetist may select the product best suited for a particular patient.

2. *Endoskeletal/Modular Systems.* Modular systems (pylons) have been developed to a point where physical laboratory testing is underway to determine the structural adequacy of the basic mechanical assembly. Several proposed standards for modular systems are currently under study, and appropriate tests are being conducted to establish a rationale for developing standards and specifications. In conjunction

FIGURE 41.—Motorette van system.

with this program, several graphite/epoxy structures are also being tested as possible substitutes for the metal components.

B. Compliance Testing

1. *Upper-Limb Components Compliance Tests were conducted on the following devices*:

a. One Sierra/APRL Voluntary Closing Hook (Tentative Standards

for Hook, Mechanical, Voluntary Closing for Upper Extremity Amputees).

b. One Hosmer External Elbow (outside locking hinge), Model E–500 (Tentative Standards for Adult Size Elbow, Artificial, External Alternating for Above Elbow Amputees).

2. *Stump Socks.* Samples of wool stump socks for lower and upper limbs were submitted by Knit-Rite, Inc. (Blue Line Stump Socks) for compliance test F.Y. 1973. All samples submitted conformed to the requirements according to VA Specifications.

C. Evaluation

Langan Below-Knee Joint. Two units were submitted for evaluation by the Southern Prosthetics Company. The samples were chrome-plated steel with a bronzed ring housed within the matched circular grooves of the clevis joint and a bronze washer between the faces of the outer bars. A large oval-head screw secures both bars, which are locked in place by a setscrew (see BPR 10–18, p. 252, Fig. 26). To determine their effectiveness in a below-knee prosthesis, the test procedure was designed to simulate body weight exerting a lateral bending moment against joint rotation. A constant moment of 6.78 Nm (5 ft.-lb.) was applied and the unit was cycled at 30 c.p.m. Both samples performed satisfactorily under test conditions.