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VETERANS ADMINISTRATION PROSTHETICS CENTER RESEARCH REPORT

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The following presents a report of progress made during the 6-month period of January 1, 1976, to June 30, 1976, on a number of research, development, and evaluation projects performed by the VA Prosthetics Center.

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I. DEVELOPMENT AND EVALUATION

A. Prosthetics

1. *Lower Limb*

a. *Graphite-Epoxy Shank for Partial Thigh Endoskeletal Prosthesis.* As described in the Spring 1976 Bulletin (BPR 10-25), two composite shanks were fitted to two young above-knee amputees. After several weeks of wearing these devices, both patients returned to the center with similar problems: knee bolts and distal attachments of the hydraulic units had loosened, and torque deflections of approximately 4 deg were discovered.

The knee joint and distal knee control attachment of the device are being redesigned.

b. *Graphite-Epoxy Knee Joint for Below-Knee Prosthesis.* Successful application of patellar tendon-bearing prostheses has significantly reduced the need for thigh lacers for below-knee amputees. Nevertheless, due to occasional stump or knee instability problems, lacers are still prescribed. The knee joint used with these lacers, which is made of steel, has remained the same for half a century.

Encouraged by the successful uses of plastics in other prosthetic and orthotic applications, we have been designing plastic knee joints. Initial attempts with polypropylene were unsuccessful because the average thigh corset wearer requires more knee-joint rigidity than polypropylene has to offer. We are investigating the suitability of graphite epoxy as a material for these joints. This material has a greater strength/weight ratio than steel. However, it may be difficult to shape the graphite epoxy bars to the individual patient's stump contour. A number of graphite epoxy knee joints have been fabricated and patients are being fitted with them.

c. *Graphite-Epoxy SACH Foot Keels.* As described in the Fall 1973 Bulletin (BPR 10-20, page 277), graphite epoxy SACH foot keels have been produced by Browning Manufacturing Co. of Morgan, Utah. This

material is superior to the conventional wood in that it provides a greater resistance to breakage and has greater tensile strength.

Bid invitations are being offered for the molding of SACH feet using the graphite epoxy keel as a core.

d. *Polypropylene Hip Joint and Pelvic Band.* Since our first report on this item in the Spring 1976 Bulletin (BPR 10-25), we have concluded our flexion and extension cycling tests, which also included some side-to-side lateral pressure. (Tests are designed to simulate as closely as possible the actual movements produced by amputees during ambulation.) After extensive laboratory tests in which no major deficiencies were noted, the polypropylene hip joint and pelvic band was fitted to 20 above-knee amputees. Preliminary results have been positive. The reduction in weight, and the extra rotational movement this semiflexible joint provides, were unanimously approved by the patients. The flexibility of the band allows it to spread, thereby providing greater comfort in sitting. And except for patients with very short stumps, (for whom we feel this device is inadvisable) stability has not been a problem. The only mechanical problem encountered was excessive friction between the polypropylene joint surfaces, solved by inserting a Teflon liner between these surfaces.

We are continuing to fit patients with the device, and will observe its durability over a longer time span. We feel it will eventually become commercially available for routine prosthetic use.

e. *Prosthetic Skin.* It is apparently not yet possible to produce a durable, esthetically acceptable, cosmetic cover with physical characteristics that do not conflict with the function of underlying knee components. Attempts to coat a composite endoskeletal above-knee limb, in which the knee joint was covered with foam, have been frustrated by the cover contracting into wrinkles when the limb was flexed through its range of motion.

George Washington University, under contract with the Veterans Administration, is currently developing an improved cosmetic technique for lower-limb amputees, using cosmetic covers of soft polyurethane foam supplied by the VA Prosthetics Center. A composition of acrylic latex, color pigment, ammonium hydroxide, and Acrysol is applied to the cover with a spatula. Then the surface is smoothed by running a wet finger in a circular motion over the cover. The cover is then dried for approximately 3 hours. Preliminary results have been encouraging.

f. *Above-Knee Endoskeletal Structures.* A design change in the Multiplex system mentioned in the Fall 1974 Bulletin (BPR 10-22, page 469) has been instituted. The single-piece unitized construction of the Multi-

plex Mark V system, which gives complete structural stability, provides a semi-rigid knee cap of polyurethane. In addition to hydraulic units which can be accommodated in the system housing, spring controls produced by the Ohio Willow Wood Co. and U.S. Manufacturing Co. can now be installed as alternatives.

B. Orthotics

1. *Upper Limb*

Functional Elbow Orthosis. The pneumatic unit described in the Fall 1975 Bulletin (BPR 10-25) has been redesigned to reflect our experiences and further understanding of the forces involved in lifting the forearm. A gas spring cylinder was designed and fabricated to meet the requirements of packaging the system more efficiently. The system (Fig. 1-3), including shoulder caps, weighs 690 grams (1¾ lb). The original forearm cuff was reduced to a narrow cuff located next to the wrist. The shoulder cap was altered to obtain an upper-arm cupping effect to stabilize the upper arm during elbow flexion, and the attachment points were modified to permit more free motion. Thus a patient with elbow extensors, but poor or no flexors, is an ideal candidate for this system because no shoulder motion or strength is needed—the shoulder cap provides all necessary support and suspension.

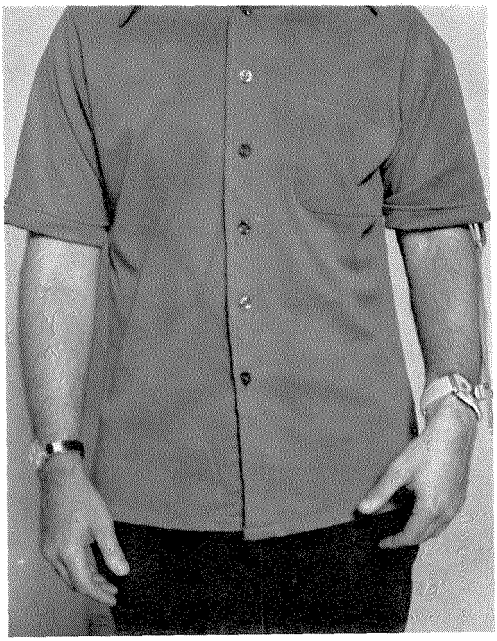
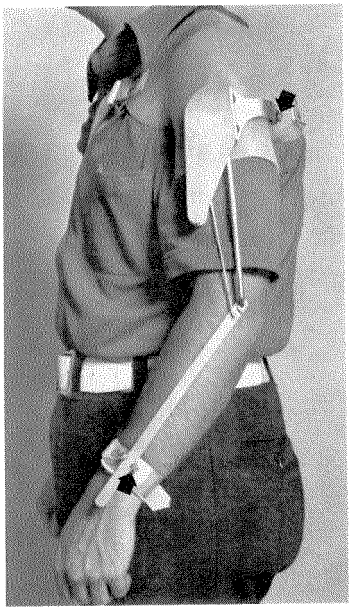


FIGURE 1.—Functional Elbow Orthosis, anterior view



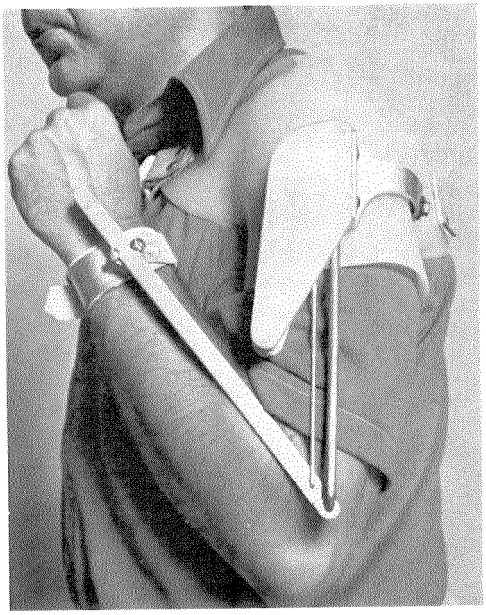


FIGURE 2.—(above) Functional elbow orthosis shown with arm in extended position: the gas "spring" cylinder is in its compressed state with arm at limit of extension. The device exerts enough pulling action between the points marked by arrows so that slight effort on the part of the triceps is required to maintain a fully extended position of the arm.

FIGURE 3.—(right, above) Functional elbow orthosis, shown with arm in flexed position. The device, with gas "spring" cylinder extended, is exerting a strong pulling action between the points marked by arrows.

This allows us to generate nonlinear forces to accomplish the following: (i) Balance the force of gravity; (ii) Provide force required to stretch the triceps (forces which increase with flexion); (iii) Overcome resistance encountered by the forearm when compressed against the biceps during flexion (forces which increase exponentially in the final 25 deg of flexion); and (iv) Correct for constantly changing forces (force reduction is brought about with linear extension by a spring constant).

The device produces a strong pulling action between the two points illustrated by arrows in Figure 3. A counterbalance is produced between the forces used to extend the cylinder during flexion and those used to compress it during extension, causing the system to stabilize against the weight of the arm. Once the elbow has been flexed moderately, an object weighing up to 1 lb still lies within the "dead zone" of the system. As flexion continues, the unit continues to flex until the triceps are activated either to slow down flexion or stop it. Slight elbow extension is required to maintain a fully extended position. (Maximum force is

required at full flexion; as the arm is extended, this force diminishes accordingly.)

C. Spinal-Cord-Injury Rehabilitation

1. *Evaluation of Environmental Control Systems*

a. *Fidelity Comfort and Communication Control System.* The Fidelity Comfort and Communication Control System was developed by the Northwestern University Rehabilitation Engineering Program. It is manufactured by Fidelity Electronics, Ltd., of Chicago, Illinois. The system was reported on in the Spring 1975 Bulletin (BPR 10-23, pp 242 and 243). Seven of these systems have since been installed in the homes of disabled veterans for evaluation.

In general there were no problems with installation procedures and the units functioned adequately. However, several malfunctions occurred involving two special features of the Fidelity System—telephone operation and the remote controller. The problem with the remote controller has been solved, but operating the telephone through the main control continues to produce malfunctions intermittently. The manufacturer has been made aware of the problems and has taken steps to correct them.

b. *ROBOT System.* The ROBOT (Remote Operation by Oral Triggering) System (Fig. 4 and 5), manufactured by Serif Corp. Ltd., Jerusalem, Israel, and distributed by Sudbury System, Inc. of Sudbury, Massachusetts, is a five-function environmental control system that utilizes four latching circuits (bistable multivibrators) and one momentary (monostable multivibrator) circuit. The latching circuits enable a patient who is immobile to independently operate a radio or television set, raise or lower an electrically operated bed, turn a lamp on or off, release an electrically controlled door lock, and generally perform similar operations. The one momentary circuit enables him to contact a nurse or an attendant.

Operation of a given appliance is activated either by depressing a front-panel remote-control pushbutton, or by blowing a coded command signal into an attached microphone. This coded signal corresponds to an assigned number of "blows" used to activate or deactivate a particular numbered power receptacle. (Each appliance receptacle has its assigned number stamped over it.) After successful completion of operational and safety engineering analyses, the ROBOT system will be clinically evaluated at the Castle Point, New York, VA Hospital.

c. *Touch-Operated Selector Control.* The Touch-Operated Selector Control (TOSC) (Fig. 6) is manufactured by Commutron Ltd., of On-

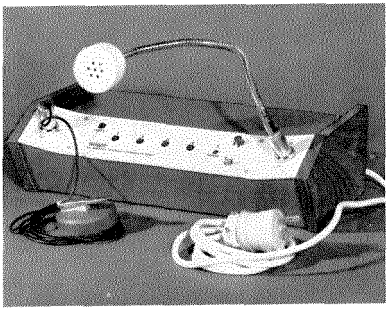


FIGURE 4.—The ROBOT System, showing remote-control pushbutton (left) and attached microphone.

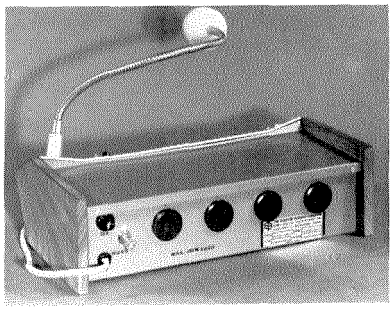


FIGURE 5. — The ROBOT system, rear view.

tario, Canada, and distributed by the Prosthetic Service, Department of National Health and Welfare, Sunnybrook Hospital, of Toronto, Canada. It is a nine-function environmental control. Standard 115V a.c. power is used to operate the device.

FIGURE 6.—Touch-Operated Selector Control (TOSC).

Two sensitive remote-control touch switches enable a handicapped person to independently activate an emergency alarm, operate an inter-

com, unlock a door, receive and make telephone calls, switch a radio on or off, operate a dictating machine, switch a television set on or off and select channels, and switch a lamp on or off and control its brightness. Three additional utility power outlets are available for additional standard appliances.

To activate these functions, the handicapped person must be able to touch the control switch with any part of his body—hand, chin, cheek, tongue, foot, etc. The touch-switch assembly is on an adjustable arm which can hold it near that part of the body used to activate the controls.

One TOSC system is currently installed in the home of a disabled veteran. So far he has been primarily interested in using the dictating machine, but he is also evaluating most of the other functions with the exception of the automatic door-lock release (he was disinclined to alter his door).

d. *VAPC Hospital Environmental Control.* The VAPC Hospital Environmental Control, manufactured by the Prentke Romich Co. of Shreve, Ohio, was described in the Spring 1974 Bulletin (BPR 10-21, page 81). The unit provides 12 channels: four are 110V a.c. standard power outlets, six are 12V d.c. outlets for remote switching systems, and two are shorting jacks for simple switching operations. Designed to be operated by severely disabled persons, the unit can be operated by having the user sip on a pneumatic tube to select the desired function, and then puff on the tube to activate the function. A rocker switch can be used in place of the sip-and-puff control.

The system was tested by the Clinical Evaluation Service for operation and safely, and has functioned successfully in clinical trials conducted at the Castle Point, New York, VA Hospital.

A final report has been prepared recommending that the Prentke Romich Co. be made an alternate source of the VAPC Hospital Environmental Control System.

e. *Fidelity Comfort and Communication System Security Sentinel.* The Fidelity Comfort and Communication System (FCCS) Security Sentinel (Fig. 7), developed and distributed by Fidelity Electronics, Ltd., of Chicago, Illinois, is an environmental control system that provides disabled persons with the means to respond to potentially dangerous home situations.

The system provides five security and safety functions: a closed-circuit television monitor that can be used to observe and identify front entrance callers; a wired intercom to communicate with a front entrance caller; a breath-controlled electric door-lock release; a heat-and-smoke detector that activates an automatic telephone dialer or an audible

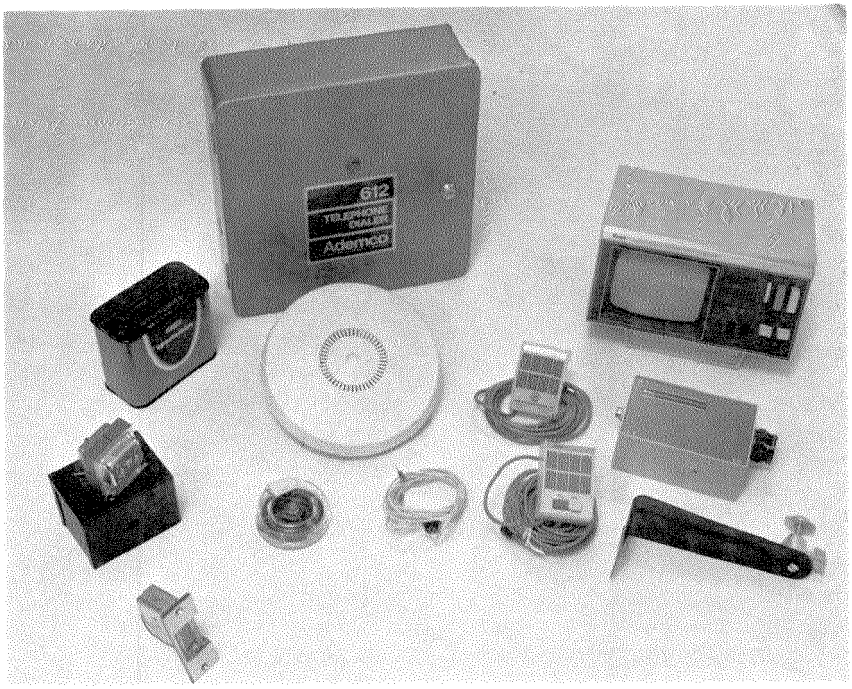


FIGURE 7.—Fidelity Comfort and Communication System Security Sentinel (FCCS).

alarm; and an automatic emergency telephone dialer. (When the dialer is activated by the heat-and-smoke detector, it automatically dials a prerecorded number such as that of the local fire department, and provides prerecorded emergency information, such as location, etc.)

Twelve of these FCCS Security Sentinel units are being installed by the manufacturer in the homes of disabled veterans.

f. *Zero-Pressure Remote Power Control.* The Zero-Pressure Remote Power Control (Fig. 8), manufactured by Med-i-electric and distributed by Medical Equipment Distributors, Inc., of Upper Darby, Pennsylvania, is a 110V control switching device enclosed in a small metal box. It comprises two capacitive switches, a power indicator lamp, a 110V socket, a 5A fuse, and a 110V power cord. Two sensitive front panel switches, an ON switch and an OFF switch, are used to activate and deactivate 110V appliances plugged into the socket. The unit was tested for safety by the Rehabilitation Engineering Service at VAPC. It is currently being evaluated in the home of a disabled veteran, where it has been functioning without requiring maintenance.

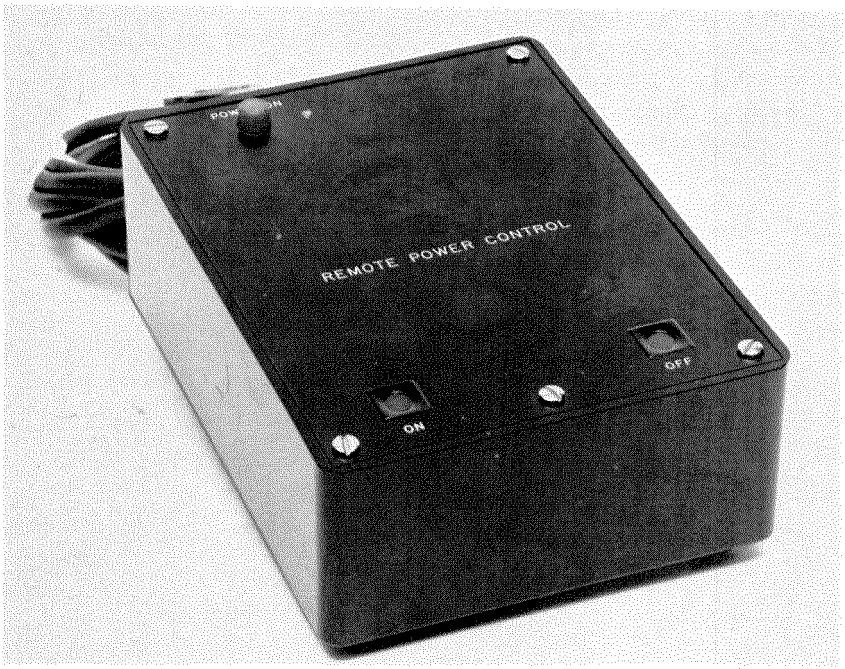


FIGURE 8.—Zero-Pressure Remote Power Control.

2. *Communication Aids*

Microfilm Reader. The Fall 1973 Bulletin (BPR 10-20, pages 294 and 295) discusses the initial VAPC development of a breath-operated microfiche reader. Six units were fabricated and deployed, with microfiche reading material, to several VA hospitals.

Clinical evaluation is now completed. The results clearly demonstrate that the small screen size, 4 in x 7 in., is not conducive to easy reading; the necessity to position the face very close to the screen is awkward. It is also clear that the outdated, as well as limited, selection of reading material does not offer sufficient motivation to use the device. Another problem is poor illumination, and focus adjustment that is not uniform over all portions of the microfiche cards. We have purchased several other microfiche readers with larger viewing screens (up to 8 in. x 11 in.), different magnifications, and improved illumination, but in our opinion the results are still unacceptable. The sparseness of popular reading material and the relatively outdated sources, the small screens and poor resolution, did not add up to a practical, useful device.

The Fall 1975 Bulletin (BPR 10-24, pages 175 and 176) describes the VAPC development of a projection-screen reading machine using 35mm color slides and a standard slide projector. The device, currently

under evaluation, offers the advantage of using ordinary 35mm slides which can be made by photographing popular reading material. The screen size, illumination, resolution of reading material, and low cost indicate probable patient acceptance.

The Spring 1974 Bulletin (BPR 10-21, page 92) refers to the VAPC development of a breath-operated microfilm reader that also uses a 35mm photographic format but with the option of using 35mm or microfilm strips rather than slides. The projection screen machine's Carousel slide-holder is limited to 120 "pages" of reading material, while the microfilm reader can accommodate up to 5 or 6 thousand "pages" of material on one strip, if resolution presents no problem.

This microfilm reader is completed (Fig. 9) and readily presents reading material by manipulation of modular actuators including breath sensors (Fig. 10), joysticks (Fig. 11), pushbutton switches (Fig. 12), and magnets (Fig. 13). We have acquired reading material presented in 35mm strip format as well as conventional 17 : 1 reduction on microfilm strips. The basic reading machine incorporated several magnifying lenses to accommodate the various photographic reductions.

The clarity of the projected microfilm "pages" is excellent, comparable to that of the projection-screen development. In addition to the substantially increased capacity of a microfilm reader, there is the advantage that the user is able to either turn the "pages of his book" one at a time or flip through a large number in seconds.

A larger library of books and magazines is available on microfilm from several sources, and other publications may be photographed on an individual basis by using a 35mm camera and splicing consecutive strips together (rather than mounting the individual page photographs in slide format as is done for use with the projection-screen device).

3. *Mobility Aids.*

a. *Stainless Medical Products Electric Wheelchairs.* The Stainless Medical Products (SMP) 12V d.c. and 24V d.c. electric wheelchairs (Fig. 14 and 15), manufactured and marketed by the Stainless Medical Products Co. of Santa Ana, California, feature lightweight, modular-frame, stainless-steel construction that enables quick assembly or disassembly (within minutes) without tools, and easy storage. A 12V d.c. electronic controller is concealed within the padded Naugahyde back of the bucket seat. This electronic controller is an omnidirectional, proportional-speed Motorette unit. In the SMP 12V d.c. wheelchair it utilizes a 12V battery to drive two 1/4-hp, 12V d.c. electric motors which drive the rear wheels through a belt transmission system. An automatic Schauer battery charger comes with the unit.

The SMP 24V d.c. electric wheelchair, similar in configuration, has two 1/5-hp, 24V d.c. electric motors, a 24V d.c. electronic controller in a

FIGURE 9. — VAPC microfilm reader.

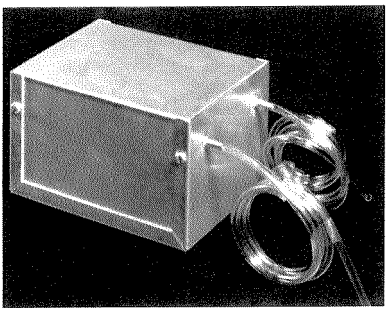


FIGURE 10. — Breath actuator for microfilm reader.

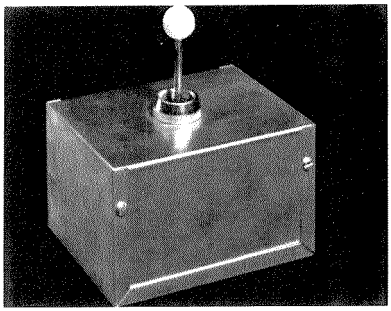


FIGURE 11. — Joystick control for microfilm reader.

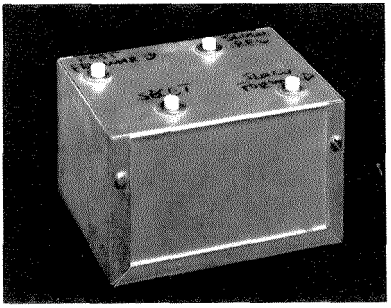


FIGURE 12. — Pushbutton actuator for microfilm reader.

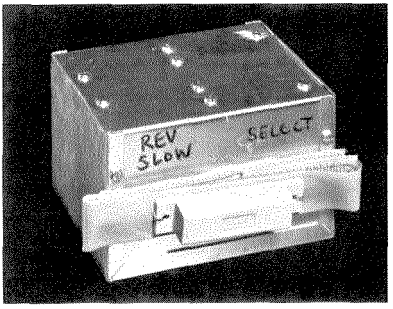


FIGURE 13.—Magnetic actuator for microfilm reader.

FIGURE 14.—Stainless Medical Products (SMP) electric wheelchair, 12V d.c. version.

FIGURE 15.—Stainless Medical Products (SMP) electric wheelchair, 24V d.c. version.

24V d.c. omnidirectional Motorette unit with two speed ranges (high and low), a 24V d.c. battery charger, pneumatic tires, and elevated leg rests.

The SMP electric wheelchairs were clinically evaluated at the Castle Point, New York, VA Hospital. Eight participants (five spinal-cord-injured patients and three patients with other neurological disabilities) evaluated the wheelchairs. Their unanimous conclusion was that the wheelchairs were comfortable, maneuverable, and performed well on inclines and on uneven surfaces, both indoors and outdoors. Two minor electrical problems with the 12V d.c. wheelchair were resolved on station by the Rehabilitation Engineering Services: faulty insulation of a diode and a shorted potentiometer were the faults.

b. *Freewheeler Electric Wheelchair.* The Freewheeler electric wheelchair (Fig. 16 and 17) is manufactured and marketed by the American Stair Glide Corp. of Grandview, Missouri. It has a lightweight aluminum frame that can be folded to 9½ in. in width (with battery removed) for transporting purposes. Two electric motors situated on the lower support frame draw their power from a 12V battery, and there is a built-in 3A charger at the right rear of the wheelchair. Control is accomplished

FIGURE 16.—Freewheeler electric wheelchair, front view.

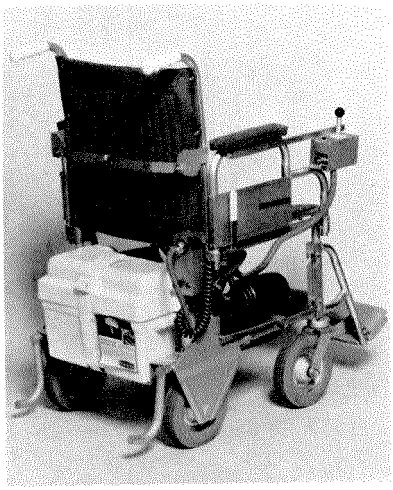


FIGURE 17.—Freewheeler electric wheelchair, rear view.

with a 2-speed hand-operated microswitch range-selector (HIGH/LOW) control unit that activates the two 15 ft-lb torque, 12V gearhead motors to drive the rear wheels via transmission belts. The wheelchair rides on four semi-pneumatic 8-in. x 2-in. wheels.

The Freewheeler has successfully met the performance test requirements of Standards Manual VA X-15296 (Oct. 18, 1972): Electrical Safety Tests and Mobility Aid Performance Tests. It is currently being clinically evaluated at the Castle Point, New York, VA Hospital.

c. *Printed Motors for Powered Wheelchairs.* The printed motor, available from Photocircuits, of Glen Cove, Long Island, New York, has been used in several configurations in efforts to design a suitable and effective drive system for powered wheelchairs. The most recent attempt incorporates these motors in a double belt reduction drive (Fig. 18) resulting in high-torque drive with average speed. The main drive-wheel belt is wrapped around a drive pulley, mechanically connected by four metal straps to the rim of the wheel. Early units were prone to structural failure of the metal straps because of stress fatigue induced at sharp corners (Fig. 19). Modification of the metal straps with more generous radii resulted in improved structural characteristics, but the high starting torque and considerable weight of the complete drive assembly and wheelchair caused other parts of the drive wheel to fail structurally (Fig. 20).

These chairs are able to climb 12-deg inclines from a dead stop with 150-lb test subjects. On level ground, maximum speed is between 3 mi/h and 3½ mi/h (5.2 km/h). The drain current on level surfaces is exceedingly low, between 4A and 5A at 24V. In its present configuration the chair is not foldable, which may present problems in salability, delivery,

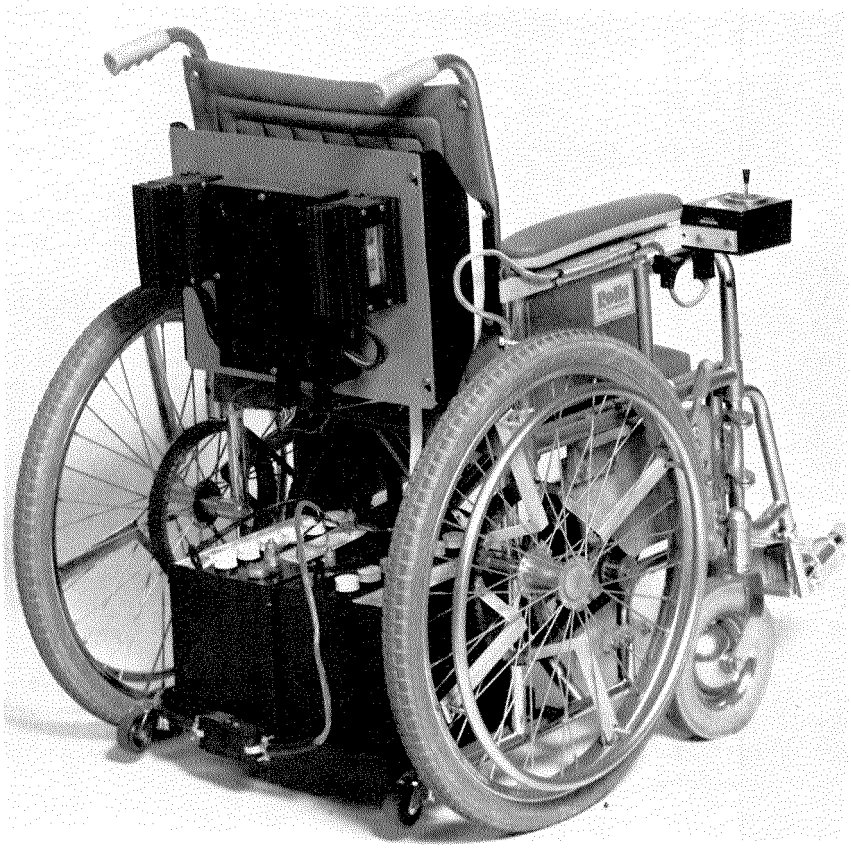


FIGURE 18.—Powered wheelchair equipped with printed motors and double belt reduction drive.

and transportation.

The most successful powered wheelchair configuration incorporating printed motors is the powered wheel or motorized hub (Fig. 21). Two versions are available and undergoing evaluation. The first incorporates a commercial Orbidrive transmission, available from Compudrive Corp., of North Billerica, Ma. The other is a more conventional spur gear assembly designed by Photocircuits.

The Orbidrive transmission (Fig. 22) comprises two interlocked multilobed cam and roller sets, each having a different number of lobes and rollers. Both cams are fastened together concentrically and mounted on an eccentric shaft. The Orbidrive assemblies require relatively low running currents, approximately 5A, and attain wheelchair speeds of approximately 4 to 4½ mi (6.8 km/h), but the ramp-climbing ability in a loaded state is limited to approximately 4 or 5 deg.

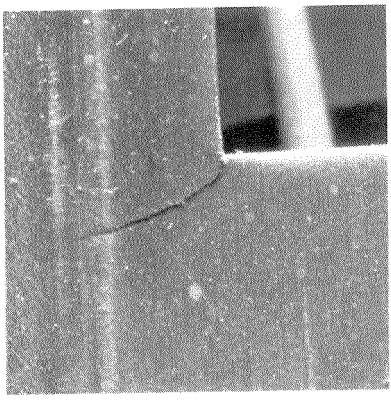


FIGURE 19. — Stress-fatigue crack induced at sharp corner in one of the metal straps connecting drive pulley to drive-wheel rim.

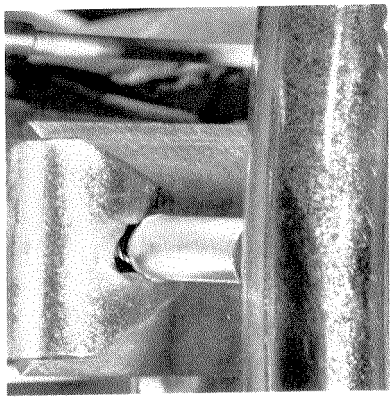


FIGURE 20. — Additional structural failure at drive-wheel strap.

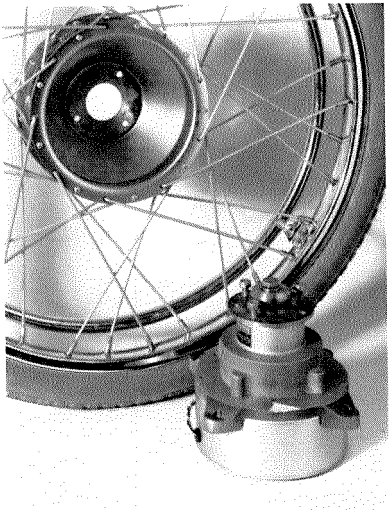


FIGURE 21. — Printed-motor-powered wheel and its motorized hub.

The Photocircuits powered wheel, on the other hand, offers higher performance with reduced energy consumption. The power train (Fig. 23) is a conventional multiple spur gear reduction assembly. Maximum speed is the same, between 4 and 4½ mi/h, but ramp-climbing capability is increased to about 10 deg. Current drain, on level ground, is between 3 and 4A, the lowest value for any powered wheelchair which VAPC has evaluated.

Clinical evaluation clearly demonstrates that in this application the Photocircuits' performance is preferable to that of the Orbidrive. The

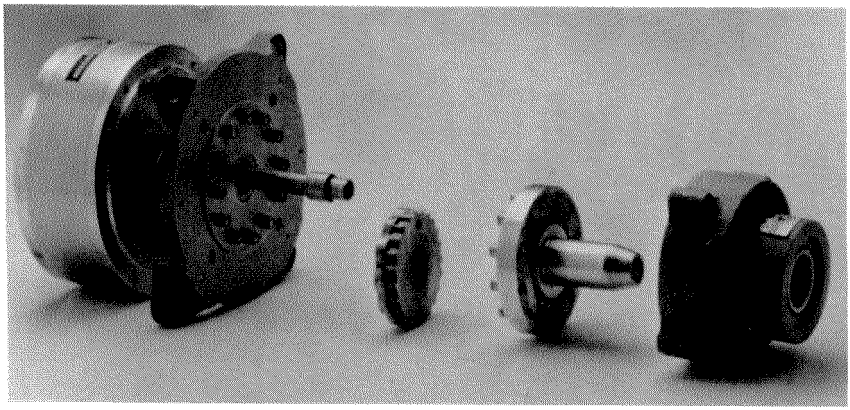


FIGURE 22. — Internal view of Orbidrive transmission.

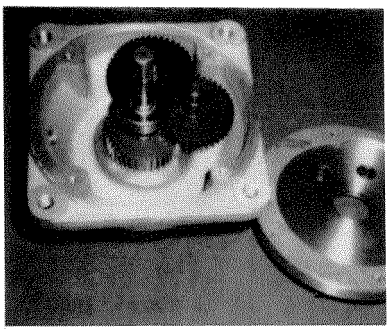


FIGURE 23. — Internal view of the gear train of a Photocircuits powered wheel.

relatively smooth ride of the wheelchair with the Photocircuits wheel, compared to the grinding, rumbling ride in the chair equipped with the Orbidrive design, is an additional preference factor.

VAPC expects to conclude the evaluation of the printed motor in a Photocircuits powered-wheel configuration within the next few months. The product may become commercially available if relatively high production costs are overcome.

d. *Indoor/Outdoor Wheelchairs.* The Spring 1975 Bulletin (BPR 10-23, pages 235 and 236) describes VAPC development of an electric wheelchair designed for outdoor as well as indoor use. The design motivation is based on veterans' needs — attending classes on college campuses, special vocational applications, activities of daily living, and general recreation.

The initial models were relatively small, well within the dimensional envelope of common powered wheelchairs. Unfortunately, these chairs exhibited continual problems with controller reliability, and could not consistently traverse rugged terrain.

A second generation design provides a larger, more comfortable automobile-type bucket seat to distribute pressure more uniformly. The vehicle is heavier than the initial version and may not be as adaptable indoors, but it handles outdoor terrain more successfully. The electronic controller and motor/gear package are reliable. The four wheels are larger; all are pneumatic and enhance riding comfort.

Laboratory tests show a maximum speed of approximately 3¾ mi/hr (6 km/h) which is substantially less than our goal of 7 or 8 mi/h (12 km/h). But ramp-climbing is excellent, as evidenced by acceleration from a dead stop on a 12-deg incline with a 200-lb test load. The braking action is sufficient to maintain the loaded chair on a 12-deg incline without motion.

Maximum surge current during acceleration is approximately 85A while steady-state drain is approximately 15A at 24V. These values are similar to those of other 12V and 24V wheelchairs.

Several models are under evaluation at this time. One of these, a standard model (Fig. 24), provides modular construction and a fixed-

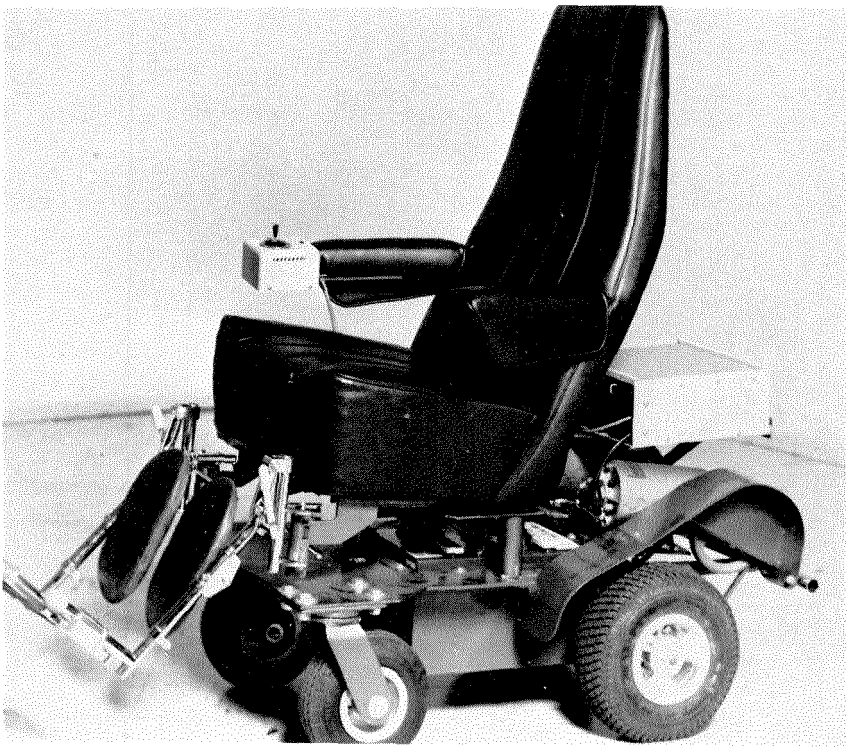


FIGURE 24.—Indoor/outdoor wheelchair, standard model. Seat-height is fixed.

height seat. A second model (Fig. 25 and 26) employs an adjustable seat-height mechanism which may be useful for certain activities, such as driving a modified van. Both chairs permit the seat to be shifted forward or backward, as required by the occupant. Stability, regardless of seat position, is excellent, but traction improves when the seat is adjusted to the rear position and a greater part of the total load is directed toward the rear drive wheels.

Arm rests may be lowered to facilitate lateral transfer (Fig. 27).

Evaluation of the current design will continue with a view toward improved performance and reduced physical size.

FIGURE 25. — Indoor/outdoor wheelchair, with elevating seat at maximum height.

FIGURE 26.—Indoor/outdoor wheelchair with elevating seat at minimum height.

FIGURE 27.—Indoor/outdoor wheelchair with armrests lowered to facilitate entry/exit.

e. *PRAHN Wheelchair.* The PRAHN (powered, reclinable, adjustable height, and narrowing) Wheelchair is shown in Figure 28. It was designed by D.M. Cunningham and D.M. Anderson of the Department of

Mechanical Engineering, Biomechanics Laboratory, University of California, Berkeley, California, and is manufactured by Falcon Research and Development of Denver, Colorado. It functions as a wheelchair for outdoor terrains, and as a driver's seat when placed in an automobile or van. The PRAHN derives its power from two lead-acid 12V storage batteries. This power, modulated by a PW (pulse width) electronic modulator circuit, drives two proportional drive 1/3-hp motors which turn the rear wheels of the wheelchair.

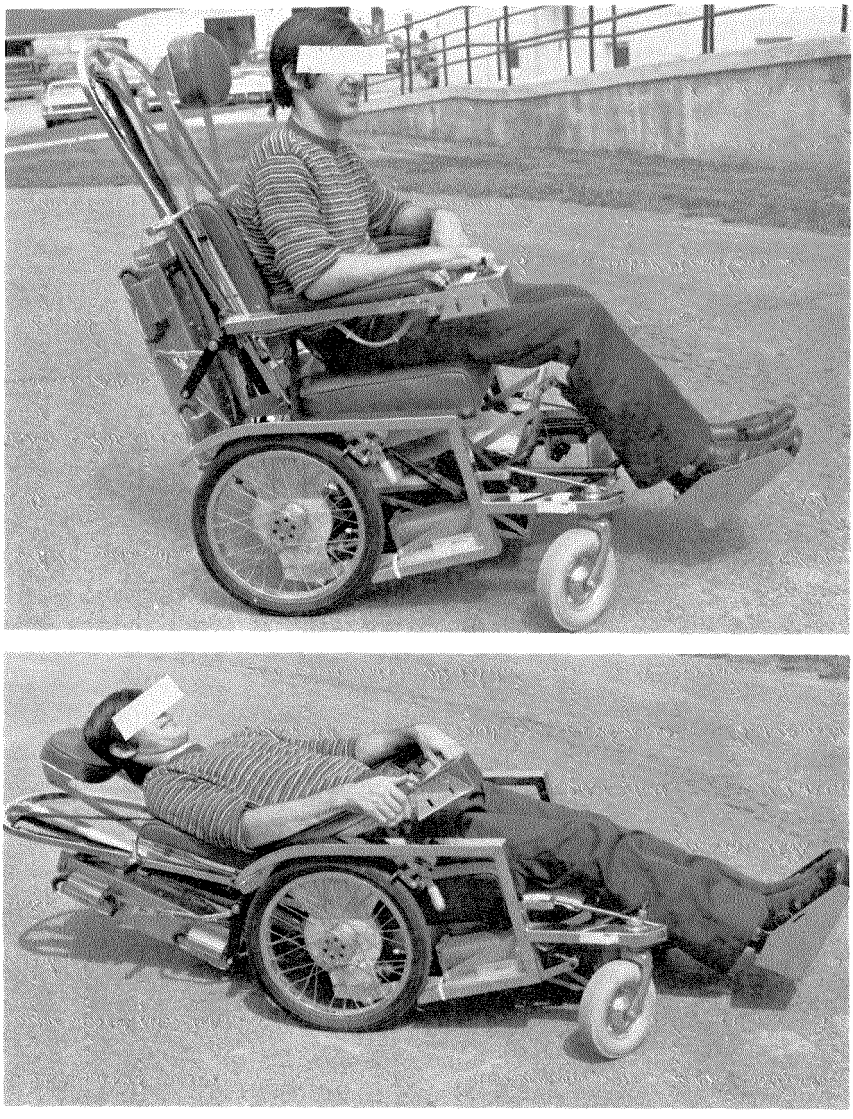


FIGURE 28.—PRAHN Wheelchair in various positions.

The wheelchair has a 15-in by 16-in medium density foam cushion seat with Naugahyde cover. A four-bar linkage that connects the seat to the fixed side frames guides the seat and its associated armrest from its lowest to highest position (from 12 to 27 in. above ground level) while maintaining a 5-deg-tilt-back posture at all times. Raising and lowering the seat is accomplished with a Saginaw ball-screw actuator (similar to a screw jack) attached between the rear axle and the backrest support top. To avoid relative motion between backrest and occupant when the back reclines, the backrest simulates a hip joint pivot by sliding up and down its support column. When the actuator is shortened to pull the seat down all the way, the seat stops and further shortening of the actuator causes the back to recline to an almost horizontal position.

Footrests, located on a second linkage, bring the occupant's legs from a nearly-extended position when the seat is low to a more-than-90-degree flexed position when the seat is high. This allows for much greater maneuverability in the high position than would otherwise be the case, and allows close access to a vertical surface or wall.

A third linkage reduces the wheelbase width of both sets of wheels (front and rear) from 25 to 21 inches as the seat rises from normal chair height to maximum height. The armrests can swing away around a horizontal axis, up and to the rear. The front casters are 8-in with solid rubber tires, and the rear wheels use 16-in by 2½-in pneumatic tires.

The protocol for the evaluation of the PRAHN wheelchair consists of laboratory testing, automotive testing, and clinical trials, as follows:

Laboratory Testing—The Testing and Distribution Service, VAPC, will test two PRAHN wheelchairs against applicable wheelchair performance standards. They will conduct special tests on functions not covered by existing standards; e.g., adjustable seat, reclinable feature, and narrowing.

Clinical Trials—One PRAHN wheelchair will be tested at each participating hospital as a powered wheelchair, both indoors and outdoors. Comparative analyses will be conducted with the help of other veterans who have used other powered, multi-function wheelchairs.

f. *Automatic Transmission for Powered Wheelchairs.* Electrically powered wheelchairs offer independent mobility for paralyzed veterans. Most powered wheelchairs used indoors (in a hospital, home, or on the job) have been reasonably well powered by using two drive motors per chair, with ratings up to, but rarely exceeding, 1/8 hp per motor. Until a few years ago, all joystick controls incorporated microswitches; now, joystick controls provide effective and desirable electronic proportional capabilities.

However, conventional electrically powered wheelchairs are not intended to meet the rigorous requirements of very active quadriplegics

such as those who attend classes on a college campus, or whose vocational needs demand extensive mobility. (Most college campuses have relatively long distances between classes and buildings, and many factories are constructed horizontally rather than vertically.)

The VA Prosthetics Center recognizes that active veterans require higher-performing non-licensed mobility aids. While an effort is under way to provide a suitable means of transportation for this class of quadriplegics (and paraplegics), sufficient evidence suggests that at present, most higher-performing mobility aids may not be structurally adequate to handle the stresses induced by increased speeds, nor are they designed to provide the necessary comfort, security and stability for the wheelchair occupant, especially over rugged terrain. Furthermore, veterans may use their mobility aids under conditions and in environments that exacerbate inadequate structural integrity, and overload power trains.

Consequently, VAPC embarked upon the development of a vehicle which would combine adequate structural characteristics with sufficient power to climb inclines, traverse difficult terrains, and attain higher speeds. Designated an "indoor/outdoor" wheelchair, this concept has generated great interest in the rehabilitation community—so much so that Everest & Jennings, General Teleoperators, National Welded Products, and other organizations are now devoting important resources to the development of this type of vehicle.

Laboratory tests and clinical evaluation of earlier experimental chairs suggest that the transmission of power from motors to drive wheels has been inadequate and inefficient. The evidence is clear that many powered mobility aids tend to bog down in certain types of terrain, are unable to climb steep inclines, lack sufficient speed, and/or suffer excessive battery current drain during these trials.

We plan to incorporate an automatic transmission in the indoor/outdoor wheelchair to mitigate these problems.

In meeting the requirements for adequate outdoor performance, it may be possible to select or design a combination of motor and electronic controller that will achieve the necessary torque and speed relationships. This is a valid approach if the weight and inefficiency associated with available mechanical transmissions are excessive. However, a properly designed mechanical transmission may reduce battery current drain and thereby extend vehicular range, with reduced motor size and weight. In the design of electric vehicles, both design approaches are successfully employed.

Theoretically, a variable-speed mechanical transmission will meet the requirements of an electrical vehicle most effectively since it reduces electric current demand to a minimum and provides maximum torque for acceleration and to climb inclines. Without such a transmission, high

torque at low speed results in high electric current drain, which boosts heat-loss and reduces vehicle range and battery life. On long ramps, excessive current drain may generate enough heat to damage the motors. It is easy to see why an automatic transmission provides significant advantages even with its anticipated losses.

When meeting high-torque and low-speed requirements, a d.c. motor necessarily develops very high starting currents. With adequate battery capacity and a suitable electronic controller, the performance demands could be met. In practice, however, wheelchair batteries (automotive variety) cannot provide high current drains of long duration. Also, electronic controllers are generally unable to handle these high power requirements without premature failure.

We believe that an automatic transmission will alleviate these problems — while providing smoother acceleration with the result of less jostling of the wheelchair occupant, especially over rugged terrain. Rugged terrain is more readily managed by the low-speed, high-torque drive trains that are readily available through an automatic transmission. Consequently, the need for specially designed motors and high-current-capacity controllers, with resultant high cost in each case, may be avoided.

The VA Prosthetics Center has incorporated a *new bicycle-type automatic transmission* on an indoor/outdoor wheelchair. It is a relatively simple mechanism and offers low weight, low bulk, and low cost — and may change the current concept of a powered mobility aid. B.E. Industries, of Garland, Texas, has demonstrated an automatic torque-converter bicycle transmission (Fig. 29) that has been applied to powered wheelchairs with initially favorable results.

The B.E. Industries design offers the advantage of infinite drive-ratio variability, resulting in a responsive transmission. The assembly provides any drive ratio within its upper and lower limits, for any load. The ratio shift occurs by relative movement between two sheave halves, either toward each other or away from each other. When the sheave halves are close together, the belt rides high in the groove of the sheave with a resultant large effective pitch diameter that provides low torque with high speed. As the sheave halves move apart, the belt "drops down" into a position that provides a smaller effective pitch diameter, thereby causing an output speed reduction with a corresponding increase in output torque (Fig. 30). The automatic transmission design causes the halves of the motor-drive sheave to move apart in response to increasing belt tension — output torque multiplication results. As the torque requirement decreases, the sheave halves move closer together and output speed increases.

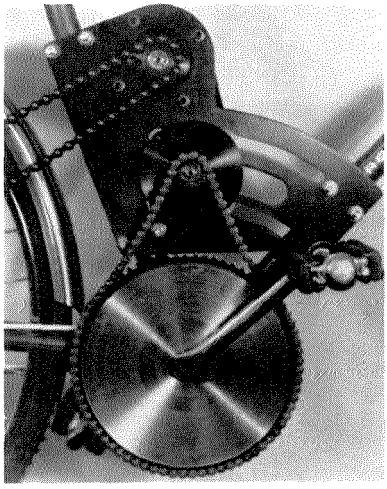


FIGURE 29.—Automatic torque converter bicycle transmission.

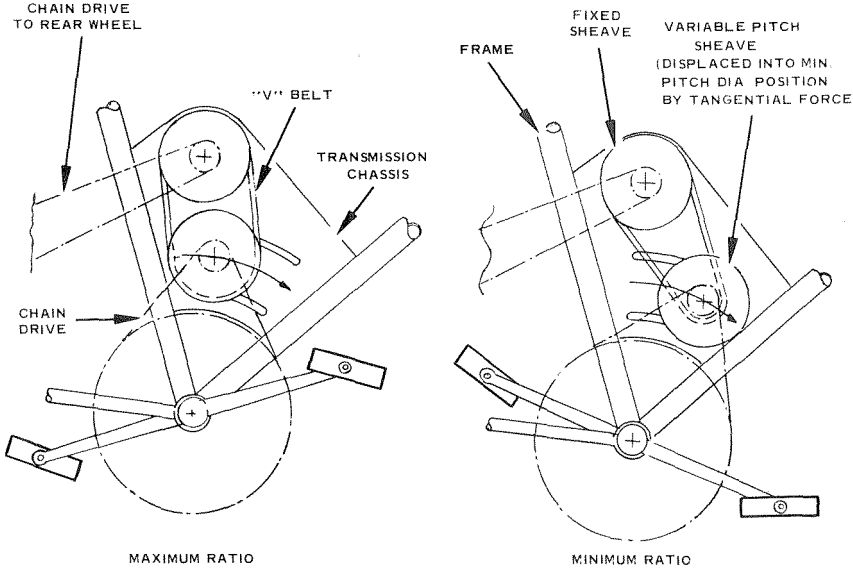


FIGURE 30.—Automatic torque converter bicycle transmission illustrating variable-pitch-ratio sheave used to vary torque/speed characteristics.

The B.E. Industries automatic torque converter bicycle transmission has been demonstrated on several prototype bicycles and on one wheelchair. (It is noted that variable pitch sheaves are common on snowmobile drives.)

g. *Special Mobility Aid for Veteran with a Left Hemipelvectomy and a Right Hip Disarticulation.* A unique request, initiated through the VAPC Clinic

Team, to fabricate a mobility aid for a veteran was handled through the Bioengineering Research Service. The veteran chronically suffered skin problems on his torso due to pressure from a special prosthetic "bucket" (Fig. 31) used to maintain him in an upright position.

FIGURE 31.—Special mobility aid for patient with a left hemipelvectomy and a right hip disarticulation.

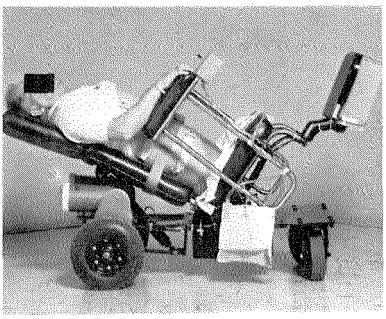


FIGURE 32.—Tilt-back feature, controlled by occupant, was a requirement of this special indoor-outdoor vehicle.

The main vehicular requirement was a "tilt-back" feature (Fig. 32) controlled by the occupant, to ameliorate a condition that tends to produce pressure sores. The vehicle was also required to provide mobility outdoors while offering a reasonable compromise for indoor use. With the assistance of an outside contractor, a mobility aid was designed and built in accordance with VAPC specifications. Although it met gross specifications, considerable modification was necessary. These modifications were completed in our laboratory.

The patient visited the New York VA Regional Office for a week and used the vehicle on the grounds of the New York VA Hospital in Manhattan. During this period, the patient expressed satisfaction with the vehicle and our Center effected further minor improvements.

The vehicle incorporates a joystick-manipulated 24V Everest & Jennings wheelchair proportional controller, two 12V batteries, and a motor/gear-reducer/belt-drive power train. It has a maximum speed of approximately 2.8 mi/h (4.5 Km/h) on level ground, and readily climbs a 12-deg incline from a dead stop with a 175-lb test subject.

With the approval of the VAPC Clinic Team, the vehicle was shipped to the patient's home in Arkansas. VAPC continues to monitor the use of this device to ascertain possible applications for other patients.

h. *Jouk Standing Ambulator.* The Jouk Standing Ambulator (Fig. 33), manufactured in France and marketed by the U.S. Manufacturing Co., of Glendale, California, is a three-wheeled platform for indoor use that supports its user in a standing position and provides him with mobility in the erect position. The front wheel is a modified Power Aid unit that draws its power from a 12V rechargeable battery mounted in a plastic case just forward of the user's legs. Steering and speed control are accomplished by means of a tiller bar and hand grip arrangement.

Ten units underwent clinical evaluation. Results indicated several shortcomings of the present design: inadequate maneuverability; poor performance on carpeting; dangerous instability when turning sharply; insufficient speed on smooth level surfaces and carpeting; and jerky proportional control. In addition, the unit could be tipped over when the user reached for something. The location of the Power Aid prevented several users from approaching certain work areas in their homes and places of employment, and the location of the battery just forward of the shins was uncomfortable for some and could lead to the development of pressure sores. The support straps did not provide the required support.

Although the Jouk Standing Ambulator is unacceptable in its present design, the concept of a standing ambulator with mobility was accepted, unanimously.

FIGURE 33.—Jouk Standing Ambulator.

i. *Davis Suspension System.* The Davis Suspension System (Fig. 34), manufactured and marketed by the MSE Corp., of Mountain View, California, is designed to replace the original caster forks found on electric wheelchairs. The device absorbs the shock sustained by the wheelchair when it is driven over door thresholds, cracks, rough terrain, small curbs, and uneven surfaces. Shock is absorbed through a built-in spring that reduces the vibration transmitted via the wheelchair frame to the occupant.

The Davis Suspension System ½-in x 2½-in diameter steel "hex" bolt is compatible with all Everest and Jennings and Stainless Medical Products electric wheelchair caster axles and vertical shafts. (It does not fit the Invacare models.)

The Davis Suspension System was clinically evaluated at the Castle Point, New York, VA Hospital by a quadriplegic who found that it improved the comfort of his particular wheelchair. To date, the system has been acceptable in reducing shock and vibrations.

j. *Guardian Folding Walker.* The Guardian Folding Walker (Fig. 35), manufactured and marketed by the Guardian Products Co., Inc. of Memphis, Tennessee, is similar to other adjustable folding walkers except that it incorporates two release buttons, located on the front horizontal bar, that when depressed disengage the locking mechanism,

allowing the walker to be folded. Folding is accomplished by first moving the left side, then the right side (or vice versa) toward the front structural support. Unfolding is accomplished by separating the sides of the walker until they lock into the functional position.

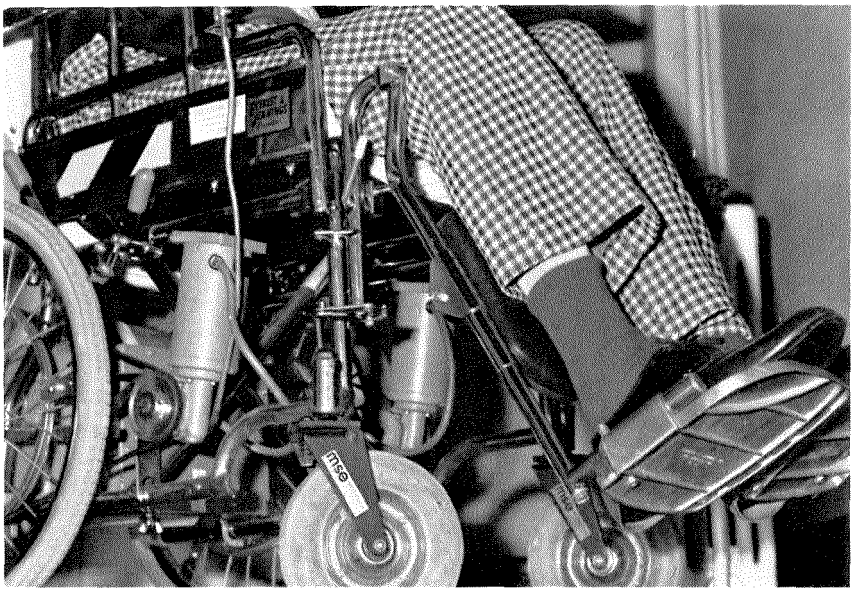


FIGURE 34. — Davis Suspension System units replace the original caster forks on this wheelchair.

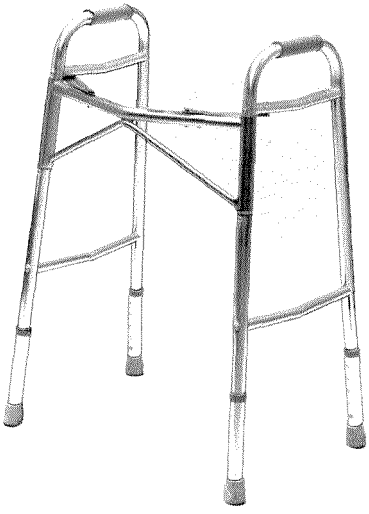


FIGURE 35.—Guardian Folding Walker.

The walker was clinically evaluated at the Castle Point, New York, VA Hospital by patients with various disabilities. They unanimously commented on the ease of operation of the device, and its usefulness during ambulation. A report is being prepared, which will recommend that the Guardian Folding Walker be made available on prescription for VA beneficiaries.

k. *Edco-Hemi Walker.* The Edco-Hemi Walker (Fig. 36), manufactured and marketed by the Edco Surgical Supply Co., Inc., of Passaic, New Jersey, is similar to standard walkers except that it incorporates a centrally located handgrip (Fig. 37) that provides three areas for hand placement instead of the standard two. The center handgrip can be rotated, either to the left or to the right, and locked into that position. According to the manufacturer, this centrally located handgrip enables a hemiplegic to utilize the walker as he would the Hemi Walkerette, a walker specifically designed for hemiplegic persons. However, this walker provides a larger, more stable base of support than does the Hemi Walkerette.

FIGURE 36. — Edco-Hemi Walker has centrally located handgrip.

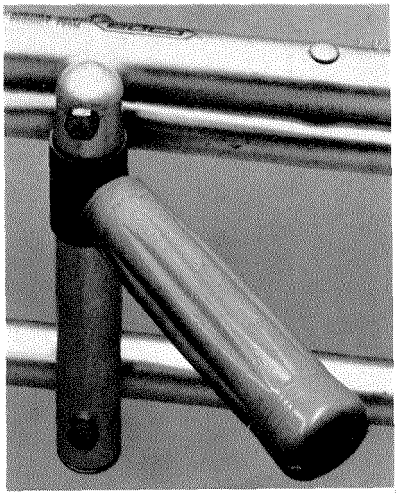


FIGURE 37. — Edco-Hemi Walker showing centrally located handgrip.

One unit has been received and is currently undergoing laboratory performance tests for walkers, as per the specifications set forth in the Fall 1970 Bulletin (BPR 10-14, pp. 229-232).

l. *Postura Adjustable Modular Support System.* The Postura Adjustable Modular Support System (Fig. 38), manufactured and marketed by the

Everest and Jennings Co., Inc., of Los Angeles, California, is a comprehensive body support system which consists of a variety of interchangeable components. This allows flexibility and adjustability in meeting the user's posture-support requirements. The support system comprises the following interchangeable component parts: adjustable lateral back support; adjustable lumbar back support; standard back support; three adjustable headrest supports (cervical, concave, and deep concave); adjustable-depth seat; commode seat; inclinable seat attachment;

FIGURE 38.—Wheelchair equipped with components of the Postura Adjustable Support System.

abduction wedge; adjustable elevating cradle leg rest; extra width arm rests; and 1-in. or 2-in. side cushions.

The Postura is compatible with all Everest and Jennings wheelchairs: full reclining back with any desired armrest style, semi-reclining back with any desired detachable armrest style, and (on the Premier model only) semi-reclining back with fixed arm rests.

The Postura was clinically evaluated at the VA Hospitals at Castle Point and Montrose, New York, and at Richmond, Virginia. The consensus was that the Postura Adjustable Modular support system was useful and versatile. The medical staff was able to reposition the wheelchair occupants comfortably and safely, and the Postura System did not interfere with transfer activities and nursing care. In addition, the Postura was used for persons afflicted with neurological, geriatric, spinal cord, and other neuromuscular disabilities. These persons unanimously concluded that the system improved comfort, and they expressed their general satisfaction with the Postura.

A final report has been prepared recommending the Postura Adjustable Modular Support System for selected VA beneficiaries on prescription.

m. *Electronic Power Conversion Kit for Wheelchairs.* The Electronic Power Conversion Kit for Wheelchairs (Fig. 39) is designed to convert most American manual wheelchairs into electrically powered wheelchairs. Manufactured and marketed by Solo Products, of Sacramento, California, the unit comprises a left and a right drive assembly; a battery case with an attached electronics compartment; a hand-operated proportional joystick control mounted on an adjustable bracket, with connecting hardware; and a battery charger. Conversion is attained by replacing the rear wheels of the wheelchair with the drive assemblies, mounting the battery on the support spreader bar of the wheelchair, attaching the electronics compartment, and connecting the drive assemblies and hand control unit.

The conversion kit is currently undergoing laboratory performance tests prior to being clinically evaluated by the VAPC Clinical Evaluation Service, at the Castle Point, New York, VA Hospital.

4. *Body Support Systems*

a. *Godfrey Standing Aid.* The Godfrey Standing Aid (Fig. 40 and 41), manufactured and marketed by Godfrey Engineering, Ltd., of Hanworth, England, is designed to support (in a standing position) paraplegics, quadriplegics with complete lesions, and patients with neuromuscular disabilities which impair standing. The device was originally reported on in the Fall 1975 edition of the Bulletin (BPR 10-24, pages 187 and 188).

FIGURE 39. — Electronic Power Conversion Kit shown mounted on wheelchair.

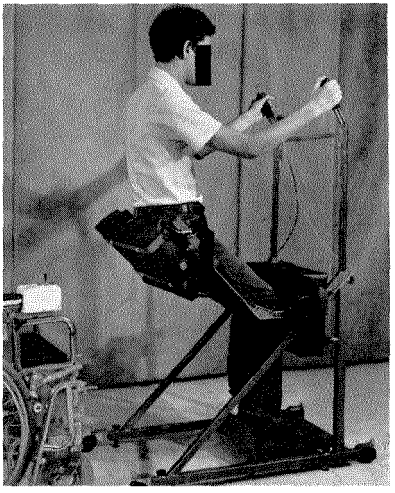


FIGURE 40.—Patient in process of assuming a standing position, using Godfrey Standing Aid.

A clinical evaluation of the unit was performed by the VAPC Clinical Evaluation Service at the Castle Point, New York, VA Hospital. Those who participated in the evaluation found the Godfrey Standing Aid to be useful in helping them to achieve and maintain an upright position easily and smoothly.

The final report, recommending that the Godfrey Standing Aid be made available for use in VA Hospitals, is being prepared.

b. *Steeper "Co Ro" Bed.* The Steeper "Co Ro" Bed (Fig. 42) is manufactured and marketed by Hugh Steeper, Ltd., of London, England. The bed is designed to continuously rotate an immobile occupant (with any disability) through an angle of approximately 55 deg on each side of neutral. A complete cycle takes 8 min. The constant bed motion is claimed by the manufacturer to provide adequate motion to assist the body in maintaining its physiologic integrity for the immobile occupant. The motion of the bed is said to enhance the body fluid flow of the occupant and thereby provide a more physiological approach to the problems of pressure sores and other complications which threaten an immobile patient.

Bed rotation is achieved by an electric motor located at the foot of the bed: a manual backup system is also included. The Trendelenberg feature incorporated into the unit does not interfere with the bed's rotation. The bed is hatched beneath the rectal area to facilitate nursing care, and provisions for urinary drainage are provided. The unit is currently being evaluated in the Spinal Cord Injury Center at the Wood,

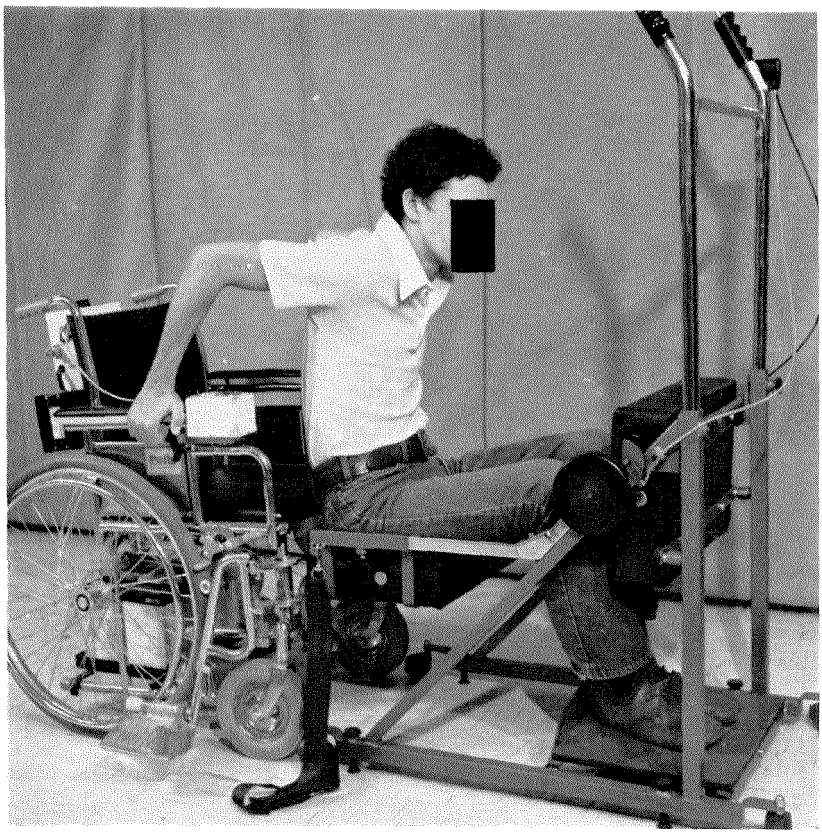


FIGURE 41.—Godfrey Standing Aid, with patient transferring from a wheelchair.

Wisconsin, VA Hospital. Data obtained on its use has generally been negative. At the request of Wood VA Hospital, the unit has been transferred to the SCI Service at the Castle Point, New York, VA Hospital for further evaluation.

c. *Sevier Mobile Bed.* The Sevier Mobile Bed (Fig. 43), manufactured and distributed by the Sevier Manufacturing Co., of Sevierville, Tennessee, is an electrically powered device that can function either as an electric bed or as a powered wheelchair. By using this device, a disabled patient can independently fold his bed into a configuration that functions as a powered wheelchair, and maneuver about a room or from one room to another.

He controls the device with an easy-to-reach control box containing a proportional, omnidirectional joystick control and two toggle switches. The switches are an ON/OFF power switch that controls the application of electrical power to the device, and an UP/DOWN positioning switch that adjusts the contour of the device by raising or lowering its various

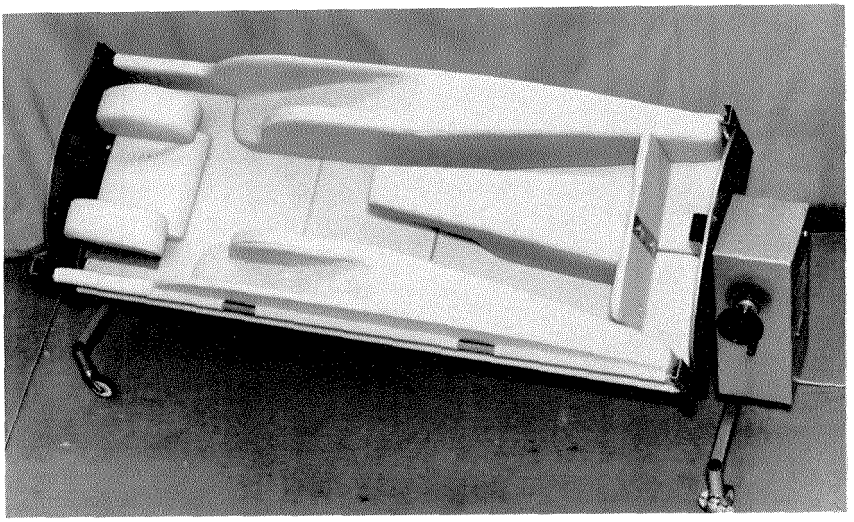


FIGURE 42.—Steeper "Co Ro" bed shown in an extreme rotated position.

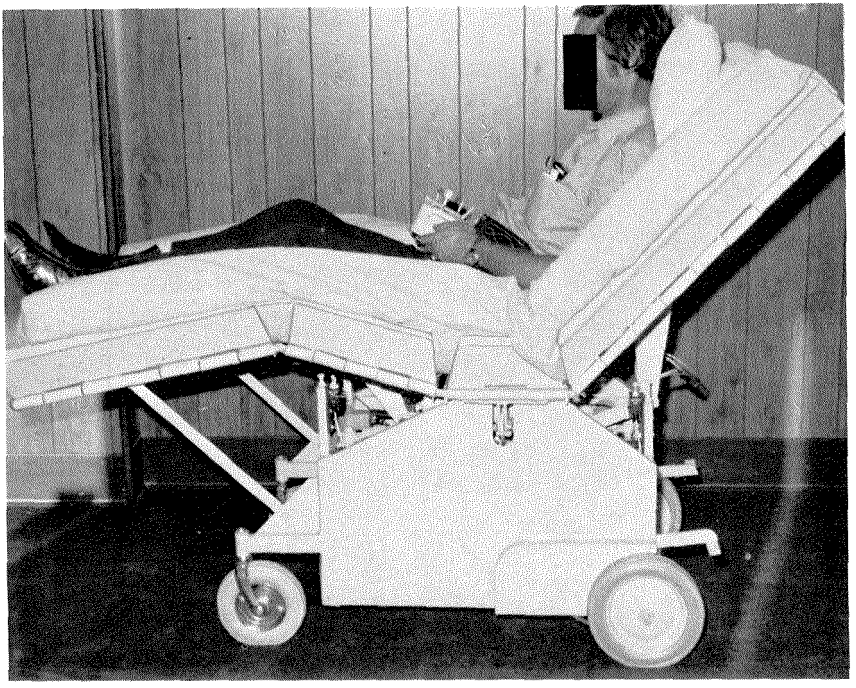


FIGURE 43.—Sevier Mobile Bed in its "reclined sitting" position.

sections after electrical power has been applied. These sections operate in unison with each other, so that the Mobile Bed can be set in a flat bed

configuration at one extreme, while at its other extreme it provides a reclined sitting posture, with the "back" set at 45 deg up from the flat position and the patient's knees up about 4 in. from the flat extreme. Any desired point in between is available.

In the reclined sitting posture, the patient is able to maneuver the device by manipulating the joystick with either his hand or his chin. The Mobile Bed is scheduled to undergo clinical evaluation shortly in various VA hospitals, nursing homes, and in private homes of outpatients. Particular emphasis will be placed on the accessibility of the controls.

d. *Hess Rotary Bed.* The Hess Rotary Bed (Fig. 44) is a turning frame manufactured by Walter Hess, of Dubendorf, Switzerland. As described in the Spring 1973 Bulletin (BPR 10-19), it provides a safe means for one person to turn a patient from a prone to a supine position or vice versa, and to raise a patient's head or feet independently. A provision is also made for both cervical and lumbar traction.

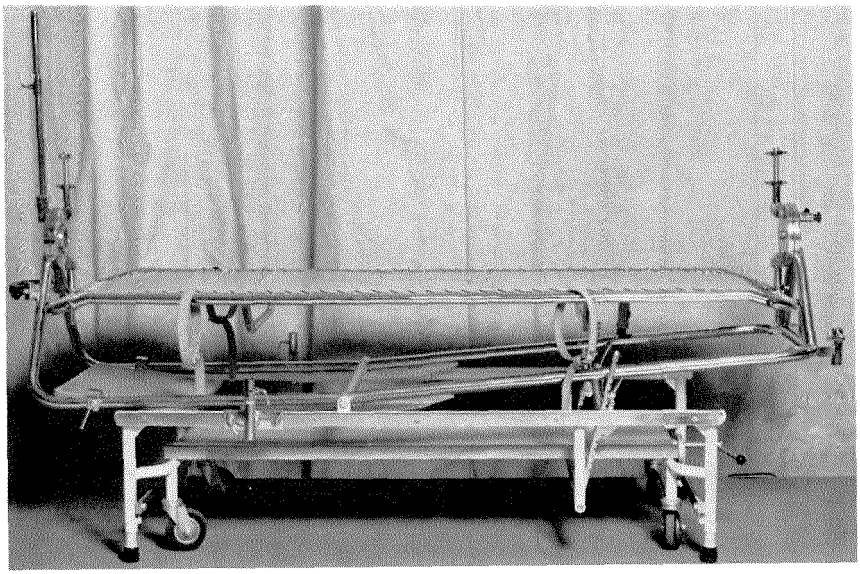


FIGURE 44.—Hess Rotary Bed.

The bed has completed clinical trials at the Castle Point, New York, and Wood, Wisconsin, VA Hospitals, where findings indicated that the bed was very useful in caring for the acute spinal cord injury patients who tried it. Staff members liked its ease of turning, and the unobstructed access to the patient it provided for nursing care. The participating patients agreed that the bed was comfortable.

Based on findings to date, the Hess bed has been recommended for

use in the care of acutely injured spinal cord patients.

e. *Gaymar High Density Fluidized (HDF) Bed.* The Gaymar High Density Fluid (HDF) support system is manufactured by Gaymar Industries, Inc., of Buffalo, New York. The HDF system is used for long-term bed-confined patients who are susceptible to pressure sores. The HDF system was described in the Spring 1974 Bulletin (BPR 10-21, pages 103 and 104). The unit has now completed clinical trials at 10 selected VA Spinal-Cord-Injury Centers. Three of these centers subsequently returned their beds after finding no use for the system. However, the HDF system was found to be satisfactory in treating patients with skin problems.

A complete report has been prepared recommending its use on prescription in VA hospitals. The contents of this report will appear in a future publication on several beds.

f. *Edco-Matic Chair.* The Edco-Matic Chair (Fig. 45 and 46), manufactured and marketed by the Edco Surgical Supply Co., Inc., of Passaic, New Jersey, provides a comfortable means of varying an occupant's sitting posture while providing a level table surface. The chair's backrest reclines about 65 deg, and a leg cushion can be positioned as required.

The Edco-Matic Chair was clinically evaluated at the VA Hospitals at Castle Point and Montrose, New York. Participating patients came from the hospitals' Nursing Home Care Units. The consensus reached by the staff and the participants was that the chair was comfortable and the accessory table was quite functional. In one case the chair has been used extensively by a multiple sclerosis patient: it has helped him to increase significantly the time spent in a chair.

A final report has been prepared recommending that the Edco-Matic Chair be made available for use in VA hospitals.

g. *Action No. 6000 Bed Pad.* The Action No. 6000 Bed Pad (Fig. 47) is a bed cushion manufactured and marketed by Action Products, Inc., of Olean, New York. It is similar in construction to the Action Wheelchair Cushion reported on by Cochran and Slater in their "Experimental Evaluation of Wheelchair Cushions: Report of a Pilot Study" in the Fall 1973 Bulletin (BPR 10-20, pages 29-61). That cushion received an above-average overall rating.

The bed cushion was clinically evaluated at the Castle Point and Montrose, New York, VA Hospitals. The participating patients were each neurologically impaired, of various ages and levels of function. The consensus reached by the evaluators supported the "above-average" laboratory rating regarding the satisfactory distribution of skin-surface

FIGURE 45.—Edco-Matic Chair.

FIGURE 46.—Edco-Matic Chair with leg cushion extended.

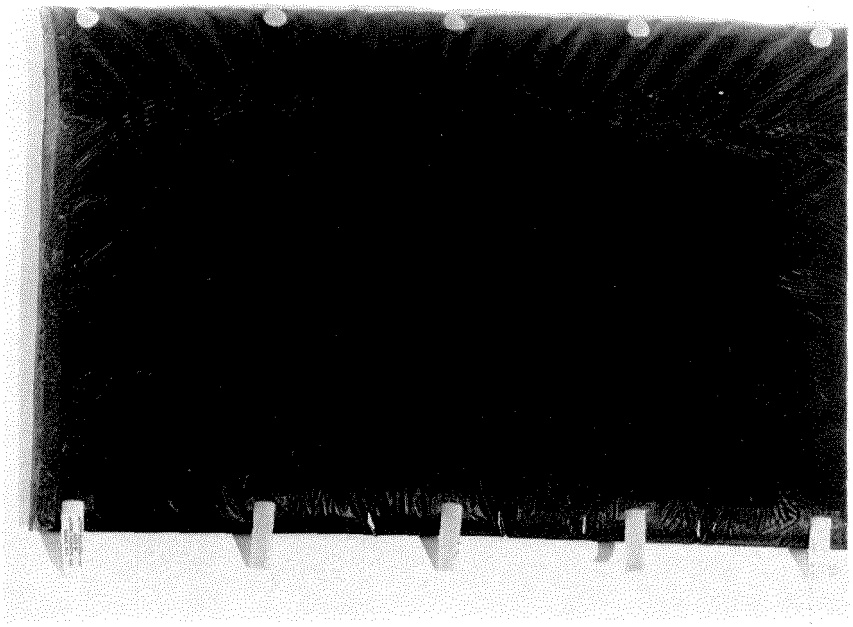


FIGURE 47.—Action No. 6000 Pad.

pressure of bed-confined patients.

A report has been prepared recommending that the Action No. 6000 Bed Pad be made available for use in VA hospitals.

h. *Royalaire Bed.* The Royalaire Bed (Fig. 48), manufactured and marketed by the Milton Roy Co., of St. Petersburg, Florida, was previously described in the Spring 1974 Bulletin (BPR 10-21, page 104). The patient is supported on a medium of silicone ceramic beads through which warmed air is pumped. The beads are covered by a loose polyester filter sheet that prevents them from escaping. The improved "low contour" model has been evaluated at 10 selected VA Hospital Spinal-Cord-Injury Centers. The results from this expanded evaluation substantiated the results described in the previous Bulletin (BPR 10-21). The Royalaire Bed has been quite beneficial in the treating of patients with decubitus ulcers, and in post-operative procedures.

A final report has been prepared recommending its use in VA hospitals.

5. *Lifts and Transfer Aids*

a. *Autolift.* The Autolift (Fig. 49 and 50) is used to transfer a nonambulatory patient from his wheelchair into and out of a bathtub in his home. The lift utilizes a manually controlled winding mechanism and

FIGURE 48. — Royalaire Bed.

accommodates weights of up to 280 lb. It can be operated independently by the patient or by an attendant. It is secured next to the bathtub to

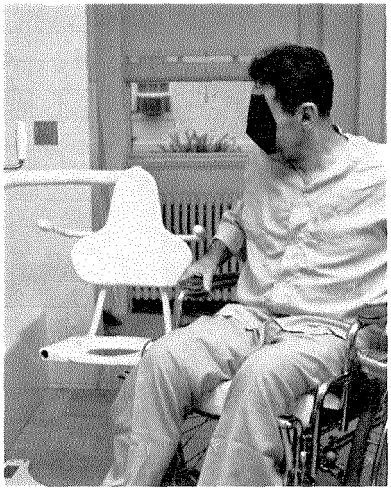


FIGURE 49. — Autolift, shown ready to receive patient.

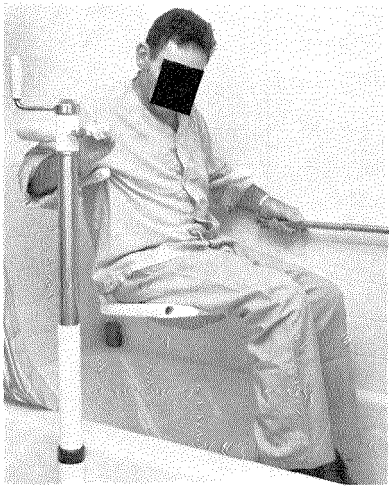


FIGURE 50. — Autolift, with patient about to lower himself into bathtub.

either a concrete or wooden floor. The center post, which fits into the base of the device and is adjustable in height, employs a four-position lock for its vertical axis.

The Autolift is manufactured and marketed by Mecanaids, Inc., of Gloucester, England. It was clinically evaluated at the Castle Point, New York, VA Hospital. While the lift, overall, and the vertical axis lock, in particular, performed adequately, the winding mechanism was found to be time-consuming and tiring for the occupant. This was possibly due to a high gear ratio which requires a minimal amount of strength to operate. The fixed armrest provides a sturdy support rail but makes transfers more precarious: transfers would be easier and quicker if the armrest could be moved out of the way.

Subjects willing to secure the lift to their bathroom floors were difficult to find. Bathroom size was also a problem because the bathroom must be relatively large for the device to function properly.

b. *Ambulift.* The Ambulift (Fig. 51), manufactured and marketed by Mecanaids, Inc., of Gloucester, England, is a versatile aid which provides a rigid seat, sling, and stretcher for lifting non-ambulatory patients. It also provides facilities for bathing, transporting, and toiletting these patients. The rigid seat can be attached to a four-wheeled frame and used as a shower chair and/or commode chair, with the commode attachment included. The armrests swing away to facilitate easy transfer, allowing a pivot or lateral transfer into or from the rigid seat. An occupant is raised by a mechanical winding mechanism. An occupant weight of up to 350 lb can be accommodated.

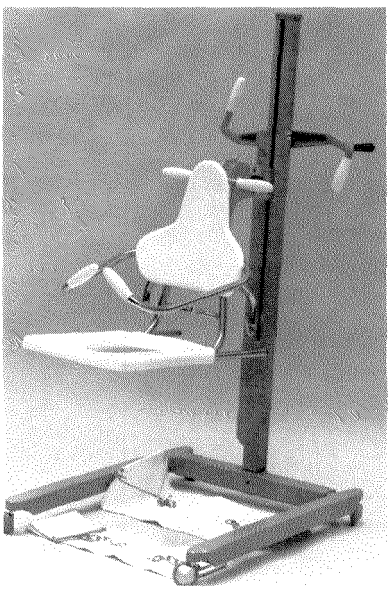


FIGURE 51.—Ambulift with rigid seat in place.

The Ambulift was clinically evaluated at the Castle Point and Montrose, New York, VA Hospitals. It was used extensively in the Spinal-Cord-Injury Service, and in the neurological and general medical services at Castle Point, where it was primarily used as a lifting (sling seat) device using the sling rest. The lift was found to be well-constructed and easy to operate, and the staff found the lift easier to maneuver than a conventional lift unit. The patients who participated in the evaluation process found it be comfortable during transfer. Two participants used the rigid seat and reported no particular problems. Further clinical trials are being conducted to further assess the functional application of the stretcher and rigid seat for possible future requirements.

c. *Mecalift.* The Mecalift (Fig. 52) is a transfer device which is used for non-ambulatory patients in their homes. A patient is hoisted or lowered in a sling by a manually controlled winding mechanism.

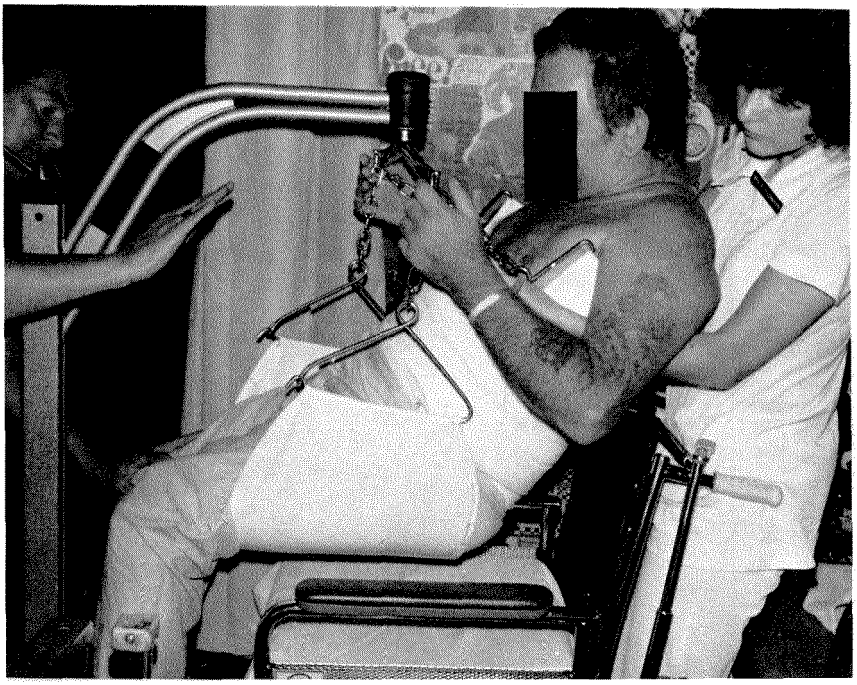


FIGURE 52.—Nurses preparing wheelchair-confined patient for transfer to bed using Mecalift.

Manufactured and marketed by Mecanaids, Inc., of Gloucester, England, the lift is compact and easy to assemble and disassemble. The sling

portion is 24 in. wide. The entire device weighs 40 lb: the chassis weighs 14 lb and the lifting arm and rest weigh 26 lb.

The lift was clinically evaluated at the Castle Point and Montrose, New York, VA Hospitals, and at the Long Beach, California, VA Hospital, where it was used extensively in the Out-Patient and Activities of Daily Living programs. It was found to be generally well-constructed, easy to operate, and quite maneuverable, particularly for domestic use. However, questions were raised concerning a lack of caster locks on the base of the lift, and the moving of patients into or from wheelchairs.

6. *Automotive Driving Systems*

a. *Power Car Door.* The Power Car Door (Fig. 53), manufactured by the Power Car Door Corp., of St. Clair Shores, Michigan, is an electromechanical device that is installed inside a car door to allow a disabled person to open his car door to the degree desired, or close and lock the door, by activating either a control switch on the instrument panel or an exterior control switch.

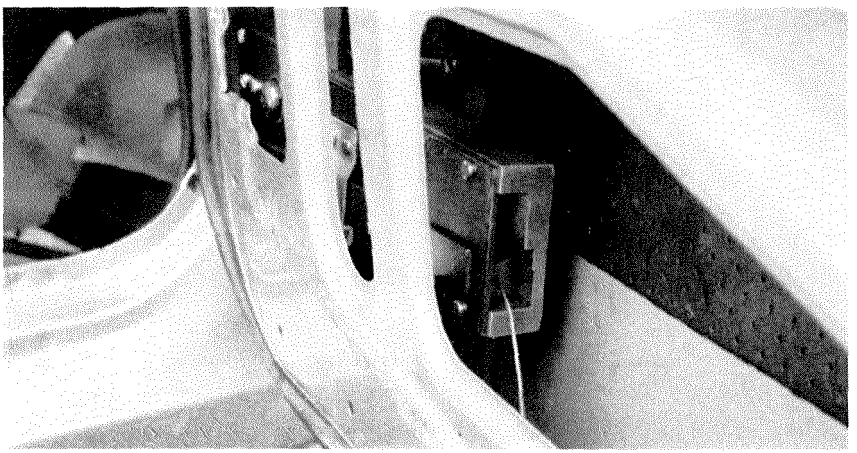


FIGURE 53.—Power Car Door device shown installed inside car door.

The Power Car Door was installed on a Volvo automobile that is currently being evaluated by the VA Hospital Clinical Evaluation Service at Castle Point, New York. The unit remained functional over a 6-month test period but needed to be repaired twice: water seepage inside the door damaged the door relay switch and (after 7 months) the door motor, causing the Power Car Door to be returned to the manufacturer for repairs (after 7 months use). A second Power Car Door unit has been purchased and is scheduled to be installed in a van.

b. *Volvo Servo-Control System.* The Volvo Servo-Control System (Fig. 54), developed and manufactured by the Volvo Corp. of Sweden, is distributed in the United States by Volvo of America Corp. of Rockleigh, New Jersey. A 1974 Volvo 142 Grand Luxe Car, specifically adapted for handicapped drivers, has been equipped with a pneumatic hand-operated servocontrol. Two servocontrols are mounted on the steering wheel, one at 9:00 o'clock and the other at 3:00 o'clock. Acceleration is achieved by pressing upward on the lever, and braking is achieved by pressing downward on the lever. The system is factory installed.

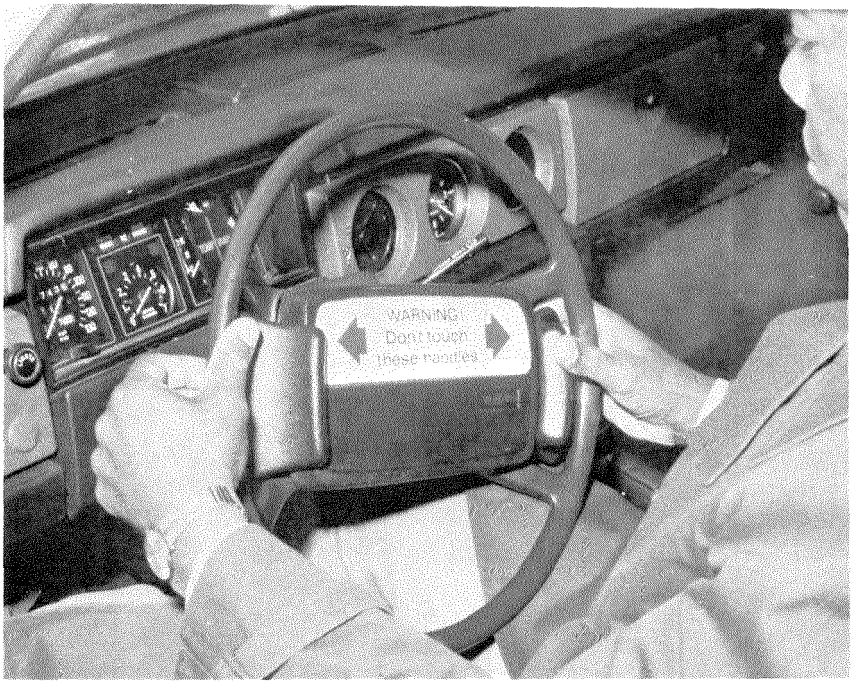


FIGURE 54.—Volvo Servo-Control System controls shown mounted on automobile steering wheel.

The Volvo Servo-Control System is currently being clinically evaluated at the Castle Point, New York, VA Hospital. Early clinical findings indicated problems in steering and braking control, and accelerating during parking, backing-up and corner-turning maneuvers. Also, it was impossible to maintain a constant speed without constantly manipulating the hand controls; on long trips the fingers grew tired from constantly pressing the controls. Because of the system's uniqueness, the clinical evaluation is being continued.

c. *Tri-Pin Quad Steering Device No. 3522.* The Tri-Pin Quad Steering Device No 3522 (Fig. 55), manufactured by Mross, Inc., of Elizabeth, Colorado, is designed to aid quadriplegics with limited hand control in steering automobiles. The Tri-Pin handle employs a wrist stabilizer adjustment for various wrist sizes, and a forward-pin adjustment to provide comfortable steering motions. The base plate can be adjusted to clamp on to a variety of steering wheels; the adjustment control is located beneath the base plate. (The device does not fit deluxe or heavily padded steering wheels.)

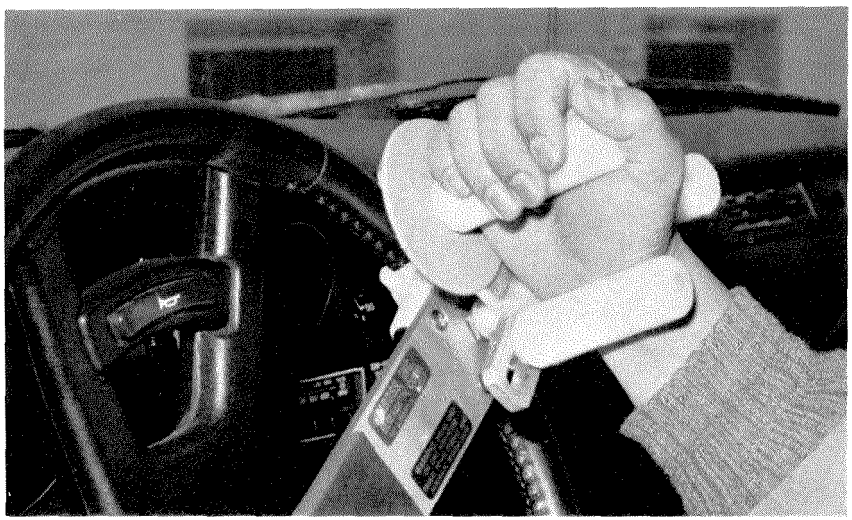


FIGURE 55. — Tri-Pin Quad Steering Device No. 3522, shown mounted on automobile steering wheel.

In its initial evaluation, the Tri-Pin handle inadvertently shifted position on the steering wheel and adversely affected the participating quadriplegic's performance when he tried to place his hand between the wrist support pins. The manufacturer installed two wave-spring washers between the base plate and the Tri-Pin handle to solve the problem.

Units have been sent to selected Spinal-Cord-Injury Centers: they are to be incorporated in their respective driver-education programs.

7. *Orthotics.*

Multi-Podus Therapeutic Foot and Leg Unit. The Multi-Podus Therapeutic Foot and Leg Unit (Fig. 56 and 57), manufactured and marketed by L'nard Associates, Inc., of Providence, Rhode Island, is designed to aid healing or prevention of decubiti; maintenance of correct anatomical position; prevention of hip contractures (internal and external rota-

FIGURE 56.—Multi-Podus Therapeutic Foot and Leg Unit.

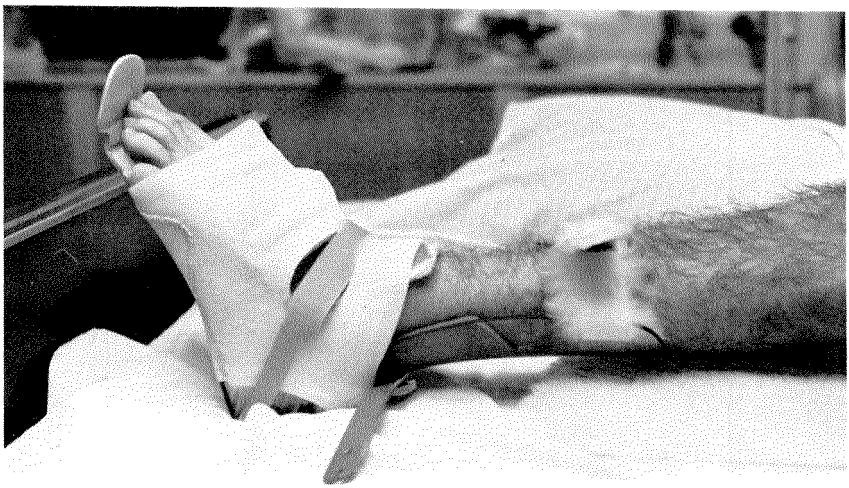


FIGURE 57.—Multi-Podus Therapeutic Foot and Leg Unit, shown with swivel bar, adjustable toe piece, and rigid plate attachments.

tion); drop foot; toe flexion contractures; and foot decubiti (particularly of the heel); and as a temporary assist in gait training. The device is constructed of Nyloplex with Velcro anklet. Attachment straps are padded with Kodel. Attachments to the basic footrest include a swivel bar for internal and external hip rotation; an adjustable toe piece for toe flexion

contractures, which also functions to keep linen off the foot; and a rigid plate which is used in conjunction with the toe piece and swivel bar to maintain the foot in a fixed positon when required. The device is described as easily applied and easily adjustable.

The device was clinically evaluated at the Castle Point, New York, and Cleveland, Ohio, VA Hospitals by a multiple sclerosis patient, two quadriplegics, and one paraplegic. While indications by hospital staff members are that, in concept, the multi-podus unit is good, clinical observations by the patients and staff also indicate that its present design falls short of their expectations. The number of subjects was limited by the size of the unit: the majority of candidates were unable to be fitted. Those who were able to be fitted found the device uncomfortable, and their findings were substantiated by staff members who observed the evaluation process.

The shortcomings have been brought to the attention of the manufacturer.

8. *Miscellaneous*

a. *Sydnor Feeder.* The Sydnor Feeder for physically handicapped people (Fig. 58 and 59) is a semiautomatic feeding machine which allows quadriplegics and similarly handicapped persons with limited upper-limb mobility to feed themselves independently. The device was developed by Garland S. Sydnor, retired former president of Sydnor Hydro-dynamics, Inc., of Richmond, Virginia.

The user operates the device by manipulating a four-position control switch, with any part of his head, first to select his food and then to guide the food to his mouth. Optional joystick and lapboard controls are also available. Standard 115V a.c. power is used to operate the device.

The Sydnor Feeder is presently in its prototype stage of development.

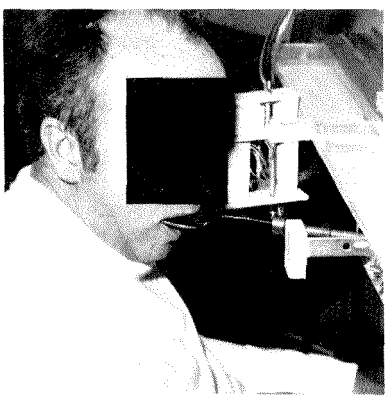


FIGURE 58.—User shown in process of eating with Sydnor Feeder.

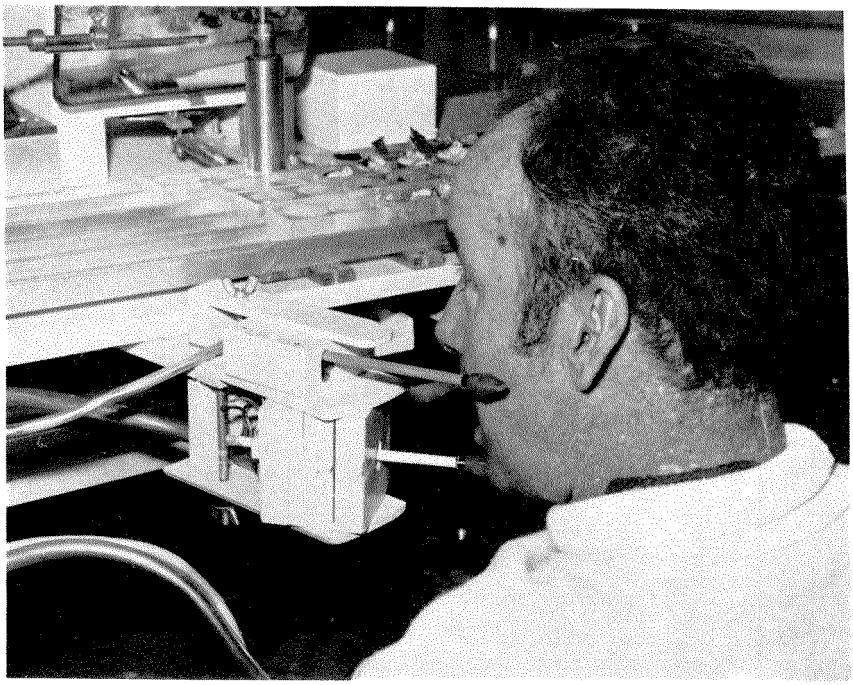


FIGURE 59.—User manipulates four-position control switch to select food independently, using the Sydnor Feeder.

Clinical trials have been completed and an evaluation report has been prepared recommending certain modifications.

b. *Gyro-Gym Therapeutic Exerciser.* The Gyro-Gym Therapeutic Exerciser (Fig. 60 and 61) is a product of L. Monti Enterprises, Inc., of Niagara Falls, New York. It is a hand-held exerciser bar, used to help tone muscles and to strengthen arms and legs. The device consists of an 18¾ in stainless steel bar, two 16-oz plastic bottles, and four 10 in. attachable bars.

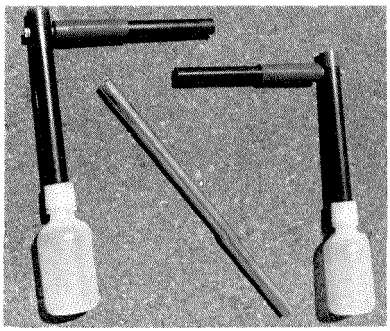


FIGURE 60. — Gyro-Gym Therapeutic Exerciser components.

FIGURE 61.—User shown exercising with Gyro-Gym Therapeutic Exerciser.

To exercise with this unit, an individual must swing the exerciser out slowly in front of him in a circular or linear motion forward and back so that the plastic bottles rotate in the desired direction. By adding water, as desired, to the plastic bottles, the patient is able to progress in his exercising. Since a standing position is the most beneficial for a patient to assume when using the exerciser, the device was found to be limited in its variety of exercises and quite difficult to use—particularly when the patient is confined to a wheelchair.

II. TESTING

A. Standards Development

1. *Test Standards for Wheelchair Cushions*

An evaluation study to develop standards for testing wheelchair cushions has continued during this reporting period. The initial report on this program can be found in the Fall 1973 Bulletin (BPR 10-20, pp. 29-61), and followup reports can be found in the Fall 1975 and Spring 1976 Bulletins (BPR 10-24 and BPR 10-25) under "VAPC Research."

The data received during our current reporting period are being used to modify test apparatus and procedures, with the ultimate aim of reproducing a simplified but effective test program that can be presented in an ASTM Test Method format.

2. *Lower-Limb Torque Absorbers*

Static and dynamic tests of lower-limb torque absorbers have continued during our current reporting period. (Refer to "VAPC Research" reports in the Fall 1975 and Spring 1976 Bulletins, BPR 10-24 and BPR 10-25.) The results of these tests, together with the results obtained in on-going clinical studies, will be incorporated in a new standard being developed for lower-limb torque absorbers.

This new standard is currently in draft form.

B. Compliance Testing

1. *Upper-Limb Components*

Hosmer-Dorrance, Inc., of Campbell, California, submitted an Internal Elbow assembly for annual compliance testing. This assembly complied with the "Tentative Specifications for Adult Size Elbow, Artificial, Internal, Alternating, for Above-Elbow Amputees" specification.

2. *Wheelchairs*

Several wheelchairs were submitted for testing and evaluation by the Division of Vocational Rehabilitation, State Board of Vocational Education, of West Virginia. The samples submitted are as follows: an Everest and Jennings Model P8A0250-770, a Colson Model A-112-H2, and a Rolls Model 328. These samples have complied with current VAPC standards.

3. *Stump Socks*

The shrink-resistant woolen stump socks reported-on in the Spring 1976 Bulletin (BPR 10-25) have undergone additional and more stringent testing. Three samples were washed and tumble-dried 50 times with highly satisfactory results: the resultant shrinkage, on order of magnitude, was better than specified limits, despite the tumble drying. A pilot wearer study is currently in progress.

III. THE VAPC CLINIC TEAM

A. VAPC Case-Load Profiles

A comparison of one period with the next suggests that the statistical breakdown of Table 1 represents a fairly typical case load of VAPC

TABLE 1.—*Statistical Breakdown of Patient Disabilities: January 1, 1976 to June 30, 1976*

Amputation		
Area of involvement	Specific level of involvement	Number of patients
Lower-limb unilateral	Below-Knee	183
	Above-Knee	133
	Transmalleolar (Syme's)	15
	Hip (Disarticulation)	7
	Mediotarsal (Chopart)	4
Lower-limb bilateral	Below-Knee	33
	Above-Knee	14
	Above-Knee/Below Knee	7
	Above-Knee/Transmalleolar (Syme's)	2
	Above-Knee/Hip (Disarticulation)	1
	Hip (Disarticulation)	2
Upper-limb unilateral	Below-Elbow	12
	Above-Elbow	5
	Partial Hand	2
Upper-limb bilateral	Above-Elbow	1
	Below-Elbow	1
Triple	Above-Knee/Below Knee/ Below-Elbow	2
		(424 total)

Neuromuscular or Skeletal Impairment		
Area of involvement	Specific level of involvement	Number of patients
Lower-limb unilateral	Ankle-Foot	111
	Knee-Ankle-Foot	2
Lower-limb bilateral	Ankle-Foot	7
	Knee-Ankle-Foot	3
Upper-limb unilateral	Arm-Elbow-Forearm; Wrist-Hand	8
	Serratus Anterior	3
	Elbow	1
Trunk	Lumbosacral Spine	13
Miscellaneous	Varied (Wheelchairs, shoes, etc.)	29
		(177 total)

Amputation and Neuromuscular or Skeletal Impairment		
Area of involvement	Specific level of involvement	Number of patients
Lower-limb bilateral	Below-Knee/Ankle-Foot	6
	Above-Knee/Above Elbow/Below-Elbow	2
	Above-Knee/Ankle-Foot	1
		(9 total)

clinical operations. (Refer to "VAPC Research, Clinical Evaluation," Table 1., in the Spring 1976 Bulletin, BPR 10-25.) Some examples that follow will further illustrate the nontypical nature of our veteran case load compared to one drawn from a general population.

Among the items that facilitate prompt handling of this case load are polypropylene ankle-foot orthoses (AFO's) available in basic prefabricated configurations. These can be adjusted quickly to fit the individual patient and can be issued to him the same day the device is prescribed. The patient can pass through the stages of evaluation, prescription, fabrication, and checkout with a minimum of delay. The availability of thermoplastic materials, and the proximity of the prosthetics and orthotics laboratory, permit this procedure to be duplicated with certain of the upper-limb orthoses as well. Similarly, a stock supply of shoes, particularly ortho-inlay (Formo-Ped) shoes with leather-covered cork inlays, means that shoes may be prescribed, adjusted, fitted, and delivered all in one day.

Some of the less-common prosthetic and orthotic fitting problems are frequently referred to the VAPC from other VA facilities, since this center has had experience with diffcult situations such as total pelvectomies, bilateral hip disarticulations, and other multiple amputations. Such patients often require, in addition to the basic clinic team, the services of our clinical engineers who are experienced in upper-limb electrical devices, and/or our engineers who have experience in special wheelchairs and environmental controls. With the cooperation of our patients, new approaches are discussed and new devices are often developed to aid in the solution of special problems.

For example, consider the patient represented in the statistical breakdown of patient disabilities by the entry "Triple" under "Area of Involvement." This patient, with right above-knee, left below-knee, and right below-elbow amputations, was seen twice in the clinic during this reporting period. He was seen initially in February 1976, when a prescription was ordered for a left below-knee prosthesis with an open-end socket, thigh corset, side joints, single-axis foot, waist belt and forkstrap. This prosthesis was delivered in March.

On the right side the patient uses an above-knee prosthesis with a soft

socket insert in the style of the Syme's, with a Dupaco hydraulic knee unit and SACH foot. The right below-elbow prosthesis incorporates a modified Figure 8 harness without a Northwestern ring, a half-cuff at the arm, rigid hinges, double-wall socket, friction wrist, Dorrance hook with Perlon cable and housing.

The patient has been a triple amputee since December of 1944. Amputation was the result of war injuries. Initially he wore a single-axis knee on the above-knee (right) side but now finds the Dupaco unit easier to control. He was fitted with a (left) PTB prosthesis in 1975 but prefers the thigh corset because of the security of something encompassing the thigh. He is currently employed as a mailroom supervisor.

B. Case Histories

1. *Case No. 1.* This veteran of World War II sustained a spinal cord injury (thoracic vertebra level T-10) in a 1962 automobile accident, with a resultant paraplegia. As a result of extensive complications he underwent a number of operative procedures: bilateral above-knee amputations, a colostomy, and an ileal loop procedure. In July of 1973 a right hip disarticulation and in April of 1974 a left hemipelvectomy were performed, due to penetrating decubitus ulcers and subsequent osteomyelitis.

The patient was referred to the VAPC in September 1975. Observed during examination was a sacral decubitus ulcer several inches in diameter without exposed bone at the base, and an extremely extensive perineal ulceration undermining the area beneath the scrotum, as well as contiguous superficial scrotal ulcerations. He appeared to have accepted his situation and his general attitude was good.

The clinic recommended a customized body socket lined with Pelite to permit the patient to be maintained in an upright position. A special wheelchair and cosmetic limbs were to be supplied, once he was accustomed to this postion.

A temporary plaster-of-paris shell was fabricated at that time. At a followup visit to the clinic in October 1975 the patient was able to maintain an erect position in the shell for half an hour; this temporary shell was used for conditioning purposes and to establish tolerance for the final body socket.

The body socket was designed to raise the patient's ischial tuberosities approximately 4 in. from the normal sitting position. This was to provide space between the inner platform of the body socket and the soft underbody tissues, so as to avoid pressure areas inferiorly. But the added height created a cosmetic problem when the patient sat. Even more important was a problem of reach—in a wheelchair it was difficult for him to reach the wheel rims.

It was decided that the patient would be best served by an amputee

wheelchair with a rigid platform seat and heavy-duty upholstery. The center of this platform seat would be lowered 4 in. to accommodate for the above described discrepancy. In line with this consideration, the wheelchair seat would be about 14 in. wide, 19 in. high at the periphery, and 15 in. at its central support segment. In addition the chair would employ a 20-in. back. The 24-in. wheels with pneumatic tires were offset posteriorly; 8-in. front casters were recommended. Toggle-type extension brake levers were specified, and armrests were to be adjustable and removable.

The wheelchair was assembled as prescribed and the patient was quite pleased (May, 1976). He functions well with the wheelchair and shows no interest in cosmetic limbs. He is able to remain upright in the socket for 2½ hours at a time.

The patient preferred a manually driven wheelchair to an electric wheelchair because it would provide him with exercise for his arms, and because he considered its maneuverability to be superior — his views coincided with those of the clinic.

2. *Case No. 2.* In October 1974 this patient sustained a cervical neck injury and was admitted to a hospital. There had been no history of neck pain or radiating pain to other parts of his body. Myelograms revealed interspace filling defects between cervical vertabrae levels C-3 to C-4, C-4 to C-5, and C-5 to C-6. Anterior disectomies were performed at these levels and the C-4 to C-5 space was fused, providing the patient with sufficient upper-limb and lower-limb muscle power to ambulate with crutches.

On January 19, 1975, the patient was hospitalized again, for progressive weakness and incoordination in both lower limbs. Examination was reported to have shown mild weaknesses of lower-limb muscles but with no impairment to superficial sensations. On January 20, 1975, a wide laminectomy at levels C-3 to C-7 was performed and on January 22, 1975, he suffered a sudden onset of quadriparesis. This was diagnosed as a probable anterior spinal artery syndrome because, while he had demonstrated weakness in the lower limbs, he was still able to ambulate.

The major loss of muscle power at this time was in the deltoids and biceps, where only a flicker of activity was reported. A muscle strength examination in early March, 1975, used the following rating system: 5=Normal; 4=Good; 3=Fair; 2=Poor; 1=Trace and 0=Zero. The patient's ratings were as follows: deltoids 1; triceps 3; wrist extensors 4; and handgrip 4 (all bilateral).

In an initial examination of the patient in September of 1975, the clinic found him to be ambulatory with fairly good wrist and hand function. However, functional elbow and shoulder muscle power was inadequate. Elbow flexor power was approximately 2− bilaterally, and

extensor power 3−. The pectorals could be felt to contract, but not at a functional level. Trapezius power was 4 bilaterally. With the effect of gravity eliminated by placing the limb in a gravity eliminated position, the elbows could flex.

An electrical transcutaneous stimulator was used to stimulate the biceps to test its ability to improve elbow and shoulder muscle power: only slight improvements were recorded and functional levels remained inadequate. Transcutaneous stimulation of the dorsal column at thoracic vertibrae levels T-3, T-4, and T-5 also produced only slight improvement in elbow flexor power, again at a non-functional level. Temporary spring-loaded orthotic devices were fabricated to assist flexion: the patient was for a short time able to accomplish elbow flexion with these devices, but he fatigued easily.

The clinic concluded that it would be worthwhile to proceed, step-by-step, from simpler to more sophisticated orthotic devices. It was reasoned that if the spring-loaded devices ultimately proved successful, it would be unnecessary to proceed further. If, however, these failed to provide the patient with adequate elbow flexion, a harness would be used, either a Figure 8 harness or a butterfly harness. And if all else failed, a Viennatone or Johns Hopkins Applied Physics Laboratory (APL) unit, a switch-controlled, electrically powered cable device, would be used to raise the patient's forearm.

During the October 30, 1975, followup visit, an attempt to have the patient elevate his arm with a spring-assisted elbow orthosis and Figure 8 harness proved unsuccessful. A Liftomatic was able to bring the patient's elbow to the 90-deg point, short of enabling him to bring his hand up to his mouth. It was therefore considered a failure, the result primarily of the present geometry of the orthotic elbow joint used with the Liftomatic. Improvement, it was agreed, could be anticipated if the geometry of the elbow joint could be changed. Thus, the clinic concluded that the geometry of the elbow joint should be changed; if there were still no improvement, then the electro-mechanical device from Johns Hopkins should be used.

No improvement was seen, therefore the patient was fitted with a functional Johns Hopkins APL unit prior to the followup clinic meeting which took place February 25, 1976.

The patient activates the unit by using his right hand to control the switch. On the right side, he has been provided with a pneumatic system employing a Liftomatic and a five-bar polycentric system. With only slight residual muscle power required from the patient, these devices enable him to flex his elbows adequately. He can bring his hands to his mouth, use utensils at mouth level, and fully extend his elbows.

Several months earlier (October 28, 1975), the patient had been evaluated at a conference conducted by Dr. Albert Cook, Professor of

Neurosurgery at the Downstate Medical School. Dr. Cook felt that his technique of electrical stimulation of the spinal cord by electrodes inserted through needles would create an improvement. As of June, 1976, the patient had not as yet decided to accept Dr. Cook's procedure.

3. *Case No. 3.* The patient sustained multiple injuries to the lower limbs in May 1975 due to an automobile accident. His left leg was amputated through the knee with patellar retention. His right leg was amputated 3 in. below the knee. Internal fixation using Rush pins was used to manage the comminuted fractured femur. In June 1975, the residual limb was extensively skin-grafted with split-thickness skin grafts for adequate coverage.

The initial clinic examination revealed on the right a clean superficially unhealed scar in the posterior distal thigh area. Alignment of the femur was satisfactory with an estimated shortening of the femur of about 2 in. Motion of the right knee was from 15 to 25 deg. The patient had been exercising his knee with extreme caution because he was fearful of re-fracturing it. X-rays revealed adequate callus formation on the left side of the fracture site. The lateral condyle of the femur was prominent, with very little underlying subcutaneous tissue. The patinet was able to tolerate mild pressure on the distal end of the residual limb. Both residual limbs were edematous and considerable shrinkage was expected.

The clinic team concluded that the patient should first be taught how to apply Ace bandages properly, and then how to change these bandages several times each day to obtain more adequate shrinkage. He should then be provided with a left above-knee temporary prosthesis, and a right below-knee prosthesis with a high thigh corset for gluteal weight bearing, outside knee joint, and single-axis foot. The clinic further advised that while the patient waited for delivery of the prostheses, the therapist should make a concentrated effort to build up the patient's residual muscles and regain as much of his knee motion as possible.

The patient did well with his temporary prosthesis. He was ready for permanent fitting in January 1976. The prostheses ordered were as follows—

Left above-knee (through the knee) prosthesis: a plastic socket (partial end-bearing as well as ischial bearing) with a medial window, in the manner of a Syme's to utilize the condyle as a means of suspension, an OHC (Orthopedic Hospital, Copenhagen) knee joint, and a single-axis foot.

Right below-knee prosthesis: a PTB socket with soft insert, gluteal weight-bearing thigh corset, outside knee joints, and a single-axis foot. The need for a waist belt and fork strap extension aid was to be decided upon during fitting.

The patient was fitted as prescribed. Range of motion and muscle strength of the right knee improved enough so that the patient could function as a conventional below-knee amputee prosthesis user. He was taught stair-climbing and, as of May 1976, had resumed his occupation as a high school teacher. His ability to ambulate, climb stairs, and return to work has significantly improved his attitude and outlook.

4. *Case No. 4.* This World War II veteran sustained injuries to his back during combat in April 1945. The injuries produced weakness and numbness in the lower limbs. After a period of rehabilitation, however, he was able to ambulate with crutches. While still in the hospital he was stricken by poliomyelitis which affected both lower limbs.

In an initial examination the clinic rated the patient's lower-limb muscle power as 2, and the muscles controlling the left ankle 0 to 2. The right ankle was rated as 0. However, right thigh muscles were rated at 4. Dorsiflexion of each ankle passively produced an effective stop at 90 deg, secondary to calf muscle contractures.

The patient wore a left knee-ankle-foot orthosis (KAFO) with a drop-lock and a 90 deg ankle stop; a right ankle-foot orthosis (AFO) with a 90 deg. stop. He used a cane while walking in the street and when climbing steps.

The clinic concluded in its initial examination that the patient should be provided with a left KAFO with a drop-lock knee joint, a spring-loaded dorsiflexion assist at the ankle with a solid stirrup: on the right side, an AFO with a spring-loaded dorsiflexion assist with a solid stirrup.

The patient was also willing to try plastic orthoses for purposes of comparison. On the left he was provided with a polypropylene orthosis with plastic shoe insert, drop-lock knee joints, and an ankle device for plantar flexion on heel strike. On the right side he was provided with a plastic shoe insert AFO which was fabricated as a posterior leaf-spring orthosis. In addition, Wilbur Coon shoes and a spare pair of ortho-inlay shoes for his plastic orthoses were prescribed.

Results were that the patient's new polypropylene orthoses and his new metal braces both fit well. The patient, an elevator operator, preferred the plastic devices because of their cosmetic advantages and lighter weight. These preferences were confirmed in a followup visit to the clinic — he continues to wear the polypropylene orthoses for the given reasons.