PARAPODIUM FOR ADULT PARAPLEGICS

Martin T. Prast
Prast Research Associates, Inc.
1094 Stony Point Road, Grand Island, New York 11072

BACKGROUND

The Problem

The brace and ambulation system discussed in this paper is designed primarily for adult paraplegics. Paraplegics, as a group, spend too little time on their legs. We unequivocally accept the view of medical authorities, psychologists, and of the recently paralyzed themselves that it is of great importance for them to regain the capability of upright standing for at least part of the day.

The increased danger of decubitus ulcer development in sitting and a presumed need for weight-bearing in arresting calcium depletion from the bones seem to be an accepted belief by most in the medical professions. Many wheelchair-bound paraplegics also appear quite sensitive about their psychologically unpleasant need "to look up" to practically everyone else all the time.

To deal with others again "on their level" becomes a powerful incentive for great exertion toward mastering ambulation on crutches. An appreciable number of the younger and stronger paraplegics have been successful in learning to ambulate while wearing conventional long leg braces. However, it is also safe to say that not all paraplegics can build up enough persistence and upper body muscular strength to learn successfully how to ambulate on crutches. This is very difficult. Others who try do not achieve this goal until years have passed after their spinal cord injury.

Somewhat tragically, all the investments by many people in various ways too often end up to be an exercise in futility. Of the paraplegics discharged from most rehabilitation centers on crutches, all but a few return in wheelchairs, as was already observed in 1956 by Dr. Henry L. Heyl, a neurosurgeon and a paraplegic himself (1). Those who succeed in learning ambulation become eventually tired of doing things the hard way. All those paraplegics we have known have eventually returned to the ease of the fulltime use of a wheelchair for the simple reason that they gained nothing from ambulation on crutches that they had not attained already with a wheelchair.

It is for these reasons that we focus on new methods that:

1. Are quickly and easily learned.
2. Are easy to use without undue exertion.
3. Leave the hands free and available to do something worthwhile while standing.
4. Tend to develop greater access to a large portion of the world presently off limits to independently moving paraplegics.

Related Work of Others

True crutchless standing first became a reality through the 1970 development of the "Parapodium" for children by Wallace M. Motloch at the Ontario Crippled Children's Center (2,3,4,5). The Parapodium is essentially a lightweight standing frame that is not tied to the floor, but is worn by the paraplegic. We were very impressed with this approach to full body bracing because of the apparent ease with which paraplegic children could don the brace, stand in it without crutches, and ambulate with crutches.

The pivot walk method of forward locomotion was also first developed for children by Motloch at the Ontario Crippled Children's Centre (6). Motloch had previously developed a practical swivel walk prosthesis for legless thalidomide children (7,8) along the lines suggested by Spielrein (9), and similar to further developments by Barry, Duncan, and Klein in Australia (10,11).

Rose and Henshaw in England have reported success in extending the original swivel walk prosthesis principle to the bracing of both children and adults having complete but paralyzed lower limbs (12,13,14,15). Motloch felt, however, that the greater stability of the pivot walk improvement is needed for safe bracing of children with legs, a view which we share for our work with tall adults.

Both swivel walking and the pivot walk improvement produce a step forward by a partial body rotation around a vertical or near-vertical axis. The center of clockwise rotation for one step is behind and slightly outside the right shoe heel in pivot walking. Counterclockwise rotation for the next step is around a point behind the left shoe heel, and so on alternately for subsequent steps as is indicated in Figure 1. In swivel walking the respective points of rotation are where the soleplates touch the floor. One "foot" actually leaves the floor, at which time the base of support area on the floor becomes much smaller than it is in pivot walking.

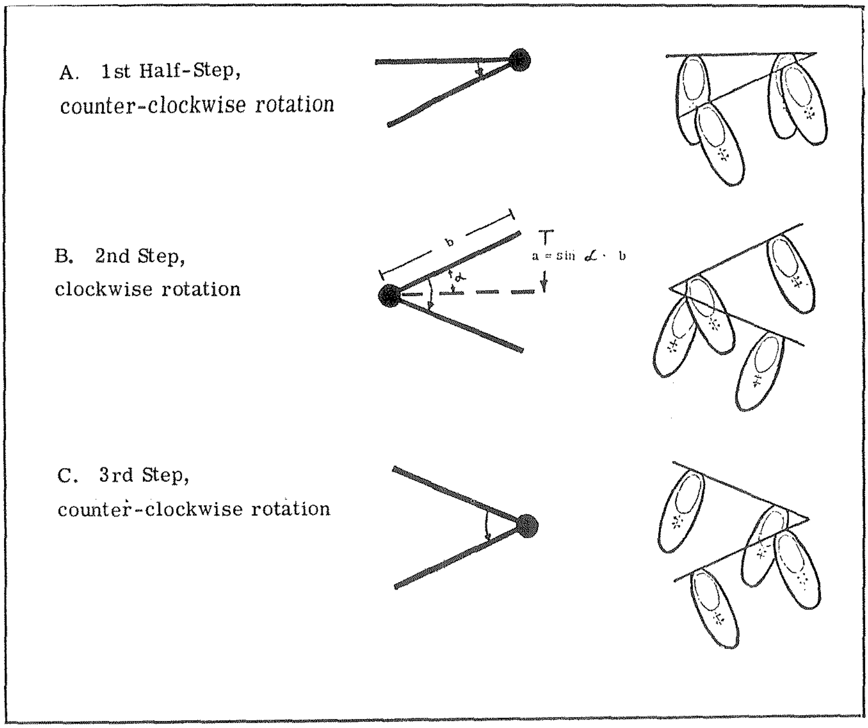

FIGURE 1.—Pivot walking, an improvement on swivel walk ambulation in that both feet stay in contact with the floor at all times, and the base of support area on the floor is therefore larger during forward steps. The diagram illustrates how a forward step is caused by body rotation around a point near the center of one heel.

Still other mechanisms of this class of forward locomotion are being developed by Glancy at the Indiana University Medical Center (16). In common with pivot walking, both feet stay in contact with the floor at all times, but there is dependence on crutches during forward ambulation.

We believe that endeavors to develop a practical crutchless robot system at the Mihailo Pupin Institute in Belgrade, Yugoslavia (17), will not be compatible with our desired timetable of reference, as we are committed to a realistic attempt of improving the situation of paraplegic Vietnam-war veterans before the last has resigned himself to a fulltime life in the wheelchair.

Feasibility Experiments by Prast Research Associates, Inc. (PRA)

An experimental adult version of a Parapodium was manufactured in 1971 to establish empirically whether it would be feasibile to extend the crutchless standing capability to a 6-ft. 2-in. tall paraplegic. Naturally, substantial design changes were necessary as we had to cope with new ratios of height- and weight-to-rigidity characteristics. Greater structural rigidity (anterior-posterior, lateral, and rotational) was in part achieved by a more suitable structure geometry. Early feasibility testing took place in 1972 with the cooperation of the VA Hospital, Castle Point, N.Y., and the Orthotics Laboratory satellite facility of the VA Prosthetics Center located at Castle Point (18,19). Lengthy troubleshooting and debugging of the first experimental brace was necessary to improve strength reliability of locking mechanisms and to minimize pressure points. Crutchless standing had been achieved immediately during a first attempt in 1971 (see Fig. 2).

An adult pivot walk attachment was fabricated and installed during April 1972. Four days later, when our paraplegic used this pivot walker for the second time, his speed of forward motion was timed. He had covered 80 ft. in 210 seconds, a notable feat for any total paraplegic when in the upright position.

More important, it had been demonstrated that both the crutchless standing and this alternative form of ambulation required no training to speak of.

PROTOTYPE BRACE DEVELOPMENT

Having decided that enough information was gathered to justify this, the design and fabrication of a new prototype brace took place later in 1972 and 1973. The new design reflects in many ways what was learned during the prior experiments (see Fig. 3).

In March 1974, the Veterans Administration awarded a contract which provides partial funding for the present phase of this research (20). The objectives are to allow paraplegics to: don and remove the devices, rise to a secure standing position, move without crutches on level surfaces, negotiate small obstacles like doorsills (using canes or hand contacts with the door frames), pass through narrow doors, and return to sitting position.

FIGURE 2.—First experimental crutchless standing brace for adults. This is the first experimental configuration in which the author, a 6-ft. 2-in. tall paraplegic with a T-8 level spinal cord injury, stood for the first time on Dec. 5, 1971, without crutches. The pivot walk attachment is not yet installed.

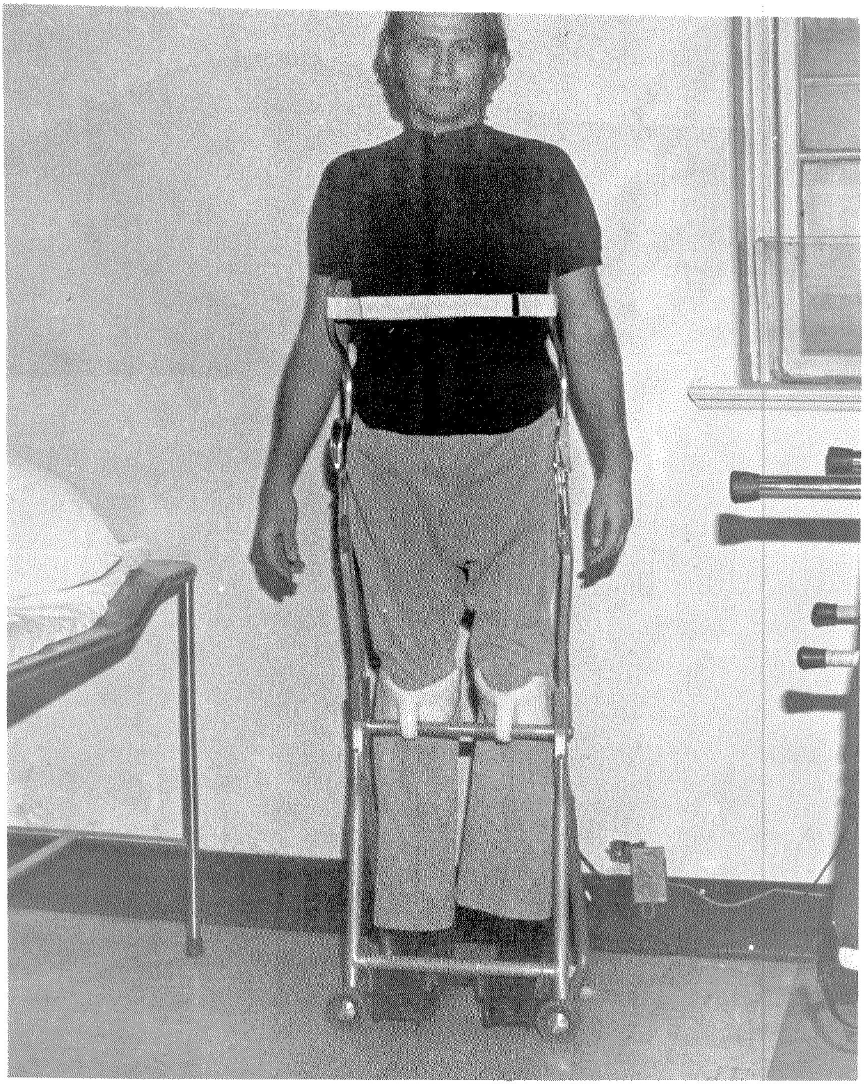

FIGURE 3.—New lightweight crutchless standing brace with integral pivot walker.

Ease-of-Donning Improvements

The following marked improvements have now been achieved: It was possible to reduce the overall weight of the brace with integral pivot walk mechanism from more than 20 lb. to less than 10 lb. This was accomplished with the more extensive use of lightweight aluminum alloys, properly heat-treated for maximum strength, and with vacuum forming of plastic parts (see Fig. 4, 5, and 6).

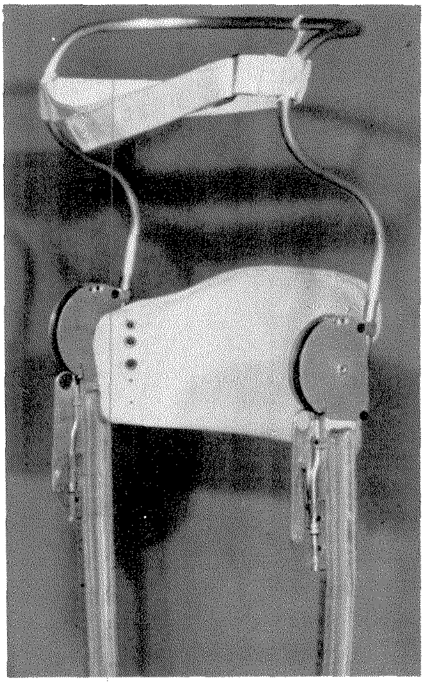

FIGURE 4.—Topmost portion of brace with vacuum-formed plastic backplate and hip joint hinges designed for automatic locking when adjacent brace sections straighten out relative to each other.

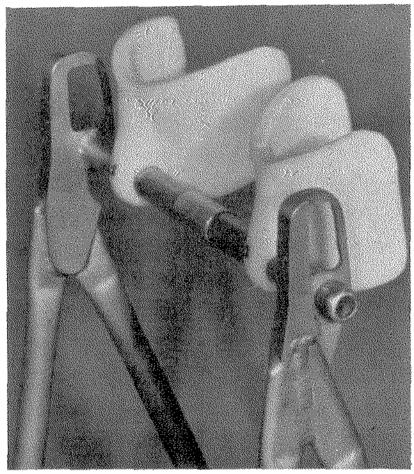

FIGURE 5.—Plastic knee supports and knee cage structure. Note the protruding tube section used for joining top-part module to this bottom-part module.

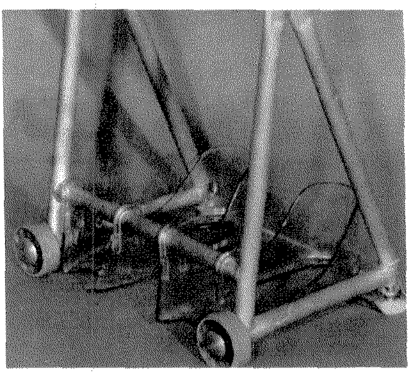

FIGURE 6.—Base portion of brace with plastic shoe supports and pivot walker mechanism. For counterclockwise rotation the paraplegic shifts his weight to the left, whereupon rotation around the white pivot point near the left heel can be initiated easily. The left pivot wheel, which then carries considerable weight, facilitates motion of this point at the perimeter.

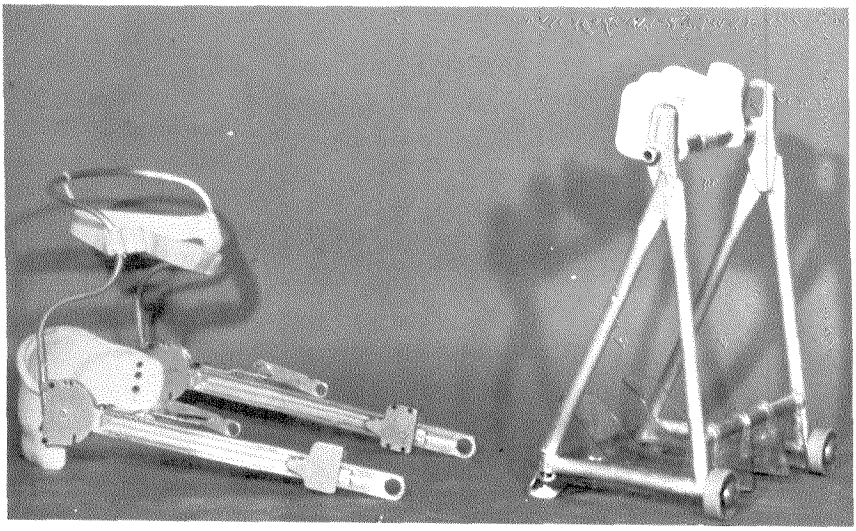

FIGURE 7.—Top-half module and bottom-half module shown separated and in the positions used for donning by a seated paraplegic.

Moreover, the new lightweight brace is designed in two detachable parts. One of these modules is the top-half which provides hip joint support (Fig. 7). In donning, the paraplegic user slides this module behind the trunk, bringing it to its proper position while he is sitting. The bottom-half module includes the knee joint supports and the pivot walk mechanism (Fig. 7). The paraplegic places this bottom-half over his shins and knees, and manually inserts one foot at a time into the shoe supports. After both feet are properly in place, the top-half and bottom-half modules are ready to be snapped together (Fig. 8). It is now much easier to put each of the two modules in place—and then join them together—as compared to donning the entire first experimental brace at once. This is due to the greatly reduced weight and bulk which needs to be handled at one time. It has also been shown that it is less time consuming for an adult paraplegic to don and remove this new lightweight crutchless standing brace as compared to conventional long leg braces. In our opinion it is also easier.

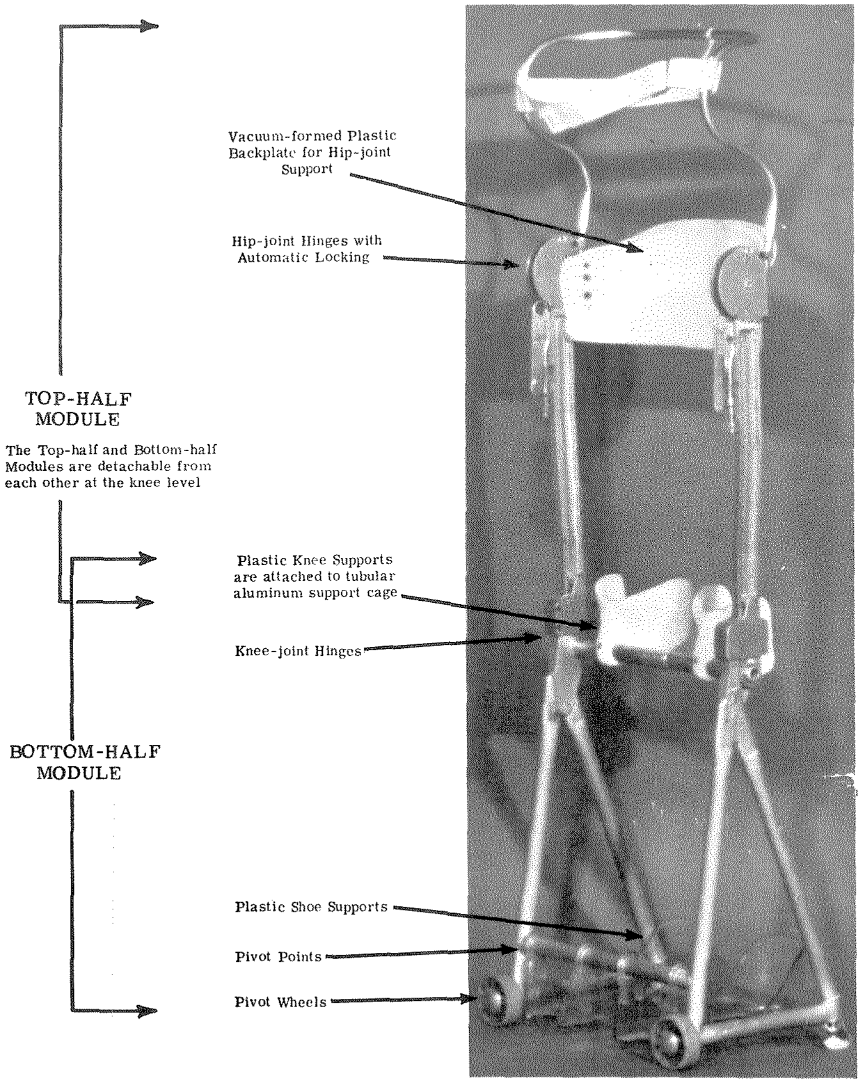

FIGURE 8.—Top-half and bottom-half modules joined together and shown in standing position. The two modules of this new lightweight brace are snapped together after donning them separately.

Toward Self-erection to Standing

The earlier experimental brace was already hinged at the hip joint and knee joint levels to make possible sitting as well as standing. The locks for the hip joint hinges now function automatically when the adjacent brace sections straighten out relative to each other. At present, the knee locks are manually locked prior to erection from a seated position, as is done with conventional long leg braces. In doing so, the hands are left free for use in pushing oneself upright into the standing position. This work is still in progress. Suitable test arrangements have been built to evaluate the most useful position for a paraplegic's hands in pushing himself up to the standing position. This is expecting to lead to wheelchair modifications in which the armrests could be flipped upward and forward. They would then serve as rudimentary parallel bars to aid in erection.

We learned in our early experiments of one disadvantage that adult paraplegics have relative to children. This is what makes the extra measures to aid in self-erection necessary. A child learns quickly that in the normal adult-scale world almost everything can be used as a grab bar. The adult paraplegic finds this not to be the case. Instead of pulling himself up to standing, he must be given means of pushing himself upward.

Next Step Plans

The obvious next step will have to be the continuing evaluation of this improved lightweight brace to determine whether weight reduction could have weakened the equipment too much for heavy day-to-day use.

Having determined that there is structural integrity through prolonged day-to-day use, brace fitting for additional paraplegics would require introduction of a multi-module design to accommodate individual size variations more easily.

BETTER ACCESSIBILITY

Few people seem to realize that much of the world is not open to paraplegics in wheelchairs. Many areas formerly inaccessible now become reachable with the crutchless standing brace. This is proving true especially in the case of access to rooms with excessively narrow doorways. A good example is the not-so-uncommon narrow bathroom door.

Pivot walking provides relief and allows the paraplegic to maneuver within a confined space. The required path width in pivot walking is a function of the length of the stride taken. The maximum width of the present brace is 18 in., allowing the paraplegic to clear doorways 22 in. wide by using short strides. We will demonstrate under the VA contractual requirements that doorways narrower than the standard 26 in. wide wheelchair can be passed through. It will also be evaluated whether door sills will pose a problem.

Even the ability to just stand comfortably and safely with one's hands free makes a great difference in overcoming many other day-to-day problems. Many wall phones, book and display cases, cloth racks, kitchen cupboards, top drawers in filing cabinets, hat racks, outlets in vending machines, and bank teller windows are too high for the wheelchair-bound. Standing with crutches does not solve anything as long as one's hands are tied up. Standing without crutches makes all the difference in the world.

The techniques discussed in this paper are not meant to replace—but to supplement—the use of the wheelchair in areas where serious gaps exist in the paraplegic's total mobility system.

One of the greatest gaps, created by society, is the problem of stairs. Stairs are an important, if not the most important remaining unconquered barrier in the way to better rehabilitation of the paralyzed. A paraplegic could usefully function at many more locations if he could at least bridge the three-to-six-step stair barrier that now blocks his access to many public, business, and private buildings. We believe that the crutchless standing brace technology will become the first essential building block toward a future stair-climbing system for conquering that barrier.

SUMMARY

Paraplegics spend too little time on their legs because little apparent gain is received from too much energy expenditure. New methods, more responsive to user acceptance requirements, would have to: 1. be quickly and easily learned, 2. be easy to use without undue exertion, 3. leave the hands free to do something useful while standing, 4. open to independently moving paraplegics more of the presently off-limits environment of the world. Feasibility experiments are needed with an experimental adult version of the Parapodium established in 1971/72 to prove that crutchless standing and pivot walking are possible for tall adults.

The prior work led to the design and fabrication of a new lightweight crutchless standing brace. Marked improvement in regard to weight reduction was achieved. The new brace is designed with separate top-half and bottom-half modules, which are joined together after donning. This feature, along with significant weight reduction, made donning and removal much easier than in our first experimental model.

Test arrangements have been built to evaluate the most useful positioning of hands in pushing oneself from sitting to an upright standing position. This is necessary due to a disadvantage adults have relative to

children. Children always find something in the adult-scale world that can serve them as a grab bar whereas there is a lack of things that could equally serve adults. Instead of *pulling* themselves up, adults must *push* themselves upright.

Pivot walking allows the paraplegic to maneuver within a confined space, such as through a narrow doorway. More important, one's hands can be freed to do something useful while standing, such as dialing a wall phone, or simply reaching things above the upper reaches of the wheelchair-bound.

It is thought that these new techniques will eventually help more adult paraplegics to graduate from the wheelchair. Perhaps more important, it will entice most to stay on their legs at least part of each day because of the greater ease in using these new methods, and because of an apparent feeling of safety. A significant lessening of the consequences of their lower-limb paralysis is therefore in sight for paraplegics.

Note: At the Conference of Prosthetics and Sensory Aids Research Leaders held in Chicago in July 1974 a 6-minute film was shown as part of the author's presentation. Highlights of this film include:

1. Pivot walking with crutches used as a redundant means of maintaining balance, but not weight-bearing.
2. Pivot walking without crutches.
3. Pivot walking including a point where the paraplegic stumbles. This episode is shown to demonstrate the ease of recovery.
4. Donning of the new lightweight brace.
5. Donning of conventional long leg braces showing the obvious time difference compared with the lightweight crutchless brace.

ACKNOWLEDGMENTS

Credit for designing this equipment belongs first of all to Wallace M. Motloch, C.O.(C), who joined us as a part-time research orthotist to explore whether his Parapodium and Pivot Walker concepts could be extended to tall adults. Other contributors include my father, Johannes W. Prast; Dr. Eugene F. Murphy, Director, VA Research Center for Prosthetics; Michael DiPompo, Chief, Orthotics Laboratory, VAPC Satellite, Castle Point, N.Y.; and Dr. Emilio Ejercito, Chief of staff of the VA Hospital Castle Point, N.Y., without whose suggestions and help the project would have failed. Funding support was received from the VA Research Center for Prosthetics (20), Sierra Research Corporation, the Prast family, The Peter C. Cornell Trust, The James H. Cummings Foundation, The Jacob F. and Wilma S. Schoellkopf Fund of the Buffalo Foundation, and numerous individuals and other organizations in the United States, West Germany, Holland, Austria, and Canada.

REFERENCES

1. Heyl, H. L.: Some Practical Aspects in the Rehabilitation of Paraplegics. J. Neurosurgery, 13(2):184-189, 1956.
2. Ontario Crippled Children's Centre: Rehabilitation Engineering Research Report. Toronto, Canada, p. 12-14, 1970.
3. Motloch, W. M.: The Parapodium. Ontario Cripped Children's Centre, Toronto, Canada. February 1971.
4. Motloch, W. M.: The Parapodium: An Orthotic Device for Neuromuscular Disorders. Artif. Limbs, 15(2):36-47, Autumn 1971.
5. Motloch, W. M.: Mobility for Spinal Cord Impaired Patients. Presented during the Workshop on Mobility of Spinal-Cord-Impaired People. Downey, Cal., Feb. 22-24, 1974. Committee on Prosthetics Research and Development of the National Academy of Sciences–National Research Council.
6. Ontario Crippled Children's Centre: Rehabilitation Engineering Research Report. Toronto, Canada, 15, 1970.
7. Motloch, W. M.: Fitting, Fabrication and Training Manual for the Swivel Walker. Ontario Crippled Children's Centre, Toronto, Canada, 1966.
8. Motloch, W. M. and J. Elliott: Fitting and Training Children with Swivel Walkers. Artif. Limbs, 10(2):27-38, Autumn 1966.
9. Spielrein, R. E.: A Simple Walking Aid for Legless People. J. of the Instit. of Engineers (Australia), 35(12):321-326, Dec. 1963.
10. Barry, R. M. and R. J. Duncan: A New Concept in Swivel Walkers—A Comparison with the Conventional (Canadian Type). Artif. Limbs, 13(1):66-68, Spring 1969.
11. Duncan, R. and R. Klein: The Swivel Walker—Further Modification, RALAS (Australia), 15(2):23-26, March 1974.
12. Rose, G. K. and J. T. Henshaw: A Swivel Walker for Paraplegics: Medical and Technical Considerations. Bio-Med. Engng., 7(9):420-425, Oct. 1972.
13. Henshaw, J. T.: The Bio-Mechanics of the Shrewsbury Paraplegic Walker. Proceedings of 1st International Congress on Prosthetics Techniques and Functional Rehabilitation. 2:155-160, Vienna, Austria, 1973.
14. Rose, G. K.: Orthotic-Surgical Integration of the Shrewsbury Paraplegic Walker. Proceedings of 1st International Congress on Prosthetics Techniques and Functional Rehabilitation. 2:161-165, Vienna, Austria, 1973.
15. Rose, G. K. and J. T. Henshaw: Swivel Walkers for Paraplegics—Considerations and Problems in Their Design and Application. Bull. Prosthetics Res., BPR 10-20:62-74, Fall 1973.
16. Glancy, J.: The Orthotic-Prosthetic Transverse Rotator. Report, Eighth Workshop Panel on Lower-Limb Orthotics of the Subcommittee on Design and Development. Committee on Prosthetics Research and Development, National Academy of Sciences—National Research Council, Los Angeles, Cal. Oct. 2-4, 1972, pp. 93-109.
17. Prast, J.W.: Prast Research Associates, Inc. Visit to Mihailo Pupin Institute, Belgrade, Yugoslavia, Sept. 20, 1971.
18. Prast, J. W.: Adult Parapodium and Other Research for Paraplegics. Report, Eighth Workshop Panel on Lower-Limb Orthotics of the Subcommittee on Design and Development. Committee on Prosthetics Research and Development, National Academy of Sciences—National Research Council. Los Angeles, Cal., Oct. 2-4, 1972.
19. Staros, A. and E. Peizer: Veterans Administration Prosthetics Center Research Report. Bull. Prosthetics Res., BPR 10-19:157-159, Spring 1973.
20. Veterans Administration Contract V101(134)P-216: Conduct a Research and Development Project on Advanced Orthotic Devices for Adult Paraplegics. Mar. 1, 1974.