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A Breath Activated Switching Mechanism for the Electric Powered Prehension Orthosis: Design and Fabrication

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INTRODUCTION

A person with quadriplegia, paralysis of all four limbs caused by lesions at high levels of the spinal cord, has extremely complex needs for rehabilitation care. Quadriplegia has a devastating effect on a person's entire life. Even after successful rehabilitation, the formerly independent person intermittently requires the help of an attendant for many activities of daily living and activities required for gainful employment or for attending school.

Because attendant care is the single greatest cost of living, exceeding even medical cost, for a person with quadriplegia,[9] any intervention that improves independent function of a person with quadriplegia enough to reduce this need for attendant care should be investigated.[2,3,5] Furthermore, if a device can allow a quadriplegic person to be gainfully employed, the cost to the individual and to society would be further reduced and the person with quadriplegia could be much more self-reliant.

Our early experience indicates that the use of a Breath Activated Switching Mechanism (B.A.S.M.), rather than the switching mechanisms that are now available, may improve the ability of quadriplegic persons to use the electric powered prehension orthoses that are already available. Furthermore, the extent of this improvement may be significant enough to reduce the need for attendant care and to improve the outlook for gainful employment.

Certain types of adaptive aides have been used to substitute for hand function. Some quadriplegic persons have received automated devices, such as environmental control units[8] (ECU) that provide some measure of independence in such activities as the turning on and off of lights and appliances and answering the telephone (Figure 1). While E.C.U.s provide much assistance to the home bound quadriplegic person, they cannot be moved from place to place. The user requires attendant care for most activities outside the home. Furthermore, automated devices do not give the user the personal satisfaction of using the hand in a "normal way."

Mouthsticks have been used to extend the functional independence of those with

Figure 1. Environmental control units (ECU) provide some measurement of independence, such as the turning on and off of lights and appliances and answering the telephone.

the most severe paralysis of the upper extremities.[4] However, they do not permit independence from an attendant and are often poorly accepted by patients who have enough upper extremity strength to move their hands about.

Most people with quadriplegia retain some use of the upper extremities. The person with C-5 level quadriplegia (in this paper, the level of lesion is named by the lowest normally functioning spinal segmental level), the most common level of traumatic quadriplegia, is left with no function in the wrist and hand complex, but has preservation of flexion at the elbow and some ability to elevate and move the shoulder joint. This person can move the hand to different positions in space; but has no grasp-release function of the hand. Some C-4 level quadriplegic persons have enough strength of the shoulder girdle and elbow to move the hand about; but, like the C-5 quadriplegic person, they also have no grasp-release function of the wrist or hand. Many persons with C-6 level quadriplegia, the next most common level, have insufficient wrist extension power to be able to use a wrist driven finger prehension orthosis[6] (Figure 2).

Most of the people will be fitted with a static orthosis (Figure 3). A static orthosis, when properly designed and fitted, will

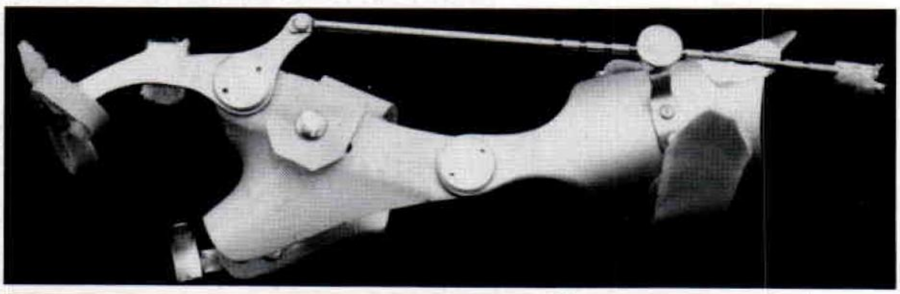


Figure 2. The wrist-driven finger prehension orthosis.

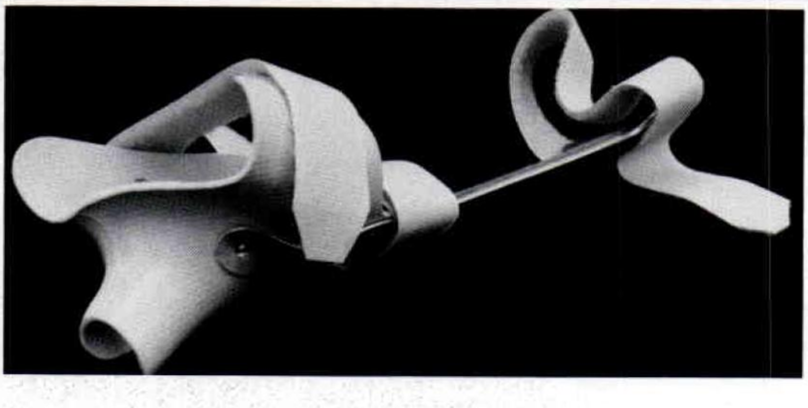


Figure 3. A static orthosis.

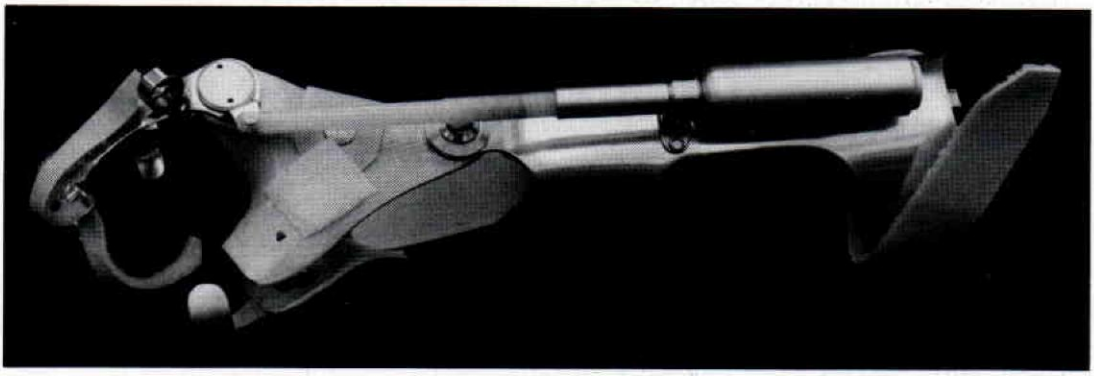


Figure 4. An electric powered prehension orthosis (EPPO) that provides a three-jaw type finger prehension.

allow the user to do some activities of daily living (ADL).

However, it is impossible for the user to accomplish many of these tasks, or to switch from one activity to another, without the assistance of another person.

If prehension and release could be provided to a quadriplegic person who is able to move his or her hand to different positions in space, most of the functional tasks needed for employment at a desk job, performing school work, activities of daily living, and participating in social activities could be accomplished without any need for an attendant. A few people have been fitted with an electric powered prehension orthosis (E.P.P.O.)[7] that provides a "three-jaw-chuck" type finger prehension (Figure 4). The E.P.P.O. has been perhaps the most promising development to improve function for quadriplegic persons who are appropriate candidates. However, the usefulness of the E.P.P.O.has been limited by the awkwardness of the switching mechanisms normally supplied with these orthoses. These mechanisms are normally pull or butterfly-type switches that are operated by movements of the shoulders or the contralateral limb, respectively (Figure 5).

Many users cannot achieve a good functional result with an E.P.P.O. because these switches do not allow them to fully concentrate on the task at hand. The major problems associated with these switching mechanisms are due to the users' impaired sensation, as well as their limited and poorly controlled movements. The butterfly switch can be especially difficult to use when visual input is the only available position sense. The user must constantly shift his/her attention from the task at hand to the operation of the switch by the other arm (assuming a functional contralateral limb).[6] The pull-type switch requires the user to have very finely coordinated movement because the three modes—open, close, and off—are in close sequence. Lack of fine control or maladjustment may cause the orthosis to react improperly.

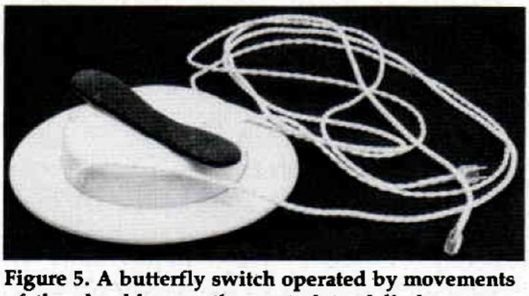


Figure 5. A butterfly switch operated by movements of the shoulders or the contralateral limb, respectively.

Many attempts have been made to solve such switching problems, because these problems can make the simplest task frustrating, unnecessarily fatiguing, or impossible. A switching problem can make the difference between acceptance and rejection of an otherwise functional orthosis. For example, as far back as the early 1950's, surface E.M.G. electrodes have been used to operate switches on orthoses and pros-

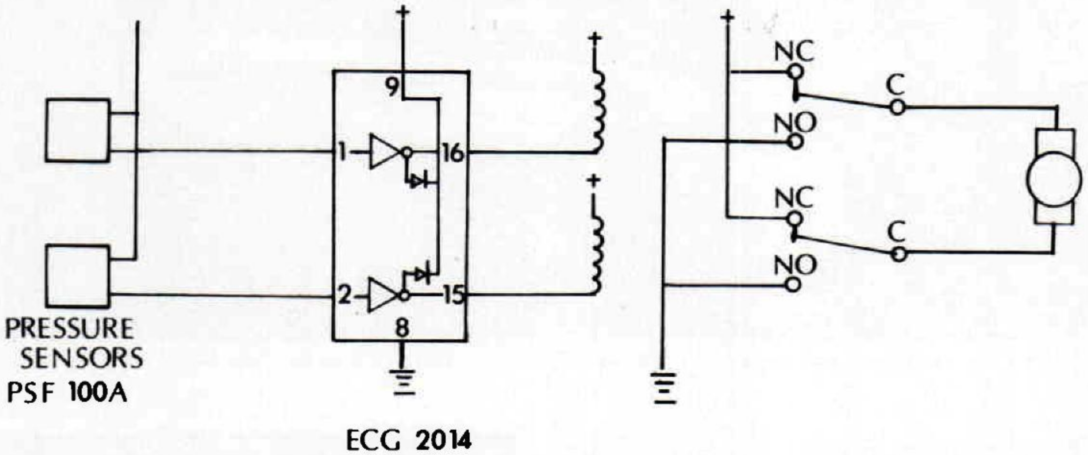


Figure 6. A schematic diagram for an interface control for a "breath activated switching mechanism" using two Fairchild Ultralow differential pressure sensors, Basic Model PSF 100 A, manufactured by Dumont.

theses.[1] However, because of problems in locating appropriate placement sites and problems with attaching the electrodes, this means of operation has achieved only limited success in practical clinical settings.

The Rehab Engineering Institute (R.E.I.) at The University of Texas Health Science Center at San Antonio (U.T.H. S.C.S.A.) became interested in another approach to the switching problem for externally powered upper extremity prostheses while conducting an evaluation procedure for a male quadriplegic patient. His neurologic level for motor and sensory function was C-5 spared on the right and C-4 on the left. The person had been fitted previously with an E.P.P.O. However, he was not able to operate the butterfly switch and consequently was not using his orthosis. One of the team members suggested that a "sip and puff" switching mechanism might be a way for this person to effectively use his orthosis. This system proved to be so clearly superior to other switching mechanisms that it has now become a standard part of all E.P.P.O.s fabricated in our center.

DESIGN AND DEVELOPMENT OF THE BREATH ACTIVATED SWITCHING MECHANISM (B.A.S.M.)

After consulting rehabilitation engineers and trying out several designs, a schematic diagram for an interface control was drawn up for a "breath activated switching mechanism" using two Fairchild Ultralow differential pressure sensors, Basic Model PSF 100A, manufactured by Dumont (Figure 7). This switch senses as little as .002 PSI of air pressure (Figure 8).

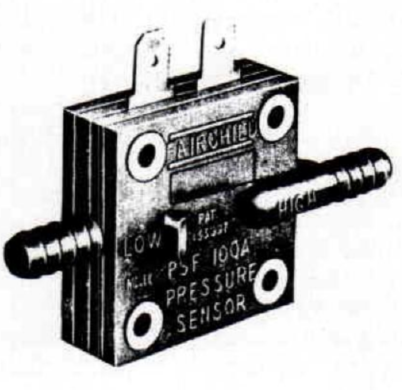
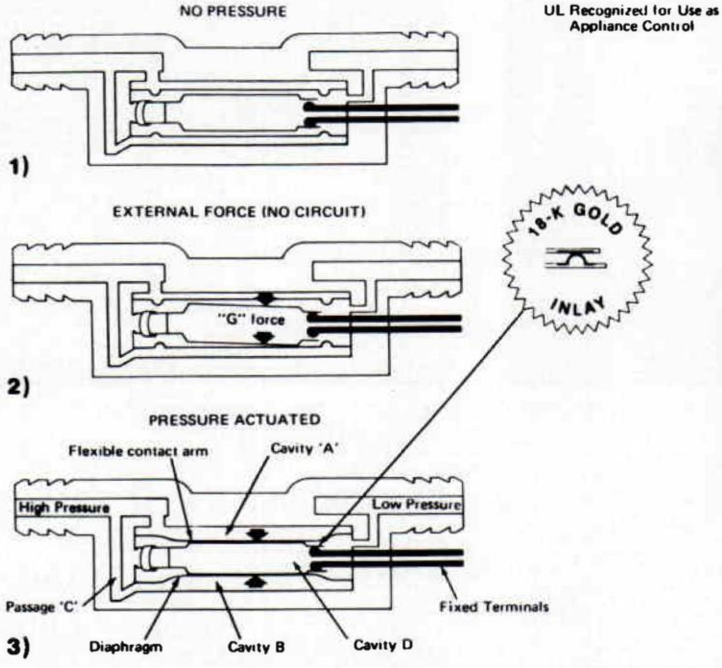


Figure 8. (right) The switch senses as little as .002 PSI of air pressure.

HERE'S HOW THE PSF 100A WORKS . . .



With no differential pressure applied, the diaphragms do not exert a force on the moveable contacts (see Diagram 1). An external force may cause one contact to close, however, the other contact moves in parallel and remains open (see Diagram 2). There is still no circuit closure. With pressure applied (see Diagram 3), air enters at the high pressure inlet port and is routed directly to Cavity A and through the manifold (C) to Cavity B. The applied pressure actuates the diaphragms inward, deflects the flexible contacts, and completes the circuit.

The following information is taken by permission from Dumont's printed form #PSF 782/37371PO.

SPECIFICATION:

Mechanical

Switch Type—SPST, Normally Open, Double Break
Switching Medium—Air
Actuation Pressure—Refer to table of standard actuation ranges for PSF 100A models
Proof Pressure—PSF 100A 100A-1.5, PSF 100A-3 8 PSIG, "C" Series 15 PSIG
Mechanical Life—More than 10 million cycles
Weight—Less than 10 grams
Shock and Vibration—At zero or above actuation pressure, will not make or break at 50G's shock. Will not make or break at 10G's shock, 50 to 2000 Hz vibration.

Physical

Mounting—Eyeletted for No. 2 screws
Case Material—Polycarbonate
Contact Materials—Gold inlay on phospher bronze
Electrical Connections—Terminals—3/16" male tab-type, for use with 3/16" female quick disconnects (ref. AMP 60972 2LP or equivalent)
Pressure Ports—Two 3/16" diameter barbed ports for use with 5/32" ID tubing. Suggested materials: Silicone, Neoprene, Polyurethane

Electrical

Current Rating—10 MA, resistive, DC norminal
Operating Voltage—AC/DC 30V or less with resistive load, 120 VAC neon lamp load (Use with SRF 100B Solid State Relay for higher loads).

A prototype B.A.S.M. was fabricated using two (2) PSF 100A sensors, one (1) RCA integrated circuit #SK-9094-2014 Darlington Array, CMOS/POMS interface, and two (2) Archer's subminiature PC relays #275-243. These were attached to a basic integrated circuit board (Figure 10).

*Schematic by Calvin P. Franke, Engineering Technician III, Department of Physiology, The University of Texas Health Science Center at San Antonio.

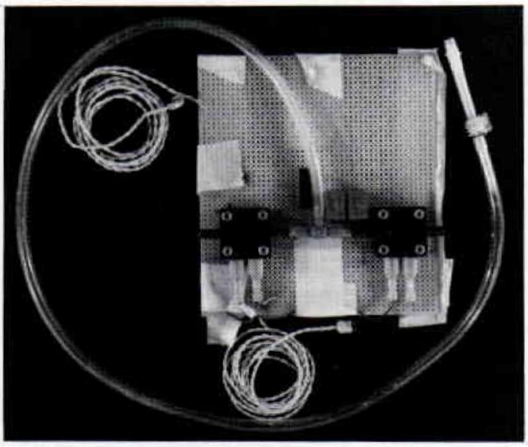


Figure 10. A prototype B.A.S.M. attached to a basic integrated circuit board.

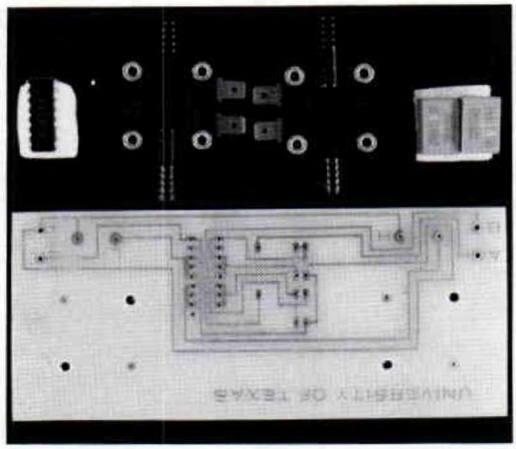


Figure 11. A custom printed board is now in use. No failures have occurred.

The B.A.S.M. was connected to the E.P.P.O. and fitted for use. The only problem with this B.A.S.M. was occasional failure of the hand wired integrated circuit boards due to faulty soldering techniques. The wired circuit board has been replaced with a custom printed board, which is now in use in nine E.P.P.O.s. No failures have occurred since the printed circuit boards were introduced (Figure 11).

FABRICATION OF THE BREATH ACTIVATED SWITCHING MECHANISM

This section consists of detailed instructions for fabrication of a breath activated switching mechanism.

A) Attach the two (2) PSF 100A sensors, one (1) RCA integrated circuit #SK-9094-2014, and two (2) Archer subminiature relays #275-243 to the printed circuit board** as shown in Figure 12.

B) After the components are attached to the circuit board, the following parts are

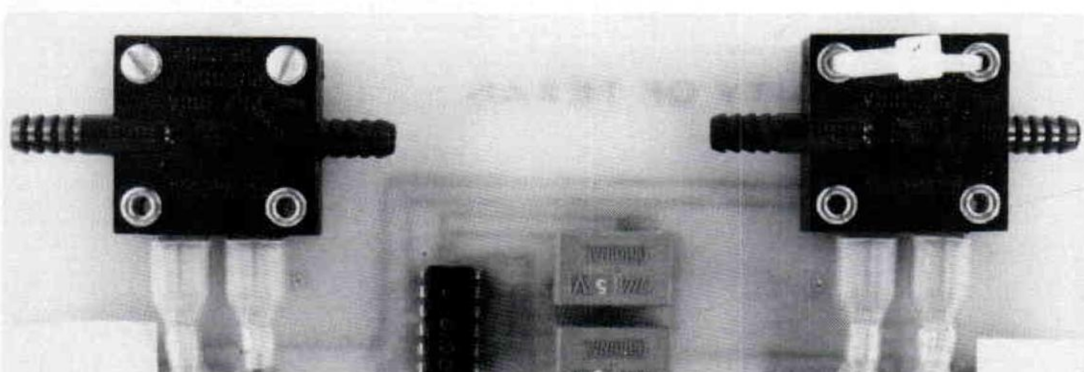


Figure 12.

** Available on request from UTHSCSA for $50.

used to adapt the B.A.S.M. to the E.P.P.O.:

1. Two pieces 5/32" transparent plastic tubing 5cm. long.
2. One piece 5/32" transparent plastic tubing 90cm. long.
3. One piece "T" connector 5/32".

(Note: The above items are available at many pet stores.)

4. One piece 5cm. wide cotton webbing about 30cm. long.
5. One piece 5cm. wide hook and adhesive-backed loop Velcro® about 5cm. long.
6. One piece 1/2" adhesive-backed loop Velcro® 5cm. long.
7. One piece 1/2" adhesive-backed hook Velcro® 5cm. long.

(Note: The above items are available at PEL Supply Company, 4666 Manufacturing Road, Cleveland, Ohio 44135.)

8. One set E.P.P.O. connector wires.
9. Battery pack for E.P.P.O.

(Note: The above items are available from Orthotic Systems, Inc., P.O. Box 20262, Houston, Texas 77025.)

10. One plastic pipette tip (available through many surgical supply houses).
11. Experimenter Box, CAT #270-232 (available at many Radio Shack stores).
12. Two 4/40 machine screws 1" long with nuts attached.

The assembly of the B.A.S.M./E.P.P.O. is shown in Illustrations A-M. Item numbers in instructions refer to items in the above list.

The B.A.S.M. can easily be adapted for use with any externally powered orthosis or prosthesis that operates on a 6-volt system. It can be adapted to operate a 12-volt system by substituting 12-volt relays and integrated circuits.

PRECAUTIONS

A few precautions must be taken by users of the B.A.S.M. The B.A.S.M. will not operate properly if the pressure introduced through the air hose to the sensors is not expelled. Expelling the air volume is easily accomplished by:

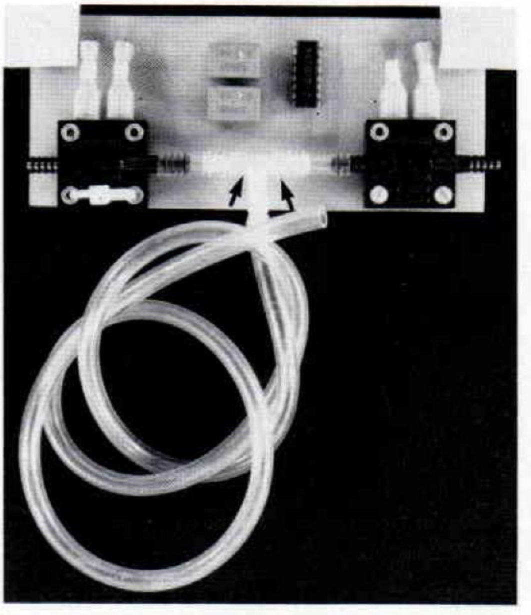
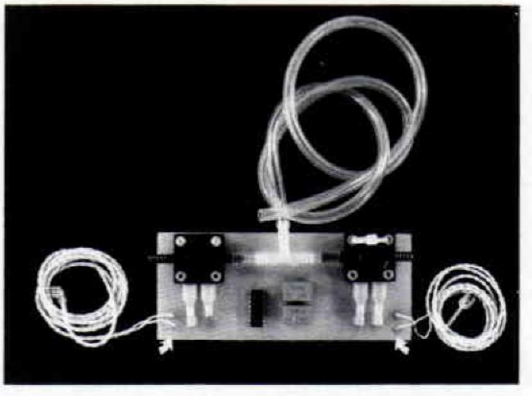


Figure 12-A. Attach Items #1, 2, 3 to pressure sensors.



Fgure 12-B. Attach Item #8 (battery and orthosis connector wires) to printed circuit board.

1. Removing the tube from the mouth; or
2. Removing the tube from the "T" connector.

Care must be taken to eliminate saliva and food particles from the tube to prevent its interferring with open parts of the sensors which must not be blocked. Special attention must be given to this precaution when the B.A.S.M./E.P.P.O. is used for eating activities. Simple, common sense

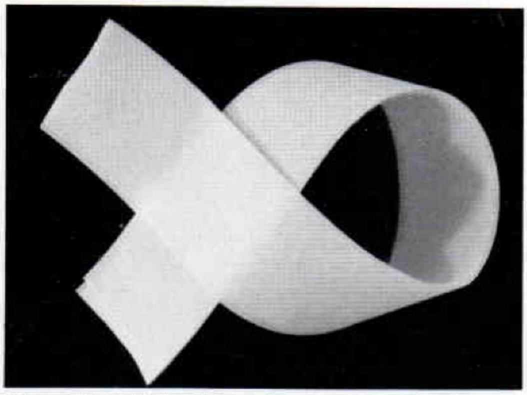


Figure 12-C. Using Items #4 and #5, make arm band.

practices such as swallowing drinks, food, or saliva prior to activation of the switch should protect the switch and should not interfere with activities.

RESULTS

Although formalized clinical evaluation using an evaluation protocol which we have developed is still underway, informal observations reveal a clear superiority of the B.A.S.M. over other switching mechanisms we have tried for the E.P.P.O. The B.A.S.M./E.P.P.O., by offering the patient some direct use of his hands,

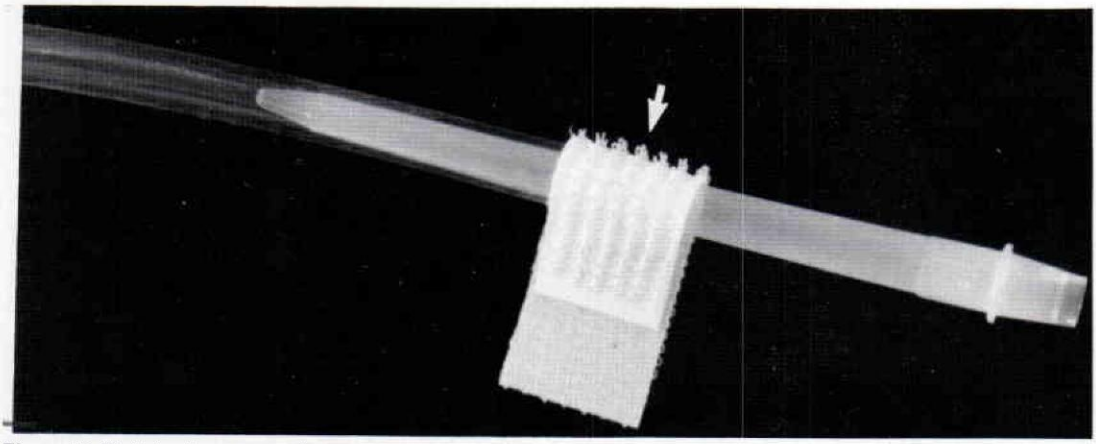


Figure 12-D. Take Item #6 and place on E.P.P.O. as shown above.

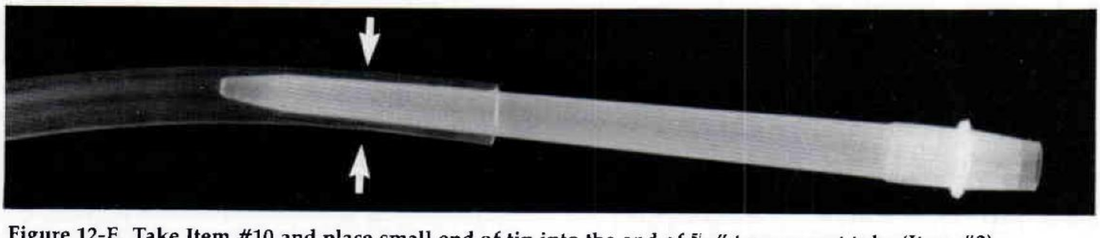


Figure 12-E. Take Item #10 and place small end of tip into the end of $^{5}/_{32}''$ transparent tube (Item #2).

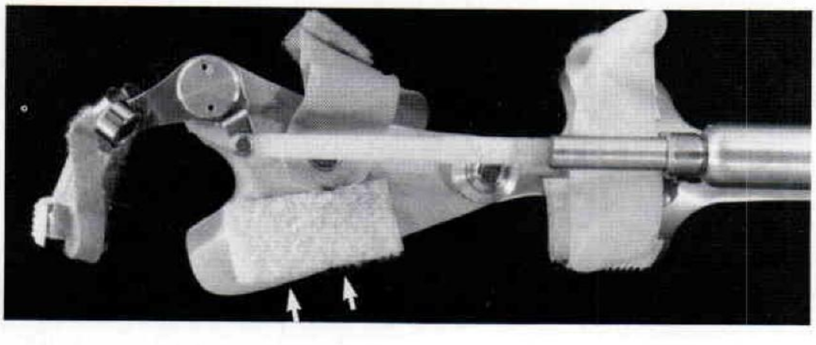


Figure 12-F. Take Item #7 and wrap around the transparent tube (Item #2) where it joins the tip.

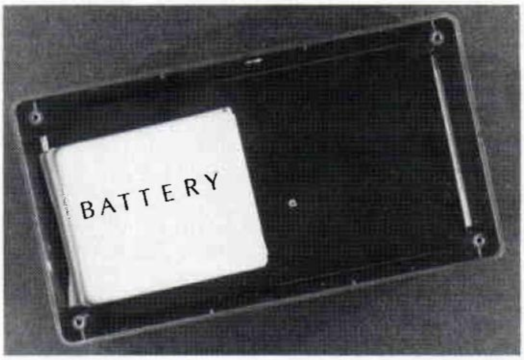


Figure 12-G. Place Item #9 in Item #11, mark location of battery charger plug and battery connector wire plug.

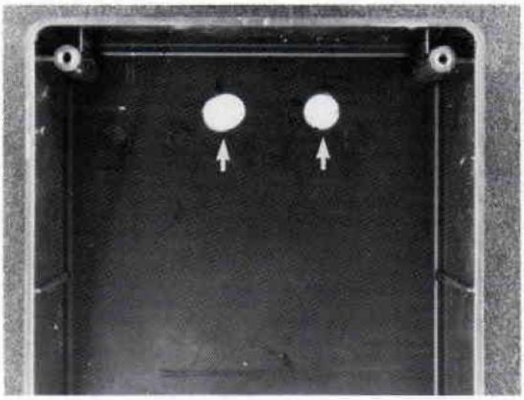


Figure 12-H. Use a 3/8" H.S. drill to drill a hole for plugs.

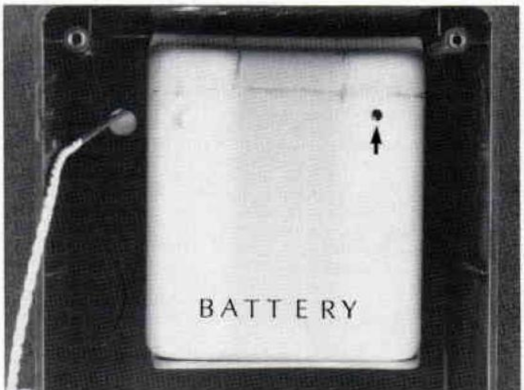


Figure 12-I. Attach Item #9 to Item #11 by drilling a 1/8" hole as shown and inserting item #12.

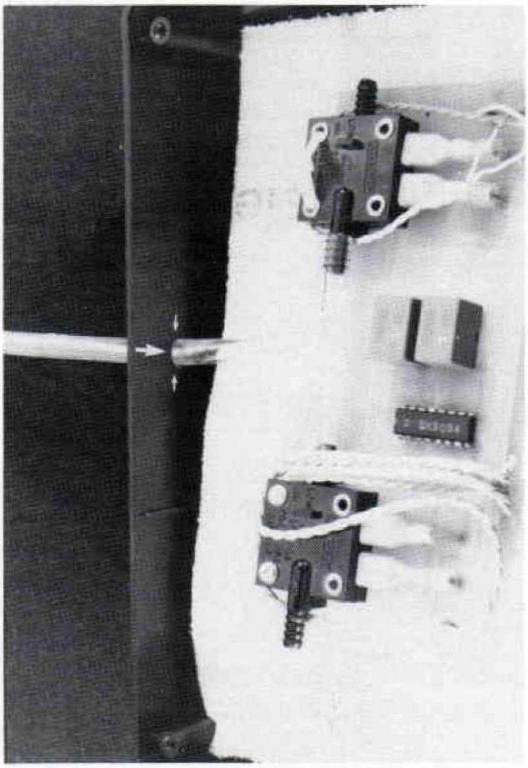


Figure 12-J. Place the B.A.S.M. into Item #11, locate the position for the 5/32" transparent tube, mark and drill with a 9/32" H.S. drill.

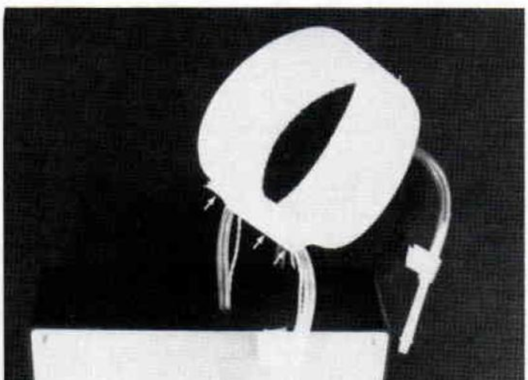


Figure 12-K. Replace the bottom to Item #11, attach the arm band to the transparent tube and orthosis wire connector as shown.

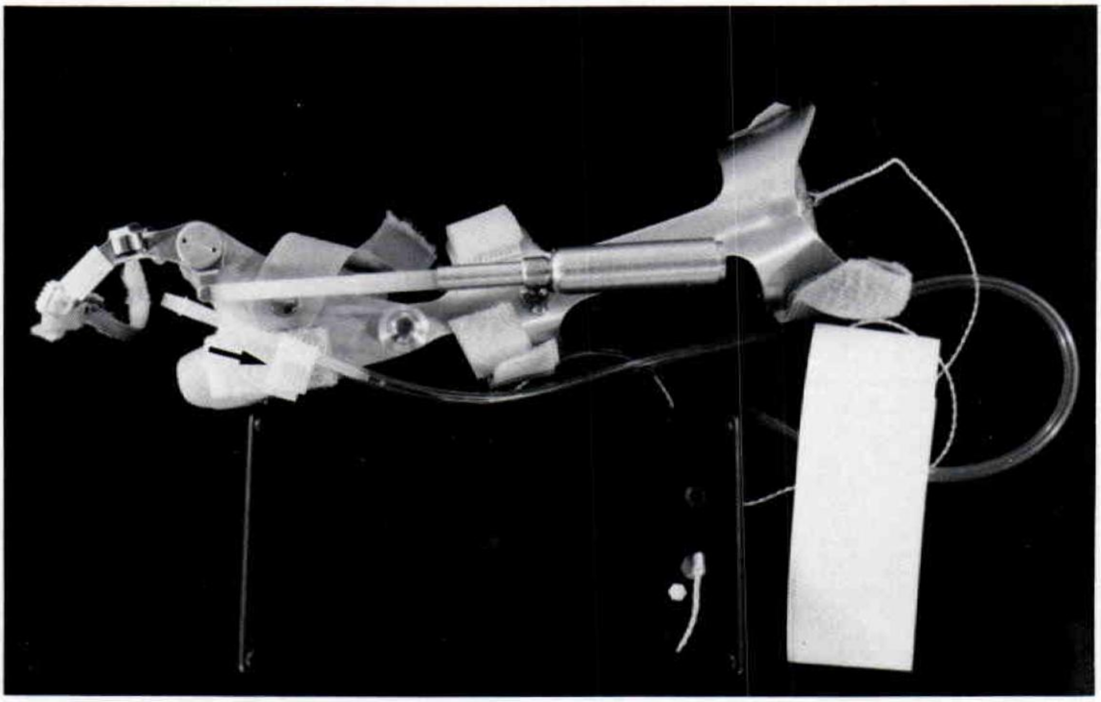


Figure 12-L. The assembled B.A.S.M./E.P.P.O.

seems to encourage the patient's participation in strengthening functions (e.g., shoulder and elbow movement) that have been spared.

The B.A.S.M. is much easier for patients to learn to use than are the other switching mechanisms. Although rehabilitative training is still important to assure optimal function and acceptance,[5,6] most of our patients have been able to operate the orthosis without difficulty after only one training session. The ease of use seems to encourage patients to try new tasks on their own with their new orthosis, for example, eating fragile finger foods such as potato chips or sandwiches.

One of the primary objectives has been to reduce the need for attendant care. It remains to be formally determined whether this objective can be achieved to a sufficient extent that it will improve the patient's abilities to attend school or engage in gainful employment. However, our patients agree that their need to request help from others has been reduced.

CONCLUSIONS

A B.A.S.M. can be simply and economically adapted for use with the E.P.P.O. to provide quadriplegic persons with easily controlled finger prehension. Operation of the B.A.S.M. does not require the muscle effort, proprioception, use of contralateral limbs or extensive training that are necessary for the use of other switching systems available for E.P.P.O. use. Therefore, the B.A.S.M. should be a useful tool to provide early restoration of independent function to certain quadriplegic persons.

ACKNOWLEDGMENTS

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Photography done by Cono Farias, Photographic Technician II, Radiology Department, The University of Texas Health Science Center at San Antonio.

REFERENCES

[1]Battye, C.K., Nightingale, A., and Whillis, J., "The Use of Myoelectric Current in the Operation of Prostheses," *J Bone and Jt Surg*, 37B:8, pg. 506–510, August, 1955.

[2]Redbrook, G.M., "Spinal Injuries with Tetreplegia and Paraplegia," *J Bone and Jt Surg*, 61B:267–284.

[3]Burtzke, J.R., "Epidemiology of Spinal Cord Injury," *Exptl Neurol*, 48:163–236, 1975.

[4]Currie, D.M., Delahunty, D., McFarland, S., and Locke, R., "Mouthstick Systems for High Quadriplegic Patients" submitted to the American Academy of Physical Medicine and Rehabilitation, July, 1983.

[5]Efthimiou, J., Gordon, W.A., Sell, G.H., and Stratford, C., "Electronic Assistive Devices: Their Impact on the Quality of Life of High Level Quadriplegic Persons," *Arch Phys Med Rehab*, 62:131–134, 1981.

[6]Engen, E.J., "Development of Upper Extremity Orthotics," *Orthotics and Prosthetics*, Vol. 24, Nos. 1 and 2, March and June, 1970, pg. 6.

[7]Orthotic Systems, Incorporation, P.O. Box 20262, Houston, Texas 77025.

[8]Prentke Romich Company, 8169 TWP Road, #513, Shreve, Ohio 44676.

[9]Young, J.S., Burns, P.E., and Wilt, G.A., "Medical Charges Incurred by the Spinal Cord Injuries During the First Six Years Following Injury," *Spinal Cord Injuries*, August, 1982, pg. 122–137.

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