

The VAPC Functional Elbow Orthosis

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A majority of functional upper-limb orthoses now available are designed for patients in wheelchairs, and are not suitable for use by ambulatory patients with partial upper-limb muscle involvement resulting from brachial plexus injury or other neurological disorders. The present method of managing these ambulatory patients is to provide an arm orthosis which usually consists of an elbow lock and a cable to lift the hand into a functional position. This arrangement requires strong shoulder muscles, which are usually absent, and the devices provided are often bulky, heavy, and too difficult to operate.

To overcome these problems, the VA Prosthetics Center has been experimenting with an orthosis that uses a pneumatic device to assist elbow flexion. The original design consisted of a shoulder cap, forearm cuff, and a five-bar elbow linkage, and the force of gravity and the force required to flex the elbow were counterbalanced by the energy stored in a pneumatic-spring cylinder. Only a minimal force was needed to initiate elbow flexion, and an increase in flexion produced a non-linear increase in force. Because the force needed to extend the system is greater than the force needed for flexion, some extension activity by the user was required. After the device was fitted to a

patient, it was found to be too bulky and inefficient; but it showed promise of useful function.

The cylinder and moving components were redesigned to meet the requirement of lifting the forearm more efficiently. The shoulder cap was altered to obtain an upper-arm cupping effect that provided more arm stability during elbow flexion. The mechanical components were made smaller and more compact, and the attachment points were modified to permit freer motion about the elbow joint. Stability and suspension are now controlled adequately by the shoulder cap and wrist cuff.

The new design allows non-linear forces to be generated to: 1) balance the force of gravity against the weight of the forearm; 2) produce the force required to stretch the triceps; 3) overcome the resistance encountered when the forearm becomes compressed against upper-arm tissue; and, 4) counteract an increase in force when the cylinder is compressed.

The device produces a strong pulling action between the wrist and upper-arm section, as illustrated by the two arrows in Figure 1. A counterbalance is produced between forces used to extend the cylinder during flexion and compress it during extension, permitting the system to be stable against the weight of the forearm.

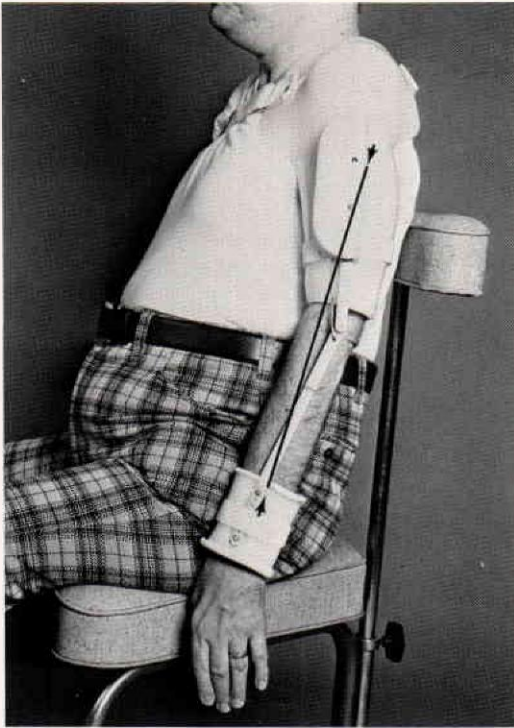


Fig. 1. A strong pulling action is exerted between the wrist and upper arm.

Once the elbow has been flexed moderately, objects weighing up to 1 lb. (448 grams) can be supported easily. Once flexion has been initiated, the unit continues to flex until the triceps are activated to either retard flexion or stop it altogether. A slight elbow extension moment is required to maintain a fully extended position. At full flexion, more extension force is needed to extend the arm, but the force required diminishes as the arm is extended.

Further evaluation of the system with patients indicated that different load ranges to lift the forearm were needed. Thus, in the final design, provisions have been made for interchangeability of three different cylinders, which provide, respectively, 200, 300, or 400 newtons of force. Clinical applications have shown

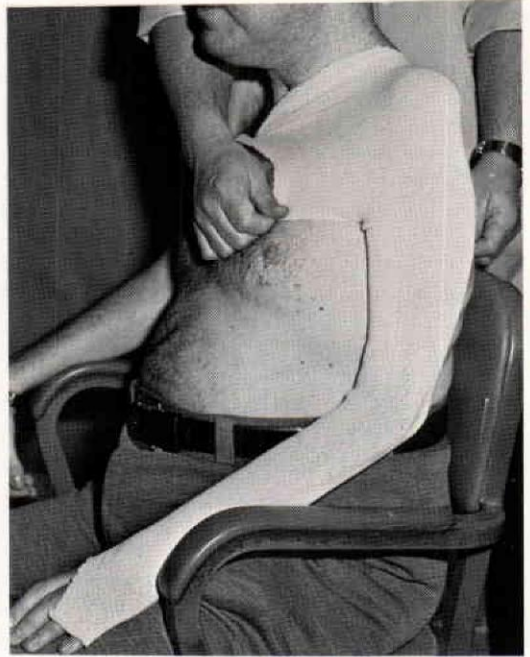


Fig. 2. The shoulder and upper arm are covered with a cotton stockinet.

this system to be lightweight, functional, and adequate cosmetically. However, the patient requires help in donning and doffing the device.

Fabrication

Fabrication of the Functional Elbow Orthosis requires: casting and modifying the cast, vacuum forming over the molds, and fitting and delivering the device.

Casting and Modification of the Cast

1. Cover shoulder and upper arm with cotton stockinet (Fig. 2), and secure in place with elastic straps and Yates clamps.

2. Mark all bony prominences and sensitive areas on shoulder, upper arm and forearm (such as the spine of the scapula, clavicle, acromium process, and

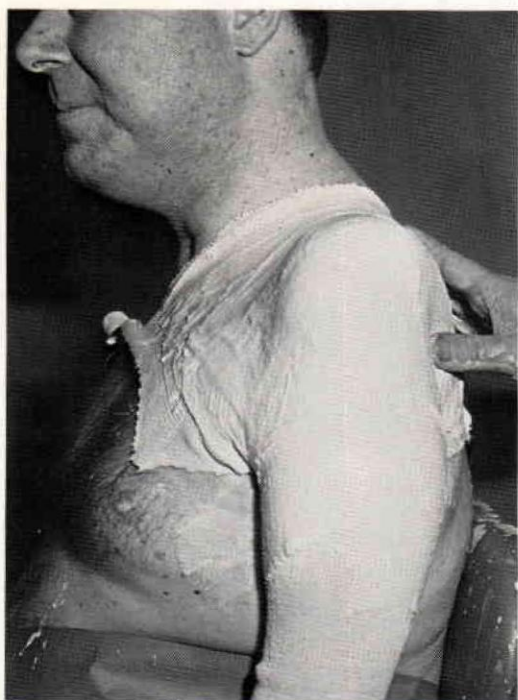


Fig. 3. A continuous plaster mold is made over the shoulder and upper arm.

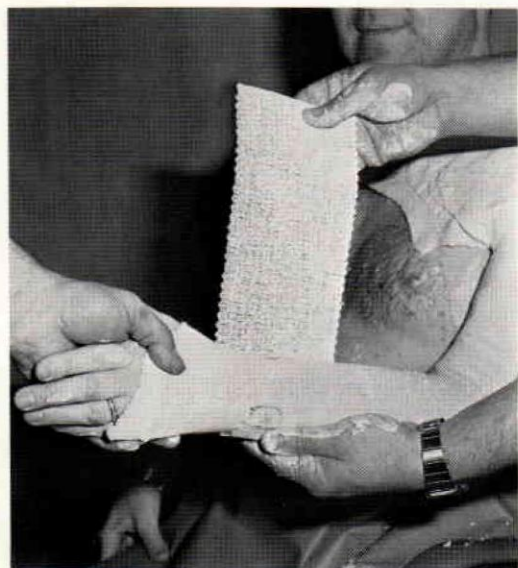


Fig. 4. A moist, 4-in. wide plaster bandage is wrapped over the stockinet that covers the wrist area.

the styloids of the wrist joint).

3. Cast the upper arm with the shoulder joint placed in about 10 deg of abduction and 5 to 10 deg of flexion to provide a position that allows the hand to get closer to the head during elbow flexion than is the case when no abduction or flexion are provided. Place wet 4-in.-wide by 18-in.-long plaster bandage strips over the shoulder and upper arm to form one continuous mold (Fig. 3). The plaster strips are placed on the upper arm so as to cover no more than three quarters of the arm's circumference, leaving a medial opening for removal of the cast without the need for a cast cutter. Four layers of plaster strips are usually used.

After the cast has hardened sufficiently, remove it by cutting the stockinet with bandage scissors on the medial portion.

4. For the forearm cuff, cover the wrist area with stockinet and mark all bony prominences. Wrap a moist 4-in. plaster bandage approximately four turns over the stockinet (Fig. 4). Allow the plaster to dry and remove it with bandage scissors.

5. Fill shoulder and wrist molds with plaster. Ensure that all modification marks are transferred to the positive mold.

6. Begin cast modification by removing all stockinet markings from both positive molds. The maximum amount of buildup over bony and sensitive areas is 1/8 in. since a Pelite or Plastazote liner will be added to both molds.

7. After completing all cast modifications, make a 3/16-in.-thick Pelite or Plastazote liner over each mold, using established prosthetic procedures (Figs. 5 and 6).

8. The molds are now ready for vacuum forming.

Vacuum Forming Over the Molds

When equipment for vacuum forming or drape molding is unavailable, regular laminating procedures may be used to

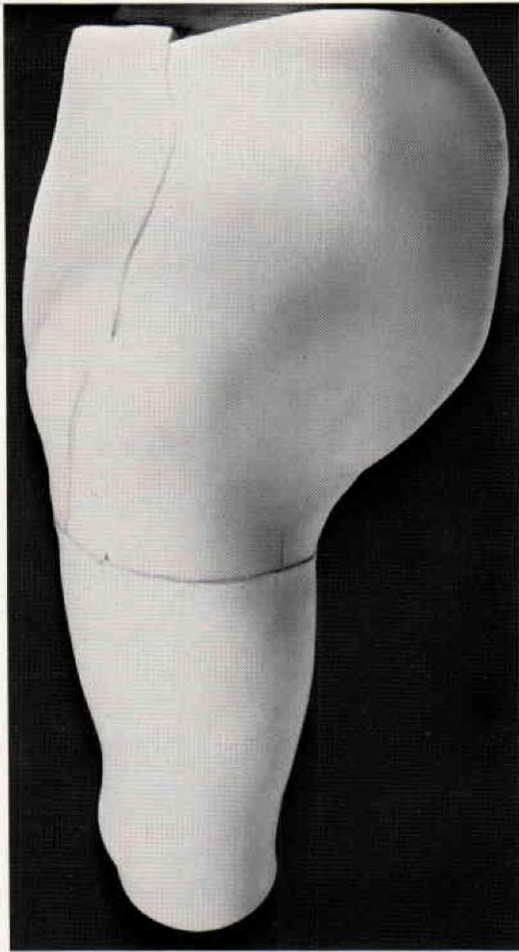


Fig. 5. A Pelite liner is molded over the positive model of the shoulder and upper arm.

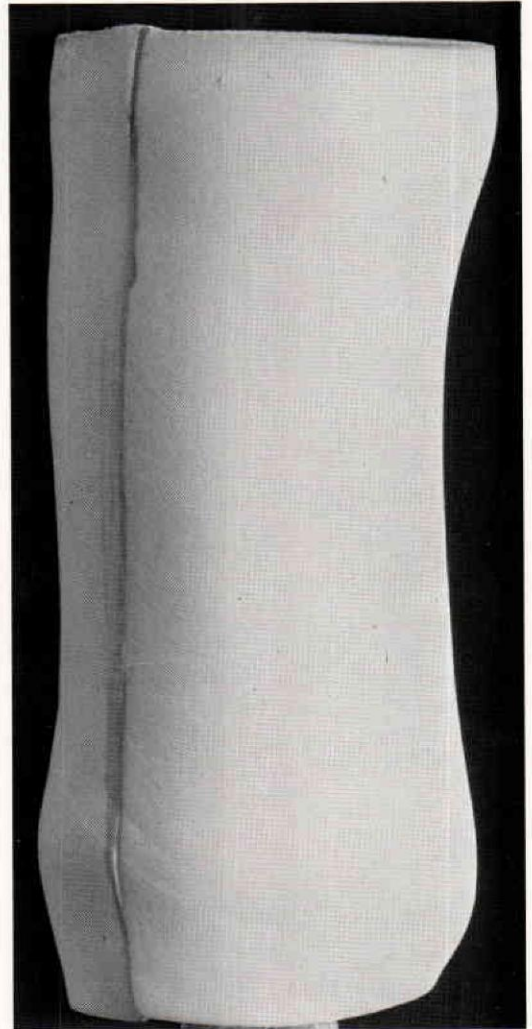


Fig. 6. A Pelite liner is molded over the positive model of the wrist area.

make the shoulder cap and forearm cuff. For vacuum forming, low density polyethylene is used. For the shoulder cap, 3/16-in. thick material is appropriate; for the wrist cuff, 1/8-in. material. Using regular vacuum forming procedures, vacuum form over both molds and their liners (Fig. 7). After the material has cooled, trim and sand all sharp edges.

Fitting and Delivery

For the fitting process the patient should wear a short-sleeved undershirt

beneath the device for added protection of the skin under the shoulder cap and in areas where the chest strap makes contact with the body.

1. *Fitting the shoulder cap.* Fit the shoulder cap, with its liner, on the patient. Mark all required areas for trimming, i.e., the neck, axilla and elbow joint areas (Fig. 8). The shoulder section should fit snugly with no restrictions while providing shoulder and arm stabil-

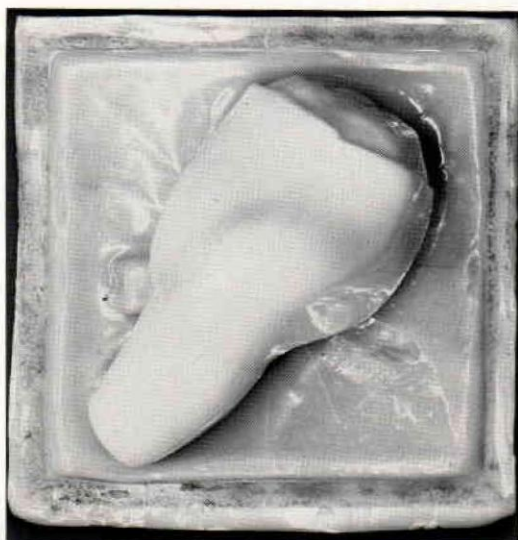


Fig. 7. Vacuum molding of the shoulder and upper-arm section.

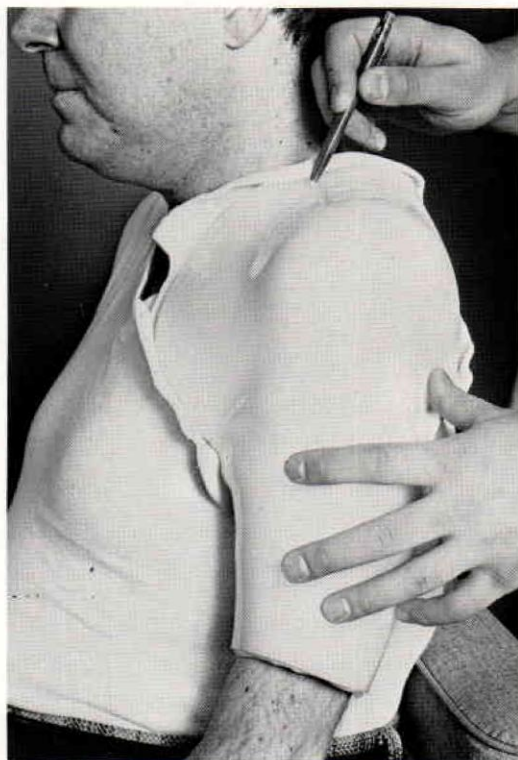


Fig. 8. Fitting and marking the trim lines for the shoulder and upper-arm section.

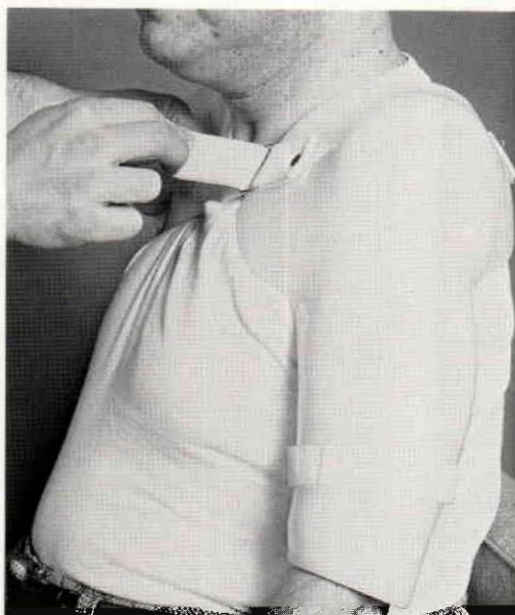


Fig. 9. Shoulder cap with cross-chest and upper-arm straps.

ity. The upper-arm section should be long enough to reach the bicipital fold at the elbow without restricting elbow flexion.

After the shoulder cap has been trimmed and smoothed, replace it on the patient, and locate the attachment points for the cross-chest and upper-arm straps so as to provide adequate support (Fig. 9). Use 1½-in.-wide webbing for the cross-chest strap, and 1-in.-wide Velcro for the upper-arm strap. Provide a tongue of a thin sheet of polyethylene on the medial side of the upper arm. The exact locations of these straps are optional, as long as they keep the shoulder cap in place and the patient is comfortable. Use tubular rivets to fasten straps and tongue in place.

2. *Fitting the Wrist Cuff.* Fit the molded cuff, with its liner, on the patient's wrist. Trim the distal and proximal edges to allow wrist flexion and extension. Its total length should be approximately 4

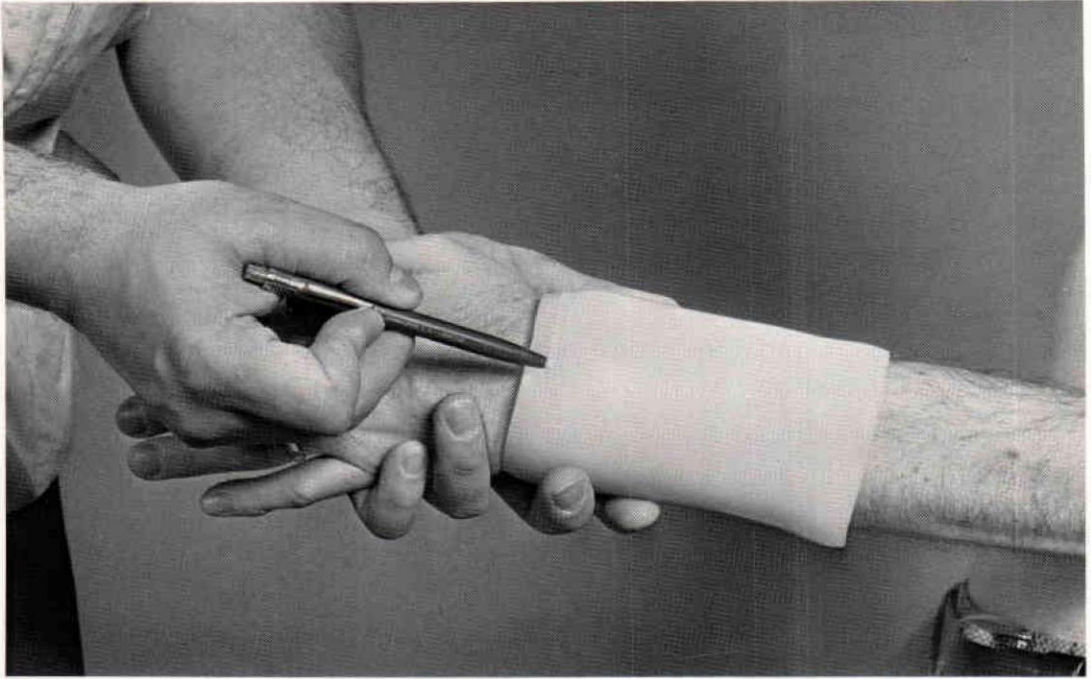


Fig. 10. Marking the wrist cuff for trimming.

in. (Fig. 10). On the initial fitting, the length of the wrist cuff is kept at 4 in. until the patient has used the device for several weeks. If it is felt after several weeks that this is too long, it can be trimmed appropriately. Because the system exerts a strong pulling force toward the elbow at the wrist, the more surface covered initially, the less pressure created on the patient's tissues. The fit should be snug, to support the pulling force.

After trimming and smoothing the edges, add one or two 1-in.-wide Velcro straps and a tongue to the wrist section by riveting them in place with tubular rivets. Location and number of the straps are optional.

3. Fitting and Aligning the Unit. Place the shoulder cap on the patient and secure all straps. Remove the two screws

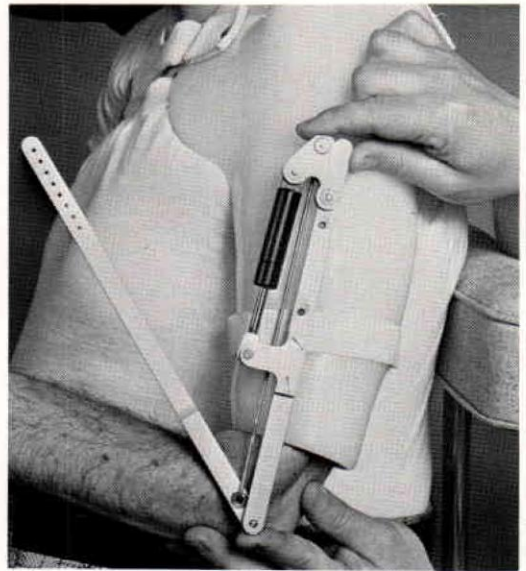


Fig. 11 Aligning the upper bar on the shoulder cap.

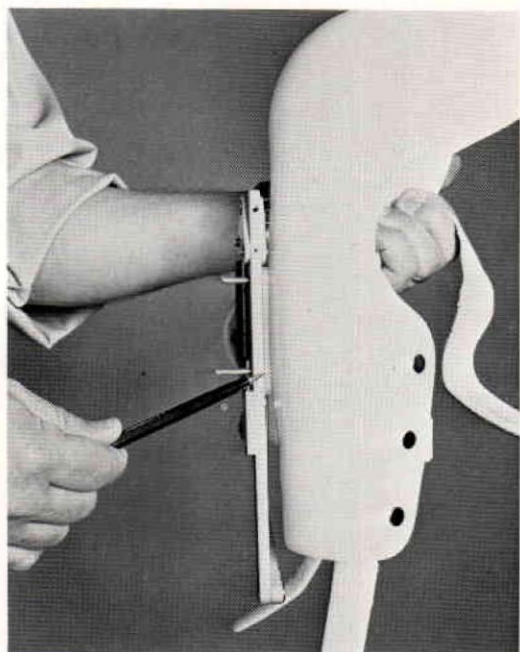


Fig. 12 A plastic spacer is placed between the upper bar and the plastic mold.

holding the plastic cover on the device. These two screw holes will be used to secure the device to the shoulder section.

Hold the patient's elbow at 90 deg while performing the following procedure. Align the orthotic joint with the anatomical elbow joint while simultaneously centering the upper section on the orthosis so that it bisects the upper arm (Fig. 11). The orthosis should be perpendicular to the floor. Mark the two holes while the orthosis is held in this position. Remove the shoulder cap and drill through these two marks with a #11 drill. Re-drill the two holes in the upper section of the orthosis with a #21 drill. Thread the holes with a 10-32 UNC tap. Using two 10-32 by 1-in. flathead screws, secure the orthosis to the shoulder cap, placing the screws from the inside portion of the arm out into the upper arm of the orthosis. Do not cut the screws that protrude from the orthosis, since they will be used

to hold the cover in place when the orthosis is finished. It may be necessary to place a 1/4 to 3/16-in. plastic spacer behind the upper bar, to allow the moving arm to function without interference on the plastic of the upper arm (Fig. 12).

Place the shoulder cap and wrist cuff on the patient, and secure all straps. Position the patient's elbow at 90 deg and extend the forearm bar until it bisects the wrist cuff (Fig. 13). Exercise care at this point, since the cylinder is now activated and will pull the bar back into flexion. Mark the position of the bar on the wrist cuff. Remove the entire orthosis and drill two attachment holes with a #28 drill. Rivet the wrist cuff to the bar with a #12 copper rivet. Two rivets should be used to hold the wrist cuff in place due to the force generated by the system.

Place the entire unit on the patient, shoulder cap first, and secure the chest and upper-arm straps. Flex the patient's elbow to 90 deg or greater to attach the wrist cuff to the patient's forearm. Open the wrist section, slip the patient's wrist into place, and secure the Velcro straps. Ensure that the anatomical elbow and mechanical joint are aligned properly.

At this point, check the fit of the lower bar near the elbow. The bar should fit near the joint and skin, while not creating pressure. Adjustments can be accomplished either by changing the thickness of the plastic spacer beneath the upper section of the orthosis, or by shaping the lower section to free the elbow joint. Check the same area while the patient flexes and extends the elbow. Adequate space should be available around the elbow to allow flexion and extension without pinching, and the orthotic joint should not protrude.

When the patient begins to flex and extend the orthosis, he or she should be able to accomplish this task effortlessly. Observe whether the orthosis is lifting the

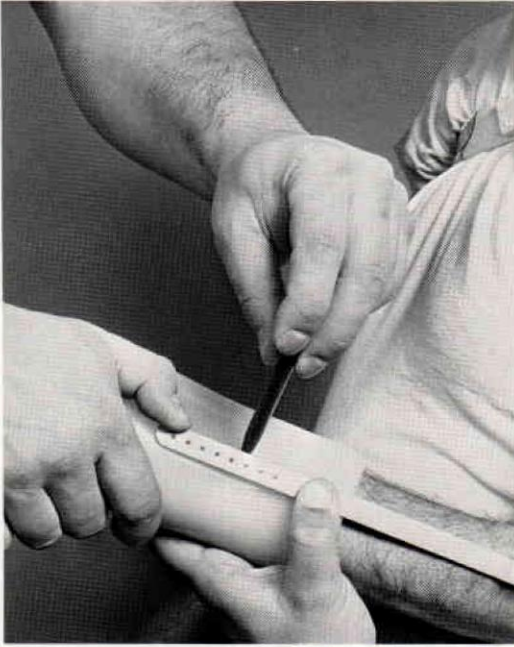


Fig. 13 Marking the lower bar on the wrist cuff.

arm at this point, since the cylinder may be either too strong or too weak. Instructions for changing the cylinder are given in an appendix to this article. If there are no problems, replace the plastic cover by using the two 10-32 UNC screws protruding from the upper bar of the orthosis. These screws should not protrude beyond the surface of the plastic cover. The completed orthosis is shown in Figure 14.

After all the adjustments have been accomplished, instruct the patient how to use the device. As with most other orthotic devices, patients need to build up a tolerance to it. Patients should begin using the device for an hour at a time and gradually increase to a full day over a two-week period. Generally, any pressure or irritations caused by the shoulder cap or wrist cuff after one hour or more of use indicates that further adjustment is required.

Patients should be seen after a period of two to three weeks to ensure that no



Fig. 14. Completed orthosis.

problems exist due to fit or the forces applied. Never provide a patient with a cylinder that produces a force greater than the strength of his or her triceps.

The VAPC thus far has fitted three patients with this system: one polio patient, one patient with a brachial plexus avulsion (C5-C6), and one patient with a neurological disorder. Two of these patients have bilateral involvement, but were fitted on only one side. The patient with the brachial plexus injury has been using the system for over a year and half, exhibiting improved range of motion at the elbow and increased strength in the triceps.

Figures 15 through 18 show the functional arm orthosis on a patient at various degrees of flexion and extension and



Fig. 15. Patient standing, arm fully extended—lateral view.

shows the cosmetic value of the system.

The development of this system has led into an investigation on the possible use of non-linear systems in other orthotic and prosthetic applications.

A program for evaluation of the elbow orthosis is planned. Orthotists interested in participating in an evaluation program should contact the senior author.



Fig. 16. Patient standing, arm fully extended—anterior view.

Acknowledgments

The authors would like to express their appreciation to Max Nacht, Technical Writer, and Werner Greenbaum, Chief, Patient Care Service, for their cooperation and assistance in preparing this article; to Berdsell Franklin, Senior Photographer, for his photographic work; and to Henry Aprea and Bennie House, Mechanical Engineering Technicians, and John Milani, Orthotist, for their help in fabricating the components.

Footnotes

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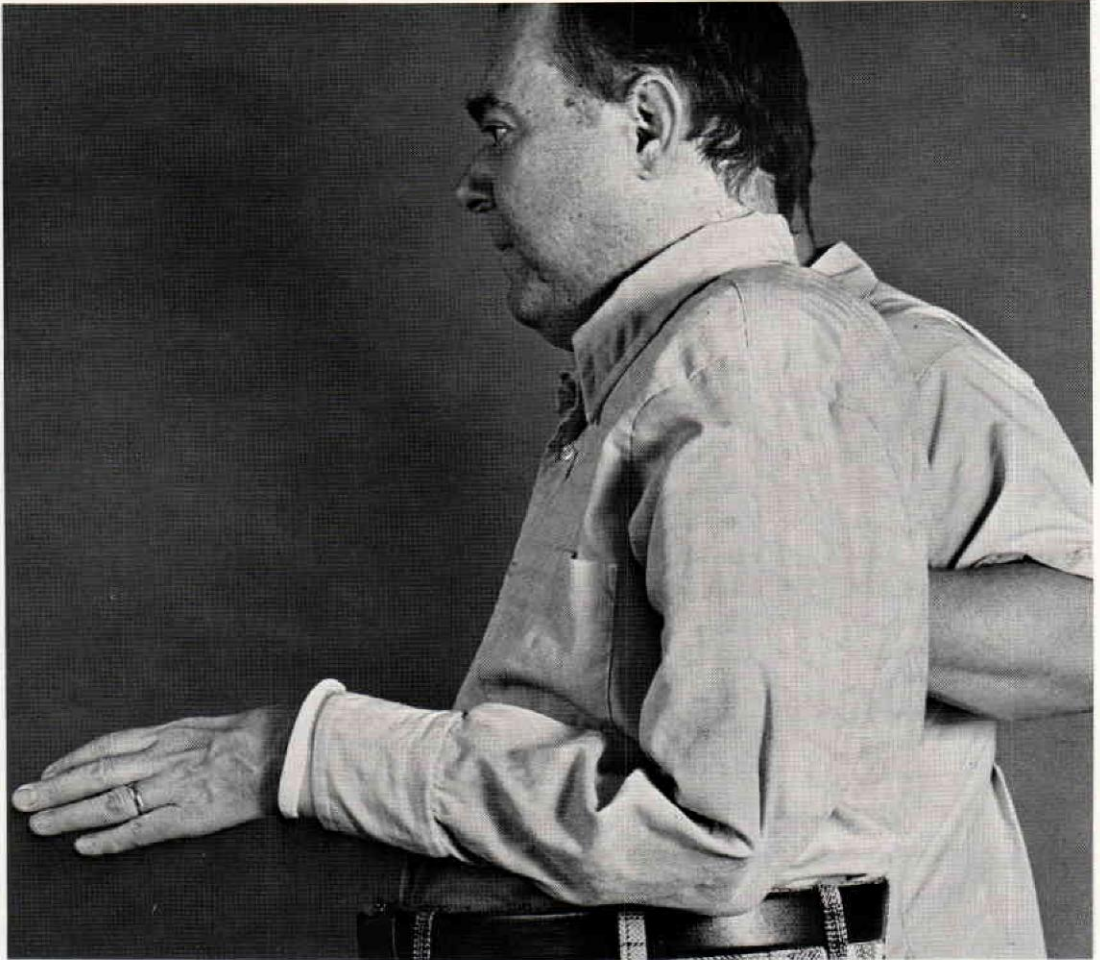


Fig. 17. Patient's elbow flexed to 90 deg—lateral view.

Appendix

How To Change the Cylinder

The cylinder can be changed either before or after fitting the patient with the orthosis. To change the cylinder, proceed as follows, and refer to Figure A for all required procedural steps:

1. Remove unit from shoulder cap by removing two 10-32 screws. Remove the plastic cover. Remove set screw shown in Figure A,4.

2. Secure upper bar (Figure A,10) in a vise. A vise with smooth jaws is preferred to prevent marking of the aluminum bar.

3. Either retract adjustment screw (Figure A, 2,7, and 12) until screw head is flush with inner surface of bar or remove screw completely.

4. Extend lower bar to expose upper portion of upper bar. This bar must be held down until cylinder pressure is released, otherwise it will flex.

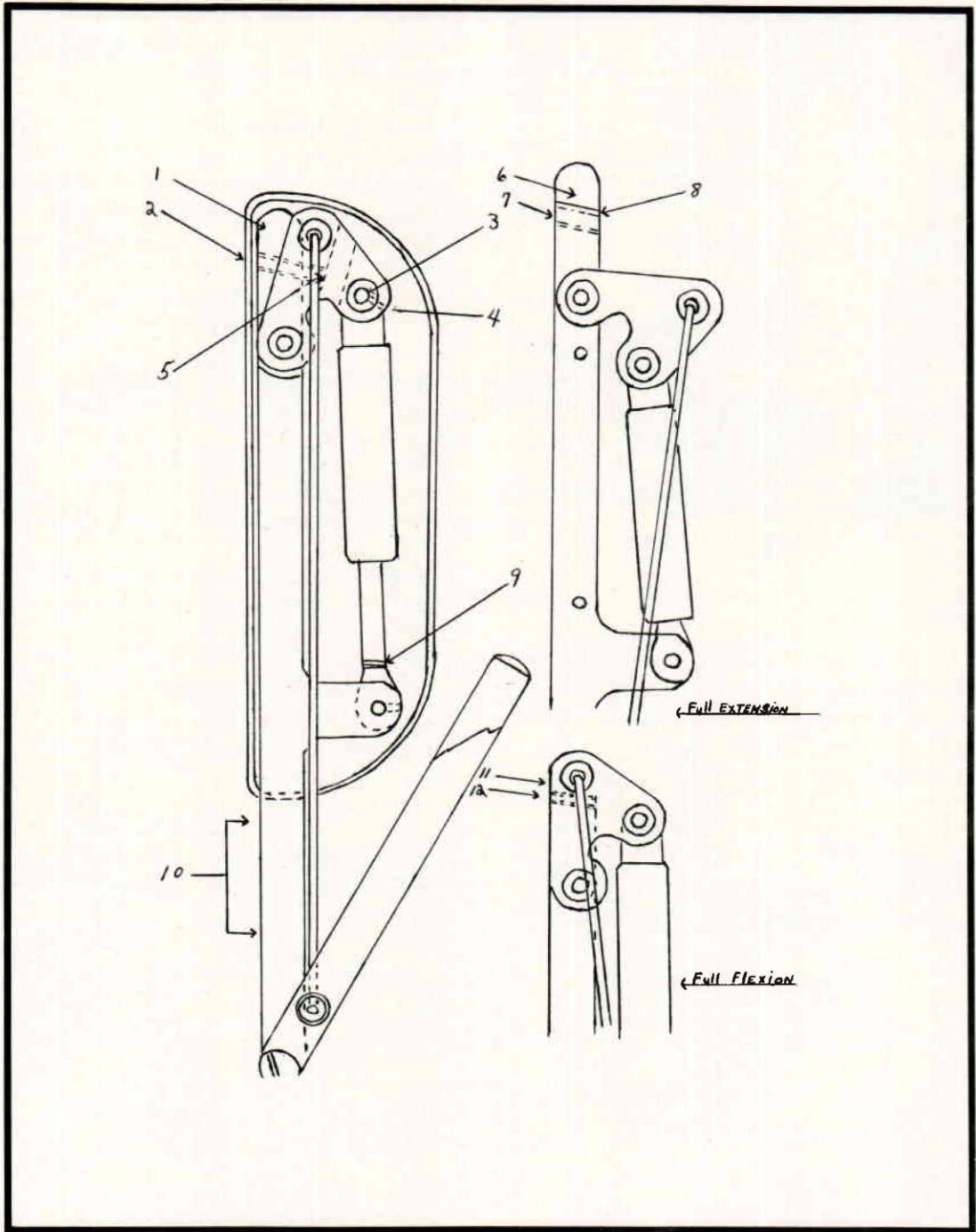


Fig. A. Cylinder locations: 1 & 6—Excessive material that must be removed; 2, 7 & 12—Adjustment screws; 3—Pin used to secure cylinder in place; 4—Set screw used to secure bushings in place; 5—Adjustment screw used to maintain cylinder pressure; 8— $3/32$ -in. space that exists between cut and set screw; 9—Lower part of cylinder, which is unscrewed; 10—Area used to secure cylinder to a vise; 11—Area where excess material has been removed to allow the cylinder to extend fully.



Fig. 18. Patient's elbow flexed to 90 deg— anterior view.

5. Mark top section (Figure A,8) just above adjustment screw. About $1/32$ in. of bar should be left after removing excess material. This is sufficient to hold adjustment screw. Sand all edges smooth.

6. Allow lower section to flex back as far as possible, to allow cylinder to extend to its full length. Using $5/32$ -in. drift pin, lightly tap pin (Figure A,3) out while se-

curing the body of the cylinder in place. Exercise care to avoid damage to bearings securing unit in place.

7. After removing pin (Fig. A,3), slide upper portion of cylinder out of its slot. Unscrew lower portion (Figure A,9) of cylinder from its bracket. If difficulty is encountered in unscrewing cylinder, use smooth jawed pliers or vise to loosen cylinder. Do not mark or bend cylinder rod, as this would impair its function.

8. Once cylinder is removed, install new cylinder. (*Note:* Before installing new cylinder, check upper sections of old and new cylinder to ensure that they are identical. Some cylinders have been sanded to fit into upper slot).

9. If both cylinders are identical, replace new cylinder by reversing above removal procedure.

10. Once cylinder is in place, set adjustment screw to apply a slight tension on cylinder. Work unit by hand several times to ensure proper operation. Replace unit on shoulder cap and refit patient to ensure that pressures are not excessive. (*NOTE:* Ensure that all filings are removed; clean and lubricate system as needed.)