CURRENT INDICATIONS FOR UPPER-EXTREMITY POWERED COMPONENTS

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Although externally powered hands and elbows have been commercially available in this country for several years, they have not been widely prescribed. Their use has been limited because optimal control methods have not been developed for general clinical use.

The externally powered components that have been successfully applied were fitted in laboratories as part of development programs or in centers with highly specialized facilities and personnel. The few powered components prescribed in ordinary clinical settings did not, in our opinion, always rest on a rational basis. They were prescribed for extremely handicapped patients in desperation since conventional components offered little functional improvement. Sometimes their novelty or simply a desire to obtain experience with new developments led to their use. Externally powered components have not yet been sufficiently utilized in the United States to consider them elements of the upper-extremity "armamentarium."

The Committee on Prosthetics Research and Development, NAS-NRC, conducted two workshop panels[a] whose objectives were to determine the clinical utility of externally powered hands and elbows currently under

[a] Sixth Workshop Panel on Upper-Extremity Prosthetic Components of the Subcommittee on Design and Development, Oct. 21–23, 1968, Santa Monica, Calif. Seventh Workshop Panel on Upper-Extremity Prosthetics of the Subcommittee on Design and Development—Externally Powered Terminal Devices, July 30–31, 1969, Santa Monica, Calif.

development. Both conferences resulted in clear recommendations for further study on the control systems needed to operate these devices.

Information on the various methods and systems for *controlling* externally powered components is urgently needed. Complex questions arise about the use of either myoelectric signals or pull-type electrical switches to control prosthetic components. While these questions are simpler to resolve for single component systems (for below-elbow amputees), optimal methods for controlling two or more externally powered components have not been determined. There is little or no information on the relative effectiveness of using two myoelectric controls, or two pull-switch controls, or mixing pull-switch and myoelectric controls for various types of patients.

To obtain this information on a comprehensive scale would entail the organization of a study program by a competent research and development group. A time lag of 1 to 2 years would be expected between the writing of a proposal for this purpose, approval and receipt of funds, staffing and equipment, and conduct of the study. While such a program would be highly useful, there is also a certain urgency about obtaining, in the meantime, information on the optimal methods now available for controlling externally powered components. Despite the lack of clear prescription indications, harnessing and control information, and training data, increasing numbers of clinicians are fitting these devices *now*.

The Eighth Workshop Panel on Upper-Extremity Prosthetics was convened in April 1970 for the purpose of determining the best methods for controlling currently available powered hands and hooks *with control devices now available*. In preparation for this meeting, the personnel of several laboratories with experience in the design of control systems were asked to undertake a series of studies on these matters. Responsibility for the conduct of each of five studies was accepted by Mr. Lawrence E. Carlson, Biomechanics Laboratory, UC-BL, Berkeley, Calif.; Dr. Dudley Childress, Director, Systems Development Laboratory, Northwestern University Medical School, Chicago, Ill.; Mr. James Allen, Medical Engineering Laboratory, Rancho Los Amigos Hospital, Downey, Calif.; Mr. Roy Wirta, Biokinetics Research Laboratory, Moss Rehabilitation Hospital, Philadelphia, Pa.; Mr. Albert Colman and Mr. Lloyd Salisbury, AMBRL, Walter Reed Army Medical Center, Washington, D.C. The Eighth Workshop Panel employed the "piggy-back" concept—an effort to capitalize on the experience and resources of highly experienced researchers in this particular field, in the shortest possible time and at the least expense, in the pursuit of limited goals.

These studies were designed to shed light on the differences in performance by patients when they control prescribed externally powered terminal devices and elbows by means of pull-switches or by myoelectric signals. Useful information was also obtained on the reactions of patients

FIGURE 1.—Training on AE subject in the separation of control motion.

FIGURE 2.—Testing the ability of a BE subject in manipulation of various objects.

and observers to both control methods as well as training methods required for myoelectric or pull-switch control systems.

The subjects of these studies were below-elbow and above-elbow amputees who normally used conventional prostheses. Prior to being fitted with externally powered hands and elbows, each amputee subject was tested with his conventional prosthesis to obtain a basis of comparison with his performance in using externally powered components. All of the subjects were trained (Fig. 1), tested (Fig. 2), and evaluated (Fig. 3) with respect to their ability to control the externally powered device. Their subjective reactions to this experience were also recorded. All of the laboratories used the same test procedures to insure the comparability of the data relating to the speed of learning, final performance speed, and error incidence in controlling the devices by myoelectric signals and/or by electrical pull-switches. Special consideration was given to developing a simplified and reasonably objective evaluation procedure for each study.

CONTROL STUDY RESULTS

All of these studies are published in the Report of the Workshop Meeting.[b] Two of these studies, one conducted by Lawrence E. Carlson entitled "Below-Elbow Control of An Externally Powered Hand," and one conducted by D. S. Childress and J. N. Billock entitled "An Experiment with the Control of a Hybrid Prosthetic System: Electric Elbow, Body-Powered Hook," are published elsewhere in this issue of the Bulletin. The significant findings are described below:

[b] Eighth Workshop Panel on Control of Externally Powered Components of the Subcommittee on Design and Development—Mar. 31 to Apr. 2, 1970, Downey, Calif.

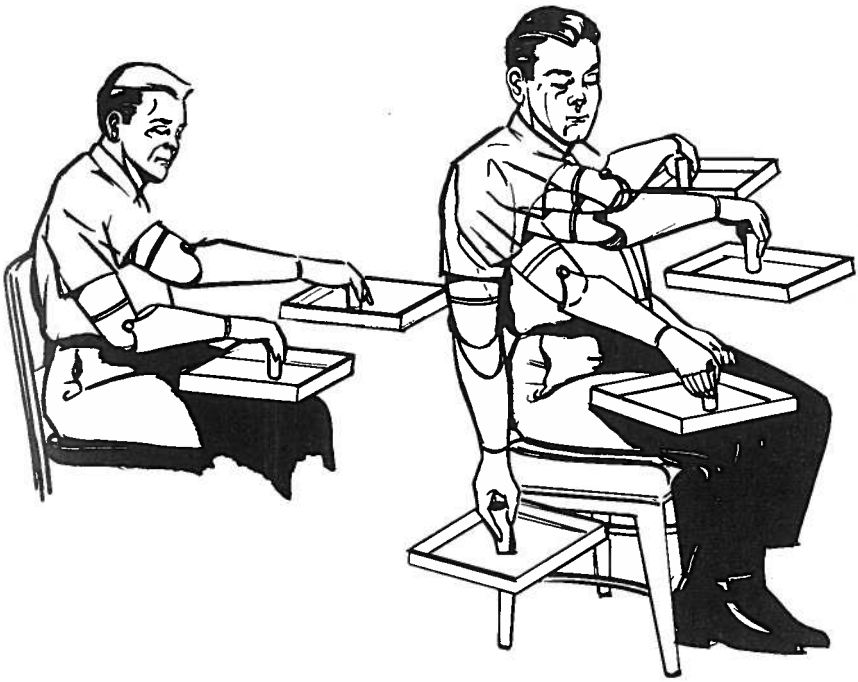


FIGURE 3.—An artist's conception of the standardized performance test selected to evaluate control of upper-extremity powered components. Test objects were moved to each of several end positions.

1. Pull-Switch versus Myoelectric Control of Hand for Below Elbow

Experiences in testing the performance of a patient using an externally powered terminal device with both pull-switch and myoelectric control indicated that myoelectric control in this instance was generally superior to pull-switch control. With myoelectric control the patient performed faster and made significantly fewer compression errors. Although the patient made slightly more grasp errors, he preferred the myoelectric control system because he could be fitted with a Münster-type socket to eliminate the harness. He also felt that he had finer and more natural control movements. Observations of laboratory personnel corroborated those of the patients in that performance with the myoelectric control looked more natural, principally due to the elimination of terminal-device displacement in grasping, and the fact that it was unnecessary for the subject to "hunt" for the switch positions.

Little difference was seen in the training time required to learn to use the pull-switch or the myoelectric control. In both cases, performance, as indicated by the decrements in test times and in incidence of

errors, leveled off within eight trials or after approximately 4 hours of training.

2. Above Elbow Fitted with Externally Powered Hand (Myoelectric Control versus Pull-Switch Control) and Conventional Elbow

In general, the performance of the above-elbow amputees fitted with externally powered hands and conventional body-powered elbows was marginally better when the externally powered hand was controlled by a pull-switch rather than by myoelectric signals. With the switch control, speed of performance was slightly faster and fewer grasp errors were made although the compression error score was about the same with both. Of the three patients studied, two preferred the switch control of the terminal device, while one preferred the myoelectric control.

The observers acknowledged their preference for the switch-controlled terminal device system but qualified this preference by basing it on technical problems encountered in administering the test program. They experienced a number of problems in maintaining the proper adjustment of the myoelectric amplifiers. The triceps muscles of the patients proved to be unreliable sources of myoelectric signals, making the placement of electrodes quite critical. Their subjects' ability to control the prescribed devices was significantly limited due to inadvertent operation with the myoelectric system, and consequently, a tendency to perform slower and to overgrasp.

Training time for the pull-switch control system was shorter as a result of the problems encountered in using the myoelectric controls. Adequate training levels, as indicated by plateaus in the performance time curves, were reached in approximately 12 sessions or 6 hours with the myoelectric system and in approximately six sessions or 3 hours with the switch-control system.

3. Externally Powered Elbow (Myoelectric versus Pull-Switch Control) with Conventional Terminal Device for Above Elbow

The performance of subjects fitted with conventional terminal devices and externally powered elbows were generally faster (two out of three cases) with myoelectric control of the elbow. There were no significant differences in the incidence of error. Patients (two out of three) and observers preferred the myoelectrically controlled system because of difficulty experienced by patients in locating switch positions and more natural appearance and better control of the myoelectrically controlled system. In both cases training plateaus were reached within seven sessions or under 4 hours.

4. Externally Powered Hand and Externally Powered Elbow (Myoelectric Control of Both versus Pull-Switch Control of Both) for Above Elbow

In general, there was little difference in the performance of patients who controlled prostheses incorporating externally powered elbows and terminal devices by means of either myoelectric signals or pull-switches. Although their performances were slightly faster when both components were myoelectrically controlled, and although they committed slightly more grasp errors when both were controlled by switches, the differences in performances were judged by the observers to be insignificant. Both patients preferred the myoelectrically controlled system principally because they found it less fatiguing.

The observer expressed the opinion that the patients' preference might also be due to the more "physiological" use of muscles with myoelectric control as against the overt shoulder movements employed with the switches. In both cases, performance times tended to level out after five or six sessions or approximately 3 hours, indicating adequate training achievement.

5. Above-Elbow Externally Powered Hand and Externally Powered Elbow

In Study 4 above, patients were tested under two conditions—when both elbow and terminal device were controlled either by pull-switch or by myoelectric signals. In Study 5 the elbow was controlled by pull-switch at all times, and the subjects were tested with the terminal device alternately controlled by pull-switch and by myoelectric signal. Performance time was significantly faster when the terminal device was controlled myoelectrically rather than by pull-switch but significantly more compression errors were made in that mode. More grasp errors were made, however, when the terminal device was controlled by the pull-switch.

The patient preferred the myoelectric system, according to the observer, because he could actuate the pull-switch control for the elbow and the myoelectric control for the hand simultaneously.

The observer felt that there was insufficient evidence to either defend or condemn one control system in favor of the other.

Regardless of whether pull-switch or myoelectric control was employed, the performance time curves reached a plateau after approximately 10 sessions or 5 hours of training.

SUMMARY OF FINDINGS

These five studies led to a number of significant observations (Table 1). Among the advantages of myoelectric control of a powered terminal

device for a unilateral below-elbow amputee of the type studied are the following:

1. *Relative Merits*
a. Faster operation.
b. Better force control.
c. Possibility of eliminating the harnessing above the socket.
d. No terminal-device displacement.
e. More natural appearance during the operation.
f. No hunting for switch position.
g. Two site/two state (two sets of electrodes w/each set on a different muscle) better than three-state control systems (one set of electrodes on one muscle to control both opening and closing).

These advantages must be balanced against such factors as availability of components, cost, and system reliability.

2. *An externally powered terminal device and a conventional body-powered elbow for an above-elbow amputee* are not recommended principally because the body control motions required to operate a conventional elbow interfere with the control of a hand and vice versa.

3. A prescription for an externally powered elbow and a conventional body-powered terminal device for an *above-elbow* amputee should specify the use of mechanical switch control at the present time in spite of the advantages demonstrated by myoelectric control in the laboratory. The pull-switch should be mounted anteriorly as shown in Figure 4. Although myoelectric control is theoretically superior, in the present state of the art the use of two-site/two-state electrode systems is seriously compromised by the unreliability of myoelectric signals from traumatized triceps muscles. With the availability of improved electronics, myoelectric control may be superior.

4. Myoelectric control of an externally powered terminal device and an externally powered elbow by an above-elbow amputee is preferred *when adequate engineering and prosthetic backup are available.* This view is based on the slightly better performance of the patient with myoelectric control and on the reduced effort to actuate the components by means of myoelectric signals. However, if the prosthesis is to be fitted in ordinary clinical settings without laboratory backup, the use of pull-switch controls is recommended. Training requirements are about the same but switch operation is more reliable, switches are more readily available, and they are more easily installed and serviced. The disadvantages of myoelectric control systems relating to electrical interference and inadvertent activity are eliminated or reduced.

5. Overriding the whole question is some doubt about reliably controlling two powered components in the same prosthesis by any means. The prescription of a powered elbow and a conventional terminal device

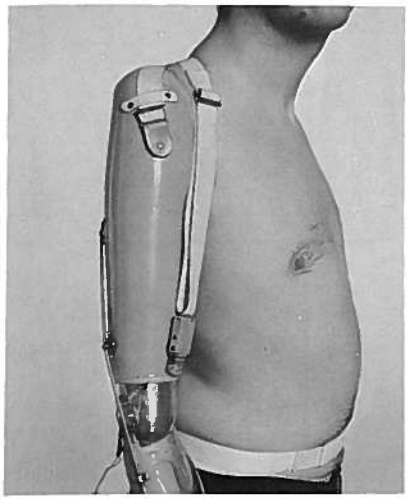


FIGURE 4.—The recommended location for installation of a pull-switch to control a powered elbow unit.

for unilateral above-elbow and shoulder-disarticulation patients may be more sensible. However, in a prescription for an externally powered elbow and terminal device, with the elbow controlled by a pull-switch, myoelectric control of the terminal device is preferred. This is based principally on patient preference for the myoelectric system and observation of a faster, less error-prone performance.

PRESCRIPTION INDICATIONS

Although not yet widespread, increasing numbers of externally powered upper-extremity components are being prescribed for patients in the absence of a rational prescription basis. With little personal experience to guide them, clinicians are prescribing on the bases of novelty, need for knowledge, and commercial brochures detailing the potential advantages of the available products. It is premature at this time to advance a comprehensive list of prescription indications for externally powered components covering all cases. However, based on our experiences in this field at VAPC and the data now available from the series of CPRD conferences on these matters, we have evolved a set of prescription indications covering certain frequently seen cases. While not yet routine in our clinics, we are prescribing increasing numbers of externally powered components according to the following prescription indications:

1. Unilateral Below Elbow with Powered Terminal Device

a. Choice

Selection of hand or hook based on occupation and other activities and on patient's personal preference. If hook is prescribed, no externally powered applications are possible at this writing or within the next

TABLE 1.—*Summary of Findings on Myoelectric Versus Pull-Switch Control*

	1. Powered hand for BE	2. Powered hand, conventional elbow for AE	3. Powered elbow, conventional hand for AE	4. Powered hand, powered elbow for AE (myoelectric control of both components vs. pull control of both)	5. Powered hand, powered elbow for AE (myoelectric control vs. switch control of hand with pull-control switch control of elbow)
PERFORMANCE 1. Speed	EMG significantly faster than pull switch (24% overall). After training, EMG 17% faster. Speed equal to conventional hook.	Switch control moderately faster	Generally faster, 2 of 3 subjects w/myoelectric	Performance time with pull-switch numerically faster, but not significantly different	Myoelectrically controlled TD with switch-controlled elbow faster than switch-controlled TD and elbow.
2. Errors	Significantly more compression errors w/switch Slightly more grasp errors w/myoelectric control Both less errors than conventional	Compression errors same for myoelectric and switch control	No significant difference in compression errors	Although statistically insignificant, there was a tendency for more grasp errors w/switch Compression errors not measured	Significantly more compression errors with myoelectric control of TD and significantly less grasp error.

PATIENT REACTION	Myoelectric control preferred: possible to eliminate harness, finer control, more natural, more physiological control, switch more awkward.	2 subjects preferred switch. 1 subject preferred myoelectric control.	2 of 3 subjects preferred myoelectric control. Better control in any position. Difficult to find switch position.	Myoelectric control preferred. Less fatiguing.	Myoelectric control preferred.
OBSERVER REACTION	Myoelectric control preferred. No TD displacement, no hunting for switch position, more natural appearance.	Preferred switch for study because of technical problems in maintaining myoelectric adjustment.	Preferred myoelectric control. More natural appearance, better position control, no hunting for switch position.	Patient preference probably result of more physiological use of muscles rather than gross shoulder motion. Patients easily and quickly trained. Limited speed of elbow prevented further reduction in performance time.	Little basis for preference of one control system over the other.
TRAINING	Performance level plateau was reached within 8 trials or approx. 4 hours total training. Training essential. No significant difference between EMG and switch.	Training time with switch significantly shorter. Problem with myoelectric control due to loss of electrode contact. Difficult to locate triceps electrodes.	Performance level plateau was reached after approx. 7 trials or under 4 hours with both systems.	Performance level plateau was reached after 4 to 5 sessions or 2 to 3 hours in both cases.	Performance plateau reached after approx. 10 trials or 5 hours of use for both systems.

1 to 2 years since there are no powered hooks available for other than certain types of child amputees.

If a hand is to be prescribed, the choice must lie between conventional body-powered hands and externally powered hands. This decision must be based on the manifest and potential advantages and disadvantages of each. The panel meeting on externally powered hands showed that in the present state of the art, it is not reasonable to expect superior performance in the manipulation of objects with powered hands. The potential advantages of powered hands lie elsewhere: reduced force and excursion to operate, possibility of eliminating all or parts of harnesses, relatively high prehension forces. The disadvantages of externally powered hands are weight, cost, system unreliability, and noise. Most currently available systems have exposed wires and battery packs.

In those cases where a powered hand is prescribed at the VA Prosthetics Center, we furnish the VAPC-Viennatone Hand (BPR 10–13, p. 25) with pull-switch control.

b. Fitting

The fitting procedure is the same as the conventional method. The hand is basically the same size as the APRL-Sierra hand and is attached to the wrist fitting in the same manner. The device, therefore, can be substituted for conventional hand or hook in a prosthesis. The only difference in the fitting procedure is the routing of the wires which pass from the switch to the hand and the installation of the control switch in the harness system.

(1) *Installation of Battery Pack.* Experience to date has shown that in general patients react negatively to battery packs worn around the waist or over the shoulder. The VAPC power pack is mounted in the forearm of the prosthesis in the section distal to the end of the inner wall. This of course limits the application of the system to patients whose stumps are approximately 3 in. shorter than the medial epicondyle to ulnar styloid dimension. As shown in Figure 5 the battery pack consists of three stacks of nickel-cadmium cells.

(2) *Installation of the Control Switch.* The control switch is attached to the control cable in any standard below-elbow harness system (Fig. 6). A conventional body-control motion (shoulder flexion) activates the switch. The control attachment strap, which in the conventional system is attached to the control cable, is attached to the posterior portion of the triceps cuff. The wire lead from the switch is secured to the cuff and forearm and passes over the medial epicondyle. A ¼-in. hole is made in the forearm immediately below the distal end of the socket to permit internal connection.

If myoelectric control is prescribed, the fitting procedure differs slightly in that the electrodes are mounted in the socket (Fig. 7). After

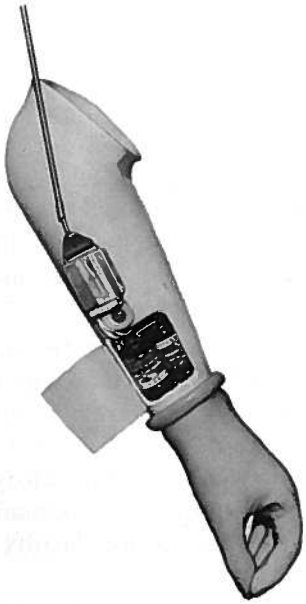


FIGURE 5.—The VAPC battery power pack is designed to fit in the distal end of the BE's prosthetic forearm.

FIGURE 6.—The VAPC pull-switch for operating the VAPC electric hand is installed in the control cable of the BE prosthesis.

selecting the optimum placement of the electrodes on the stump, the location is transferred to the socket. Whenever possible the Münster-type socket is recommended to further minimize the harness system.

c. Training

In all cases where powered components are prescribed, training is essential. In general the training regimen follows traditional lines in that both control training and use training procedures are employed. In addition, however, it is absolutely essential to train patients on the

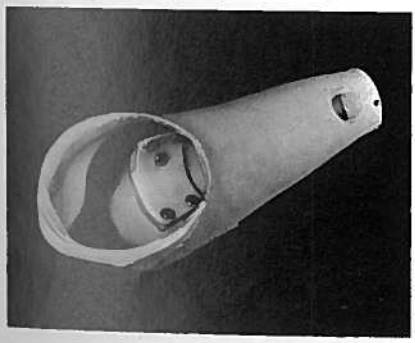


FIGURE 7.—BE prosthesis showing the location of myoelectric switch in a BE socket.

care and maintenance of their equipment. This means they must be taught to charge batteries correctly and to care properly for the electrodes. This discussion is limited to upper-extremity *controls* training on the assumption that unilateral below-elbow previous prosthesis wearers are sufficiently familiar with the usual self-care techniques taught as a part of *use* training. *Use* training and self-care techniques are not appreciably different from those employed with conventional hands or hooks (or elbows). Non-previous prosthesis wearers receive the prescribed regimen of *controls* training outlined below *followed* by the more general *use* training in self-care activities.

As a part of the overall controls training, the following areas are covered: 1. familiarization with the operational characteristics of the VAPC switch and hand, 2. care of the terminal device, 3. care and maintenance of the power supply, 4. donning the prosthesis, and 5. *controls* training. Two other areas that must also be covered if a myoelectric-type control is prescribed are: 1. preparation of the stump prior to donning the prosthesis and 2. some muscle reeducation to develop facility in grading myoelectric output.

As the first step in training, the amputee is instructed in the operational characteristics of the VAPC switch (Fig. 8). This is best accomplished with the therapist demonstrating the operation of the switch-hand by holding the prosthesis and pulling on the control attachment strap (CAS) to actuate the hand. The amputee is taught that the VAPC switch is "OFF" at *both* ends of its range of motion; i.e., it is "OFF" when no tension is exerted and it is also *"OFF"* when more than 2 lb. of force is exerted. The subject has to realize that in between this narrow range of *force* (0–2 lb.) *two* different "ON" positions occur, depending on the amount of force exerted on the switch. The first "ON" position closes the VAPC hand (prevents accidental inadvertent opening) and the second "ON" position opens the prosthetic fingers.

The therapist demonstrates opening and closing the fingers of the terminal device and guides the patient through the following sequence:

(1) *Opening the fingers.* From the "rest" position (no force), pull on one end of the VAPC switch with approximately 1 lb. of force. This amount is sufficient to bypass the first "ON" switch position (finger closure) and stop at the second "ON" switch position (finger opening).

The fingers will continue to open to the full limit as long as this switch is activated. The fingers of the terminal device can be stopped in any desired width opening by either eliminating all tension or by exerting slightly more force which "bottoms out" the switch (also an "OFF" switch position).

(2) *Closing the fingers.* From the "rest" position, pull on the switch with approximately ½ lb. of force which is enough to move to the first

OPERATION OF VAPC SWITCH
(H A N D)

Switch Position	Function
1. Normal rest position, amputee relaxed, no tension on switch.	1. Hand remains locked.
2. First active position requiring 1/16 inch of excursion. This position must be maintained by amputee. If he relaxes, the switch will return to position No. 1.	2. Hand closes continuously while switch is in this position.
3. Neutral position requiring 1/16 inch of additional excursion.	3. Hand stops closing and locks.
4. Second active position reached by additional excursion of 1/16 inch.	4. Hand opens while in this position.
5. Neutral position requiring another 1/16 inch of excursion. End point is a stop which transmits force to control cable.	5. Hand stops opening and locks.

FIGURE 8

"ON" switch position (finger closure). This first "ON" position can also be reached from the bottom out position (greater than 2 lb. force has been executed). In this event reducing the force to approximately ½ lb. will bypass the second position and stop at the first "ON" switch position.

(3) Once the subject understands the operational characteristics of the switch, he should be asked to don the prosthesis. Once donned he should relax and let the therapist "guide" the arm through the humeral flexion range with just enough force and excursion to actuate opening and

closing of the terminal device. This helps the subject acquire the kinesthetic sense of the range and force requirements.

2. Unilateral Above Elbow with Conventional Elbow and Powered Terminal Device

We do *not recommend* fitting above-elbow amputees with a powered terminal device and a conventional elbow. In addition to problems of inadvertent operation, there is another disadvantage: It requires a patient to lift heavier loads by means of a conventional elbow due to the generally greater weights of externally powered hands and their associated power packs.

3. Unilateral Above Elbow and Shoulder Disarticulation with Powered Elbow and Conventional Terminal Device

a. Choice

The prescription of externally powered switch-controlled elbows and conventional body-powered terminal devices is *recommended* for unilateral above-elbow and shoulder-disarticulation patients. Externally powered elbows can be expected to produce significant improvements in performance, particularly with respect to speed of *purposeful* function, reduction in force/excursion requirements, and improvement of terminal-device control by sharply reducing terminal-device displacement to lock and unlock the elbow. Clinicians should consider the prescription of externally powered elbows for *all* above-elbow and shoulder-disarticulation patients.

This prescription must also be weighed against other factors such as weight, system reliability, and cost. Elbows are available which do not weigh more than conventional elbows. Switch control as against myoelectric control of an externally powered elbow significantly reduces cost to a point which does not substantially exceed cost for conventional elbows. Some externally powered elbows provide reasonable reliability.

b. Fitting

For cases of this type at the VA Prosthetics Center, we prescribe the VAPC electric elbow (Fig. 9). The fitting procedure is basically the same as the conventional method. The elbow is exactly the same size as the Hosmer E-400 elbow, and it is attached to the turntable and forearm in the same manner. The device, therefore, can be substituted for the conventional elbow in a prosthesis. Wherever possible, it should be installed in the subject's conventional prosthesis, if the socket fit is satisfactory. If a new socket is made, the VAPC elbow is installed in the same manner as the conventional elbow. The only difference in the fitting procedure is the internal mounting of the battery pack and the installation of the control switch in the harness system.

(1) *Installation of the Battery Pack.* The battery pack is mounted in

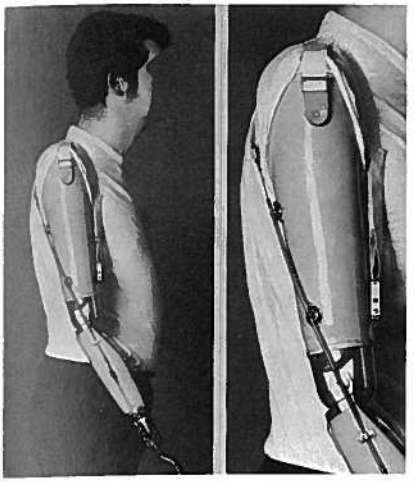


FIGURE 9.—The VAPC electric elbow is the same size and dimension as the conventional prosthetic elbow.

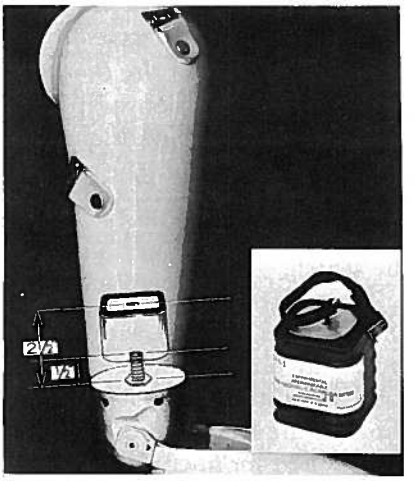


FIGURE 10.—The VAPC battery power pack for AE is designed to fit in the distal end of the socket.

the distal end of the humeral section, immediately below the inner socket (Fig. 10). A minimum of 3 in. between the turntable and distal end of the inner socket is required for the installation. A "window," approximately 3 in. x 3 in., is made in the distal-medial side of the humeral section to permit internal mounting of the battery pack. The battery pack is secured in place leaving the terminal connectors accessible for daily recharging of the batteries. Since the wires from the elbow pass through the hollow attachment stud of the elbow, all electrical connections are made within the humeral section.

For long stumps whose lengths do not permit this type of installation, the battery pack is mounted in the proximal portion of the forearm (Fig. 11). With the batteries secured in place, and the elbow in full extension, the wires are placed over the medial elbow joint and secured

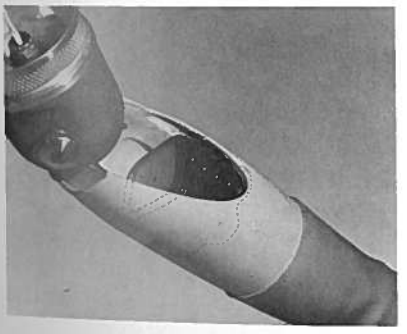


FIGURE 11.—For AE amputees with long stumps, the VAPC battery can be installed in the proximal end of the prosthetic forearm.

with keepers. The wires should not restrict elbow flexion. The terminal connectors should be accessible for daily recharging of the batteries.

(2) *Installation of the Control Switch.* The control switch is attached to the front suspension strap (FSS) in any standard above-elbow harness system (Fig. 4). A conventional body control motion (shoulder extension) activates the switch. The switch has four externally mounted rubberbands which automatically return the switch to its closed position. Rubberbands can be removed to decrease the force required to activate the switch.

The switch is attached to the humeral section by means of a leather or Dacron loop fastened with two screws. A ½-in. hole is drilled near the switch to provide an access hole for the control wires. The anterior suspension strap (non-elastic) is attached to the switch and doubled back through the length adjustment buckle. Tension adjustments which may be required for finer control of the switch can be made with the buckle.

The leather lift loop normally attached to the forearm should be removed or not installed in a new prosthesis. It is not necessary with the powered elbow. However, the Bowden control cable, for the conventional terminal device, must pass directly over the elbow joint when it is fully extended, and it must be secured to the forearm by means of a keeper. This will prevent slack in the cable when the elbow is flexed. The terminal-device control cable is attached to the control attachment strap in the conventional manner.

An alternate method is to insert the switch in the control attachment strap (CAS) of the conventional above-elbow figure-8 harness. However, in certain cases the slight motion of the switch across the back may be uncomfortable or interfere with function when a patient sits in a seat. Installation in the CAS is not recommended for use with voluntary-closing, conventional terminal devices featuring automatic locks. "Meeting the load" or unlocking the hand, causes inadvertent operation of the switch. The preferred method is to install it in the front support strap of the above-elbow figure-8 harness. In this case, the basic control motion is abduction/extension of the shoulder and/or depression of the scapula.

In the shoulder-disarticulation prosthesis, the switch is attached in the control attachment strap (CAS) and the wearer actuates the switch by scapular abduction.

c. Training

Conventional above-elbow prostheses provide prehension, elbow flexion/extension, and an elbow-locking mechanism. The body motion used for controlling these functions is flexion of the shoulder. The force required to flex the elbow is always less than the force required to open (or close) the terminal device. With the elbow unlocked, flexion of the

shoulder flexes the elbow; with the elbow locked, flexion of the shoulder operates the terminal device. To operate the elbow lock, a second independent control motion is used: extension and abduction of the shoulder accompanied by scapular depression.

Conventional shoulder-disarticulation prostheses also provide prehension, flexion/extension, and an elbow-locking mechanism. Shoulder-disarticulation amputees are provided with a dual control system, in which the control motion for prehension and elbow flexion/extension is abduction of the scapula. Locking and unlocking the prosthetic elbow is accomplished by a chin control or by elevation of the scapula.

Because the *VAPC electric elbow* is "automatically" locked whenever it is not flexing or extending, one control motion is eliminated or sharply reduced in excursion. Nudge controls and/or waistbelts for shoulder disarticulations are unnecessary.

Training for the below-elbow, above-elbow, or shoulder-disarticulation wearer of a VAPC electric hand or elbow begins with thorough familiarization with the operational characteristics of the VAPC pull-switch. Emphasis is on *controls* training rather than *use* training on the assumption that previously fitted patients are already familiar with self-care activities. The training of new amputees will not differ in method or technique.

The amputee is instructed in the operational characteristics of the VAPC switch (Fig. 12) with the therapist demonstrating its operation by holding the prosthesis and pulling on the control strap to actuate the device. The amputee must be made aware that the VAPC switch is "OFF" at *both* ends of its range of motion; i.e., it is "OFF" when no tension is exerted and it is *also* "OFF" when more than 2 lb. of force is exerted. The subject must realize that in between this narrow range of *force* 0–2 lb., *two* different "ON" switching positions occur depending on the amount of force exerted on the switch. The first "ON" position is used to actuate extension of the VAPC elbow (prevents accidental inadvertent elbow extension) and the second "ON" position actuates flexion of the VAPC elbow.

The therapist demonstrates flexion and extension of the elbow in the following sequence.

Flexing the elbow—From the "rest" position (no force), pull on one end of the VAPC switch with approximately 1 lb. of force. This amount is sufficient to bypass the first "ON" switch position (elbow extension) and stop at the second "ON" switch position (elbow flexion). The elbow will continue to "automatically flex" to the full range as long as the switch is activated. The elbow can be stopped at any desired attitude by either 1. eliminating all tension or by 2. exerting slightly *more* force which "bottoms out" the switch (also an "OFF" switch position).

OPERATION OF VAPC SWITCH
(E L B O W)

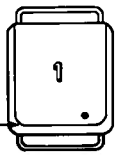
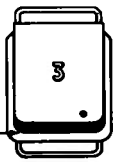
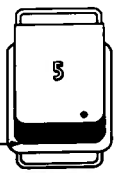
Switch Position		Function
1. Normal rest position, amputee relaxed, no tension on switch.		1. Elbow remains locked at any angle of flexion or extension.
2. First active position requiring 1/16 inch of excursion. This position must be maintained by amputee. If he relaxes, the switch will return to position No. 1.		2. Elbow extends continuously while switch is in this position.
3. Neutral position requiring 1/16 inch of additional excursion.		3. Elbow stops and locks.
4. Second active position reached by additional excursion of 1/16 inch.		4. Elbow continues flexing while in this position.
5. Neutral position requiring another 1/16 inch of excursion. End point is a stop which transmits force to control cable or harness.		5. Elbow stops and locks.

FIGURE 12

Extending the elbow—From the "rest" position, pull on the switch with approximately ½ lb. of force which is enough to move to the first "ON" switch position (elbow extension). This first "ON" position can also be reached from the "bottom-out" position (greater than 2 lb. force has been exerted). In this event "reducing" the amount of force to approximately ½ lb. will bypass the second position and stop at the first "ON" switch position. The subject should next be encouraged to pull on the switch and to operate the elbow. This should help him understand the relationship of force and excursion to flexing and extending the VAPC electric elbow.

Once the subject understands the operational characteristics of the switch, he should be asked to don the prosthesis. He should relax and let the therapist "guide" the arm through the humeral abduction-extension range with just enough force/excursion to flex and extend the elbow. This helps the subject to acquire the kinesthetic sense of range and force requirements.

4. Unilateral Above Elbow and Shoulder Disarticulation with Powered Elbow and Terminal Device

a. Choice

Prosthetic hands, of any kind, are less frequently prescribed for above-elbow and shoulder-disarticulation patients than for below-elbow patients. It is clear that many of the same reasons for not prescribing mechanical prosthetic hands for these patients remain valid in respect to externally powered hands. There is, however, a small group of unilateral above-elbow and shoulder-disarticulation patients who might be prescribed an externally powered hand for psychological, cosmetic, or even certain functional reasons. Control of both components by pull-switches is recommended in the present state of affairs. The differences between the APRL conventional hand, for example, and an externally powered hand (pull-switch controlled) as regards weight, cost, and function are not necessarily great. With the patient already carrying a power pack for the elbow, the differences in hand weight are perhaps of the order of 1 or 2 oz. Battery capacity to accommodate both components is available in the VAPC battery pack. The cost of an externally powered hand operated by *pull-switch control* is less than twice the cost of a conventional hand. This means that for an apparently acceptable increase in cost for an externally powered hand, the patient may be provided sufficient pinch force and improved controls with sharply reduced excursion. However, the higher operating noise level must also be acceptable. In this connection the pull-switch control of the externally powered *elbow* should be mounted "anteriorly," i.e., as in the conventional elbow-lock control strap, in order to reduce problems of inadvertent operation, particularly with voluntary closing terminal devices.

b. Fitting

If a powered hand is to be used in conjunction with a powered elbow, the hand control switch is attached to the control attachment strap (CAS) (Fig. 13). The hand control switch is inserted in the CAS by the same method used to install the elbow-control switch in the anterior support strap. The wire leads which exit through the mounting stud of the hand should be secured in place with the elbow in full extension. The wires are placed over the medial elbow joint and secured with keepers. Both the elbow and hand wire leads are connected to the internally mounted battery and must be accessible for daily recharging.

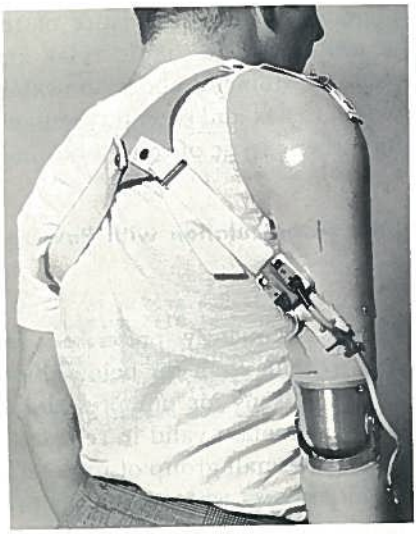


FIGURE 13.—For AE's wearing a VAPC electric hand in addition to a VAPC electric elbow, the control switch for the hand is installed in the control attachment strap (CAS).

c. Training

Training consists of combining the procedures given above for terminal devices with those given above for elbows.

To date we have fitted 12 patients with either the VAPC electric hand, the VAPC electric elbow, or both. Eight additional patients have been fitted with these components in other facilities across the country. These patients have been wearing the VAPC components for periods ranging from 4–18 months, during which time these components have demonstrated reasonable durability and functional advantages, and they seem to be clearly preferred by their users over conventional components. On the basis of this experience we have initiated a large scale field evaluation program in which approximately 200 arm amputees, the majority of whom are Vietnam-era veterans, will be prescribed various combinations of VAPC electric arm components. Participating in this program are 15 VA clinics, where patients will be prescribed for, trained, and evaluated. The purpose of this study is to determine the functional significance of electric components, redesign requirements (if any), and to arrive at a decision whether to make electrical components a part of the upper-extremity armamentarium.