

SELF-CONTAINMENT AND SELF-SUSPENSION OF EXTERNALLY POWERED PROSTHESES FOR THE FOREARM^a

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SUMMARY

1. The experience of fitting eight below-elbow and wrist-disarticulation amputees with electrically powered prostheses of various types is discussed and five fittings are shown. A number of conclusions concerning design, configuration, and patient care are presented.

2. It is concluded that externally powered prostheses for forearm amputees should be self-contained and self-suspended.

3. It is evident that a powered hook, interchangeable with the powered hand, is highly desirable for the forearm amputee fitted with an externally powered prosthesis.

4. Experience indicates that most self-suspension methods need improvement to allow for increased utilization of residual supination-pronation of the forearm and flexion-extension of the elbow.

5. Forearm prostheses with soft exteriors appear to be desirable.

6. The use of proportional control, where the prehension force and the closing rate of the terminal device are proportional to the degree of activity at the control site, is found to be desirable for good prehensile control. This is particularly true of terminal devices having rapid dynamic response and large prehension forces.

7. It is evident that some elementary form of sensory feedback would be beneficial in control of prehension.

8. Three-state control methods (i.e., control of the terminal device from one control site) were required in several fittings. On the basis of this experience, the three-state control approach appears to be a necessary adjunct to two-state, two-site methods since some forearm amputees do not have two readily usable control sites.

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9. It is concluded that prosthetic fitting and training should start on the day of surgery and that the amputee should at no time be without a functioning prosthesis.

INTRODUCTION

It would seem that the optimal way to solve the prosthetic problem of an amputee would be to induce the missing limb to regenerate. However, this is more a problem for the molecular biologist or geneticist than the engineer and also would appear to be only a distant possibility of the future, if possible at all. Thus, the problem of improved prostheses, even for the forearm amputee, remains major. In this paper an attempt is made to define a direction for development of prostheses for the forearm. It seems in order to look at the future, the present, and the past.

The Future

Science fiction writers rarely write anything about prosthetics and so it is highly interesting when they do because they often see future developments with much imagination. Therefore, the lower-arm prosthesis of Manuel O'Kelly in Robert Heinlein's science fiction novel *The Moon is a Harsh Mistress*^c is very intriguing. The year is 2075 and Manuel, who works on computers and lives on the moon, has lost his arm in a laser beam accident. He explained about his left arm as follows:

You see, from elbow down I don't have one. So I have a dozen left arms, each specialized, plus one that feels and looks like flesh. With proper left arm (number-three) and stereo loupe spectacles I could make ultraminiature repairs that would save unhooking something and sending it Earthside to factory—for number-three has micromanipulators as fine as those used by neurosurgeons.^d

Obviously his 21st century prosthesis had the ultimate in interchangeability, not merely the simple hook-hand interchange as discussed in this paper. Also there was the cosmetic prosthesis which was soft and which perhaps had sensation. These are, of course, all features which intuitively seem desirable and which now seem to be indicated from our limited experience of fitting forearm amputees with devices which do not have these features.

The attachment of O'Kelly's prosthesis was also unique. He described it to a female companion in this way:

"No longer a miner," I explained. "That was before I lost this wing." Raised left arm, let her see seam joining prosthetic to meat

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arm (I never mind calling it to a woman's attention; puts some off but arouses maternal in others—averages).^d

Perhaps the self-containment and self-suspension features put forth in this paper are positive steps toward a prosthetic device which joins to the body at a seam in the way Manuel's did.

Manuel's prosthetic left arm was very functional, perhaps more functional than his right arm in some ways, but as good as it was he still didn't want to trade in his right arm. He pointed this out as follows:

I didn't say left arm more versatile than right—she was correct; don't want to trade in right arm. Need it to pat girls if naughty else.^d

Although O'Kelly was still not willing to part with his physiological hand it appears that the prosthetic hand was so good that he was in no way handicapped. In fact, his prosthesis permitted some rather significant advantages such as in computer repair. Perhaps it is just fancy but if the idea is pushed one step farther one wonders if physiological organs may someday be voluntarily replaced by artificial ones which are better.

A forearm prosthesis of the 21st century variety should be our goal. Hopefully the concepts of self-containment, self-suspension, neuromuscular control, hook-hand interchangeability, and electric power form the embryo from which such a prosthesis will grow.

The Present

In the year 1970 the use of external power in forearm prosthetics is a controversial subject and one which will, most likely, not be soon resolved although hopefully before 2075. Nevertheless, external power offers an interesting and exciting alternative for fitting forearm amputees today. It is hoped that those concerned with such fittings will freely consider this alternative and be open to new developments and improvements in this area as they become available.

The concept of using external power for terminal devices is by no means new, having been discussed early in this century by Schlesinger (1) (1919) and no doubt earlier by others. However, the successful application of this concept to amputees has been rather limited in scope, particularly in the United States.

It is proposed in the discussion which follows that external power for forearm amputees is used to its greatest advantage when the prosthesis is entirely self-contained and self-suspended. This means that the prosthesis contains all elements of the system, including the energy source, within its anthropomorphic shape and that the prosthesis is supported without external harnessing. Therefore, the control must come from within the socket of the prosthesis with the possible exceptions of voice

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control, control by telemetry signals from implanted transmitters, or some other form of transmitted signal.

Control from the stump must inevitably involve the neuromuscular system remaining within the stump. Therefore, it seems proper to refer to this as neuromuscular control. Such neuromuscular control may be accomplished in a number of ways with a partial list including movement of the stump within the socket, muscle bulging, motion of residual fingers, muscle tension, muscle hardness [as proposed by Mauch (2) (1967)], and myoelectric activity. These methods all involve activity of the remaining neuromuscular system of the stump. It is presumed that other approaches which could be put forth for control from the amputee's stump would also involve some aspect of this system.

The experience reported here involves the use of myoelectricity for control of electrically powered hands and summarizes experience with eight amputees. Nevertheless, the fundamental ideas presented have application to a broad spectrum of control and power concepts. In fact, the summary statements, already presented, are general and not specific to any type of neuromuscular control method nor to the use of a particular energy source. These statements are a result of the author's own experience and of the synthesis of concepts proposed by many others. They are presented here for emphasis and are not considered original.

The use of self-contained prostheses which do not use body power for their activation has made the general term "external power" somewhat of a misnomer since the power comes from within the prosthesis. Therefore, the designation might just as well be "internal power." More precisely such units could be referred to as internally powered prostheses which are periodically recharged from external power sources. Of course, broadly speaking the muscles of a normal limb fall in this category. It seems preferable to specify the precise form of power used: body, pneumatics electric, electrohydraulic, or some other form and to use the general term "external power" less frequently.

The Past

The recent practical applications of myoelectric control seem to mark the beginning of its third stage of development. Whether this form of neuromuscular control will continue to develop remains to be seen, since technological developments may make other forms of neuromuscular control more attractive. Nevertheless, myoelectric control has now advanced to the clinical level.

The first stage of myoelectric control development, the laboratory stage, began about 1945 and ended around 1959 with a hiatus between 1948 and 1955. The second stage, from 1959 to about 1967, was marked by experimental work with amputees but there was limited practical application. After 1967 commercial components became available for

myoelectric systems and the design and technology improved as clinical experience was gained. Thus, it appears that a new developmental stage has arrived.

It is not necessary to review most of the early developments in this field as reviews may be found in papers by Bottomley et al. (3) (1963), Bottomley (4) (1965), and Scott (5) (1966) among others. However, the very early work of Reiter (6) (1948) has not been acknowledged to any extent in English literature on the subject. Therefore, because of the omission of this historically important contribution and because of its relationship to the material being presented it seems appropriate to briefly review this early work.

Figure 1 shows a series of pictures which illustrate Reiter's work on myoelectric prostheses. The myoelectric activity for the opening and closing operations of an artificial hand is shown in Figure 1a. Opening of the prosthetic hand was accomplished by short muscle contractions followed by immediate relaxation. A smaller contraction with slow relaxation was used to close the hand. Reiter (6) (1948) describes this as control through two different contraction rhythms of the same muscle. It is interesting that this very early application of myoelectric control was a form of three-state control where one muscle controls the opening, closing, and quiescent states of the prosthesis. Later developments in the 1950's mostly used systems employing two muscle sites. Figure 1b shows the electrode configuration of the three-state system.

Reiter's three-state approach, using contraction rhythms, is related to the approaches recently proposed by Ruch (7) (1968) and Childress (8) (1969) in which muscle contraction rates are used to activate different prosthetic functions.

The electromechanical hand used in this early electronic prosthesis was a modified Hufner hand which had a magnet type of actuator incorporated into it. The hand is shown in Figure 1c.

The electronic system is shown in Figure 1d. Of course, the amplifier used vacuum tubes and therefore this first unit was made only for bench operation. The unit was about the size of an attaché case and required power from the mains for its operation. It is ironic that Reiter's work was published in 1948, the same year that Bell Laboratories announced the development of the transistor. Solid-state technology was essential to the reduction of size and power requirements of the electronic control systems and this technology has made self-contained myoelectric control units technically feasible.

It is unfortunate that Reiter's early work was terminated during its infancy since it undoubtedly would have had significant influence on later development in prosthetics had it been continued.

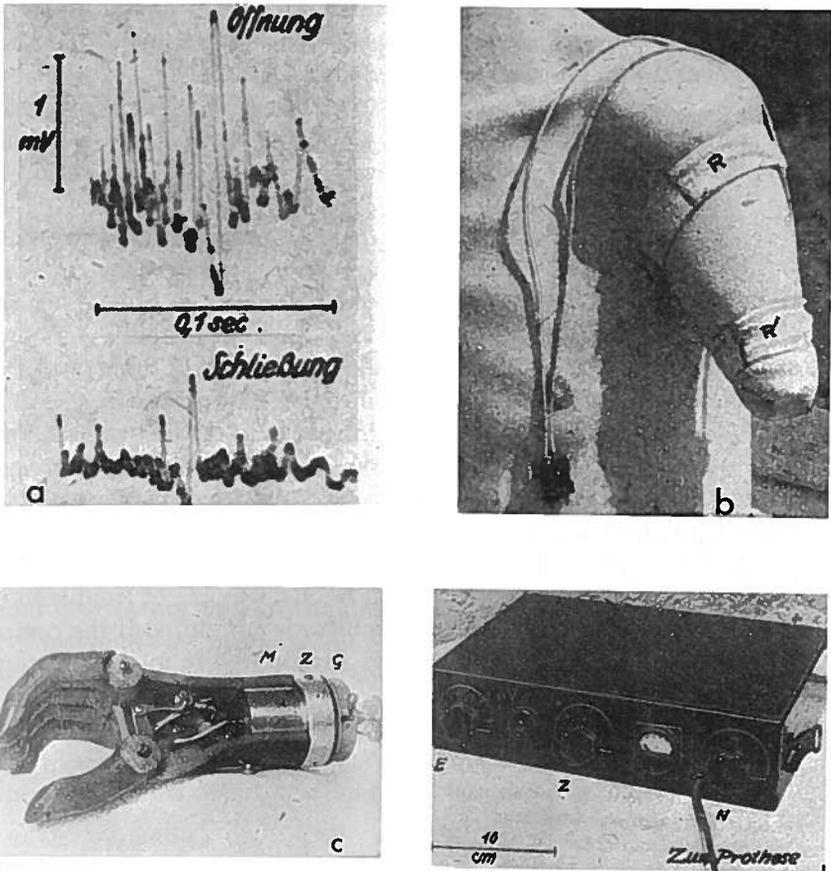


FIGURE 1.—Early myoelectric prosthesis (circa 1946) : a. myoelectric signal during opening and closing of prosthetic hand, b. electrodes, c. electric hand, d. electronic controller. Used by permission of Urban & Schwarzenberg, Verlag für Medizin und Naturwissenschaften, München, Germany.

PROSTHESES FOR THE BELOW-ELBOW AMPUTEE

The concept of a prosthesis being self-contained and self-suspended is widely used in the management of lower-extremity amputations (e.g., the patellar-tendon-bearing-supracondylar below-knee prosthesis and the suction socket above-knee prosthesis). However, except for passive prostheses which are worn only for cosmetic purposes, this concept has not been used to any extent with upper-extremity amputees in the United States.

The self-contained upper-extremity prosthesis, when coupled with self-suspension, provides several advantages to the amputee. The most obvious is the relief from what may be an annoying harness and control

cable. This makes possible more natural movement of the limb which contributes to improved general appearance and comfort of the wearer. Gross body motions are no longer required for control and this also contributes positively to appearance. Also, the self-contained prosthesis is neat in appearance and easy to keep clean. A further advantage arises from its being easily donned or removed. This may even be accomplished without the removal of garments.

It must be admitted that the principal advantages of the self-contained and self-suspended powered limb, as presently conceived, are in appearance and comfort. Nevertheless, some functional advantages may be obtained with external power of the below-elbow prosthesis. An obvious one is the ability to use the limb while it is in various orientations with respect to the body. The ratio of pinch force developed to the energy expended by the user may be greatly increased. Compared with voluntary opening (body-powered) units the powered units have the advantage of being able to maintain a given force (even less than maximum) indefinitely without expenditure of energy.

Electrical system reliability also is enhanced by self-containment. The breakage of exposed wires has been a frequent source of trouble in electrical systems for prostheses. This problem is minimized if the complete unit is inside the prosthesis shell and not allowed to move with respect to the prosthesis.

It seems clear that below-elbow prostheses which use external power lose much of their advantage if a harness is used for suspension. Harness or other paraphernalia should therefore be avoided if the optimum use of external power is to be achieved.



FIGURE 2.—Self-contained and self-suspended below-elbow prosthesis (myoelectric control, electric hand) for short below-elbow amputee. Subject R.S.

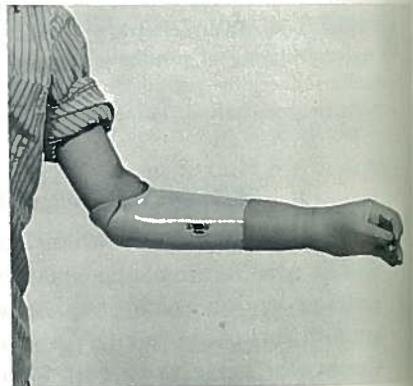


FIGURE 3.—Self-contained and self-suspended below-elbow prosthesis (myoelectric control, electric hand) for congenital amputee. Subject N.B.

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Examples of self-contained and self-suspended myoelectric prostheses are shown in Figures 2, 3, and 4. In each case a Hepp-Kuhn (Münster) type of suspension was used and the electronics and battery are within the forearm shell. An "on-off" switch, easily visible in Figures 2 and 3, is readily accessible so that the system may be deactivated as required. A charging plug is located adjacent to the switch.

The electronic control systems used in these prostheses were designed and fabricated at the Northwestern University Prosthetic Research Center, but the electromechanical hands shown were obtained from commercial sources. The hands in Figures 2 and 4 are from Viennatone Hörgeräte, and the small hand shown in Figure 3 is from Otto Bock Orthopedic Industry, Incorporated.

The prosthesis shown in Figure 4 is temporary and is made of a thermoplastic material (Polysar®). This material, in tubular form (2½ in. x ¾ in.), was molded directly on the stump. A baffle was inserted at the distal end of the stump and the battery and electronics were inserted at the open end of thermoplastic tube. The tube was then sealed around a wrist unit to which the hand was attached. This procedure is fast (a few hours for fitting) and well suited for temporary fittings, particularly those following immediate postsurgical fitting.

The prostheses shown in Figures 2 through 4 are crustaceous. Although it seems that a soft exterior would be preferable, none has been evaluated with this configuration.



FIGURE 4.—Self-contained and self-suspended temporary prosthesis (Polysar construction, myoelectric control, electric hand) for mid-length below-elbow amputee. Subject D.M.

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Proposed Prosthetic Configuration

The type of prosthetic configuration which is proposed for below-elbow amputees who are amputated at least 1.5 to 2 in. above the wrist is shown in Figure 5. The energy source should be located proximally followed by the control system and the terminal device. The wrist unit should have the quick-disconnect feature with passive wrist rotation and wrist flexion. Of course, active wrist rotation and flexion may be desirable but, in the interest of making the unit as light and simple as possible, it seems prudent that passive units be used, at least for the present.

The sockets illustrated in Figure 5 are not shown over the elbow since the desired configuration would leave the elbow free. This would give added comfort, allow for full range of flexion and extension of the elbow, and permit some rotation of the forearm. Such a socket, while very desirable, may not be easily attained and, therefore, this aspect of the configuration represents a goal to be achieved rather than an accomplished fact.

It has been possible to modify the Hepp-Kuhn socket (e.g., see Figures 3, 4, 6, and 10b) to increase elbow extension and flexion. Still this remains a problem. It seems fair to conclude that increased effort needs to be expended in the development of self-suspending sockets which allow a wide range of elbow motion and forearm rotation.

Components of a self-contained and self-suspended prosthesis are shown in Figure 6. The prosthesis shell consists of two parts so that the socket may be removed for the insertion of the batteries and controller at the proximal end. A preferable approach would be to insert these from the distal end. This should be possible with a wrist unit with a

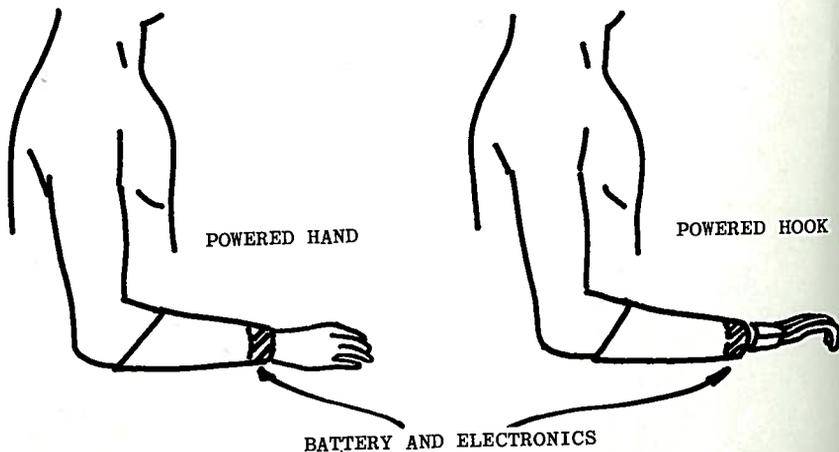


FIGURE 5.—Desired prosthetic configuration for below-elbow fitting of powered prosthesis. Note hook-hand interchangeability and location of energy source and controller.

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wide opening. More compact packaging of the energy source and electronics would also aid in this procedure.

Assembly of the components of the prosthesis would be even simpler if an endoskeletal structure were used for connecting the socket and terminal device. The energy source and electronic controller could then be placed around or in this skeletal structure and then covered with a soft material to give the arm the proper shape. This would also enhance the appearance of the prosthesis since it would have a flesh-like feel. Such a prosthesis is presently feasible and should be tried. LeBlanc and Bechtol (9) (1968) have already shown the usefulness of this configuration in body-powered systems.

The electrodes shown in Figure 6 are stainless steel rivets ($\frac{3}{8}$ in. head diameter) which were pushed through holes in the socket. This makes them a permanent part of the prosthesis. The amputee is requested to moisten the electrodes with water before donning the prosthesis. Body perspiration is sufficient to keep them moist thereafter.

PROSTHESES FOR THE WRIST-DISARTICULATION AMPUTEE

The problem of making a prosthesis self-contained is more difficult with the wrist-disarticulation amputee. The control system and energy source must be contained within the prosthetic hand or at least within the hand and socket. Such a fitting is shown in Figure 7a. The bony prominences of the wrist are used to suspend the prosthesis which weighs $1\frac{1}{2}$ lb.

A comparison of the conventional type of fitting with the self-contained and self-suspended prosthesis using neuromuscular control may be made by observing Figures 7a and 7b.

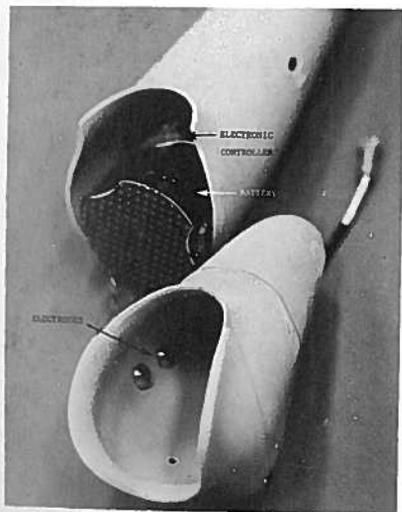


FIGURE 6.—Present assembly method for the self-contained below-elbow prosthesis.

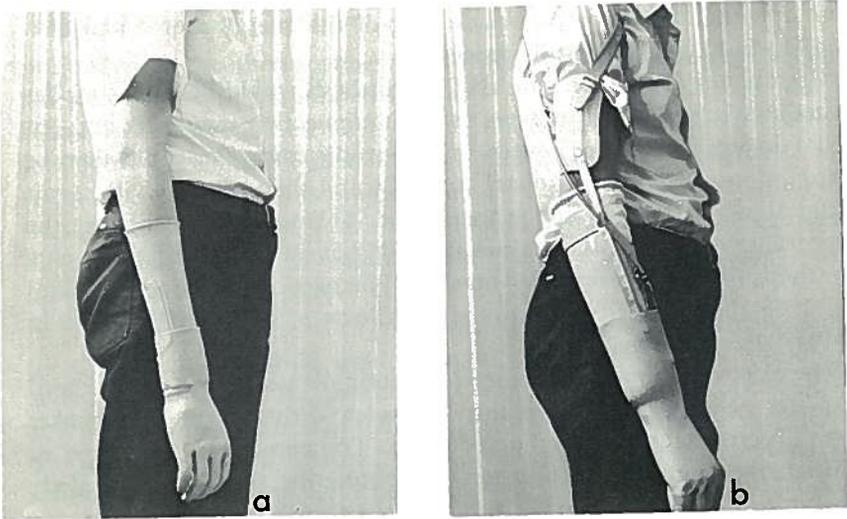


FIGURE 7.—Wrist-disarticulation fitting: a. self-contained and self-suspended prosthesis using myoelectric control and electric hand, b. conventional wrist-disarticulation prosthesis. Subject R.R.

The self-contained prosthesis for the wrist-disarticulation amputee shown in 7a may be seen opened in Figure 8. The batteries are located within the hand and the electronics within the wrist plate. The socket is kept short to allow maximum rotation of the hand (130 deg. in this case).

Suspension at the wrist may not always be possible. Suspension may

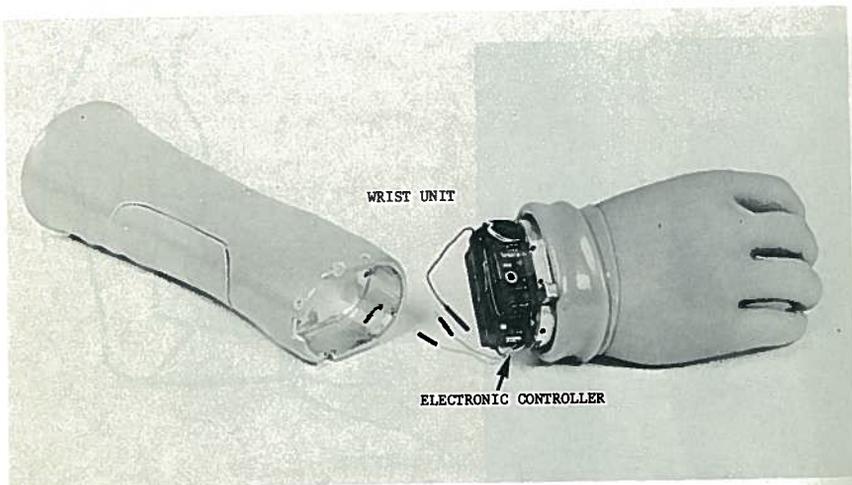


FIGURE 8.—Self-contained wrist-disarticulation prosthesis showing electronic controller of the wrist unit. The battery is inside the hand.

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then be obtained with straps over the humeral epicondyles or with a Münster socket which is divided in its mid-section and held together with straps. The latter suspension arrangement is shown in Figure 9 with a prosthesis which was not self-contained (the battery is on the upper arm). This approach is unwieldy and not very cosmetic. Therefore, it is believed that arrangements involving suspension straps and/or cuffs should be avoided if possible.

CONCEPTS FOR THE POWERED FOREARM PROSTHESIS

Control Sites

It is the author's opinion that control units which use two control sites, one for each externally powered motion, give the amputee the fastest and most positive control (at least when compared with most three-state controllers currently in use); and it is felt that the forearm amputee who is fitted with only one powered function should use two control sites, if such are readily available. However, of the eight amputees fitted in this laboratory three could not readily use two-site systems. One had lost the flexor muscles of the forearm in the accident which necessitated the amputation. The second had flexor muscles which caused painful cramps when they were used, and the third was a congenital amputee.

The congenital amputee (short below elbow) case was interesting since the muscles of the stump did not show normal neurological control. For example, normal agonist-antagonist activity could not be ascertained. All the muscles of the stump seemed to act in synchrony and this necessi-



FIGURE 9.—A suspension method for wrist-disarticulation amputee having conical-shaped stump. Subject R.H.

tated use of three-state myoelectric control. This characteristic was unexpected but seems logical and may be rather common with congenital amputees. There is no reason to expect normal neuromuscular control in a congenital amputee's stump since the muscles there have controlled no body extremities and therefore have not developed for this purpose. Another complicating factor in fitting myoelectric units to congenital amputees is their lack of a "phantom limb" sensation. This may make it more difficult for them to learn to control a myoelectric prosthesis. Nevertheless, the congenital amputee can be fitted with neuromuscular controllers. In fact the self-contained and self-suspended myoelectric arm would appear to be well suited to the cosmetic problems of the young, female, congenital amputee. Also, it seems possible that patterned activity of the stump muscles could be learned through laboratory sessions which present the individual with proper feedback information about the activity of the stump muscles.

Three-state control, where only one control site is used to control the two active and one quiescent states of a powered device, was used for the three amputees just described. The system used has been described by Childress (8) (1969). This system responds to the initial rate-of-change of the processed myoelectric signal. If the initial rate exceeds a specified value, the hand opens and remains in the opening mode until the muscle at the control site is relaxed. If the initial rate of muscle contraction is below this specified value, the hand closes with a velocity which is approximately proportional to the amplitude of the processed myoelectric signal. Likewise if the hand is gripping an object, the gripping force is determined by the amplitude of the myoelectric signal. This force may be increased to its maximum value but may not be reduced without opening the hand.

Three-state control has proved to be necessary when there is only one usable control site, when the amputee does not have the ability to separate muscle function (e.g., some congenital amputees), or when the contraction of functional muscle groups cause pain. Thus, three-state systems are a useful adjunct to the systems which require two electrode sites for forearm amputees. Three-state units also are readily adaptable to multiple function control. For example, the control of three separate functions (six motions) has been described and demonstrated using three-state control from only two control sites [Childress (10) (1968)].

The basic design of the myoelectric amplifier and processor used in the fittings shown here has been described elsewhere [Childress (11) (1969)]. The key problem was to make the electronics and power supply small enough to be self-contained. A cordwood technique was used to miniaturize the electronic components, and battery size was reduced by limiting the quiescent current drain. Quiescent power drain of less than 10 milliwatts is recommended to make the major portion of the stored

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energy available for the actuator. Batteries having 180 mah. capacity have proved adequate for 16-hr. usage, approximately 300 full cycles of the actuator (Viennatone hand) and 20 percent energy reserve. The problems of power drain and miniaturization will soon be alleviated as integrated circuits having low quiescent power drain become available at reasonable cost.

Nickel-cadmium batteries have been used because of their reliability, ruggedness, and longevity. However, other batteries having higher power densities would be physically smaller for a given energy supply and would be advantageous for self-contained units provided they are reasonably durable. Another way to reduce battery size is to reduce the power required by the actuator. It appears that the power requirements for terminal device actuators may be reduced by a factor of two or three from that presently used in commercial units (5 watts), but order of magnitude reductions do not appear feasible.

Powered Hook

A suitable powered hook which could be interchanged with the powered hand appears to be very desirable and the Seventh Workshop Panel on Upper-Extremity Prosthetics of the Committee on Prosthetic Research and Development (12) (1969) favored such a device. Certain activities such as picking up small objects require more dexterity than the hand can offer and the bulky hand often obscures small objects. The hook can handle such tasks easily although a unilateral amputee most often will use his sound hand when fine manipulation is required. The hook is also more durable for heavy work and will not stain.

Powered hooks would greatly increase the number of amputees for whom myoelectric prostheses could be prescribed. For example, bilateral below-elbow amputees, for whom hooks are almost mandatory, could use myoelectric control if electric hooks were available. In fact, powered hooks coupled with myoelectric control, self-containment, and self-suspension should be very effective in the management of the bilateral amputee. Of course, unilateral amputees who are engaged in heavy labor or who work in dirty surroundings could also be fitted with external power if a powered hook were available.

Prescription indications for myoelectric control which are currently used in this facility when a hand is the only available terminal device are as follows:

1. The amputee desires this type of prosthesis and can afford it.
2. He is engaged in light work (e.g., student, salesman, etc.).
3. He is a unilateral forearm amputee.
4. He has suitable stump muscles.
5. Cosmetic factors are important to him.

Proportional Control and Sensory Feedback

The prehension forces and closing rate of the terminal device need to be finely controlled from the control site for good prosthetic function. "On-off" control of the terminal device is adequate if the device is very sluggish. However, a fast responding system requires some form of proportional control.

The voluntary opening hook which is body-powered has a rapid response and the powered terminal devices need this same quickness. A minimum closing time of 0.5 sec. may be desirable in the powered terminal device. Of course, this would necessitate good control. Likewise, the user of the body-powered unit receives sensory information about the terminal device through the control cable. The powered devices also need some simple form of sensory feedback to improve their performance.

MYOELECTRIC IMMEDIATE POSTSURGICAL FITTING

It appears beneficial to fit the upper-extremity amputee with a prosthesis as soon as possible following surgery. Immediate postsurgical fitting has proven to be a very satisfactory procedure in upper- as well as lower-extremity amputations [Sarmiento et al. (13) (1968), Loughlin et al. (14) (1968)]. A main prosthetic advantage to the upper-extremity amputee, besides the psychological one, is the immediate training and use of the prosthesis while recovering from the amputation surgery. Perhaps this will discourage the singlehandedness so often evident in unilateral amputees.

The same benefits derived from the immediate postsurgical fitting of a conventional prosthesis may be obtained when neuromuscular control is used in the immediate fitting. In addition the exercise of the neuromuscular system of the traumatized stump may promote healing and diminish disuse atrophy of muscles.

Four patients have been successfully treated using an immediate postsurgical myoelectric fitting technique which has been described elsewhere [Childress et al. (15) (1969)]. The interesting idea which has emerged from this experience is that the amputee can always have a functioning prosthesis. For example, a myoelectrically controlled below-elbow prosthesis may be fitted immediately following surgery. The rigid dressing is formed as a Münster socket to which the electromechanical hand is attached. The thin electrodes are placed on the skin beneath the cast and the electronics and batteries are contained in a packet carried by the amputee. After 2 weeks the cast is taken off for suture removal and examination of the stump. A new cast and prosthesis are applied and allowed to remain for 2 more weeks. Following removal of this cast a socket made of Polysar^e is formed and the control system incorporated

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into it. This temporary prosthesis is worn for several months until the stump has stabilized in size and is then replaced by a permanent prosthesis. Figure 10a shows an amputee, fitted with this procedure, at the time of the second cast removal. Figure 10b shows the same patient fitted on the day of cast removal with a temporary, self-contained myoelectric unit. The immediate fitting of plaster could also be self-contained except that the weight of components, when added to an already heavy cast, would make the total weight excessive, particularly for a healing stump.

The procedure just described allows the amputee to have the same prosthetic hand and same control from the day of surgery until the permanent fitting. This is a desirable procedure but one which demands close coordination of the individuals associated with the surgery and prosthetic fitting.

ABOVE-ELBOW PROSTHETICS

It also appears possible to fit many above-elbow amputees with self-contained and self-suspended prostheses which are controlled by neuromuscular means. A difficult problem with this condition concerns how to attain coordinated movement without excessive system complexity. Nonetheless, the prospect of a self-contained unit having a powered elbow, a powered hand, and possibly a powered wrist which are easily controlled by the neuromuscular system of the stump appears promising.

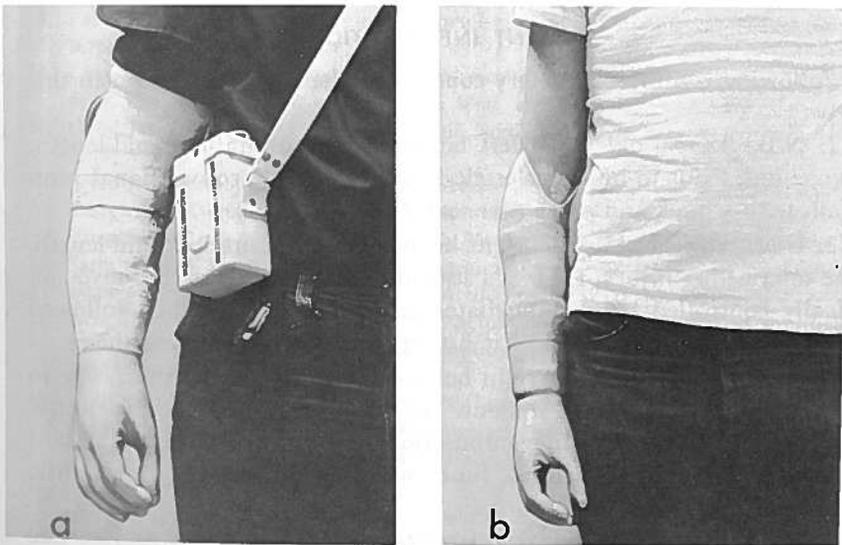


FIGURE 10—Myoelectric immediate postsurgical fitting procedure and temporary fitting: a. plaster cast and functional electric hand, b. temporary myoelectric prosthesis (self-contained and self-suspended) fitted on day of cast removal. Subject D.M.

CONCLUSION

Neuromuscular control coupled with self-containment and self-suspension can be of significant benefit to the forearm amputee using non-body-powered systems. There remains, however, much room for improvement, and the initial fittings illustrated in this paper are only a crude beginning. Hopefully the trial prostheses reported here and the suggestions for their improvement give some direction for their further development. Although higher level amputations of the arm cause more functional loss and present more difficult prosthetic problems, forearm amputees account for the greatest percentage of upper-extremity amputees and if their prostheses can be substantially improved this should be done even though all would agree that the problems of the higher level amputee should be tackled with equal vigor.

One disturbing fact concerning neuromuscular control, primarily myoelectric control, is the high cost of components. This cost problem must be overcome if widespread use of myoelectricity as a neuromuscular control approach is to come about in the near future.

The ideas which have been presented for improved management of the problems of the forearm amputee are practical and within our technical capability. In fact, the class of problems presented by the forearm amputee seem quite tractable. Nonetheless, even the tractable problems need to be carried to sound solutions and the solutions carried into clinical practice.

PATIENT INFORMATION

Following is a brief summary concerning the amputees shown in this paper:

1. N.B.: 13-year-old male, left below-elbow amputation, mid-length, congenital. Prior to his myoelectric fitting he wore a conventional prosthesis with a hook and a Münster socket.
2. D.M.: 20-year-old male, right below-elbow amputation, mid-length, due to crushing injury. D.M. is a student. He was fitted with a myoelectrically controlled hand immediately after surgery and then followed through a temporary myoelectric fitting to the permanent prosthesis.
3. R.S.: 23-year-old male, right below-elbow amputation, short, due to electrical burns. R.S. is a student. He was fitted with the myoelectric prosthesis 2 years following amputation surgery. He wore a standard below-elbow prosthesis with a functional cosmetic hand prior to the myoelectric fitting.
4. R.R.: 18-year-old male, right wrist-disarticulation amputation, due to crushing injury. R.R. is a high school student. He was fitted with a myoelectrically controlled hand immediately after surgery. After post-surgical followup he was fitted with a conventional prosthesis. The self-

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contained and self-suspended prosthesis was fitted 6 months following surgery.

5. R.H.: 32-year-old male, right wrist-disarticulation amputation due to crushing injury. R.H. is a salesman.

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REFERENCES

1. Schlesinger, G.: Der mechanische Aufbau der künstlichen Glieder. In Ersatzglieder und Arbeitshilfen, p. 386, Verlag von Julius Springer, Berlin, 1919.
2. Mauch, H.: Summary Report on Research and Development in the Field of Artificial Limbs. VA Report, June 30, 1967.
3. Bottomley, A., A. B. Kinnier Wilson, and A. Nightingale: Muscle Substitutes and Myo-Electric Control. *J. Brit. I.R.E.*, 26:439, 1963.
4. Bottomley, A.: Myo-Electric Control of Powered Prostheses. *J. Bone & Joint Surg. (Brit.)*, 47-B (3):411, 1965.
5. Scott, R. N.: Myoelectric Control. *Science Journal*, March 1966.
6. Reiter, R.: Eine neue Elektrokunsthand. *Grenzgebiete der Medizin*, 4:133, 1948.
7. Ruch, C.: Dept. of Orthopaedics, Univ. of Pretoria, personal communication, Houston, 1968.
8. Childress, D. S.: A Myoelectric Three-State Controller using Rate Sensitivity. 8th Intl. Conf. on Med. and Biol. Engng., Session 5-4, 1969.
9. LeBlanc, M. and C. O. Bechtol: Endoskeletal Upper-Extremity Prosthesis. Final Report SRS-RD-2708-M-68, 1968.
10. Childress, D. S.: Myoelectric Control of Devices having Several Degrees of Freedom. 21st Annual Conf. on Engng. in Med. and Biol., 10:26B3, 1968.
11. Childress, D. S.: Design of a Myoelectric Signal Conditioner. *J. of Audio Engng.*, 17 (3):286, 1969.
12. Seventh Workshop Panel on Upper-Extremity Prosthetics of the Subcommittee on Design and Development, Externally Powered Terminal Devices, Committee on Prosthetics Research and Development, National Academy of Sciences, 1969.
13. Sarmiento, A. et al.: Immediate Postsurgical Prosthetics Fitting in the Management of Upper-Extremity Amputees. *Artif. Limbs*, 12 (1):14, 1968.
14. Loughlin, E., J. W. Sanford, and M. Phelps: Immediate Postsurgical Prosthetics Fitting of a Bilateral, Below-Elbow Amputee, A Report. *Artif. Limbs*, 12 (1):17, 1968.
15. Childress, D. S., F. L. Hampton, C. N. Lambert, R. G. Thompson, and M. J. Schrod: Myoelectric Immediate Postsurgical Procedure: A Concept for Fitting the Upper-Extremity Amputee. *Artif. Limbs*, 13 (2):55, 1969.