

Upper Limb Prosthetic Terminal Devices: Hands Versus Hooks

by John N. Billock, C.P.O.

No one would argue that the human hand is the most complex and challenging structure of the human anatomy to replace and restore. The hand is an extremely complex structure which moves with a precision and dexterity that has long challenged the minds of researchers in medicine and engineering. Beyond its kinematic capabilities, the hand is also one of the most intricate sensory mechanisms of the human body—with unequaled proprioceptive and sensory feedback capabilities. With this in mind, it is easy to understand why prosthetic terminal devices today (hand and/or hook) offer very little in the way of true functional restoration to individuals with upper limb deficiencies.

This is not meant to be critical of past developments, but puts into proper perspective the complexities and challenges of duplicating the human hand. Further emphasis of this is found in a commentary by Murphy⁹ in which he stated, "Though engineers and prosthetists have made substantial contributions, they need perspective and humility to inspire and guide the very long, sustained efforts required to replace even a few of the roles of the hand." This challenge will doubtlessly keep researchers in prosthetics, and now those involved in robotics, busy with the task of trying to duplicate the kinematic and sensory capabilities of the human hand for years to come.

PROSTHETIC TERMINAL DEVICES TODAY

There exists today a significant number of prosthetic terminal devices for treating both adult and juvenile complete hand deficiencies. These terminal devices are designed as either mechanical or electromechanical systems and, as such, are either body-powered or electric powered. The body powered terminal devices

function by utilizing forces generated by body movement as described by Taylor.^{13,14} An electric powered terminal device functions by utilizing the electrical force stored within and generated from a battery. Further, these sources of power can activate or control a terminal device in different ways. The three most commonly used control systems are the Bowden cable control, myoelectric control, and switch control. In order to fully understand the functional potential of a particular terminal device, it is important to understand the control approach or system being used to actuate the device.

PROSTHETIC CONTROL SYSTEMS

Professional opinions vary considerably regarding the most appropriate terminal device and control system to utilize in the design and development of a functional upper limb prosthesis. Bowden cable control systems harness the motions and forces generated by gross body movement to actuate and control, primarily, a mechanical terminal device. They require an adequate degree of force and excursion to actuate and control an upper/limb mechanical terminal device.^{7,13,14} The most common example of this would be the Bowden cable control system of a totally mechanical below-elbow prosthesis (Figure 1). This type of control system harnesses the body motion and forces generated by flexion-abduction movements at the glenohumeral joint to actuate and control the terminal device. It is important to note that this form of control does produce a certain degree of sensory feedback related to force and position.³

Myoelectric control systems utilize the existing neuro-muscular system for actuation and control of an electromechanical terminal device

Bowden Cable Control System

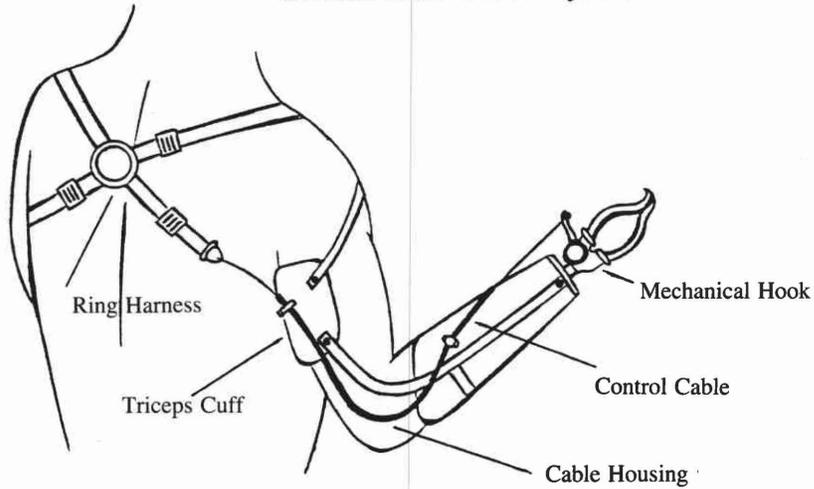


Figure 1. Illustration of a typical conventional body powered Bowden cable controlled below-elbow prosthesis with a mechanical hook terminal device actuated by "gross" body movements.

Myoelectric Control System

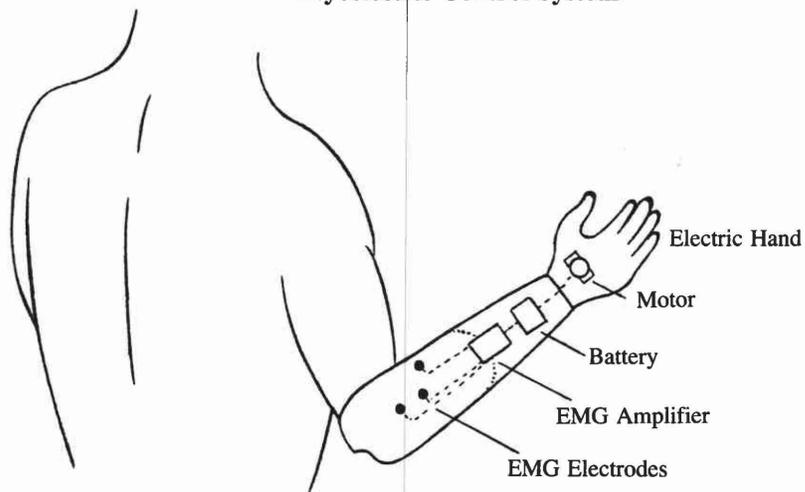


Figure 2. Illustration of a typical electric powered, myoelectrically controlled below-elbow prosthesis with an electromechanical hand terminal device actuated by EMG potentials.

Switch Control System

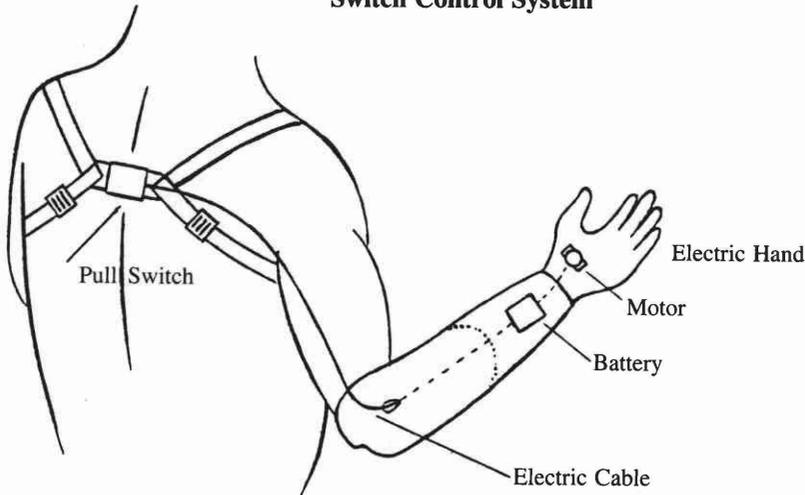


Figure 3. Illustration of a typical electric powered switch controlled below-elbow prosthesis with electromechanical hand terminal device actuated by "fine" body movements.

(Figure 2). EMG potentials are monitored with surface electrodes placed over appropriate muscle or muscle groups within the residual limb and are used for either digital or proportional control of the terminal device. This type of control is considered to be quite natural since it utilizes the existing residual neuromuscular system for control.^{2,3,4} This is especially true with synergistic muscle contractions, particularly related to natural hand functions, which can be selected for actuation and control of the terminal device. The use of myoelectric control enhances the feasibility of designing a totally self-contained and self-suspended prosthesis which has proven to be an acceptable and reliable design approach.¹⁻⁵

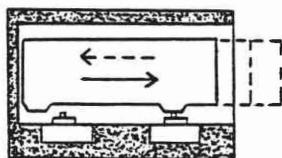
Switch control systems are those which utilize the motions and forces generated by "fine" body movements to actuate and control an electromechanical terminal device (Figure 3). They require considerably less force and excursion than a Bowden cable controlled system to actuate and control a terminal device. Switch control systems can incorporate a variety of different types of switches, such as, pull, rocker, push-button or toggle type switch for activation of the terminal device (Figure 4). This type of control is typically indicated in situations when limited body motion and forces are available for Bowden cable control and/or

when EMG potentials are inadequate or inappropriate for control of the terminal device.

MECHANICAL HOOKS AND HANDS

Following World War II and especially since the development of the APRL Voluntary Closing Hand and Hook in 1945, considerable controversy has existed regarding the functional aspects of hands versus hooks as terminal devices. Prior to the introduction and clinical use of electric hands in the early 1960's, this controversy only related to mechanical hands and hooks. Mechanical hands, although certainly more aesthetic, were felt by many professionals to be too heavy and awkward for fine prehension activities. Mechanical hooks, by way of contrast, weigh approximately one third the weight of a mechanical hand and provide dexterity comparable to a pair of tweezers. Mechanical hooks were also considered to be more durable because of their simple mechanical design, and the fact that a cover to protect internal mechanisms or provide aesthetics is unnecessary. Because of these mechanical advantages, very little regard was given to the social-psychological advantage and need for a prosthetic hand versus the hook terminal device.

Types of Switches



Pull



Push Button



Rocker



Toggle

Figure 4. The actuation characteristics of a typical pull, rocker, push button and toggle switch are illustrated. Switches are generally designed to produce one or more functions such as opening and/or closing of an electromechanical terminal device. (a) Pull (sliding) switch for actuation of two functions; (b) Rocker switch for actuation of two functions; (c) Push Button switch for actuation of one function; (d) Toggle switch for actuation of two functions.

In fact, it became common practice within prosthetic clinics and teaching institutions to encourage use of a hook terminal device first before providing the individual with a hand terminal device. The purpose of this practice, which continues today, is to develop the individual's appreciation for the functional advantage of the mechanical hook over the mechanical hand. Further, it was the opinion and experience of many clinics and prosthetists that many individuals, if provided a hand and hook terminal device simultaneously, tended to reject the hook for aesthetic reasons and not develop an appreciation for its functional advantage. Conservative estimates indicate, however, that approximately only fifty percent of those individuals provided with conventional type mechanical prostheses are wearing their prosthesis as reported by LeBlanc.⁸ This estimate does not distinguish between actual functional use versus simple wearing of the prosthesis.

It is the author's opinion and experience that the introduction of a hook terminal device in the early stages of the prosthetic rehabilitation process may in fact be the primary cause of the high incidence of total prosthetic rejection since little, if any, attention is given to the social-psychological aspects of the individual's limb deficiency. The social-psychological aspects of an acquired or congenital upper limb deficiency

should be regarded as the first and most significant problem which has to be understood and dealt with appropriately if successful prosthetic rehabilitation and functional use of a prosthesis is to be achieved. Dembo, Leviton, and Wright⁶ clearly identified the social-psychological problems individuals, as well as those around them, have to deal with in accepting limb loss as part of the total rehabilitation process. If an individual has not accepted a limb loss, or in the case of a congenital limb deficiency, the parents have not accepted the limb loss, it is unlikely that successful prosthetic rehabilitation and functional use of a prosthesis will be achieved.

Dr. Howard A. Rusk, recognized by many as the "father of physical medicine and rehabilitation," has identified motivation and timely rehabilitation services as the key elements to achieving successful rehabilitation of an individual's disability.^{10,11} An individual can receive the best rehabilitation services available and be provided with the best prosthesis today's technology has to offer. However, if they are not motivated to overcome their disability or adjust to it, acceptable rehabilitation is unlikely. Likewise, the child born with a congenital limb deficiency will not be encouraged to adapt to or functionally utilize a prosthesis if the parents have not accepted their child's disability.

ELECTRIC POWERED HOOKS AND HANDS

The introduction of electric powered hands into clinical practice in the early 1960's brought about a new era in prosthetics. Acceptance of these "electric hands" by the American prosthetics profession was much slower than in the European countries where they were initially developed. They are, moreover, still considered by many to be not as functional as mechanical hook terminal devices. It is felt that much of this belief can be traced to the attitude that regards mechanical hands as being less functional than mechanical hooks. Electric powered hands, however, have one primary major functional advantage over mechanical hooks and hands.

Electric hands can produce finger prehension force which is equal to, and in some cases greater than, that of an adult or juvenile human hand. The average adult male, for instance, can produce an average of 20 to 24 lbs. of finger prehension. The average tolerable amount of prehension that an adult male can generate with a Bowden cable controlled prosthesis and the more commonly used voluntary opening me-

chanical hook terminal device is approximately 8 to 10 lbs. Voluntary closing mechanical hands and hooks obviously are able to provide greater finger prehension than voluntary opening hooks or hands; however, they have not been widely accepted or used.

Another key advantage of an electric powered hand is that it provides forceful "3 jaw chuck" palmar type prehension. This type of prehension has been identified as early as 1919 by Schlesinger,¹² to be the most commonly utilized hand-finger prehension pattern for picking up and holding objects in activities of daily living (Figure 5). Table 1 shows the percentage of use to pick up and hold objects with an electric powered hand. The predominance of "3 jaw chuck" palmar prehension in our activities of daily living accounts for the reason all mechanical and electric powered hands of today are designed with the thumb in opposition to the second and third fingers. The forceful palmar prehension of the electric powered hand, therefore, enhances its overall functional value as a prosthetic terminal device.

The only electric powered hook available for clinical use at this time is the Otto Bock "Griever"¹⁵ which was introduced in the U.S. in the late 1970's. As an electric powered ter-

Types of Prehension

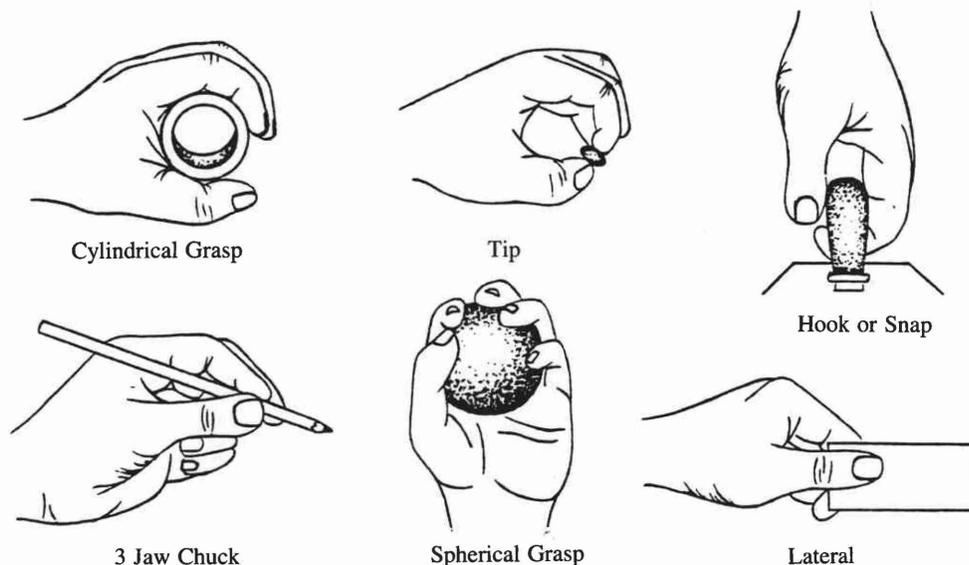


Figure 5. Of the six commonly used hand/finger prehension patterns, described by Schlesinger,¹⁰ "3 jaw chuck" palmar type, tip type and lateral type prehension are considered to be the most frequently used during activities of daily living.

FREQUENCY OF PREHENSION PATTERNS			
FUNCTION	Occurrence of Prehension Type		
	PALMAR (%)	TIP (%)	LATERAL (%)
Pick up	50	71	33
Hold for use	88	2	10

Table 1.

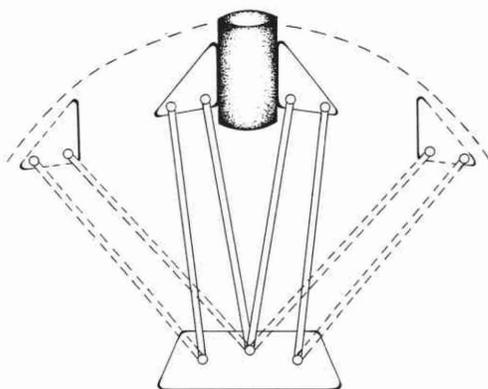


Figure 6. This diagram illustrates the angular relationship of the prehension surfaces and the object being held, utilizing a multi-axis prehension design approach, such as in the Otto Bock "Griever."¹⁵

terminal device, it has the quality of providing "forceful" prehension. Along with this, it is uniquely designed with multi-axis fingers to keep the grasping surfaces parallel during the entire range of opening and closing (Figure 6). This design feature allows for even pressure throughout its range of opening and closing which enhances its grasping ability over mechanical hooks. The grasping surfaces of a mechanical hook angle away from one another as the active finger moves in relationship to the stationary finger (Figure 7). Therefore the larger the object to be held in the mechanical hook terminal device, the less contact with the object and, consequently, the more force required to stabilize the object, dependent upon its shape. The "Griever," on the other hand, is heavier than the heaviest stainless steel me-

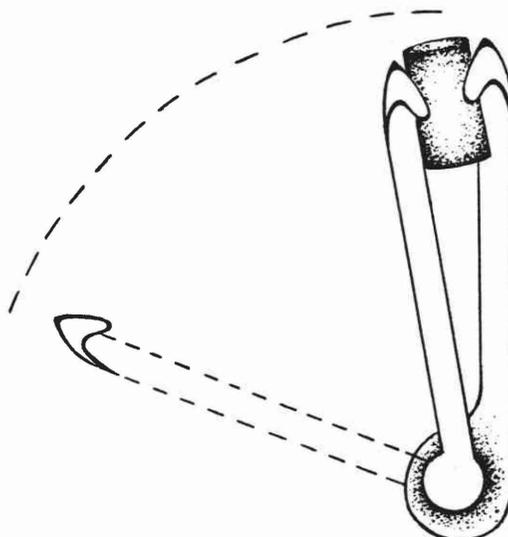


Figure 7. This diagram illustrates the angular relationship of the prehension surfaces and the object being held, utilizing a single-axis prehension design approach, such as in the Hosmer/Dorance¹⁶ mechanical hook series.

chanical hook and is not as durable, primarily because its design is more complex than the single axis mechanical hooks.

CLINICAL EXPERIENCE

The terminal device of the prosthesis plays an important key role in developing the motivation which will, hopefully, lead to successful prosthetic rehabilitation. It has been the author's experience, in over 300 cases involving individuals with congenital and acquired limb

TERMINAL DEVICE PREFERENCES		
DEVICE	Based on 300 Subjects	
	ADULT (%)	JUVENILE (%)
Mechanical Hand	1	0
Mechanical Hand	4	0
Electrical Hand	94	100 **
Electrical Hook	1	0

** Includes parent preference for children under age 5.

Table 2.

CASE LOAD BY AGE						
Percentages Based on 300 Subjects						
AGE RANGE	0/5 (%)	6/15 (%)	16/30 (%)	31/45 (%)	46/60 (%)	61/75 (%)
Male	1	3	10	52	16	2
Female	3	3	4	4	1	1
TOTAL	4	6	14	56	17	3

Table 3.

deficiencies from the wrist to the shoulder, that 95 percent or better of those individuals preferred to have a prosthetic hand rather than a hook terminal device (Tables 2 and 3). In all cases involving juvenile subjects (which represents approximately ten percent of the total case load), the parents and children over the age of five years preferred hand terminal devices to hooks. Forty percent of the total juvenile case load involved children under the age of five years, and in all cases, the parents preferred hand terminal devices. Parents were also found to prefer a passive nonfunctional hand as opposed to the more typically used passive type nonfunctional mitten for children up to 1½ years of age.

One might quickly draw the conclusion that this preference was specifically related to the

aesthetics of the hand and not necessarily related to function. There is no doubt that the aesthetics of the hand played a key role in the decision. However, this preference also emphasizes the strong social-psychological need for individuals, as well as the parents of children with limb deficiencies, to visually feel as normal as possible within our society. The aesthetics of a hand terminal device obviously satisfies this need more appropriately than a hook terminal device.

Beyond this, it is also interesting to note that approximately only one percent of those provided a prosthesis with hand are utilizing a mechanical hand terminal device. Therefore, 99 percent utilize electric powered hands in their prostheses; eighty percent of these are controlled myoelectrically. It is estimated that total

rejection of an electric powered hand prosthesis has been approximately 15–20 percent. Actual percentages of rejection have been difficult to verify because of lack of follow-up by the patients, and it is felt that 5–10 percent of the patients are now being followed-up elsewhere. Nevertheless, total prosthetic rejection is considerably less than those provided with conventional upper limb prostheses.⁸ It is not felt that the acceptance rate of electrically powered hand prostheses is specifically related to aesthetics of the hand. If this were the case, one would expect more individuals to have been utilizing mechanical or passive hands prior to the development of electric powered hands.

CONCLUSION

Clinical experience has definitely proven, in the author's experience, that an electrically powered prosthetic hand terminal device which is proportionally controlled, utilizing myoelectrical EMG potentials from synergistically related muscles within the residual limb, is the most acceptable and functional upper limb prosthetic design for individuals with complete hand deficiencies.

It is further felt that the terminal device is the most important component of the prosthesis; just as the hand is to the normal upper limb. Whenever possible, a prosthetic hand should be preferred to a hook terminal device, in consideration of the individual's social-psychological needs. The individual's social-psychological needs must be of primary concern initially and must be considered before vocational needs can be effectively addressed. This is also true when managing children and is especially important in addressing the social-psychological needs of parents of children born with congenital upper limb complete hand deficiencies.

If the vocational or avocational needs clearly indicate the need for a hook terminal device, this must be clinically tested and proven, or the individual must personally desire the hook terminal device. This has been found to be true for all levels of upper limb deficiencies involving the hand, wrist, elbow, and shoulder. This criteria is obviously not the case for everyone with an upper limb deficiency; however, it is felt to be true for the majority and especially those with unilateral upper limb involvement.

The prosthetic hand should be thought of as an assistive device to the sound limb, just as the nondominant normal hand is to the dominant normal hand. Many have felt it is important to be able to perform fine motor prehension activities with a prosthetic terminal device and this has been a major argument in favor of hook terminal devices. The fact is, the majority of those individuals with upper limb deficiencies are unilaterally involved and do not use their prosthesis for fine motor prehension activities; just as a non-involved individual does not typically utilize the nondominant hand for such activities. The prosthetic terminal device is most important for gross prehension activities, to hold and stabilize objects while the sound limb performs the fine motor prehension activities. An electrically powered hand terminal device, with adequately controlled functional prehension, best serves this need for the majority of an individual's activities of daily living. It is important to remember that we live in a world made for hands, and most everything we encounter in our activities of daily living is made to be hand held.

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¹⁵ Otto Bock "Griever" is a registered trade mark of the Otto Bock Orthopedic Industry, Inc., Duterstat, West Germany/Minneapolis, Minnesota.

¹⁶ Hosmer Dorrance is a registered trade mark of the Hosmer Dorrance Corporation, Campbell, California.

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