Clinical Prosthetics & Orthotics

Upper Extremity Prosthetics

Volume 10, Number 2 Spring, 1986


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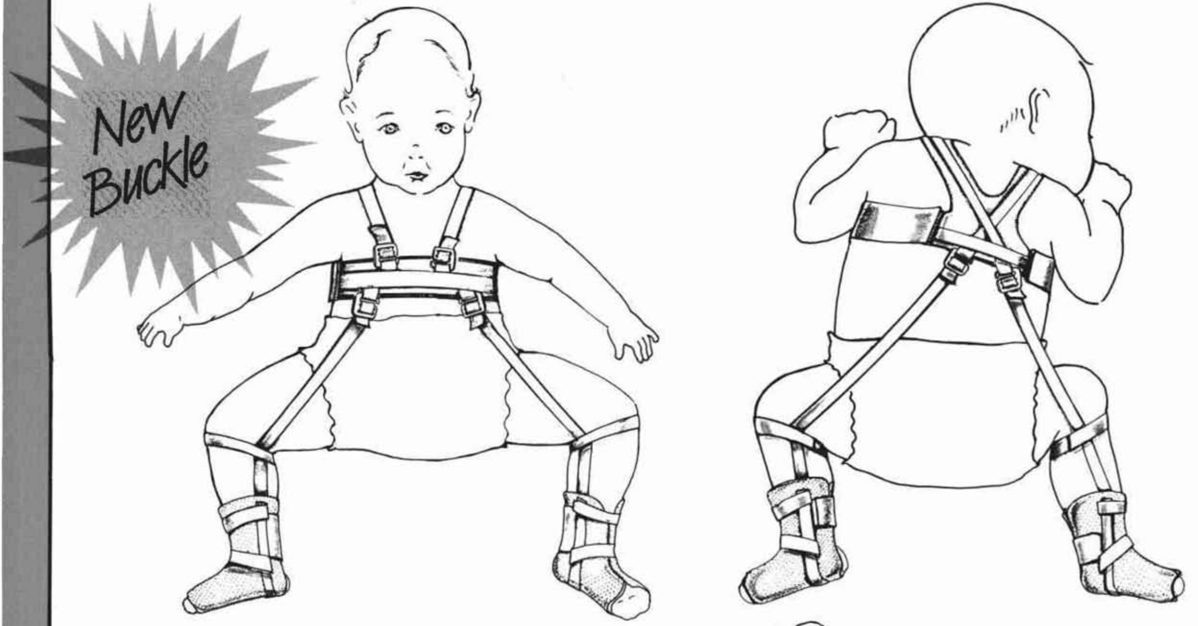
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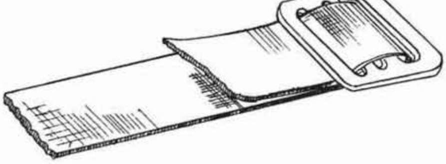

Clinical Prosthetics & Orthotics

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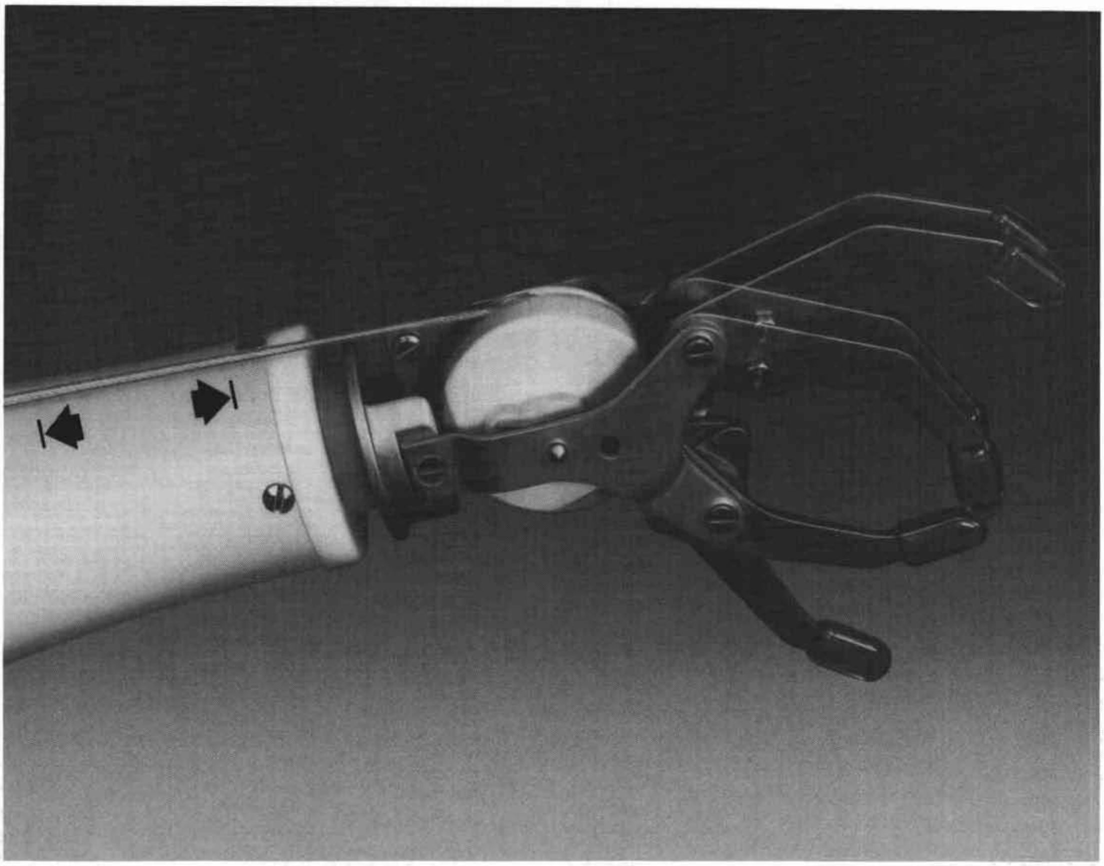

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Letters to the Editor

Dear Editor,

In John Sabolich's article (CAT-CAM: Introduction and Basic Principles), published in *C.P.O.* volume 9, number 4, I have been listed in the acknowledgments as a perpetrator in and supporter of this project. I do not understand the nature of this acknowledgement to the extent that it implies a direct, theoretical, and practical contribution which I have not made.

In the second paragraph of the "Future Plans" section of the article, Mr. Sabolich has suggested a more radical "locking" or encompassing of the ischial tuberosity. The extent that this radical design differs from the socket illustrated in figure 9, and from the general RML (reduced medial-lateral design) principles previously suggested by Ivan Long, CP, is the extent to which I hold a contrary point of view. I have followed Mr. Sabolich's suggestions regarding increased contouring around the ischial tuberosity above and beyond the original NSNA concept, and have found this consistently non-workable. If the medial shelf is brought significantly medially and superior to the medial aspect of the ischial tuberosity, the trimline of the socket will crowd the anus during standing and weight-bearing, and will apply unacceptable pressure to the ischium and ramus while sitting.

I share Mr. Sabolich's and Mr. Long's point of view that the essence of partial thigh prosthetics rests in medial-lateral control and stabilization of the femur and pelvis, and that anterior-posterior control and stabilization characteristic of RAP (reduced anterior-posterior design) sockets is secondary. I encourage practitioners to incorporate this concept in the prosthetic management of partial thigh amputation surgery.

Sincerely yours,
Michael Wilson, B.S., C.P.O.

Dear Editor,

After receiving a copy of Mike Wilson's letter addressed to the Editor of *Clinical Prosthetic and Orthotics,* I considered the possible reasons why Mike has had problems with getting the ischial tuberosity and ramus in the socket proper to more adequately capture this valuable skeletal element. After receiving this letter, I phoned Mike.

We concluded that the reason might possibly be that he is not utilizing the total flexible brim concept which is more forgiving of possible pressure to the anus. The total flexible brim lets one be more aggressive with the ischial ramus area since the anus lies medial to the ischial tuberosity and at the midline of the body. The fact that the brim is thin also reduces bulk in this area. I and several other prosthetists with whom I work closely have had no problems with pressure in this area.

Since Mike tried the SCAT-CAM method as the result of telephone conversations rather than an actual fact to face practical hands-on transfer of information, I feel that much communication was lost that might have solved the problems he has encountered. This points up again that if a very high caliber of prosthetist such as Mike Wilson has problems, then prosthetists should seriously consider hands-on extensive instructural courses rather than replying on phone or casual conversations to implement complicated concepts. It should be remembered that SCAT-CAM embraces much more than just greater control of the ischial tuberosity, but also an AP locking effect on the femur itself, capturing of this bone in a triangular lateral trough.

I apologize if I implied that Mike and I agree on every aspect of the article I wrote. I was simply trying to give him credit for the many years that we collaborated our experiences in CAT-COM procedures and I felt he deserved credit.

The reason I have gone to a more aggressive approach to ischial containment is that I have had medial proximal soft tissue pressure problems when I did not have the ischial tuberosity well contained, especially in women and soft residual legs. This, of course, was due to the fact that if one does not have the tuberosity-ramus adequately contained, then the medial proximal soft tissue must bear the entire counter force to maintain adequate femural stabilization when the contralateral side is in swing phase.

John Sabolich, C.P.O.

Clinical Prosthetics and Orthotics, Vol. 10, No. 2, pp. 55–56

Rehabilitation: Goals or Shoals?

by Samuel A. Weiss, Ph.D.

In the pre-1960 period, the dominant aim of rehabilitation personnel working with amputees was the restoration of the amputee to maximum pre-morbid functioning. Lower-extremity amputees had little choice. A degree of prosthetic restoration consonant with some ambulation was necessary in order to provide some independence and self-sufficiency. Upper-extremity amputees were also presented with the goal of maximum functional restoration. While comfort and cosmesis were given their due, the explicit dogma was restoration to as much pre-morbid functioning as was mechanically feasible. The writer remembers the dictum of one expert, "a hook for work and a functional, cosmetically acceptable hand for recreation." An upper-extremity amputee might plead that he had learned to "manage" with his intact hand and was, therefore, interested only in an acceptable, passive appendage to fill a sleeve and allow him to mix in society inconspicuously. All in vain. He was regarded virtually as a self-denigrating quitter who was undermining his own livelihood, as well as a heretic in our work ethic society. To an appreciable extent this pejorative judgment was then true because in the pre-60's period there were, as yet, no "Great Society" programs which were to introduce alternative means of financial support. To a worker in the pre-60's period, functional restoration was the life raft which prevented him from sinking unless he was content to gasp through life on the dole and undergo the psychological angina pains of conscience.

When the "Great Society" programs were introduced, the work ethic, for better or worse, was to a considerable extent attenuated. Moreover, improvements in technology, reduction in the need for manual labor, and the proliferation of new types of jobs allowed amputees better viability because an entirely intact body was no longer necessary for self-support. Yet the dogma of total, functional restoration hovered in the consciousness of rehabilitation personnel. While society in the 60's became more interested in immediate self-gratification, rehabilitation experts, who had been trained to make men and things "work," retained their pure work ethic consciousness. Physicians desired that body functioning become normal; physical and occupational therapists knew that somatic improvement required vigorous exercise; psychologists believed in maximum self-realization; and engineers and prosthetists yearned for more powerful mechanisms to provide normality. The old-fashioned work ethic had, to a considerable extent, been replaced by a new pay ethic—more pay for less work and poorer service for higher fares. We rehabilitation workers, however, remained aloof on Mt. Sinai, in our pristine innocence, proclaiming the Ten Commandments to stiff-necked and stiff-limbed rehabilitants who preferred to dance around the golden calf of entitlements.

While recent political changes are striving to restore the work ethic to its former glory, the average person does not readily relinquish the desire to be presented with a set of options from which to choose. Attempts to enforce one set of standards or goals equally on all rehabilitants are doomed to fail.

Perhaps some examples of individual personality types I have encountered among amputees seen at NYU Medical Center and in private practice will illustrate the distinctive rehabilitation goals of different people.

CASE STUDIES

''A'' applied as a volunteer experimental prosthesis wearer. He had lost his non-dominant hand in an accident. During the interview, he impressed the writer with his stability. His psychological test profile was exceptional. The writer remembered ''A's'' well-executed and orderly Bender-Gestalt drawings and recommended him for a position at an agency where he is still employed. I never saw ''A'' wear anything but a hook when I visited the agency. He never attempted to emphasize his functional restoration goal. His good-natured and efficient performance with his hook spoke for itself. In my conversations with him on various topics, both vocational and personal, he would often become enthusiastic and wave his hook in front of my eyes to emphasize a point. I never ''saw'' the hook. His efficiency and personality preempted his amputation. All I saw was the person, not the disability.

''B'' was a double hand amputee volunteer. He was gainfully employed and wished to contribute to amputee rehabilitation. ''B'' underscored his conviction of absolute normality. He wished to demonstrate this to the staff by maneuvering his two prostheses and a sheet of paper to pick up a dime. He failed a number of times before succeeding, but the note of triumph in his eye compensated for the failures. ''B'' had convinced himself that he was normal and who were we to question him? He was gainfully employed, easy to deal with, and adjusted to his environment. His ''super normality'' was irrelevant since this illusion did not interfere with his various roles as a human being.

''C'' did not require functional restoration for his work. He wore an active, cosmetic hand because of his desire not to attract attention to his disability, and his prosthesis was useful for minor tasks. He refused to wear a hook for more inclusive manual functioning. His goal was mainly cosmetic. The limited function of the type of prosthetic hand then available was satisfactory to him.

''D'' wore a passive hand with no function. His main goal was to appear normal to the casual observer. To some work ethicists on our staff ''D'' was regarded as an unactualized individual, but ''D's'' goals were not the attainment of complete self-actualization, but merely a wish to blend with the crowds on the trains and street.

''E'' was a prosthesis wearer interviewed for phantom limb experience. Our explanation as to the potential value of the study was misinterpreted by him. He somehow gained the impression that further knowledge about phantom limb sensation and neurological functioning would enable scientists to grow a new, natural limb on his amputation stump (as is the case with some lower animals). He nervously inquired ''Will I lose my pension?'' This veteran was so satisfied with his prosthesis (and disability pension) that he seemingly rejected the ultimate restoration, a reborn limb!

''F'' lost his left hand in an accident. He absolutely refused to wear his prosthesis because of discomfort and because he functioned adequately with his intact limb. His empty sleeve was virtually ''filled'' by his outgoing and warm personality. His interpersonal behavior was the best camouflage for his amputation. He was an amputee who had the best prosthesis of all—his total personality. Unfortunately, he later died, following a disease unrelated to his amputation. The large funeral chapel was packed with people from numerous walks of life.

Each of these individuals represents a different personality type with distinctly different goals and levels of achievement, satisfactory to each if not to rehabilitation personnel.

My experience as a psychologist has convinced me that different patients are ready for varying levels of growth. Some patients who have made appreciable, but not optimal gains in psychotherapy will leave. A percentage of these will return months or years later, after they have assimilated their original gains, to strive for a higher level of achievement. The choice must be voluntary.

AUTHOR

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Clinical Prosthetics and Orthotics, Vol. 10, No. 2, pp. 57–65

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 Murphy[9] 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

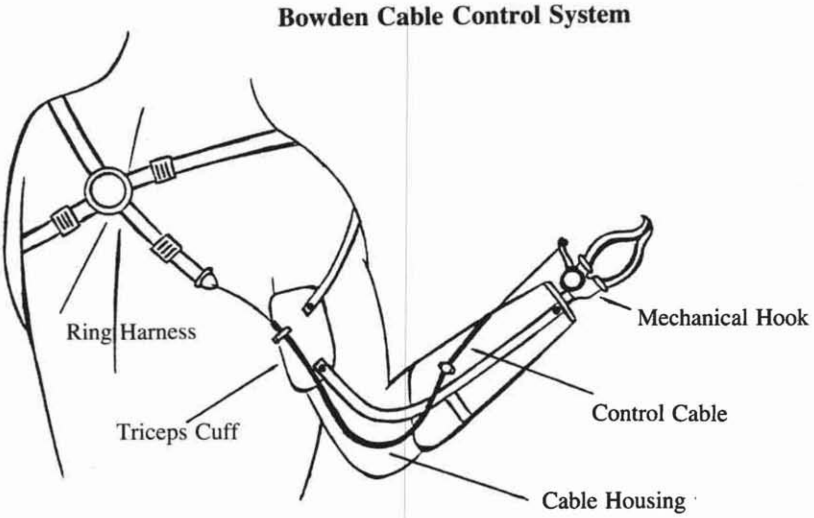


Figure 1. **Illustration of a typical conventional body powered Bowden cable controlled below-elbow prosthesis with a mechanical hook terminal device actuated by "gross" body movements.**

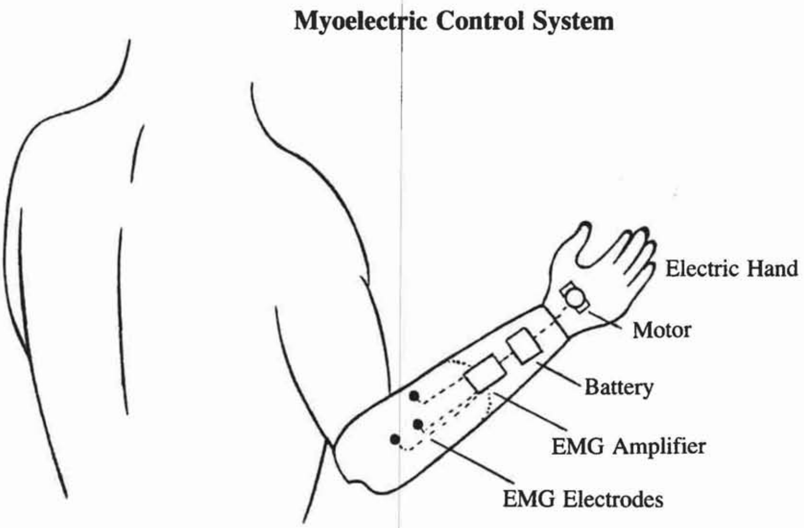


Figure 2. **Illustration of a typical electric powered, myoelectrically controlled below-elbow prothesis with an electromechanical hand terminal device actuated by EMG potentials.**

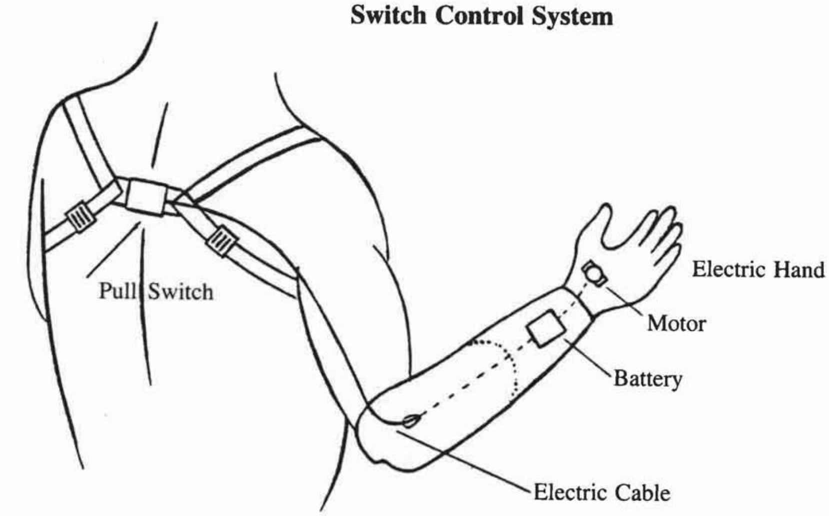


Figure 3. Illustration of a typical electric powered switch controlled below-elbow prosthesis with electromechanical hand terminal device actuated by "fine" body movements.

(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.

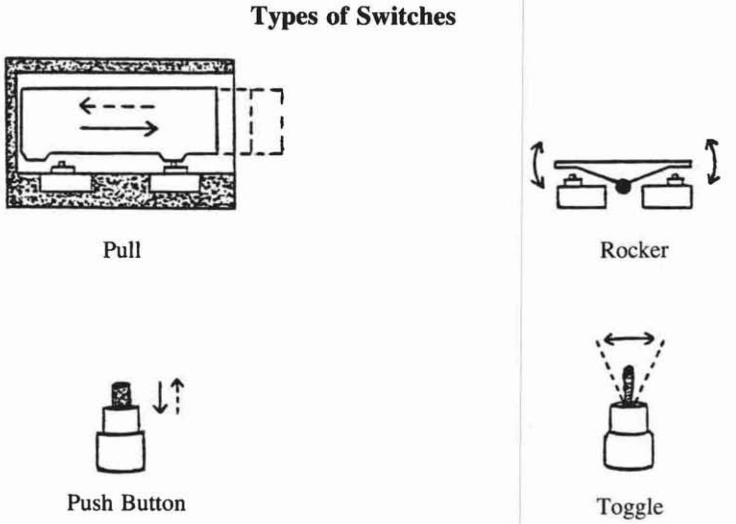


Figure 4. The actuation characteristics of a typical pull, rocker, push button and toggle switch are illustrated. Switches are generally designed to produce one or more functions such as opening and/or closing of an electromechanical terminal device. (a) Pull (sliding) switch for actuation of two functions; (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 Wright[6] 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

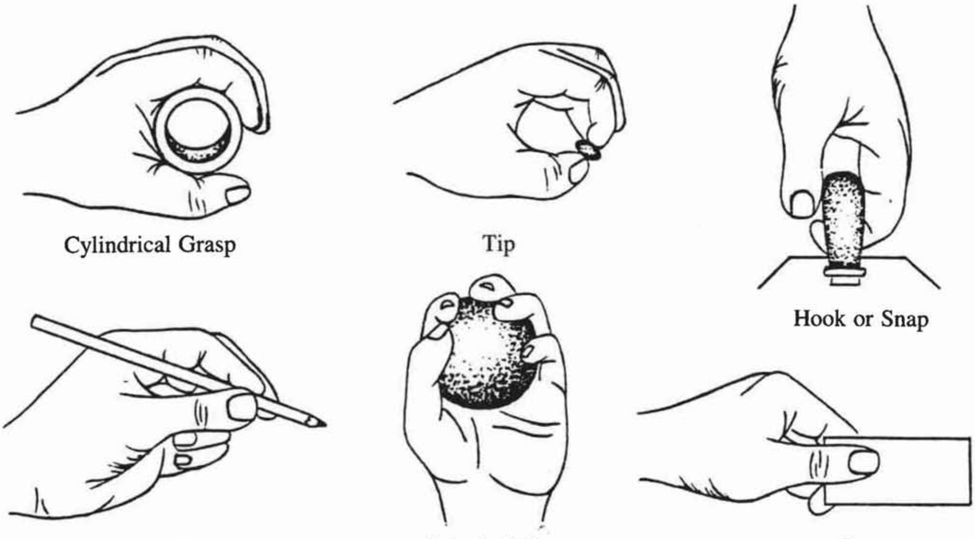
The introduction of electric powered hands into clinical practice in the early 1960's brought about a new era in prosthetics. Acceptance of these "electric hands" by the American prosthetics profession was much slower than in the European countries where they were initially developed. They are, moreover, 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 mechanical 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 "Griefer"[15] which was introduced in the U.S. in the late 1970's. As an electric powered ter-

Types of Prehension



Cylindrical Grasp

Tip

Hook or Snap

3 Jaw Chuck

Spherical Grasp

Lateral

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

Table 1.

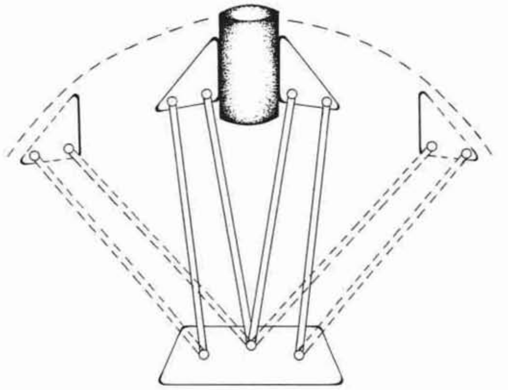


Figure 6. This diagram illustrates the angular relationship of the prehension surfaces and the object being held, utilizing a multi-axis prehension design approach, such as in the Otto Bock "Griefer."[15]

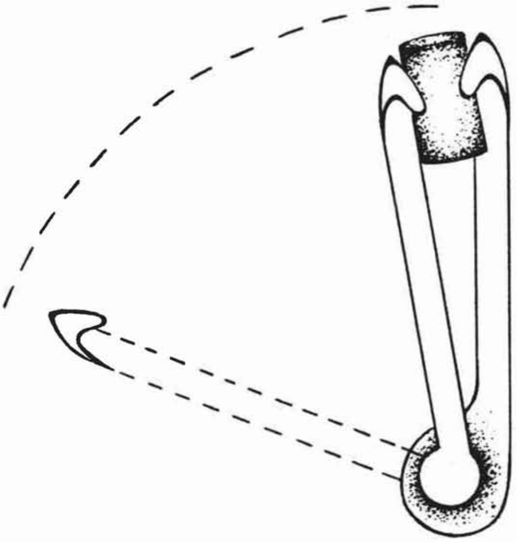


Figure 7. This diagram illustrates the angular relationship of the prehension surfaces and the object being held, utilizing a single-axis prehension design approach, such as in the Hosmer/Dorrance[16] mechanical hook series.

minal 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 "Griefer," on the other hand, is heavier than the heaviest stainless steel mechanical 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		
	Based on 300 Subjects	
DEVICE	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 "Griefer" 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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Upper Limb Powered Components and Controls: Current Concepts

by John W. Michael, M.Ed., C.P.O.

In order to review the current offerings in powered upper limb components, it is necessary to agree upon certain standardized terms. The following suggestions, based upon a survey of the existing literature, are intended to help insure we are all speaking a common language.

Practitioners with strong opinions regarding alternate definitions are encouraged to publish their views as well. It is critical that we agree upon some definition; which particular version is of much less importance.

The focus of this paper will be on externally powered prostheses—specifically, those that are electrical in nature. The opposite concept is the familiar body powered prosthesis, which is powered by muscular action and transmitted from remote body locations.

Many prosthetists have some experience at the below-elbow level with the components produced by Otto Bock, and assume they have fitted myoelectric devices. Technically, that is not completely correct.

The MyoBock system is most accurately termed "Myoswitch" control. This is a much simpler version than true myoelectric control. In the Otto Bock system, the residual myoelectric signal does not directly control the terminal device. Instead, the patient must generate a sufficiently strong signal to cross a threshold, which triggers an electronic switch.

A good analogy would be that of sound-activated devices which can be installed in lieu of a standard light switch. Clapping one's hands turns the light on. If the clap is too faint, nothing will happen, but an extremely loud clap has no more effect than one just loud enough to trigger the switch. This is sometimes described as "digital control."

This approach does not allow proportional control. That is, the light is either all on, or all off. There is no in-between. Proportional control is provided by a rheostat, which allows one to gradually dim or brighten the lights as the mood dictates.

Proportional control is, in this author's opinion, the key distinction in true myoelectric systems. The below-elbow system marketed by Fidelity Electronics is an example of such a design. In this version, a mild myoelectric impulse causes a slow, gentle movement of the hand, while a strong impulse creates a rapid, powerful movement of the hand. Many authorities feel this is the most physiologically natural control, and offers the greatest degree of prehension control as well.[7]

A good analogy is the accelerator in an automobile, which allows proportional control of the speed of the vehicle. Imagine a switch-controlled car with the throttle either at idle or wide open! Otto Bock has a very clever solution to this dilemma: the automatic transmission.

The MyoBock prosthesis has two speeds: a quick, gentle motion when opening and closing, and a slow, powerful motion once the fingers grip an object. This might not be a reasonable solution for the auto industry, but it has proved to be clinically acceptable in prosthetics.

The third available control mode is pure Switch Control. This is the least expensive approach and generally requires less bulky electronics. For these reasons, it is often used in juvenile below-elbow designs (for example, Variety Village). It also does not require any myoelectric signals, which can be helpful when control sites are limited or unavailable.

Switch controls come in three basic varieties.

1) **Rocker Switches** are similar to the on-off control for stereo equipment, and are sometimes used where a mobile acromion is present.
2) **Button Switches** are also adaptable for acromion control, for use with phocomelic digits, and any other mobile body parts. They are the electronic analogue of mechanical nudge control.
3) **Pull Switches** are useful when harness control is desired. Most are multipositional, where initial excursion will cause one motion, and further excursion the opposite motion. These are somewhat analogous to the alternating lock used in the conventional elbows with one motion controlling two or more functions.

These are simply the most common types; literally hundreds of variations can be obtained from electronic supply stores. On rare occasions, they can be arranged in a piano keyboard array, allowing several degrees of freedom to be controlled from one location.[5]

Another set of related concepts are "site and state."[12] Site refers to the number of distinct muscle signals required. Thus, the original Myobock system was a "two site" version, requiring one myosignal for hand opening and a separate signal for hand closing.

The University of New Brunswick (UNB) was one of the first groups to develop a commercial system that required only one myosignal. This is particularly advantageous when dealing with young congenital below-elbow patients. Very often they can only generate one mass contraction in the residual limb, and space considerations alone may preclude more than one electrode. UNB termed their system "Single Site/Three State" control. The term "Three State" means that the myopulse both opens and closes the hand; the "third" state is "off."

In the last couple of years, Otto Bock has introduced their version of this concept. As in the UNB design, it is a digital "Myoswitch." A quick, hard myopulse causes the hand to open, while a slow, gentle myopulse causes closure. Bock calls this "Double Channel Single Site" control. "Double Channel" accurately identifies the capabilities: one channel opens and the other closes.

Unfortunately, the word "channel" has established meanings in other fields that may be a source of confusion. For maximum clarity, the term "Function" is probably preferable.[2] This has a clear intuitive meaning. Thus, the system just described would be termed a "One Site-Two Function" system.

With suitable changes in the terminal device electronics, Otto Bock can offer what they term "Grip Force" control which is a kind of psuedo-proportional control. In this application, the patient can use the quick, strong pulse to automatically downshift the transmission, thereby increasing the grip strength.

A logical extension of this approach is Bock's "Four Channel" design. One electrode controls terminal device opening and closing while the other controls electric wrist pronation and supination—four distinct functions.

Clearly, if suitable sites could be found, additional degrees of freedom could be controlled using existing technology. Experience has shown, however, that this is rarely feasible.

In the above-elbow realm, the developers at Motion Control argue strongly that proportional control is the ideal. Therefore, they avoid the digital control mentioned thus far. Yet, they have developed a system permitting only two muscle sites to operate elbow raising and lowering, as well as terminal device opening and closing. Thus far, their solution is unique in the field of powered components.

The Motion Control design uses a very clever method of electronic switching to separate elbow and terminal device functions. When the arm is first powered on, the two muscle sites proportionally control elbow flexion and extension. (In an ideal candidate, biceps and triceps are the remnant muscles yielding physiologically normal control as well.) Whenever the elbow is in motion, things remain in this mode.

However, if the elbow is stopped in a flexed position and held steady for a moment, the arm "senses" that one intends to perform a grasping function. It then locks the elbow and automatically switches itself into a "grasping" mode. The same two sites now control proportional, bidirectional grasp. To return to the "elbow" mode, the patient co-contracts in a specific fashion. The co-contractures cancel each other out so that no motion of the TD occurs, and the electronic switch senses this and changes modes.

This strategy can be termed "Sequential Control", and is directly analogous to the familiar mechanical elbow joint where the same shoulder motion moves first the elbow and then the terminal device.

The most sophisticated control for a high level amputee would be Simultaneous Proportional Control. Northwestern has done some fascinating work in this area,[4] as has the Illinois Institute of Technology and others.[6] This would be the most natural-appearing motion, since our biological arms move through multiple degrees of freedom simultaneously with every gesture.

However, there are numerous technical and control difficulties with this approach, and all seem to be far from commerical production right now. One major issue is control site availability. Even if one conceives of an arm offering twenty simultaneous degrees of freedom, where on the high-level amputee are twenty independent controlable sites to be found?

Much of the current research involves reading data from a few sites and using computer algorithms to simulate multi-degree control.[15] Most currently require a mainframe computer to process the data in real time, but perhaps the future will see microchip processors with these capabilities built into upper limb devices.

But, for now there are less spectacular components to choose from. What follows is an overview of currently available hardware. Specific details change almost weekly; contact the manufacturer for the latest updates.

The final caveat is: the ideal system does not exist. All the components have strengths and weaknesses. When prescribed correctly, one can achieve very satisfying results. When used inappropriately, failure is the inevitable result. As prosthetists gain more collective experience and confidence in the realm of powered upper limb prosthetics, perhaps we can learn to "mix and match," as we do in body powered fittings, to maximize the benefits for our patients.

OTTO BOCK

In the United States, Otto Bock is viewed as the "father" of electrically controlled prostheses. Although all their current designs are digital controls, they offer one of the largest arrays of interchangeable electric components of any manufacturer. At this time, all Otto Bock components are designed for below-elbow use, although they are equally adaptable for higher levels.

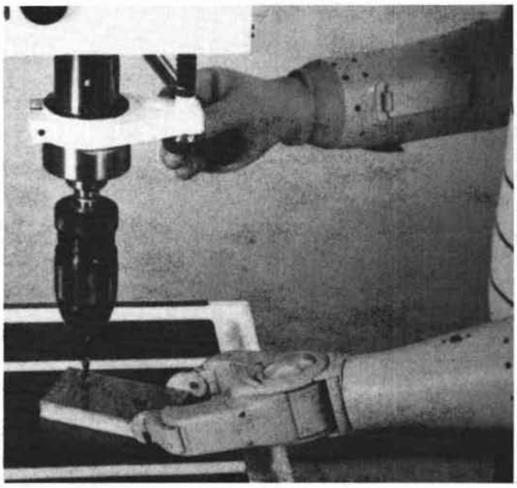

Figure 1. Otto Bock electric hand and electric hook (Greifer). Bilateral powered fittings can be successful in carefully selected cases. ***(Courtesy of Otto Bock Industries.)***

One ramification of this is that since 1976, they have been using six volts as their standard. (Twelve volt terminal devices can be obtained for use with other manufacturers' systems.) Six volts offers lower battery weights while still providing adequate power for terminal device operation.

Otto Bock's battery is a relatively small package, easily interchangeable, but for slow recharge only. Their "Griefer" is the only adult-sized powered hook currently on the market, and it readily interchanges with their adult hands. They also have the only electric wrist rotator currently available.

They currently offer four hand sizes, for older children, teens and ladies, standard adult, and large adult males. These have become the *de facto* standard in the industry; virtually every other company can interface their system with a MyoBock hand. An assortment of wrists are also available.

All their electrodes are digital, myoswitch types, as already discussed. They offer optional floating electrode mounts for cases where a change in residual limb volume is anticipated.

Since their terminal devices are set up for myoswitch control, it is relatively easy to use regular switch control as well. Otto Bock offers both a rocker switch and a harness pull switch version.

With their typical attention to detail, a complete set of *Technical Information Bulletins*, courses, and specialized tools are available. Otto Bock also offers a variety of well thought out accessories, such as a tweezer (pincer) for the hands, blank Griefer tips for machining custom gripping surfaces, and so on.

VARIETY VILLAGE

Variety Village components complement Otto Bock's nicely, as they are targeted for smaller children, and include a powered elbow. All their components are switch controlled.

They market three switch types: a toggle for phocomelics, a button type, and a pull strap version. In addition, their elbow can have the pull switch built in, or be ordered for use with remote switches.

Their elbow is available in either 6 or 12 volts; their hands are 6 volts exclusively. Their smallest hand (for 2–6 year olds) has just been redesigned. Although similar to the Swedish hand, it is three ounces lighter.

Their original hands (Models 105 and 106) have been discontinued. Research is currently underway to create the smallest electric hand yet available: thirty percent smaller than their VV2-6. Only prototypes exist at this time, however.

They market several battery configurations, including a "Battery Saver Circuit" designed to prevent children from draining the electrical charge by stalling the motor. None are of the quick-charge variety, however.

HUGH STEEPER LIMITED

Steeper is the British corporation responsible for upper limb prosthetics in the United Kingdom. They have recently announced the availability of powered hands for small children.

These are now being distributed by Liberty Mutual in the United States. The sizes complement the Swedish hand, in that the Steeper hands are a bit larger than either Swedish version. Sometime in 1986, they will probably offer a larger hand for the early teen.

Figure 2. Variety Village VV2-6 electric hand: the smallest and lightest powered hand commercially available. ***(Courtesy of Variety Village Electrolimb Production Centre.)***

These are 6 volt, switch controlled devices for the most part. However, Steeper also offers a "Servo-Control" option. This is a unique kind of proportional switch control: the harder the child pulls on the switch cable, the stronger the grasp. With minor adaptations (which Liberty Mutual will make), they can also be controlled by Otto Bock or UNB myoswitches.

SYSTEM-TEKNIK

System-Teknik is a Swedish company with two children's hands on the American market. Production rights for these hands have just been aquired by Steeper, so design changes can be expected. Liberty Mutual is the American distributer.

including the battery. Therefore, it is self-contained with minimal risk of wire damage. However, this also prevents fitting very long residual limbs and concentrates all the weight at the distal portion of the prosthesis.

Long residual limbs require the use of a switch-controlled version, thus eliminating the wrist module. This hand is sized for adult males only (7¾).

Fidelity also offers a switch-controlled elbow (again, in adult size only). This is an 8.75 volt system, with its own built-in battery pack. It utilizes an exoskeletal soft foam forearm set-up.

HOSMER DORRANCE

As the "grandfather" of upper limb prosthetics in North America, Hosmer is in a unique position to develop a system of powered components. Their basic philosophy has been to focus on light-weight, straightforward, relatively inexpensive designs.

For years, they have offered the "Michigan Hook," which is the familiar child's hook, closed by a rubber band, but opened with a small motor winding a string. Last year, they announced an adult version of this concept, called the "NYU Prehension Actuator." This is a conventional forearm set-up with an electric "winder" included. It can be mated with a variety of voluntary opening hooks, using up to five rubber bands or so. Although it is currently switch-controlled, a single-site "MyoPack" will soon be available, offering the option to convert both the Michigan Hook and the Prehension Actuator to myoswitch control.

Hosmer has also released the "NYU Hush" elbow. This is unique in several respects. First, it is designed to permit the familiar mechanical elbow to be substituted for the electric one, even in a finished prosthesis. Secondly, they elected to use standard "grocery store" nickel cadmium batteries to power the system. This dramatically reduces the cost to the consumer. Four AA NiCad cells yield a 5 volt system; if desired, five can be used for 6.25 volts. Either version is rechargable with an inexpensive "dimestore" trickle charger.

Hosmer hopes to offer in 1986 a "Free Swing" option for their elbow, which could be retro-fitted to existing units in the field. Once the elbow attains full extension, it would automatically enter the free-swing mode. In addition to enhancing the dynamic cosmesis during ambulation, this may offer some special benefits to bilateral patients. Those who depend on the prosthesis for feeding would then have the option of resting the forearm against the table and using "body English" for elbow flexion.

Figure 6. The Prehension Actuator provides powered opening for a variety of conventional hooks. Closing force is controlled by the number of rubber bands applied. *(Courtesy of Hosmer Dorrance Corporation.)*

Finally, it can be used with either an endoskeletal or exoskeletal forearm, as desired. This is a switch-controlled elbow, again keeping the costs lower, which is currently available in a large and medium size, corresponding to the familiar E-400 and E-200 mechanical elbows. Thus, it is suitable for many older children as well as adult men and women.

Hosmer's switches have recently been redesigned to increase reliability. In addition to the familiar button and harness switches, they also offer a "Three-Position Harness Switch," permitting one control motion to operate both elbow flexion-extension and the NYU Prehension Actuator.

The latest addition to the Hosmer line is an adult male (7¾) switch-controlled hand to complement their elbow. This also uses readily available NiCads for 5 or 6.25 volt operation. The "Synergetic Hook" designed by Dr. Dudley Childress at Northwestern University [3] should be available sometime in 1986. Beyond change in residual limb volume is anticipated.

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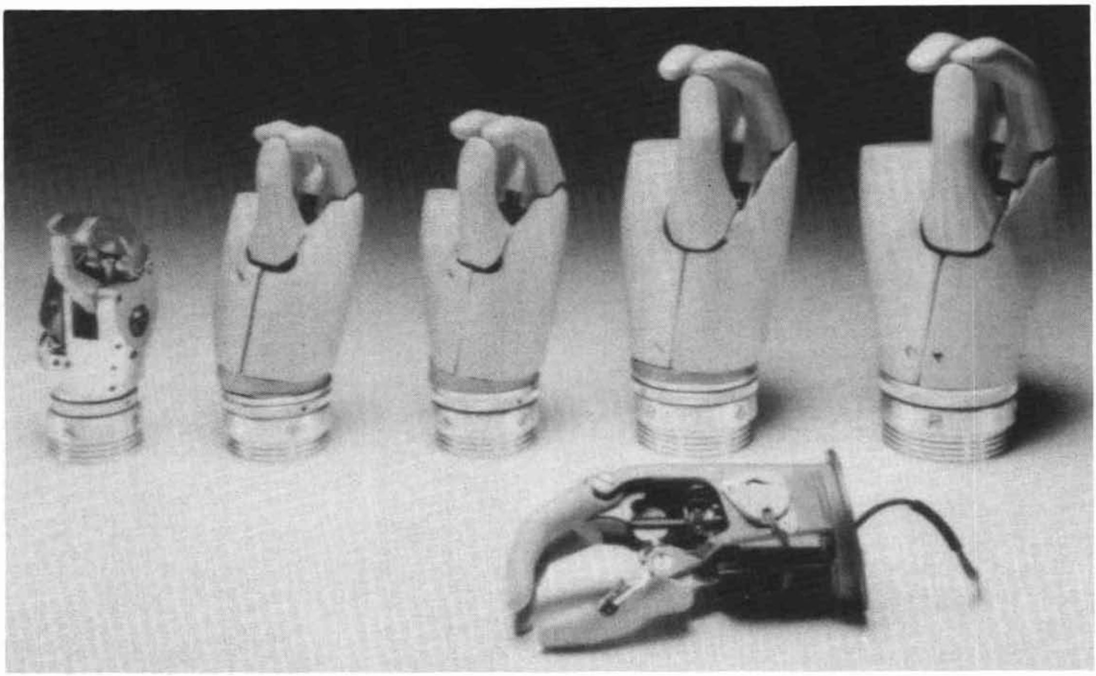

Figure 3. Electric hands imported by Liberty Mutual. The smallest is the System-Teknik from Sweden; balance are Steeper hands from England. ***(Courtesy of Liberty Mutual Research Center.)***

At the present time, two Swedish hands are available: one for 2–6 year olds and another for 5–9 year olds. Both are 6 volts, and they use the same size forearm laminating ring for easy interchange.

They can be controlled by either the UNB or Otto Bock myoswitches and switch controls. UNB designed its batteries to be mounted within the forearm shell. If space permitted, Otto Bock's could be used as well.

To simplify the fitting procedure, Liberty Mutual plans to offer a special wrist unit option, containing all necessary electronics. Planned for use with both the System Teknik and Steeper hands, it will come in one version containing the battery supply, and a shorter version for longer residual limbs with remote battery mounting.

UNIVERSITY OF NEW BRUNSWICK

All UNB products are available through Liberty Mutual in the United States. When ordering their "Single Site" system, there are three options for battery placement: built-in to the electronics package, mounted inside the forearm section, or mounted externally. As is the case with all manufacturers, you must purchase their particular myotester/trainer to properly adjust their system.

In addition, UNB offers a unique single site system with built-in sensory feedback. To aid in myotraining small children, they also market a "Toy Controller," which can be adapted to run with Otto Bock electrodes as well.

FIDELITY ELECTRONICS

Fidelity Electronics distributes the proportional below-elbow system originally developed at Northwestern University. At one time the United States Manufacturing Company also carried these components, but Fidelity is currently the sole source. This is sometimes referred to as the "VANU" hand.

Several things are unique about this product. First, it is a 12 volt system. Secondly, all the electronics are located in a "wrist module,"

Figure 4. Variety of powered components supplied by Liberty Mutual, including the UNB Toy Controller. *(Courtesy of Liberty Mutual Research Center.)*

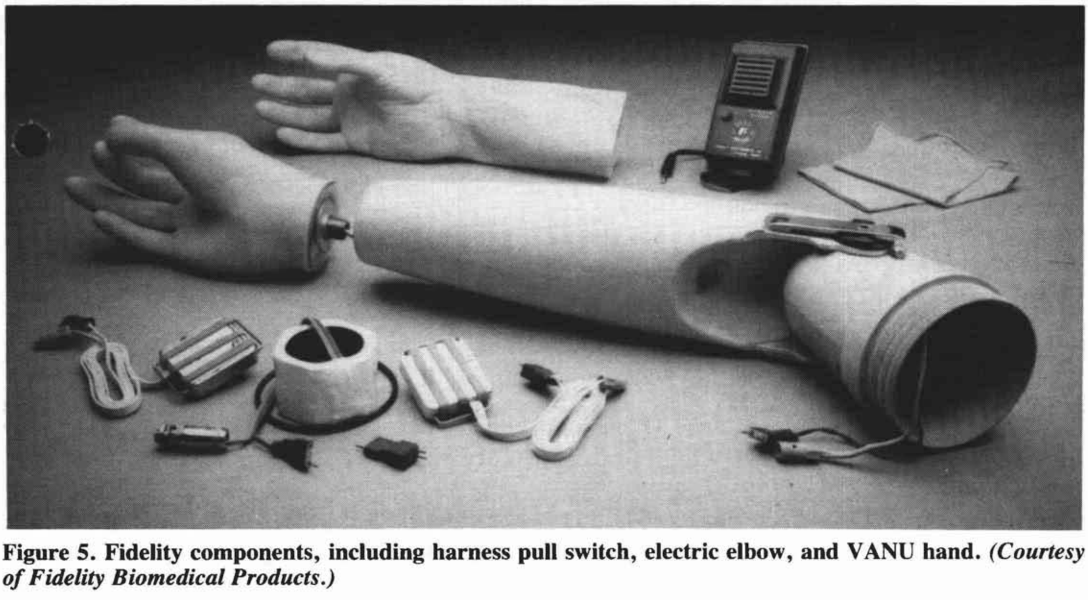

Figure 5. Fidelity components, including harness pull switch, electric elbow, and VANU hand. *(Courtesy of Fidelity Biomedical Products.)*

including the battery. Therefore, it is self-contained with minimal risk of wire damage. However, this also prevents fitting very long residual limbs and concentrates all the weight at the distal portion of the prosthesis.

Long residual limbs require the use of a switch-controlled version, thus eliminating the wrist module. This hand is sized for adult males only (7¾).

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As the "grandfather" of upper limb prosthetics in North America, Hosmer is in a unique position to develop a system of powered components. Their basic philosophy has been to focus on light-weight, straightforward, relatively inexpensive designs.

For years, they have offered the "Michigan Hook," which is the familiar child's hook, closed by a rubber band, but opened with a small motor winding a string. Last year, they announced an adult version of this concept, called the "NYU Prehension Actuator." This is a conventional forearm set-up with an electric "winder" included. It can be mated with a variety of voluntary opening hooks, using up to five rubber bands or so. Although it is currently switch-controlled, a single-site "MyoPack" will soon be available, offering the option to convert both the Michigan Hook and the Prehension Actuator to myoswitch control.

Hosmer has also released the "NYU Hush" elbow. This is unique in several respects. First, it is designed to permit the familiar mechanical elbow to be substituted for the electric one, even in a finished prosthesis. Secondly, they elected to use standard "grocery store" nickel cadmium batteries to power the system. This dramatically reduces the cost to the consumer. Four AA NiCad cells yield a 5 volt system; if desired, five can be used for 6.25 volts. Either version is rechargable with an inexpensive "dimestore" trickle charger.

Hosmer hopes to offer in 1986 a "Free Swing" option for their elbow, which could be retro-fitted to existing units in the field. Once the elbow attains full extension, it would automatically enter the free-swing mode. In addition to enhancing the dynamic cosmesis during ambulation, this may offer some special benefits to bilateral patients. Those who depend on the prosthesis for feeding would then have the option of resting the forearm against the table and using "body English" for elbow flexion.

Figure 6. The Prehension Actuator provides powered opening for a variety of conventional hooks. Closing force is controlled by the number of rubber bands applied. *(Courtesy of Hosmer Dorrance Corporation.)*

Finally, it can be used with either an endoskeletal or exoskeletal forearm, as desired. This is a switch-controlled elbow, again keeping the costs lower, which is currently available in a large and medium size, corresponding to the familiar E-400 and E-200 mechanical elbows. Thus, it is suitable for many older children as well as adult men and women.

Hosmer's switches have recently been redesigned to increase reliability. In addition to the familiar button and harness switches, they also offer a "Three-Position Harness Switch," permitting one control motion to operate both elbow flexion-extension and the NYU Prehension Actuator.

The latest addition to the Hosmer line is an adult male (7¾) switch-controlled hand to complement their elbow. This also uses readily available NiCads for 5 or 6.25 volt operation. The "Synergetic Hook" designed by Dr. Dudley Childress at Northwestern University [3] should be available sometime in 1986. Beyond that, work is ongoing for a myoelectric elbow and hand, but neither is presently available.

LIBERTY MUTUAL

Liberty Mutual is the world's largest workmen's compensation insurer. In the United States, one in fifteen workers is insured by this company. Thus, they have a dual motivation in offering sophisticated prosthetic components: both to help the clients they insure, and also to enable the clients to return to work, thus reducing the company's liability.

The 12 volt Liberty Mutual "Boston Elbow" can be categorized as a working man's device. And, in fact, it is one of the most durable electric elbows on the market. Although the original version was widely criticized because of the noise it made when operating, the current generation is markedly improved.

This is the only elbow offering dual battery chargers. Although Liberty Mutual recommends overnight "trickle" charging for longer battery life, they offer a "quick charge" option, in case the internal battery becomes discharged before the day is over.

This is also the only elbow designed to easily convert from proportional myoelectric control to switch control. Simply altering one wire makes the conversion. This can be very useful, for example, in fitting patients early with switch control, then later upgrading to myocontrol as their residual limb matures.

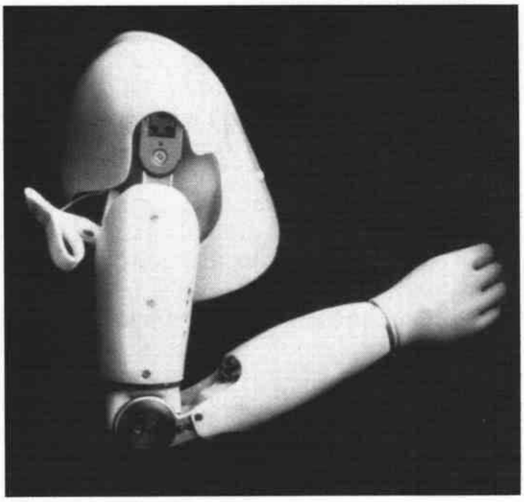

Figure 7. Boston elbow, combined with a Hosmer mechanical shoulder joint and Otto Bock electric hand. Combining various international components can enhance prosthetic restoration. (Prosthetic Design by John C. Hodgins, C.P.O.; *(Courtesy of Liberty Mutual Research Center.)*

As mentioned elsewhere, Liberty Mutual also distributes the UNB, System-Technik, and Steeper components.

MOTION CONTROL

Motion Control is marketing the powered elbow system originally developed by the University of Utah. In contrast to Hosmer's strategy, this group sought to offer the most technologically advanced components possible. Undoubtedly, they have succeeded in this goal.

However, most sophisticated does not necessarily mean best; simpler technology is often more reliable than state-of-the-art. Nevertheless, Motion Control has a unique addition to the prosthetic armamentarium.

Their electronic locking mechanism and Sequential Proportional Control have already been discussed. Originally designed for mechanical terminal device operation, this 12 volt elbow can also be ordered with an Otto Bock hand. In this case, however, Motion Control discards the electronics and substitutes their own, thus offering true proportional myoelectric control of the Otto Bock hand.

Of all the systems on the market, particularly above-elbow systems, this is the most "prosthetist friendly." All the inner components are modular and easily exchangeable in the field. The quick-change battery pack is built into the humeral section, but below the elbow axis. This permits fitting longer residual limbs than is possible with other systems, and means there are no external wires to fray and fail.

Further, this version offers by far the most adjustments to "fine tune" the elbow for a particular patient. There is a price to pay for this degree of technology, of course. In addition to being the most sophisticated, the Utah Arm is also by far the most expensive powered device available today.

It is now possible to add an Otto Bock powered wrist rotator to the Utah Arm, using a variety of control strategies, including UNB or Otto Bock's single-site electrodes, two-site electrodes, and assorted switches. If a mechanical terminal device has been used, the Utah Arm mechanism can be modified to provide

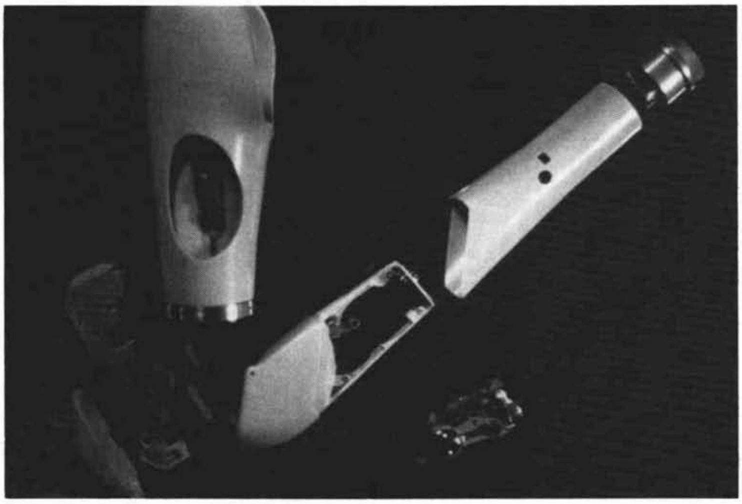

Figure 8. Exploded view of the Utah elbow. Highly modular construction facilitates servicing in the field. *(Courtesy of Motion Control, Inc.)*

dedicated proportional control of the wrist unit. Also, their highly sensitive myotester is finally a commercial reality.

Beyond that, Motion Control has just announced the availability, to prosthetists trained in the elbow fitting procedures, of a proportionally controlled below-elbow system, using Motion Control electronics to power an Otto Bock hand with 12 volts in a below-elbow prosthesis. Currently, this requires mounting two Otto Bock batteries, which can present some difficulties, although other battery sources can be utilized in selective cases.

Finally, and perhaps most significantly, Motion Control has become the first supplier to offer a rental program for myoelectric components. In marginal cases, if funding has been conditionally approved, the components can be rented on a monthly basis for about ten percent of the total cost. Most of the rental is applied toward purchase of the arm if the fitting proves successful; if not, the parts are returned to Motion Control.

SUMMARY

Our powered upper limb armamentarium is now surprisingly complete. Although one must select components from all over the world, it is possible to fit virtually any patient from two years old to adulthood with an externally powered prosthesis.

Otto Bock components remain the most widely utilized, and their hands and connectors are becoming the *de facto* standards in the field. Their own components are designed for below-elbow use, but are routinely adapted to higher levels. Otto Bock has chosen to develop a variety of myoswitch controls, but does not offer true proportional control.

Although several voltages are used, a general trend toward 12 volts for above-elbow systems and 6 volts for below-elbow is apparent. And, switch control is used almost exclusively for very small children, progressing to myoswitch control as they mature; proportional control is most commonly reserved for adults.

The children's components are all from outside the United States: Sweden, England, and Canada currently offer toddler hands. American designs are often targeted to adults: the Hosmer and VANU hands and Boston Elbow toward males, in particular.

Hosmer is aggressively pursuing the inexpensive, low-tech end of the market, emphasizing interchangeability with the familiar mechanical counterparts. Motion Control is equally aggressive in pursuing the high tech, high cost end.

Lack of funding is probably the major factor limiting the number of powered fittings currently undertaken. With the ready availability of various switch, myoswitch, and proportional controls, virtually any patient could operate an electric prosthesis.

Questions about who is a suitable candidate for powered fittings are still largely unanswered. The evidence suggests that the highest

EXTERNAL POWER CONTROL OPTIONS

Muscle Sites	Control Type and Mechanism	Number of Functions	Typical Application	Manufacturer†
Zero	Digital, Switch	One	Open*	2
Zero	Digital, Switch	Two	Open, Close	1,2,3,5,6
Zero	Digital, Switch	Three	Flex, Ext, Open*	2
Zero	Digital, Switch	Four	Flex, Ext, Open, Close	1,2,3,6
One	Digital, Myoswitch	One	Open*	2
One	Digital, Myoswitch	Two	Open, Close	3,5
Two	Digital, Myoswitch	Two	Open, Close	5
Two	Proportional, Myoelectric	Two	Open, Close	1,3,4
Two	Digital, Myoswitch	Four	Open, Close, Pro, Sup	3,5
Two	Proportional, Myoelectric	Four	Flex, Ext, Open, Close	4

* Close with rubber bands

† Key to Manufacturers: 1. Fidelity Biomedical Products, 2. Hosmer-Dorrance Corp., 3. Liberty Mutual Research Center, 4. Motion Control, Inc., 5. Otto Back Industry, 6. Variety Village Electrolimb Production Centre.

Table 1.

COMMERCIALLY AVAILABLE POWERED COMPONENTS†

Population	Hook	Hand	Wrist	Elbow
Under 2 years	2(Michigan)	–No–	–No–	–No–
2–6 years	2(Michigan)	3,6	–No–	–No–
5–9 years	2(Prehension Actuator)	3	–No–	6
9–12 years	2(Prehension Actuator)	5	5	2,6
Teens	2(Prehension Actuator)	5	5	2,6
Adult Males	5,2(Prehension Actuator)	1,2,5	5	1,2,3,4

† Key to Manufacturers: 1. Fidelity Biomedical Products, 2. Hosmer-Dorrance Corp., 3. Liberty Mutual Research Center, 4. Motion Control, Inc., 5. Otto Back Industry, 6. Variety Village Electrolimb Production Centre.

Table 2.

failure rate is with bilateral fittings.[9] Perhaps the simplicity and resultant reliability of body powered prostheses makes mechanical solutions more succcessful here.

The best system cannot be found, and few practitioners are brave enough or experienced enough to freely mix these international components. The issues of proportional vs. digital control, high tech vs. low tech design, hybrid vs. purely mechanical vs. purely powered fittings are all open to debate.

And some very provocative data is emerging suggesting that the issue of when to fit is at least as significant as the issue of what to fit.[8]

It is beyond the scope of this paper to resolve these complex issues. Rather, the intent is simply to bring into focus the basic concepts, components, and controversies in the field of powered upper limb fittings. It is hoped that clarifying these issues will encourage prosthetic practitioners to deepen their involvement and understanding in this rapidly evolving area. As we struggle collectively with these problems, our patients and our profession will ultimately reap the benefits.

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APPENDIX

V.A.N.U. Products
Fidelity Biomedical Products
6000 N.W. 153 Street
Miami Lakes, Florida 33014
(800) 327-7939

Hush Elbow; Prehension Actuator
Hosmer-Dorrance Corporation
561 Division Street
P.O. Box 37
Campbell, California 95008
(800) 538-7748

Boston, UNB, Steeper, Systek Products
Liberty Mutual Research Center
71 Frankland Road
Hopkinton, Massachusetts 01748
(617) 435-9061

Utah Elbow, BE System
Motion Control, Inc.
1005 South 300 West
Salt Lake City, Utah 84101
(800) 621-3347

MyoBock Products
Otto Bock Industry
4130 Highway 55
Minneapolis, Minnesota 55422
(800) 328-4058

Variety Village Products
Variety Village Electrolimb Production Centre
3701 Danforth Avenue
Scarborough, Toronto
CANADA MIN 2G2
(416) 698-1415

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In Support of the Hook

by Eugene F. Murphy, Ph.D.

If this were a perfect world, each person would have two perfect, versatile, beautiful hands. Unfortunately, there are individuals who lack one or both of these exquisite devices, whether cogenitally or adventitiously. Thus far, any substitute can only represent a very limited compromise and partial selection of varying fractions among the many desirable functions and cosmetic features needed for a true replacement. There seems no reasonable hope of providing the numerous muscles, nerves, reflexes and voluntary controls needed to position and stabilize mechanical imitations of the multiple joints in the natural hand. Because uncontrolled flexibility, like a loose chain, is merely unstable, the designer is forced to limit the joints severely, providing fixed curves which offer rigidity, yet maximize function.

Fortunately, the customary wrist disconnect mechanisms allow reasonable interchanges to suit specific needs. These changes may not be quite as simple for the amputee as for the normal person who dons warm gloves for cold weather, picks up tongs, tweezers, or pliers to "handle" hot, tiny, or rough objects, or scrubs and manicures in preparation for a party. Nevertheless, the possibility of interchange does allow considerable versatility rather than a forced, even heartbreaking, choice of a single limited terminal device. Each amputee may use an artificial hand with substantial but limited function, and lifelike cosmetic glove when appearance is important, but, then change to a considerably more functional terminal device when appropriate, much like changing evening or business clothes to sports clothes or overalls.[1] In this context of voluntary choice, then, let us consider the appropriate roles for split mechanical hooks.

Note that we can assume that we are far beyond the single hook with sharpened point made notorious by Captain Hook, useful as that was in its time. For the near future, though, we seem limited in practice to a single active control that provides adequate force at any point in a reasonable range of motion and is capable of rapid change, delicate adjustment, and prolonged holding, and preferably offers substantial sensory feedback. The typical Bowden cable (secured to shoulder harness, activated by body motion, and providing some sensory feedback from kinesthetic awareness of human joint position and tactual perception of pressures) provides a substantial degree of function. A source of external power under a single voluntary control, whether valve, switch, or myoelectric signal, may have greater or lesser speed of response, precision of adjustment, and maximum force, but so far it probably supplies less sensory feedback. Occasional adjustments, locking, or presetting of parts can be made by a unilateral amputee with the other hand or by a bilateral amputee through gross motion of the prosthesis to press the terminal device against an object, or squeeze it between the knees, etc.

Thus far, both practical clinical experience and research studies have indicated that additional substantial sources of power, control, and feedback are so limited that they are better used for other functions like elbow flexion, elbow locking, or perhaps wrist rotation instead of for additional motions within a hand or hook. If additional practical sources do become available, of course, they can be used to improve both hand and hook by reshaping either for still greater versatility, or to actuate and release a lock, thereby improving both devices. The hook, though, is intrinsically more versatile than a mechanical hand of equivalent control and sophistication.

It may be useful to recall that the Klingert artificial arm and hand at the end of the Eighteenth Century attempted to control some ten independent motions by cords ending in knobs which the unilateral amputee could move with his good hand along a vest-like garment.[2] Presumably the user soon decided to use the good hand directly for most tasks!

Like many current robots, remotely operated manipulators for nuclear "hot cells" have typically been designed with seven degrees of freedom, including grasp by simultaneous and equal motion of opposing surfaces of the terminal device. Usually a single able-bodied operator has controlled two manual master-slave manipulators, one with each arm, plus assorted leg and body motions to assist in positioning. Even so, we were told some years ago,[3] performance of relatively simple tasks typically took eight to ten times the time needed to do them directly with the bare hands, and early unilateral electrical manipulators took over ten times as long as mechanical master-slaves! At a series of conferences called Project ROSE with participants in the prosthetics research program and others,[4] experts from the nuclear and space programs seemed awed to learn that no bilateral arm amputee (even though substantially limited in independent body motions) needed anywhere near that additional time to perform complex tasks of industry or of daily living. The current interest in applications of robotics to aid quadriplegics may help to revive these interdisciplinary exchanges.

It may be suggested that the performance advantages of the amputee lie not only in motivation, past therapy, and full-time usage, but in basic design philosophy. The classic UCLA studies summarized by Taylor[5,6] and Taylor and Schwarz[7] pointed out the great complexity of the human hand and upper extremity, analyzed the motions and forces used for a variety of activities, suggested reasonable priorities and limitations, and preset or limited position selections in contrast to the equal priority and great range assigned to all motions in many manipulators. The designs of prosthetic hooks typically provide a fixed point of reference for arm placement in the fixed finger. This allows relatively easy and accurate positioning against one side of an object, followed by closing of the hook to surround and grip the object as securely as desired. (The slowly moving thumb or "finger" of the Northwestern University[8] synergetic hand or hook substantially follows this concept, with the rapidly moving member(s) encircling and the high-force thumb then clamping.) In contrast, if both hook fingers (or the thumb opposing the index and middle fingers of a hand) move simultaneously, the user must initially position the arm in relation to an imaginary centerline while mentally allowing for subsequent (perhaps even unequal) motion of the opposing surfaces. This harder task can be learned by long practice and tolerance of frequent error (as we know from sports involving catching objects), but it seems relatively risky for approaching tall unstable objects like laboratory glassware. It also requires good vision, emphasizing the importance of the large safety window in a hot cell and the limitations of periscopes, mirrors, and television systems.

The vast resources of the human hand allow very rapid shaping, grasping, and squeezing to hold objects of assorted sizes, with a reflex adaptation that grips more tightly if slippage starts yet also minimizes the risk of crushing fragile objects. A natural hand spontaneously exerts only modestly more gripping force than needed, whereas the amputee tends to overgrip. With a single control, an artificial terminal device must have a single general shape, though the opposing fingers of the hook may be markedly different. They should encircle and pull in objects within a wide range of sizes rather than extruding them from a V-shaped clamp. At least three contact points are needed for stability; two flat tongs are inadequate or at least require substantial forces to grip rounded objects. The two-position thumb of the APRL hand, preset to normal or wider positions by pressure against some object, is helpful but does not allow the flattening needed to enter pockets.

Attempts have been made to provide unusually large thumb motion. This is to allow the choice of palmar prehension of the finger tips against the thumb or more complete flexion of the fingers into the palm, e.g., the Tomovic Beograd (Belgrade) hand.[9] That kind of versatility requires at least sensor pads and relatively complex logic such as that used by Tomovic or preferably a second hand control. The addition of independent lateral prehension of the thumb, in which the thumb is rotated to press against the partially flexed fingers, is a commonly used human motion, but is limited to small objects and is not considered useful as the primary grip. It might even require dedication of a third control to the terminal device.

In contrast to the severe limitations of an artificial hand with present control sources, a split mechanical hook or other gripping tool may be designed to grasp objects of a wide range of sizes, yet remain sufficiently slim near its closed position to enter pockets to retrieve coins or other objects. Instead of imitating natural form and motion, the hook can be designed solely for function, attaining a sleek though mechanical appearance. In addition, it can be used to push, pull, pry, hammer, touch and hold hot or cold objects, and in general perform many tasks for which even the wonderful human hand requires tools. By ingenious shaping of fingers and choice of axis, the same hook may be used as tweezers for pins, to securely grip many medium-sized objects of daily life, and to surround and lift large objects.

Mass-produced hook fingers (in contrast to earlier hand-forged and slightly variable models) may be economically provided with vulcanized rubber lining for higher friction while retaining a slippery metallic outer surface. (In early field tests with this feature, everyone liked the ability to slip easily into pockets or sleeves. However, one subject, who was long accustomed to starting a sewing machine by pushing the flywheel, complained of the absence of the chemical laboratory tubing used over older hooks. Nothing is perfect!) There may well be a major role for softer external surfaces, especially for children's terminal devices so to prevent injuries. Obviously, the materials should be nontoxic, nonallergenic, noncarcinogenic, and durable.

The APRL and Northrop-Sierra hooks were designed with symmetrical lyre-shaped aluminum fingers held to the case by jam nuts, allowing replacement. Among the many unfinished items on the old research agendas discussed at the frequent conferences and workshops, was the deployment of stainless steel fingers and alternative shapes, including axes canted in relation to a thin sheet gripped by the hook fingers. Occasionally, there was speculation about color in place of the customary polished metal, or of a cosmetic glove designed to fit over a hook.

Greater use of the three-jaw chuck concept, characterized by the index and middle fingers of the APRL hand moving in somewhat inclined planes toward the thumb, is sometimes suggested. However, greater stability must be balanced against greater bulk when closed.

The literature, particularly in patents, discloses a great variety of concepts and shapes of terminal devices. Many were invented by amputees to meet their individual needs, especially in farming or industry. Some designers, notably Steeper in England, emphasized development of many special-purpose tools for daily living as well as for agriculture, industry, and avocations, together with disconnect devices for easy interchange. The demonstrator typically had a fitted case carrying a wide assortment. English colleagues have mentioned that a specific amputee typically received a dress hand, a split mechanical hook, perhaps a single tool appropriate to his particular trade, and (particularly in the case of a bilateral) a long straight split device helpful for grasping toilet paper.

Since 1945, American research programs have emphasized the development of devices to permit any amputee to independently conduct the activities of daily living. Bimanual activities are so varied, due to the size of objects and the gripping force and dexterity required, that vocational guidance for a motivated amputee should include the selection of appropriate vocations which can be carried out with the same device(s) used in daily living. Indeed, most personal tasks are performed on or close to the body, perhaps suggesting wrist flexion devices, whereas vocational tasks normally are conducted on a table or workbench that do not require wrist flexion.

A wide network of clinic teams is available to assist amputees select a prosthesis, return to former occupation, or choose a new vocation. In addition to a reasonably functional hand with cosmetic glove, the unilateral normally receives a versatile hook. The bilateral amputee rarely can function adequately with two artificial hands; sometimes he can use one hand and one hook, if appearance is more crucial than dynamic and independent function. Commonly, the bilateral amputee selects two hooks for routine use.

Fortunately the number of bilateral amputees is very small, yet their needs are particularly great. Paradoxically, to meet their special needs, it has been necessary to first develop devices and techniques which are sufficiently versatile and which are accepted by a majority of the much larger unilateral market (and the professionals who serve amputees). Though present terminal devices are useful and cosmetically acceptable, further research on the specific problems of bilateral amputees is needed.

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Voluntary Closing Control: A Successful New Design Approach to an Old Concept

by Bob Radocy, M.S.T.R.

The arrival in early 1980 of the "Prehensile Hand,"[1] a new design and concept for terminal devices, sparked a revitalized interest in body power and voluntary closing control. Voluntary closing control and terminal devices are not new to prosthetics, but little interest in this system and technology has existed since the 1950's. Retrospectively, voluntary closing control never achieved dramatic success nor did it have any permanent, positive influence on the direction of upper-extremity prosthetic development until recently, meaning 1980–1985.

The acceptance and success of the "GRIP,"[2] (Figure 1) and more recently the children's "ADEPT"[3] terminal devices, are strong indicators that voluntary closing control is an extremely viable concept. Furthermore, it confirms previous opinions that poor performance characteristics, reliability factors, and the inappropriate design criteria of early volunteer closing control systems and terminal devices[4] were responsible for the demise of voluntary closing systems and correspondingly for the dominance of voluntary "opening" control systems and terminal devices in the profession today.

This is not to say that voluntary closing devices and systems were not put to excellent use by certain amputees, but that they failed to appeal to the majority of the upper-extremity limb deficient population, i.e. the traumatic or congenitally limb deficient below-elbow unilateral amputee.

The standard voluntary opening split hook has continued to be the primary body-powered prescription, while experience now strongly il-

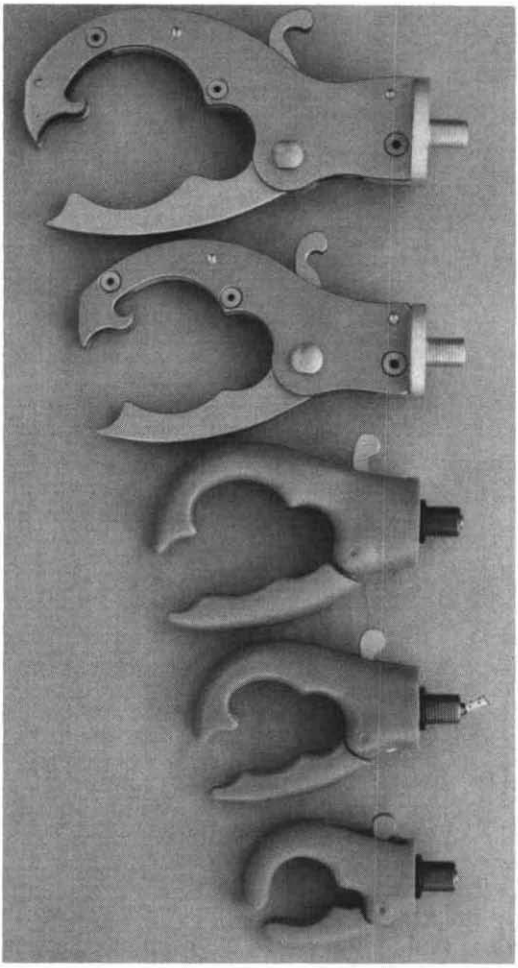

Figure 1. (Top to bottom) GRIP I, GRIP II, ADEPT B, ADEPT C, and ADEPT I.

lustrates that correctly designed voluntary closing terminal devices offer superior performance to the limb deficient. Training is no more difficult with voluntary closing; gripping force range is expanded and directly proportional to output, reflex grasping actions are improved, muscles of the affected limb and shoulder are utilized continuously and more effectively, and "feedback" sensations (Figure 2) are produced inherently† and are more easily assimilated, thereby enhancing control, than in voluntary opening systems.

The mere fact that children three to six years of age have accepted the concept and have either learned with or converted to voluntary closing control and achieved good to excellent performance should open the minds of even the most conservative in our profession as to the value of the voluntary closing control prescription.

Recently, we have seen and heard a great deal about the success of myoelectric devices for children and how a child's performance is improved with myoelectric systems as compared to "body-powered" systems.[5] Unfortunately, body power in these comparisons refers only to the voluntary opening split hook systems, and not to voluntary closing systems. It is my firm belief that, if given proper training, limb deficient children will perform as well or better with voluntary closing body powered systems than with myoelectric systems. Furthermore, considering the cost and reliability of externally powered limbs, voluntary closing body powered terminal devices should be prescribed as the primary complements to external powered units, rather than voluntary opening split hook systems.

The logic for this assertion is simple. First, muscles of the torso and limb are used more actively with the voluntary closing system, and healthy, strong muscles can only enhance externally powered control and utilization. Second, the new designs in voluntary closing terminal devices offer an opposed thumb and finger gripping configuration, similar to powered hands, enabling the user to incorporate already "learned" patterns of gripping behavior, rather than having to constantly switch patterns of grasp to accommodate "split hook" prehension. Third, children with voluntary closing systems can achieve gripping prehension which equals or exceeds their anatomical capabilities, while voluntary opening systems remain inferior in this area. Comparable prehension bilaterally can only encourage bilateral function and increase prosthetic usage, two primary goals in prosthetic rehabilitation.

The success of voluntary closing systems can be related to the design rationale and criteria of the 80's systems. Rationale and criteria are as follows:

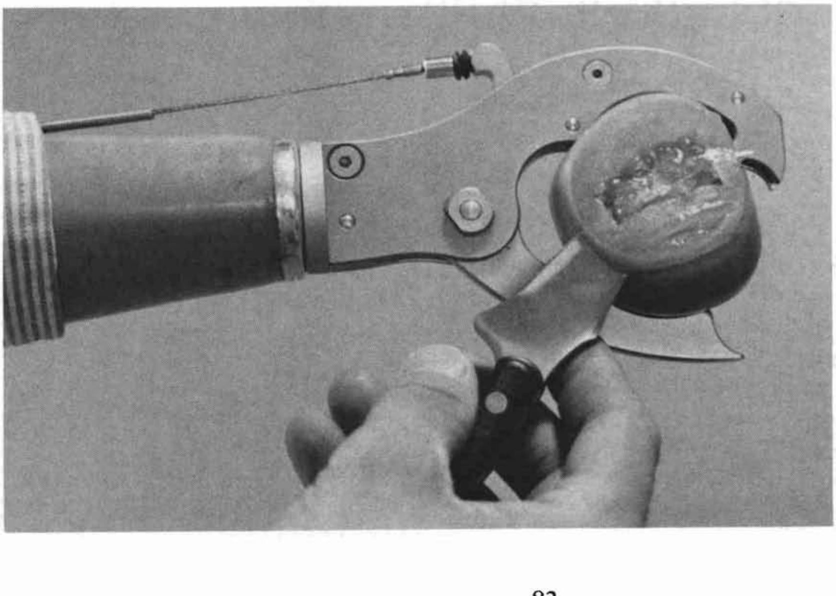

Figure 2.

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† A major objective of externally powered systems is to develop a reliable "feedback" system for improved prehension control. Voluntary closing, body-powered systems offer the feedback system inherent in the design.

1) Utilize an accepted natural prehension configuration. Previous studies indicate that cylindrical, palmar, and lateral are the most often used gripping patterns.[6] Opposed thumb and forefinger prehension satisfies these patterns.
2) Design gripping shapes and surfaces to allow for a wide variety of holding tasks. Complementary curved gripping surfaces enhance cylindrical control and are especially important due to the vast numbers of curved object surfaces we handle daily (Figure 3). Additionally, a "clevis" tip configuration imitates the three point chuck of the thumb, index and long finger, important for utensil and implement control (Figure 4).
3) Emphasize a simple, anesthetic, easily maintained, reliable design that can be understood and accepted by the user—a design with positive psychological connotations, reflecting the capability of the user.
4) Incorporate passive support and suspension capacity (internal hook or bump) for carrying objects with handles or for supporting body weight while climbing or hanging.
5) Require continuous control for grasping and holding to discourage muscle atrophy, enhance muscle development and allow for rapid reflexive grasping. Continuous control also creates an uninterrupted flow of pressure feedback information required for performance handling of objects.
6) Select materials suitable for individualized age groups, rather than a single material for all models. Consider both the needs and the characteristics required for each population and design the model accordingly for each targeted group.
7) Consider weight as a factor, but balance the need for light weight against the strength requirements for the terminal device. Also consider the tolerance the need for light weight against cause variation in age and corresponding tolerances vary.

Figure 3.

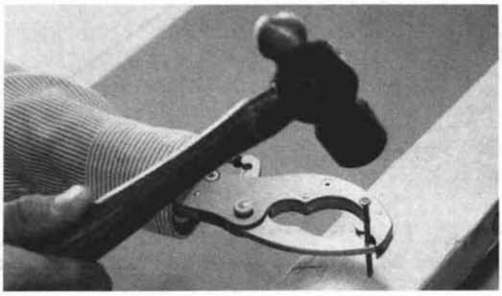

Figure 4.

8) Redesign models as necessary to better answer the needs of the population they serve.

Exclusive of these criteria, a variety of factors exist which have aided the reintroduction of voluntary closing systems and which will increase the use of these systems in the future. Compatibility, harnessing, prosthesis design, proper rehabilitation and weight conditioning are all important if good to excellent prosthetic use is to be achieved.

Voluntary closing terminal devices are compatible with all standard prosthetic components. Minor cable modifications or adjustments are usually required to optimize the user's energy output. Unlike previous voluntary closing designs, the user is harnessed under "controlled tension" rather than into a "no tension" system. Accordingly the thumb of the terminal device is not fully open, but pulled partially closed when the arms are relaxed at the user's sides. This tension harnessing allows for improved control of objects, during initial training, and while objects are manipulated close to the medial line of the body.

Harnessing should be as simple as possible. A modified Northwestern #9 when possible is excellent, utilizing a ring and "rapid adjust" type buckle.[7] This harness system will enhance range of motion control at the shoulder, improve object manipulation overhead, and enable quick excursion adjustments.

Prosthesis design should lean towards self suspending (supracondylar) sockets to minimize harnessing. Modified Muenster, Otto Bock, and similar designs can be employed depending on the limb's morphology. New designs such as ISNY or similar flexible sockets may also prove valuable. New patients should be educated in range of motion and pre-prosthetic exercise techniques.[8,9,10,11,12,13] This is especially important for traumatic limb loss and in instances where complete rehabilitation was lackingand the shoulder girdle and upper limbmusculature is weak and atrophied. Similar atrophication can occur due to disuse of the prosthesis or lack of vigorous bilateral use.

Initially, muscle soreness at the shoulder may be experienced by the converting amputee, or the new amputee undergoing rehabilitation. This early soreness is a positive sign of muscle rejuvenation and should be regarded as improved health. However, long term muscle aggravation and soreness may be an indicator that the prosthetic system is not operating optimally.

Prior to prosthetic fitting and after initial rehabilitation with the new voluntary closing prosthesis, weight training can be encouraged. Pre-prosthetic training can be accomplished by a knowledgeable therapist and should include a range of motion exercises, dynamic tension, and active bilateral resistance exercises using cuff weights, specialized training equipment, or a simple weight harness in conjunction with dumbbells. Post-prosthetically, the voluntary closing terminal device is capable of handling adjustable resistive weight equipment or free weights, although the former are easier to use, safer, and enable rapid, satisfactory results. An emphasis on strength and endurance conditioning rather than muscle building is suggested due to the needs for adequate range of motion in prosthetic control. This dictates lower resistance loads with more repetitions of exercises.

Special applications for voluntary closing systems have also arisen in recent years. Brown[14] has achieved excellent success in patients with partial hand amputations. The success, I believe, is due to the common sense simplicity of the prosthesis and harness design, and the utility of the terminal device, which allows prehension in excess of 100 lbs. This amount of gripping force enables the partial hand amputee to be functionally bilateral in a manual working environment. Other terminal devices applied to the case of partial hand amputation cannot offer all the advantages of the new voluntary closingsystems. Obviously, the partial hand prosthetic user will not wear the prosthesis all the time, but it is an effective functional tool for many occupations. The increased potential may enable the partial hand amputee to maintain an existing vocation rather than consider retraining for an entirely new occupation.

In summary, the new voluntary closing systems offer a great deal of potential for the upper-extremity limb deficient of all ages. They can offer superior performance compared to any other systems, body powered or externally powered, and complement the externally powered prescription, when cosmesis is the primary consideration and function considered only of secondary importance.

Voluntary closing systems are not a cure-all for the upper limb deficient individual, and the system is not applicable to everyone, even though all types and levels of amputees including bilaterals have used the technology successfully (excluding shoulder disarticulates). Success also has a lot to do with the attitude of the amputee and the capability of the rehabilitation team, including the prosthetist.

Voluntary closing systems will continue to increase in popularity because the technology is reliable, improves performance, and more closely imitates the natural system.

The voluntary closing systems will also continue to improve as more innovative research and development in better "total" body powered and hybrid body powered/external powered prosthetic technology evolves.

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Clinical Prosthetics and Orthotics, Vol. 10, No. 2, pp. 87–89

Upper Extremity Cosmetic Gloves

by Sandra Bilotto, M.A., C.P.O.

INTRODUCTION

Upper extremity rehabilitation includes the restoration of function and cosmesis to simulate the human hand.[6] Producing a replica of the hand which is functionally and psychologically beneficial to the amputee and quite importantly, acceptable to those with whom the amputee socially interacts,[4] is both challenging and of high priority.

The technology for producing either custom made or mass produced cosmetic gloves has changed little in more than 20 years.[2] However, within the last several years, with the advent of new materials, there have been new developments. More specifically, there have been developments in a family of silicone elastomers the application of which offers solutions to problems associated with existing cosmetic glove technology.

Briefly, cosmetic gloves have been made with latex, urethanes, and RTV silicones, but these materials were not successful because they had serious drawbacks. Latex skins were impermanent, coloration was unacceptable, tear strength was very low, absorption of clothing dyes was common,[5] and they did not last very long before deteriorating. Urethanes held promise, but the components to produce a plastic film are very difficult to control in small laboratories. They are too sensitive to moisture and extraneous contaminants, and require precise measuring. After limited use, they are weakened by ultraviolet light and thus their useful life as terminal device coverings is limited.[8] RTV or room temperature curing silicones, when first utilized in prosthetic restorations and glove-making, proved ineffective because the material required complicated molding procedures, was often manufactured pre-colored, had extremely low tear strength, and had very low elasticity and flexibility. In addition, one small tear would easily propagate, rendering the glove useless.

PVC GLOVES

PVC, or polyvinyl chloride, has dominated glove making and still does to the present. Historically PVC is inexpensive and readily available. Gloves can be fabricated en masse in metal molds or custom made in flexible slush molds. In either technique, the plastisol cures against the wall of the mold, producing a thin skin of vinyl which can either be intrinsically and/or extrinsically colored.[6] Stabilizers and plasticizers are introduced to make the cosmetic glove flexible and resistant to degradation by ultraviolet light. Replication of the human hand has been adequate using PVC and thus these gloves have been widely available for most amputees. However, there are disadvantages associated with PVC as a material for use in prosthetic gloves.

First and foremost is the inability of PVC to resist attack by most chemicals, soiling and staining agents, and newsprint. These substances are absorbed by the plasticizing agents and are impossible to remove. At temperatures close to freezing, the PVC stiffens and its flexibility is greatly reduced. This can inhibit the proper functioning of an electric or mechanical hand as the inability to open a finger or thumb can render a terminal device useless.[9] In warm temperatures, the plasticizers and stabilizers tend to bleed to the surface of the glove, causing peeling of the extrinsic coloring, as well as darkening and stiffening. PVC "feels" like plastic and not like human tissue, and for the most part, unless a PVC glove is custom made and tinted, the surface is rather opaque and cadaverous looking. Custom made PVC gloves present all of the above problems, but do match skin tone, hand shape, and surface characterization of the intact hand better. The time required to fabricate a custom glove is much longer because the technique is more elaborate, and as a result more expensive. Of course, the success of the glove is directly proportional to the ability of the prosthetist to make the cosmetic glove appear natural and reasonably well matched to the other hand.

No matter what technique is utilized, the consensus is that PVC gloves are rather short lived: two weeks to eight months on average. Efforts to strengthen the glove with nylon fabric reinforcement or to retard discoloration by spraying clear solutions on the surface of the glove produce disappointing results.[2] Finally, there is a problem donning and doffing a PVC glove due to the inflexibility of the material proximal to the wrist. This gave rise to the practice of sewing zippers into gloves. Besides being bulky and unsightly, zipper installation is time consuming and the zipper may be easily jammed or broken. Thus, a better material which might resolve some of the above problems is needed.

SILICONE GLOVES

Silicone rubber offers excellent solutions to some of the aforementioned problems, and they now have properties which make them more readily processed in glove making.[3] In general, the new generation of silicones are tougher, more resilient, more durable, and more permanent than previously utilized materials. While not ideal, the silicone gloves presently being developed resist chemicals, dyes, soiling, and staining almost completely. The skins may be washed with mild detergents and water for cleaning. Unlike PVC, lower or higher temperatures have little effect on the strength, flexibility, or elasticity of the glove.[7] The result is better functioning of electro/mechanical hands, and in some cases, the elastic resistance of gloves can actually enhance functioning of the terminal device.

Unlike PVC, silicone rubber may be modified to increase its elasticity where necessary without loss of tear strength. Cosmetic gloves of silicone elastomers may be intrinsically or extrinsically colored as with PVC. However, there is much greater adhesion of external pigments to silicone gloves and the resultant glove rarely sheds its external tinting. It is more color stable and is less affected by ultraviolet light than its PVC counterpart; Silicone neither darkens nor stiffens with the passage of time. Once fabricated, the glove is non-toxic as compared with PVC. This is an obvious advantage when fabricating gloves for babies and toddlers, as harmful agents do not leach out to the surface of the glove to enter the baby's mouth. Silicone can be formulated to reflect and absorb light in much the same way human skin does, producing a more natural and life like appearance. Likewise, silicone also simulates the "feel" of skin more closely as it relates to softness and texture.[1] Its higher coefficient of friction helps prevent glasses and other objects from falling out of the hand's grasp.

DISCUSSION

There are some disadvantages in the production of silicone gloves which need to be addressed. The cost of manufacturing, the increase in fabrication time, and the slightly higher cost of silicone rubber[3] is retarding the availability of such gloves.

However, if the technology to produce silicone gloves improves, and if they become more widely available, their cost and fabrication time should decrease. They have greater durability and esthetic appeal than PVC, and there can be no doubt that silicone offers possibilities heretofore unavailable with PVC.

Silicone cosmetic coverings for the lower extremity are a future possibility. Swim and sport legs could be greatly inhanced by these tough, resilient and cosmetic coverings. Silicone compounds are presently used in maxillofacial prosthetics, breast prostheses, partial hands, partial feet, leg and arm buildups, and other body restorations.[1]

There is no doubt that a more natural, functional, esthetically and psychologically appealing cosmetic glove is needed by upper extremity amputees and that silicone gloves, despite some imperfections, will prove to be more promising and acceptable than PVC gloves.

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Technical Note: The Soft Socket

by Arthur Forman, B.S., M.A.

INTRODUCTION

Oftentimes we are presented with an above-knee amputee who poses difficult problems for a successful prosthetic fitting. Some of these problems include advanced age, atrophy, trigger points, bony prominences, surgical implants, cardiopulmonary problems, short residual limbs, and other complications. Any one of these conditions might make for a difficult fitting, but any combination of these could contribute to an unsuccessful fitting, or a situation which precludes ambulation.

It is my contention that given the current generally accepted practices and when presented with an involved patient as indicated above, we are doomed to failure, in terms of comfort and ambulation. Further, it is my contention that very often, although these patients may be confined to a wheelchair even after prosthetic fitting, it is of paramount importance that they be fitted as comfortably as possible. Although they have lost a limb, they may be just as motivated as any other patient and can suffer psychological stigma.

Therefore, it is our duty as prosthetists to provide a prosthesis that will allow these patients to ambulate as much as possible, resulting in both psychological and physical benefits.

SOFT SOCKET RATIONALE

As we all know, the quadrilateral above-knee socket was originally designed and fitted for World War II traumatic amputees. They were fairly young, usually with no other complications, good musculature, and in many cases of long length. Today we are faced with a high geriatric amputee population with conditions quite different than the World War II veteran. The quadrilateral above-knee socket design impinges directly on the neurovascular bundle in the area of the scarpa's triangle. The posterior seat area bears directly on an anatomical area which is usually atrophied to the point of being uncomfortable. These features alone call into question the viability of the quadrilateral design when considering an involved patient as described previously. The soft socket design as described, owes its inception to the CATCAM design.

The soft socket is almost an exact anatomical negative duplication of the residual limb without extreme scarpas impingement and without concentrated ischial weight bearing. It is lined with ½″ thick Plastizote, or similar forgiving material that enhances soft tissue bearing, hence "soft socket." It is compatible with all existing above-knee components, far more cosmetic, aligned using current practices, and is fabricated only in a slightly different fashion. Also, it will allow the amputee to ambulate in a comfortable non-restrictive manner.

CASE STUDY

A seventy-six year old man was presented for prosthetic fitting. He was a traumatic amputee who had lost his leg during the Korean War and was left with a four inch length femur. He had been wearing an exoskeletal system with an hydraulicly controlled knee, conventional quadrilateral socket, hip joint, and pelvic belt. The prosthesis weighed approximately 13 pounds. The lateral wall of the socket was modified at mid-femoral length to impinge on the femoral shaft. The patient had recently undergone surgery to repair a fractured femoral head on the amputated side due to a fall. He had also recently developed emphysema and had lost a significant amount of weight. During weight bearing on the sound leg, he exhibited extreme fatigue and loss of breath. Despite these contraindications to prosthetic fitting, he expressed great motivation.

I proceeded with the standard impression technique using the Berkeley brim. The patient experienced discomfort while suspended in the Berkeley brim. He indicated specific areas of discomfort including the ischial/gluteal area and the lateral femoral area. This continued despite angular adjustments to the brim. An impression was taken. Upon examination of the impression and after discussion with colleagues, it was decided that a conventional fitting would not work. After mulling over the situation, it was decided to hand wrap a new impression, while the patient laid on his sound side. This was done in a very particular way, encompassing the gluteals, and hand forming the medial and posterior wall. A very anatomic impression was obtained. Modification was minimal and consisted mainly of smoothing up and adding a layer of ½″ Plastizote (Figure 1) after lamination. The prosthesis weighed 7½ pounds. This included a modular safety knee, extension assist, hip joint, pelvic belt, foam cover, foot, and shoe (Figure 2). The patient has been wearing this prosthesis and is quite satisfied.

CONCLUSION

It is my belief that we, as prosthetists, should approach our patients as individuals and if necessary, modify or completely discard commonly accepted techniques in order to success-

Figure 1. The Berkeley brim above the AK prosthesis with hip joint and pelvic band. Note presence of Plastazote pad in the ischial seat area.

Figure 2. The completed prosthesis.

fully fit the uncommon patient. We should continue to examine our techniques in order to upgrade our profession and better serve the community.

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Below-Knee Prosthesis with Total Flexible Socket (T.F.S.): A Preliminary Report

by John Sabolich, B.S., C.P.O.
Thomas Guth, C.P.

Recent efforts in Oklahoma City, and San Diego have borne fruit to a promising new way to fit below-knee amputees. The basic design consists of a thin walled thermo-plastic socket secured in a frame by nylon strapping tape so that most of the socket is left exposed and unsupported (Figure 1). This design, named the Total Flexible Socket (T.F.S.), was conceived out of necessity with a few patients that were so difficult to fit that even aggressive techniques such as multiple transparent diagnostic sockets, alginate injections, total surface bearing modifications, and silicone gel inserts failed to provide a measure of comfort acceptable to them. It was felt that a more unconventional method would have to be implemented. Currently, this

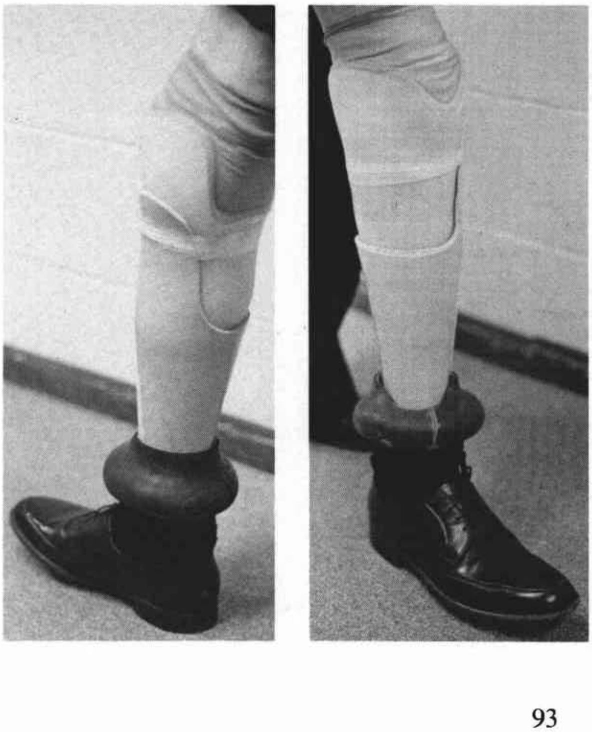


Figure 1. Medial and lateral views of T.F.S. in an exoskeletal version. Suspension sleeve and cosmetic hose rolled down for clear view of socket secured in place with band of fiberglass tape.

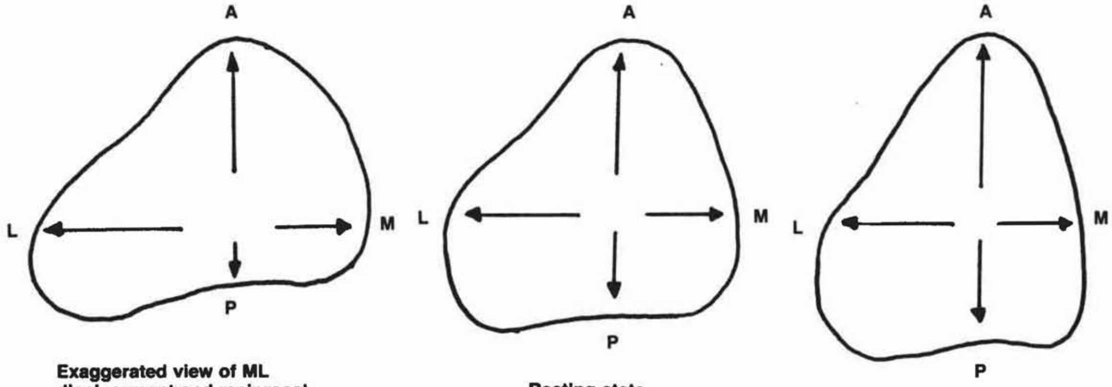
technique is being used with most of the geriatric population seen, and with time and experience it is being applied to an ever increasing proportion of the total below-knee amputee population served. Forty or more of these sockets have been fitted over the past five months to patients ranging in age from ten to 89 years with results that were beyond initial expectations. Patient reaction has been extremely positive. Plans are to submit an up-dated article when over 100 documented fittings with the described technique have been accomplished.

The idea for the T.F.S. design was prompted during the course of fitting a patient with a flexible diagnostic test socket. The patient was comfortable in this socket even when bearing his full weight on a padded fitting stool. Subsequently, when a full socket receptacle for the test socket was laminated and it was rigidly contained, this comfort was lost. The patient still complained of pressure even when holes were cut out over bony prominences.

Finally, when the maximum amount of material was cut away and the former socket receptacle was reduced simply to a means of attaching the socket to the rest of the prosthesis, thus allowing the socket to return to its former measure of flexibility, comfort was regained.

Several interesting phenomenons were noted:

1. Since the T.F.S. design is totally flexible, allowing ML as well as AP expansion and retraction, the socket finds and seeks its own level of pressure distribution. If the AP is too tight, it automatically expands, causing the ML to tighten up, wrapping around the tibial flare and the fibula. This, of course, is not true when a receptacle is only opened up over bony areas allowing no reciprocal ML-AP displacement and minimal flexibility, even over bony areas. With the T.F.S., if the ML is too tight, then the AP automatically tightens as the ML loosens, and vice-versa if the AP is too tight (Figure 2).
2. The AP-ML "Milking" action seems to have a positive effect on circulation since the residual limb seems palpably warmer when a T.F.S. is removed, as compared to when a rigid socket is used. In the case of flexible sockets thinner than 3/32 inches thick, the entire socket moves with the residual limb, seeming to expand and contract due to the open nature of the frame. This phenomenon can be felt better than seen by holding the socket as the patient alternately places weight on the prosthesis and removes it, especially after the socket warms up to body temperature.



Exaggerated view of ML displacement and reciprocal AP contraction.

Resting state.

Exaggerated view of increased AP displacement and reciprocal ML contraction.

Figure 2. Transverse view of a socket cross section showing, in an exaggerated fashion, the reciprocal AP-ML displacement.

This dynamic socket movement and improved circulation could be very significant for the geriatric P.V.D. patient. This action also seems to enhance atmospheric suspension: when the patient removes weight, the socket collapses and grips the residual limb like the familiar childhood toy, a Chinese fingertrap.

3. Atmospheric Suspension (A.S.) assorted methods of achieving suction suspension for the below-knee amputee have been tried for years, with varying degrees of success. The main reason behind this effort is the desire to solve the number one problem of the below-knee amputee, that of skin shearing and pistoning between the residual limb and socket. Another major problem has been that of the patient wanting a lighter weight, more responsive prosthesis. With the T.F.S.A.S. combination, most patients have been responding favorably with such comments as "It feels like my own leg!" and "It feels like part of me!" With atmospheric suspension, the patient no longer needs to wear a suspension sleeve to maintain full suction. The Total Flexible Socket holds suction better than a rigid socket because the socket can move and conform to the changing contours of the residual limb, through all phases of gait and sitting. A loose elastic knee cage is recommended to enhance proximal brim seal during knee flexion past 90°. For sports prostheses, use of a rubberized sleeve of choice is recommended. Cosmesis is also enhanced since the patient no longer has the extra bulk of socks or inserts increasing calf circumference. It's a little too early to tell, but it is felt that atmospheric suspension may well become the standard below-knee fitting technique for all types of patients.
4. Use of a cuff suspension strap is improved since the cuff and socket brim can contour in about the patella (Figure 3). Use of a suspension sleeve with the T.F.S. is also possible, and if anything, enhances the function of a T.F.S. since the suspension sleeve supports the socket brim and soft tissues, holding the two in close conformity through the full range of knee motion.

5. Flexibility allows greater containment posteriorally in the popliteal region. The posterior wall can be higher since it flexes away during sitting. Little posterior flare is needed. In fact, this area could be rolled in slightly, similar to how the cubital fold is contained in myoelectric below-elbow arms (Figure 4). If the practitioner desires, the socket can be made flexible all the way down to the distal tibia. This is accomplished by building a thick distal end pad (with or without an insert) inside the socket, or an extension on the exterior of the socket which extends the trimline of the frame distally, allowing total flexibility in the distal regions of socket.
6. The ML measurement of the knee becomes wider as the knee flexes. This can be demonstrated by placing an ML gauge on the knee and watching the gauge as one puts the knee through its range of motion. The T.F.S. design allows for this dynamic variance.

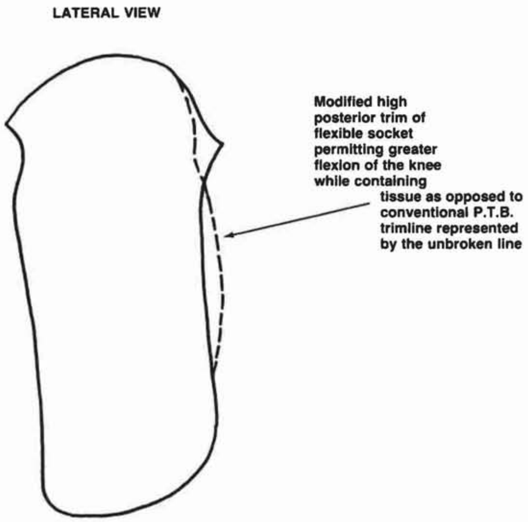


Figure 4. Lateral view of T.F.S. showing suggested modified contour.

Last but not least, overall hygiene and circulation seem to be dramatically improved. Especially impressive is the absence of red marks on the skin following doffing of the T.F.S. There are none of the usual red marks left by conventional sockets. Patients who had to have many reliefs before in their rigid sockets now require none.

Since several prosthetists have been fitting these sockets successfully, using various modification techniques, it has been concluded that it is irrelevant which particular modification technique is used. Results from all modification techniques have been improved utilizing the Total Flexible Socket. The use of negative modifications only is recommended. One simply does not need to add positive build-ups to the model since the reciprocal AP-ML displacement dynamically accommodates the patient's anatomy. The bony areas are accommodated automatically (most of the time) as the patient ambulates. It is, of course, most exact to use multiple transparent diagnostic sockets, alignate, or oil injection procedures (as well as other means) to obtain the best fit possible.

The flexible socket seems to work so well that it is tempting to skip the check socket stage. Do not succumb to this temptation, or you will never know just how comfortable the socket can be once you get the patient fairly

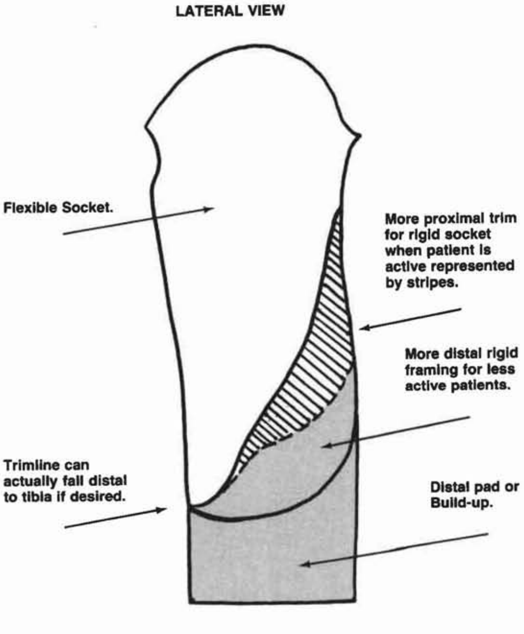
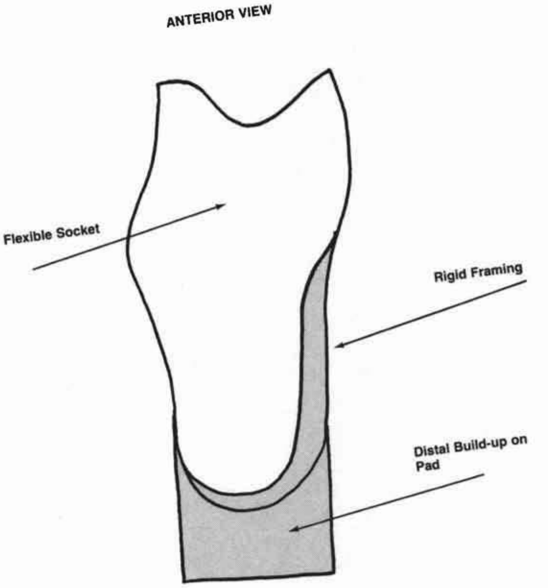
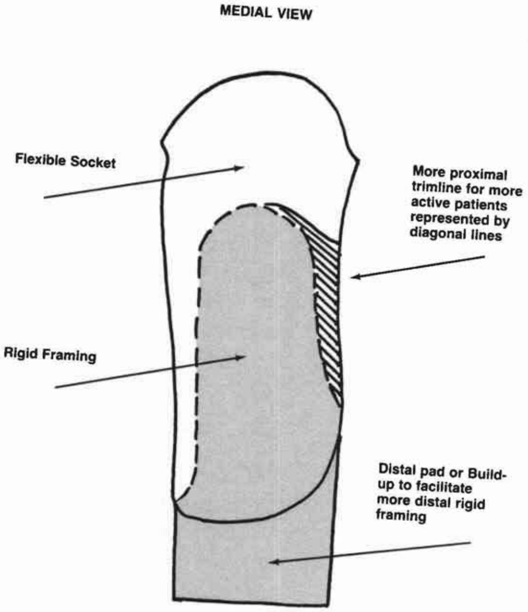
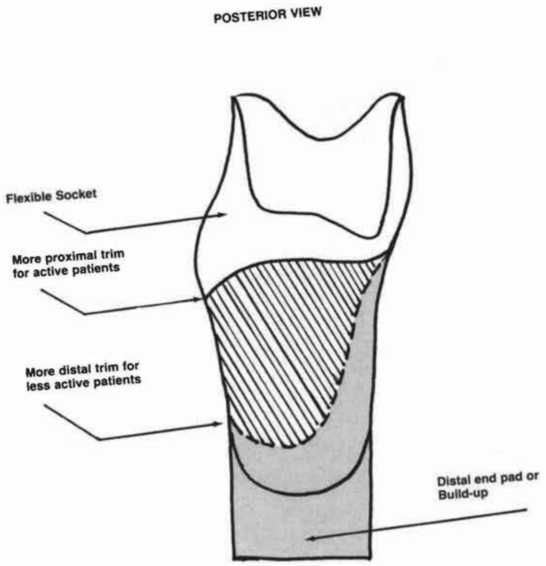


Figure 5. Four views of the T.F.S. showing sports and geriatric trimlines and distal end pad or buildup. Distal buildup is especially useful when it is desired to cut the anterior trimline below the distal tibia.







comfortable in the rigid transparent socket and clone it to the T.F.S.

After the hard socket is fit, it is necessary to remove an additional ¼″ to ⅜″ of plaster from the positive model around the superior brim, close to the patella, to allow a flexible clamping action about the proximal brim. Use of this extra modification can not be emphasized enough for final comfort and stability. An intimate fit must be maintained around the proximal brim with the T.F.S. design. No other additions or modifications are necessary.

If a liner or insert is used, it is fabricated over the positive model with a thick distal end pad to provide extra distance distally. This extra length is necessary if one desires to make the distal tibia area flexible since the frame can be trimmed more distal, even past the end of the distal tibia. Alternately, as mentioned, an extension can be added to the socket following vacuum forming.

One can use any of four materials for the flexible part of the socket: The first is Surlyn,® which is preferred in most cases. This material can be molded fairly thin, and yet it provides excellent structural strength and integrity. Surlyn® stock material of ⅛″–3⁄16″ thick is used (depending on the degree of flexibility) for vacuum forming. A final thickness of about 1⁄16″ or less is adequate. It is not necessary for this socket to be extremely flexible, as with a fenestrated socket, since the majority of the socket is open and flexible in all directions with two adjacent sides being able to move relative to the frame.

The second material is polyethylene, which is more flexible and sometimes more desirable for children or geriatrics who are somewhat inactive. The third is Streifylast, which is a material that is being utilized more and more lately since it has a high level of flexibility while maintaining its structural integrity, and is especially resistant to tearing and breakage. A fourth material called Polyethylene Plus® (available through Maramed) seems to be superior even to Streifylast and has an extremely good tear resistance.

Once the socket is vacuum formed, a fiberglass nylon polyester frame is fabricated. Carbon fiber and acrylic resin can be used, if one desires greater strength and less weight, but is not necessary in most cases. The thickness of this frame depends on the activity level of the patient, but usually ranges in thickness from 1/16" to 1/8".

As in Figure 5, there are two basic frame designs: one for geriatrics, and one for active or sports oriented patients. The geriatric type extends proximally to the medial tibial flare and is cut away everywhere else except around the distal end pad (Figure 6). The sports type frame for younger patients comes more proximal posteriorally, lending more strength. It maintains total AP-ML flexibility since it still has only two sides adjacent to each other. As long as one does not place a third wall on the frame, reciprocal AP-ML flexibility is preserved and provides for automatic pressure distribution. It must be emphasized that these are only guidelines and the actual trimlines of the frame are variable and modified as the patient's needs dictate.

The flexible socket can be attached to the rest of the prosthesis by using two or three bands of nylon fiber tape wrapped circumferentially about the frame and socket to provide strength, while not affecting flexibility. If one desires even more strength, pressure sensitive tape can be wrapped over the nylon tape or even over the whole frame and socket. The socket can be riveted or fastened with Chicago screws in addition to the tape, for additional security.

The final finishing of the prosthesis is relatively simple. If an endoskeletal approach is used, the soft foam cover hides the socket frame interface as well as the nylon strapping tape and results in a very cosmetic prosthesis (Figure 7). The T.F.S. prosthesis finishes especially well as an endoskeletal since it feels more life-like all the way up the prosthesis. If one desires an exoskeletal finish, one can easily use polyurethane foam for shape, laminate the outer covering, remove the flexible socket, and grind the foam away from around the frame and cosmetic shell as desired. This leaves a void or hollow of about 1/8" (all that is necessary) between the flexible socket and cosmetic shell. Alternately, the prosthesis can be shaped and finished about the socket in the same fashion as an endoskeletal prosthesis. The proximal external contours can then be established with a soft fairing of PE-LITE™ or Plastazote glued to the flexible socket and frame.

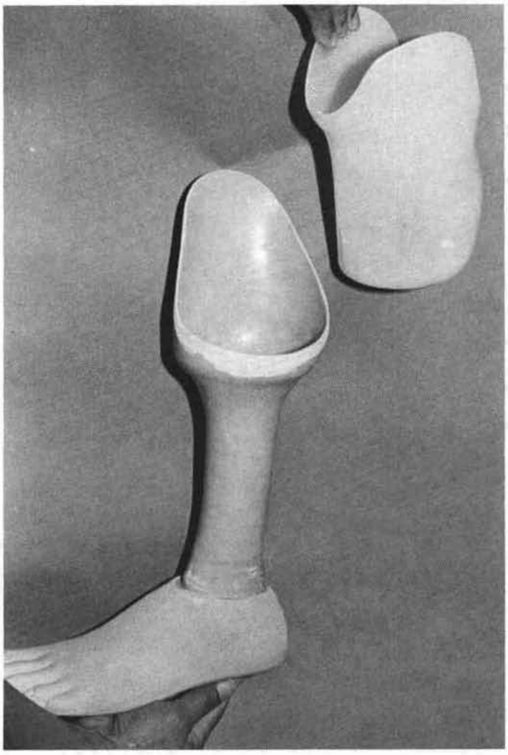


Figure 6. T.F.S. showing geriatric trimline. Ultralite construction.

Fabrication of an Atmospheric Suspension Socket is the same as for any T.F.S., except for the placement of either an expulsion valve or a small suction valve on a 45° angle at the distal posterior of the total flexible socket (Figure 8).

Modification on the other hand, is a little different than a non-atmospheric suspension T.F.S. The socket must be a little snugger to accommodate total self-suspension. After achieving the "perfect skin fit" with a clear diagnostic socket and the alginating proce-

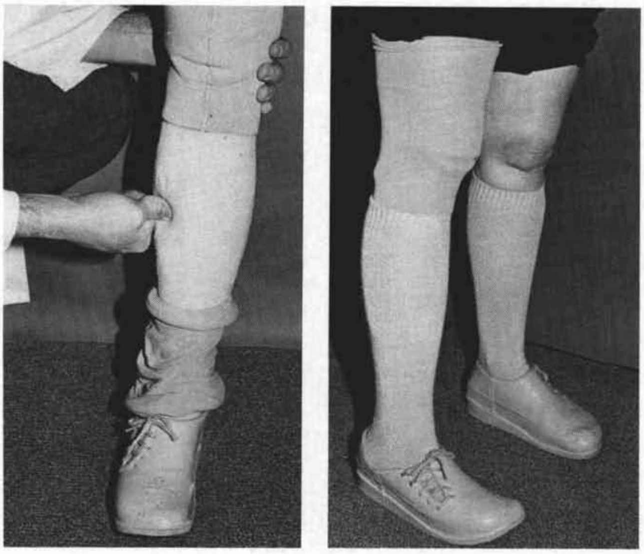


Figure 7. T.F.S. with soft cosmetic covering.

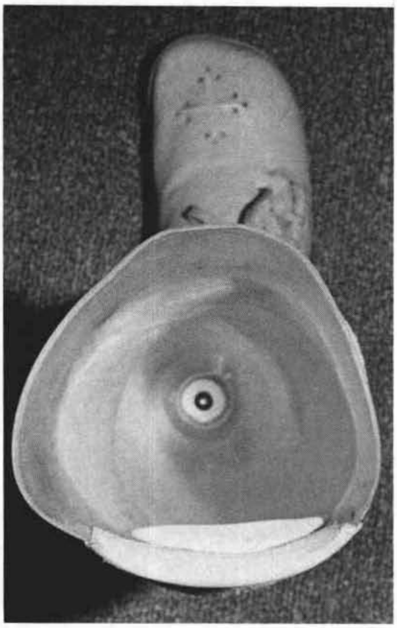


Figure 8. T.F.S.-A.S. showing placement of valve distally.

dures, the model is poured and modified the same as any T.F.S. by slightly tightening it about the patella area. The technician then takes the modified model and laminates a two layer cotton rigid socket over it, which is rolled or slushed twice with promoted liquid polyester resin to tighten all areas of the socket equally. This socket, with reduced internal dimensions, is then poured with plaster of Paris and the T.F.S. socket is subsequently vacuum formed over the resulting positive model. It is felt that this extra tightening is necessary to compensate for the fact that a rigid diagnostic socket cannot be donned as easily as a T.F.S. of equal or greater tightness.

In conclusion, a new concept for the fabrication of a below-knee prosthesis has been described, as well as the preliminary results of fitting some 40 patients for up to five months. It is sincerely hoped that other prosthetists will find it as beneficial to their patients as it has been found to be in both Oklahoma City and San Diego.

ACKNOWLEDGMENTS

We would like to thank one of our own prosthetists, Bill Etheridge in Oklahoma City for forcing John out of conventional thinking so we could aggressively research this interesting phenomenon.

We would like to thank Mary Healy, San Diego, for her help in Atmospheric Suspension Technique.

We also wish to thank Alan Finnieston, CPO for materials research and for finding an appropriate tear resistant thermoplastic.

AUTHORS

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Analysis of Questionnaire—New Concepts In AK Sockets

There were 16 respondents to the questionnaire; the respondents were unanimous in their response to questions one and two. All of them were dissatisfied with the conventional quadrilateral socket and all of them felt that there was room for change. In answer to question three, ten of them (62.5%) said that they felt that the techniques of Long and Sabolich were the correct approach. One of these respondents qualified his response by identifying the technique of Long. The rest of the respondents, 6, said maybe, including 4 who had experience with the involved techniques. Thirteen (81%) said that they had experience with the techniques and three said that they did not. Nine (56%) said that they had fit as many as 15 such prostheses and two said that they had fit more than 45. Eight (50%) of the respondents said that they had fit as many as five flexible wall sockets and three (19%) said that they had fit at least 10. Four (25%) had fit 25 or more flexible wall sockets. Ten (62.5%) felt that the flexible wall socket was of advantage to the patient, three (19%) felt that it was indicated for selected patients and three said it was not advantageous.

In summary, it would seem that many prosthetists feel that the conventional quadrilateral shape is inadequate. It is interesting to speculate, however, how many prosthetists were satisfied with their quad fittings before they learned of the new concepts now being publicized and how much of the dissatisfaction was stirred up by the publicity. In light of the number of respondents who have at least some measure of experience with the techniques described, it seems that the new concepts have achieved a rapid measure of penetration into common practice.

Charles H. Pritham, C.P.O.
Editor

Calendar

1986

May 4–5, Northwest Chapter of the Academy Seminar, Portland, Oregon. Contact: Robert Lebold, CO, Salem Orthopedic & Prosthetic, Inc., 675 12th Street SE, Salem, Oregon 97301; tel. 503-581-9191.

May 7–9, Second Annual Course on Practical Upper Extremity Prosthetics, East Meadow, New York. Contact: Daniel Shapiro, M.D., Program Director, Department of Physical Medicine & Rehabilitation, Nassau County Medical Center, 2201 Hempstead Turnpike, East Meadow, New York 11554.

May 7–10, Annual Meeting of the Association of Children's Prosthetic-Orthotic Clinics, Milwaukee, Wisconsin. Contact: Francis J. Trost, M.D., Program Chairman, 2545 Chicago Avenue South, Minneapolis, Minnesota 55404.

May 16–17, American Academy of Orthotists and Prosthetists Continuing Education Conference 2-86, "Lower Limb Prosthetics," Kansas City, Missouri.

May 28–30, S. M. Dinsdale International Conference on Rehabilitation, "Towards the 21st Century," hosted by the Royal Ottawa Regional Rehabilitation Centre, 505 Smyth Road, Ottawa, Ontario K1H 8M2. Contact: Education Dept. tel. 613-737-7350, ext. 602.

June 2–6, Fitting Procedures for the Utah Artificial Arm, Northwestern University Post Graduate Medical School, Department of Prosthetics and Orthotics, Chicago, Illinois. Contact: Harold Sears, Ph.D., Motion Control, Inc., 95 South Elliott Road, #105, Chapel Hill, North Carolina 27514; tel. 919-968-8492.

June 6–8, AOPA Region IX, COPA, and the California Chapters of the Academy Combined Annual Meeting, Newport Beach Marriot, Newport Beach, California.

June 19–22, AOPA Region VI and Academy Midwest Chapter Combined Annual Meeting, Lakelawn Lodge, Delavan, Wisconsin.

June 23–27, RESNA 9th Annual Conference on Rehabilitation Technology, "Employing Technology," Radisson South Hotel, Minneapolis, Minnesota. Contact: RESNA, Suite 700, 1101 Connecticut Avenue, NW, Washington, D.C. 20036; tel. 202-857-1199.

June 24–28, 6th National Veterans Wheelchair Games, University of Texas at Arlington, Arlington, Texas. Contact: Terrance J. Wickman, Games Coordinator, Dallas Veterans Administration Medical Center, Attn.: Recreation Service (11K), 4500 S. Lancaster Road, Dallas, Texas 75216; tel. 214-372-7012.

July 18—19, American Academy of Orthotists and Prosthetists Continuing Education Conference 3-86. "Disarticulation Prosthetics," Milwaukee, Wisconsin. Contact: Academy National Headquarters, 703-836-7118.

August 11–15, 1986 UNB Myoelectric Controls Course and Symposium, Fredericton, New Brunswick, Canada. Contact: Director, Bio-Engineering Institute, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 5A3; tel. 506-453-4966.

August 22–23, American Academy of Orthotists and Prosthetists Continuing Education Conference 4-86, "Pediatric Prosthetics," Newington, Connecticut. Contact: Academy National Headquarters, 703-836-7118.

September 10–12, 6th Annual Advanced Course in Lower Extremity Prosthetics, East Meadow, New York. Contact: Daniel Shapiro, M.D., Department of Physical Medicine & Rehabilitation, Nassau County Medical Center, 2201 Hempstead Turnpike, East Meadow, New York 11554.

September 13–16, The 39th Annual Conference on Engineering in Medicine and Biology, Omni International Hotel, Baltimore, Maryland. Contact: The Alliance for Engineering in Medicine and Biology, Suite 700, 1101 Connecticut Avenue, NW, Washington, DC 20036.

September 19–20, American Academy of Orthotists and Prosthetists Continuing Education Conference 4-86, "Powered Limb Prosthetics," Albany, New York. Contact: Academy National Headquarters, 703-836-7118.

October 22–31, UCLA Advanced Prosthetics Techniques, Los Angeles, California. Contact: Timothy B. Staats, MA, CP, UCLA POEP, Room 22-46, 1000 Veteran Avenue, Los Angeles, California 90024.

October 24–25, American Academy of Orthotists and Prosthetists Continuing Education Conference 5-86, "Spina Bifida," Cincinnati, Ohio. Contact: Academy National Headquarters, 703-836-7118.

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January 22–27, American Academy of Orthopaedic Surgeons, Annual Meeting, San Francisco, California.

February 15–22, Academy Annual Meeting and Scientific Symposium, Hyatt Regency Tampa, Tampa, Florida. Contact: Academy National Headquarters, 703-836-7118.

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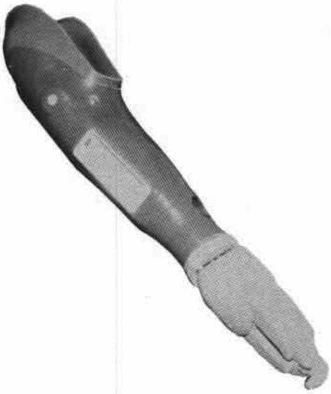

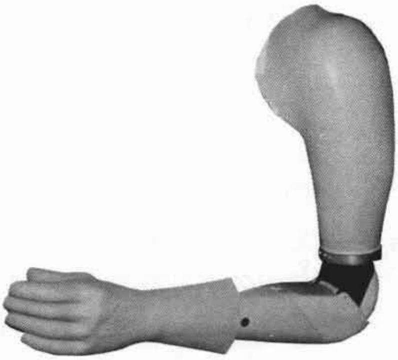

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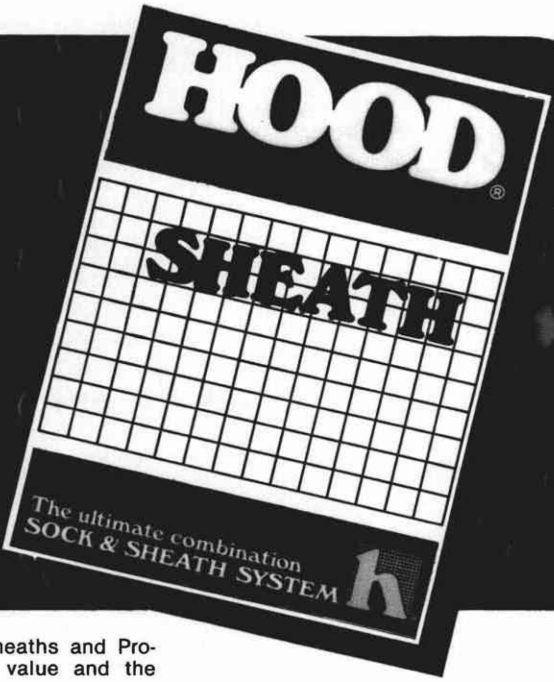
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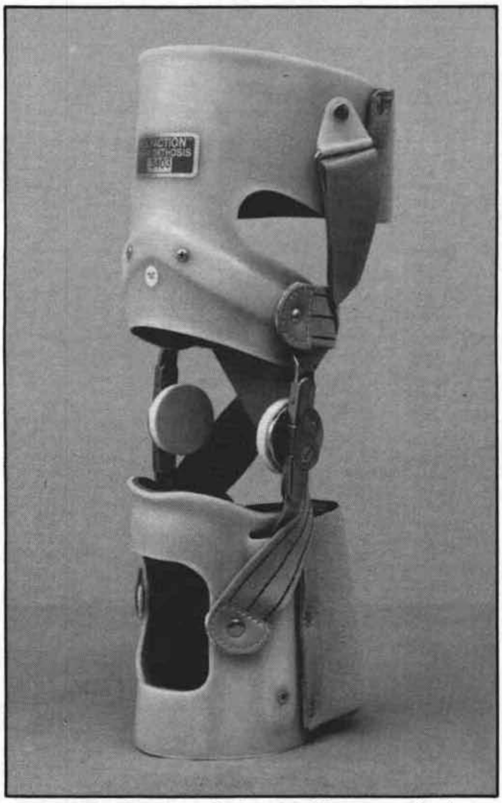
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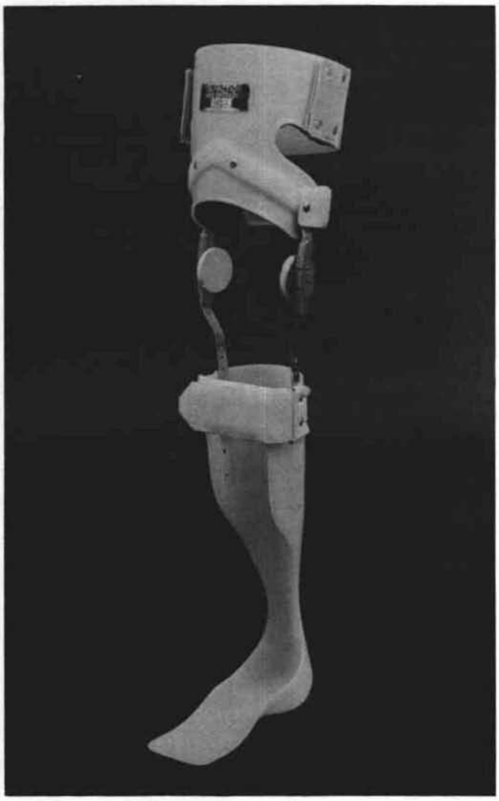

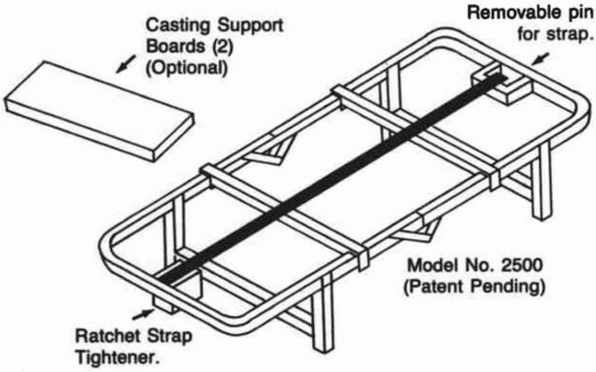
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