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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.

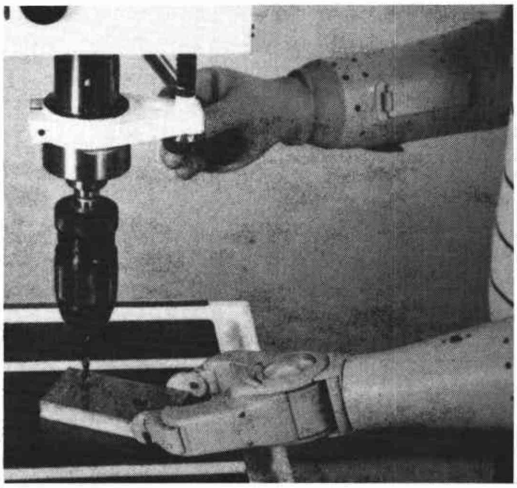

Figure 1. Otto Bock electric hand and electric hook (Greifer). Bilateral powered fittings can be successful in carefully selected cases. ***(Courtesy of Otto Bock Industries.)***

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.

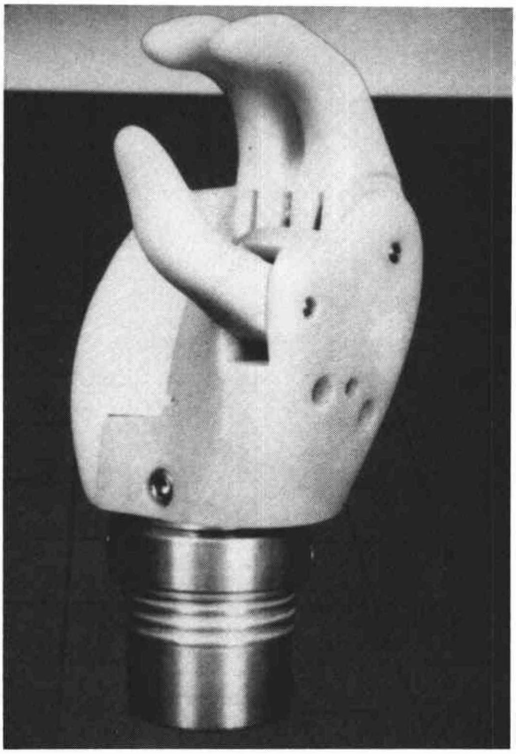

Figure 2. Variety Village VV2-6 electric hand: the smallest and lightest powered hand commercially available. ***(Courtesy of Variety Village Electrolimb Production Centre.)***

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.

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.

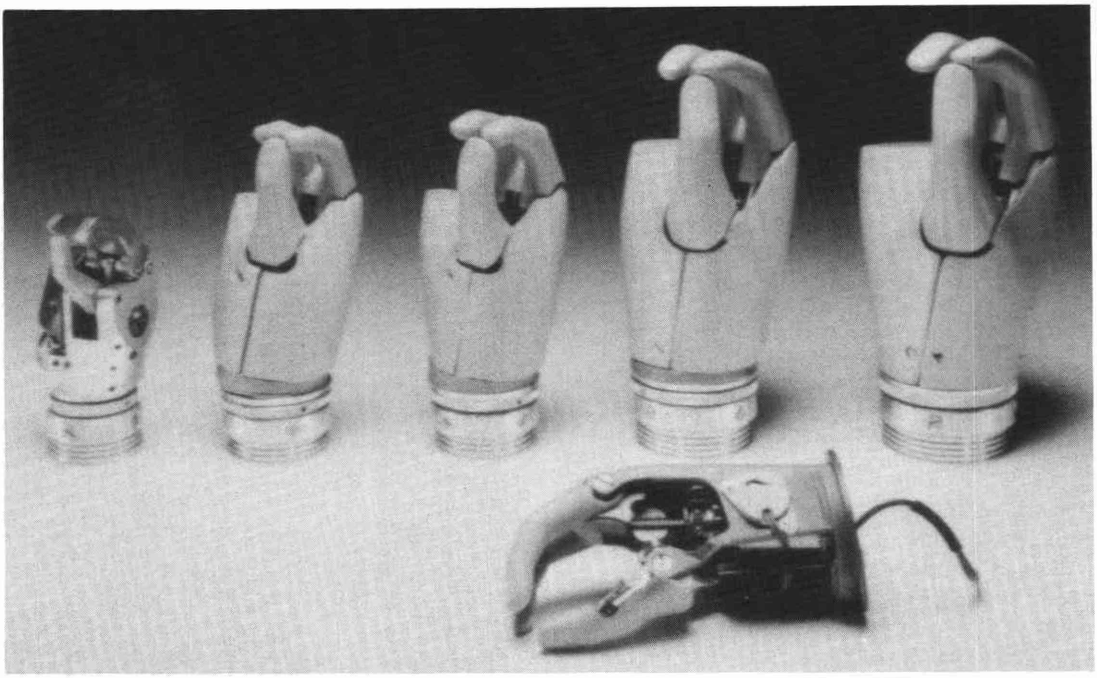

Figure 3. Electric hands imported by Liberty Mutual. The smallest is the System-Teknik from Sweden; balance are Steeper hands from England. ***(Courtesy of Liberty Mutual Research Center.)***

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.)***

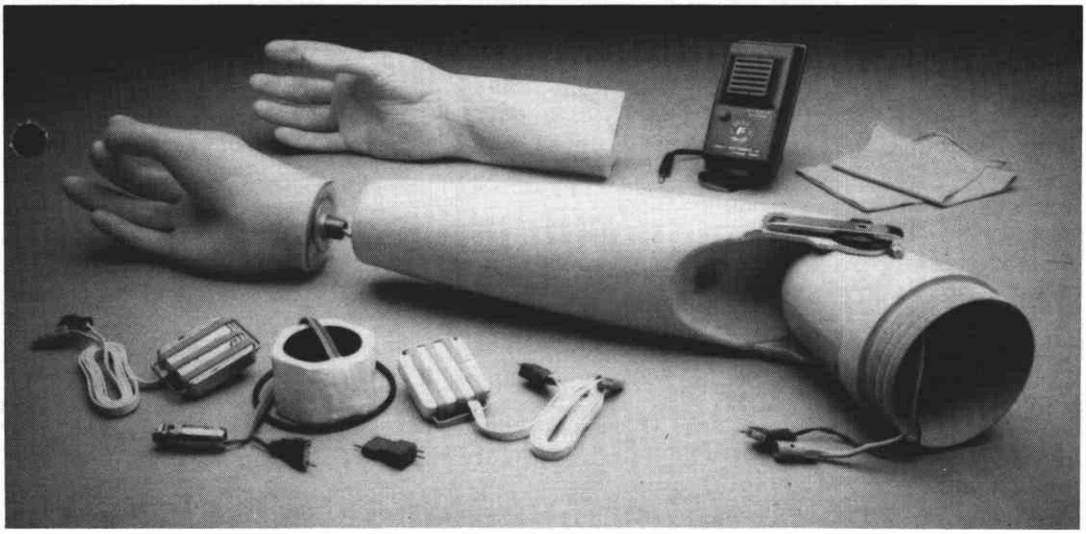

Figure 5. Fidelity components, including harness pull switch, electric elbow, and VANU hand. ***(Courtesy of Fidelity Biomedical Products.)***

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).

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.

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.)*

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.

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.

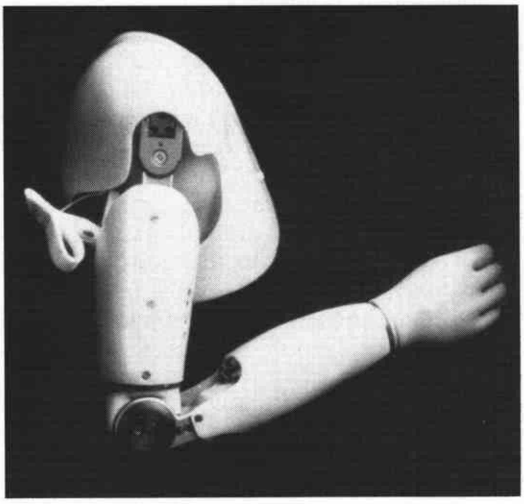

Figure 7. Boston elbow, combined with a Hosmer mechanical shoulder joint and Otto Bock electric hand. Combining various international components can enhance prosthetic restoration. (Prosthetic Design by John C. Hodgins, C.P.O.; *(Courtesy of Liberty Mutual Research Center.)*

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

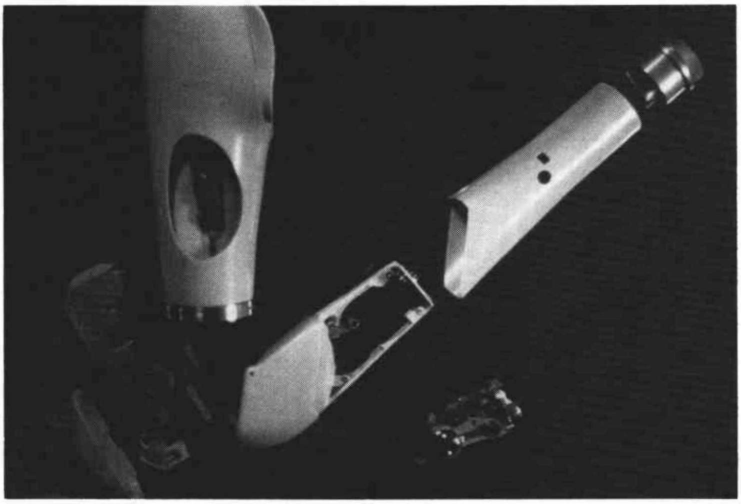

Figure 8. Exploded view of the Utah elbow. Highly modular construction facilitates servicing in the field. *(Courtesy of Motion Control, Inc.)*

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.

REFERENCES

1 Agnew, J.P., "Functional Effectiveness of a Myo-Electric Prosthesis Compared with a Functional Split-Hook Prosthesis: A Single Subject Experiment," *Prosthetics and Orthotics International,* 5(2), pp. 92–96, 1981.

2 Billock, John N., "Upper Limb Prosthetic Management—Hybrid Design Approaches," *Clinical Prosthetics and Orthotics,* 9(1), pp. 23–25, 1985.

3 Childress, D.S., "An Approach To Powered Grasp," *Proceedings of the Fourth International Symposium on External Control of Human Extremities,* Dubrovnik, Yugoslavia; pp. 159–167, 1973.

4 Doubler and Childress (1984), "Design and Evaluation of a Prosthesis Control System Based on the Concept of Extended Physiological Proprioception," *Journal of Rehabilitation Research and Development,* 10(39), pp. 19–31.

5 Ferguson, Shirley, "Electric Power In Upper Limb Prosthetics: The Michigan Experience," *Inter-Clinic Information Bulletin,* 18(4), pp. 1–8, 1983.

6 Graupe, et al., "A Multifunctional Prosthesis Control System Based on Time Series Identification of EMG Signals Using Microprocessors," *Bulletin of Prosthetics Research,* 10(27), pp. 4–16, 1977.

7 Jacobsen, et al., "Development of the Utah Artificial Arm," *IEEE Transactions on Biomedical Engineering,* BME-29, (4), pp. 249–269, 1982.

8 Malone, et al., "Immediate, Early, and Late Post-surgical Management of Upper-Limb Amputation," *Journal of Rehabilitation Research and Development,* 21(1), pp. 33–42, 1984.

9 Millstein, Heger, and Hunter, "A Review of Failures in Use of the Below-Elbow Myoelectric Prosthesis," *Orthotics and Prosthetics,* 36(2), pp. 29–34, 1982.

10 Murphy and Horn, "Myoelectric Control Systems—A Selected Bibliography," *Orthotics and Prosthetics,* 35(1), pp. 34–47, 1981.

11 Northmore-Ball, et. al., "The Below-Elbow Myo-Electric Prosthesis: A Comparison of the Otto Bock Myo-Electric Prosthesis with the Hook and Functional Hand," *Journal of Bone and Joint Surgery,* 42-B(3), pp. 363–367, 1980.

12 Scott, Robert N., "Myo-Electric Control of Prostheses," *Archives Of Physical Medicine and Rehabilitation,* 47(3), pp. 174–181, 1966.

13 Scott, R.N., *An Introduction to Myoelectric Prostheses.* Bio-Engineering Institute, University of New Brunswick, Fredricton, N.B., pp. 37, 1984.

14 Spaeth and Klotz, *Handbook of Externally Powered Prostheses for the Upper Extremity Amputee,* C. Thomas, Springfield, IL, p. 107, 1981.

15 Wirta, Taylor, and Finley, "Pattern-Recognition Arm Prosthesis: A Historical Perspective—A Final Report," *Bulletin of Prosthetics Research,* 10(30), pp. 8–35, 1978.

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
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