DEVELOPMENT AND EVALUATION OF EXTERNALLY POWERED UPPER LIMB PROSTHESIS

SUMMARY OF RESEARCH PROJECT ACTIVITIES

July 1970—July 1971

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During the first half of 1971, clinical evaluation was continued on the four upper-limb prosthesis External Power and Control (EXPAC) units which had been fitted during calendar year 1970; in addition, evaluation was initiated on four units newly fitted in 1971.

The units were organized into two basically different equipment configurations: the Above-Elbow (Type A) configuration and the Below-Elbow (Type B) configuration. Type A (Fig. 1) is characterized by motor location within the prosthesis. Type B (Fig. 2) is characterized by motor location remote to the prosthesis, e.g., on the amputee’s belt. Whereas the Type A configuration is appropriate for amputations through or, preferably, proximal to the elbow joint, Type B is appropriate for amputations through or distal to the elbow joint; however, Type B can, presumably, be used for amputations at any level as well as for powered braces. Both configurations can be connected to provide either terminal device function or elbow flexion or both. Both configurations also have the theoretical capability of powering wrist rotation.

Test amputees with an assortment of occupations and ages and with a full range of amputation levels were selected to determine system versatility and reliability as well as other factors related to user accept-

* Based on work performed under VA contract.
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All amputees were fitted with functional, conventional, Body-Powered (BP) prostheses to facilitate comparison with the Externally Powered (EP) prostheses. All amputees were interviewed and examined periodically.

Unit #1—In February 1970 this unit was fitted to a 27-year-old wrist-disarticulation amputee, medical student, who had had approximately 5 years experience with a BP prosthesis. He was a highly skilled full-time prosthesis user. His amputation had been performed for trauma.

His EP unit is a configuration Type B. The motor and battery are mounted on a single plate designed to hook onto the trouser belt. Force is transmitted from motor to VO terminal device by Bowden cable. The single-site EMG sensor is mounted in the stump socket near the common extensor tendon.

During the current report period, this amputee used his EP prosthesis preferentially for special activities when absence of a shoulder harness, reduced stump end pressure, and extended reach capabilities of the EP system were so advantageous that the increased weight and bulk did not seem to matter. He listed specifically: in very hot weather, after bruising the end of his stump, when lubricating his car, when changing the baby’s diapers, and when reading in bed.

For other activities he preferred to use his BP limb due to 1. shoulder muscle feedback, 2. the ability to maintain a steady force by setting his shoulders against the harness, 3. more rapid response, 4. higher velocity, and 5. less weight and bulk.

His personal preference would be to have both a BP and an EP prosthesis, but if restricted to one, he would retain his BP prosthesis.

His recommendations for certain alterations in configuration of the belt pack and for faster terminal device response have been carried out.

This amputee was filmed performing a variety of functional activities for documentation and further study.

Unit #2—In August 1970 this unit was fitted to a 22-year-old above-elbow amputee, college student, who had had 9 months experience with a BP prosthesis. Although he was unenthusiastic about his BP prosthesis, he used it most of the time and with moderate skill. His amputation was performed for a combat-sustained injury when in Army service during the Vietnam era.

His EP unit is in configuration Type A. The motor is located in the elbow space and connected to provide either opening of a VO terminal device or elbow flexion. Serving as a selector switch, the lock on the external elbow hinges is operated in the traditional manner with an elbow-locking strap attached to the front of the shoulder harness. The battery is hooked to the trouser belt. The single-site EMG sensor is mounted in the stump socket over the proximal end of the biceps muscle.

This amputee became very enthusiastic about the EP prosthesis. De-
spite the fact that his BP prosthesis was rebuilt and its socket replaced during this report period, he continued to use his EP limb exclusively. He has worn it without difficulty for continuous periods as long as 18 hours. He demonstrates excellent control of the terminal device over a wide range of arm positions and even with the arm raised above shoulder level.

His recommendations for relocation of the battery switch to a more accessible site, strengthening of the battery cases, and conversion of the battery packs from 14-hour to 4-hour charge periods were carried out.

This amputee was filmed performing a variety of functional activities for documentation and further study.

Unit #3—In October 1970 this unit was fitted to a 17-year-old mid-below-elbow amputee who was a high school and piano student and has had approximately 1 year’s experience with a BP prosthesis. He used the BP prosthesis well and full-time. His amputation had been performed for a malignant tumor in the hand.

His EP unit is in configuration Type B. The motor and battery are hard-mounted on a stylishly wide waistbelt, an arrangement which the amputee preferred to hooking them to the trouser belt. Force is transmitted from motor to VO terminal device by Bowden cable. The single-site EMG sensor is mounted in the stump socket near the common extensor tendon. A large battery is used for long piano practice sessions.

This amputee has not established an overall preference. He has been alternating between the BP and EP prostheses, wearing each one for portions of almost every day. He prefers the BP prosthesis for some activities and the EP for others. It was possible to fit his EP socket more snugly than the BP one without causing discomfort due to the development of high compression forces in the end of the stump in reaction to shoulder control motions. He seems to prefer this very snugly fitting prosthesis for activities requiring maximum stump/socket stability, whereas, he prefers the more loosely fitting BP prosthesis when quick application is important, such as when he is late for school.

He was found to be twisting his Bowden cable inadvertently when applying the EP prosthesis, thereby increasing cable friction and reducing the speed of terminal-device response. This problem was solved by teaching him to use one of the colored wires attached to the cable as a twist indicator.

He had a very weak EMG signal when first fitted. This signal rapidly improved by a factor of 2 to 3, necessitating the readjustment in electronic system gain. The EMG output has remained constant at this level since.

This amputee’s piano playing as well as other functional activities were extensively filmed for documentation and further study.
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Unit #4—In December 1970 this unit was fitted to a 54-year-old elbow-disarticulation amputee who had lost his forearm 7 months previously in an accident at work with a soap cutting and processing machine. By the time he received his EP prosthesis he had had his BP prosthesis for 2 months and had developed only slight skill.

His EP unit is in configuration Type B. The motor and battery are hard-mounted on a wide waistbelt. Force is transmitted from motor to terminal device by Bowden cable to provide either terminal-device opening or elbow flexion. Serving as a selector switch, the elbow lock is operated in the traditional fashion with an elbow-locking strap attached to the front of the shoulder harness. In this case a conventional Hosmer internal locking elbow was used. The single site EMG sensor is mounted in the stump socket over the proximal end of the biceps muscle.

Within a month after receiving his EP prosthesis, this amputee returned to his former job on a full-time basis. He has been enthusiastic about his EP prosthesis. He wears it from the time he gets up in the morning until he returns from work in the afternoon. Usually he does not wear it while resting at home, but he reapplies it for household chores or if he goes out. Although a new and better fitting BP prosthesis was constructed for this amputee near the end of the current report period, he has worn it only to verify its fit and serviceability.

Negative experiences have included breaking a battery case, some temporary difficulty with electrode contact, minor episodes of inadvertent openings of the terminal device, and slow operating speed. The causes of these problems have been identified and corrected.

Unit #5—In December 1970 this unit was fitted to a 48-year-old short below-elbow amputee who is a part-time mechanic and farmer. He had lost his hand in an injury at work about 1 year earlier. By the time he received his EP prosthesis he had had a BP prosthesis for about 8 months. He was disappointed in his BP limb and, although he wore it full-time, he did so almost entirely for appearance and rarely used the hook.

His EP unit is in configuration Type B. The motor and battery are hard-mounted on a wide waistbelt. Force is transmitted from motor to VO terminal device by Bowden cable. The single-site EMG sensor is mounted in the stump socket near the common extensor tendon. A Muenster socket is used with no additional harness.

This amputee's response to his EP prosthesis has been highly favorable. He adapted to it immediately, without training, and uses it exclusively and full-time. He greatly favors the terminal-device interchange capability which this system provides since he likes to use his VO hand in a work glove to manipulate farm hand tools but prefers to switch to a VO hook to manipulate small metal objects in his machine shop.

He has found that a freshly charged battery lasts him about 9 hours. He does not consider it a significant inconvenience to take another
battery with him when he expects to be away from home for a longer period.

He has found that when straining to force a grasped object, he has occasionally opened his terminal device unintentionally. Independently, he discovered that he can ensure maintenance of a firm grip by switching off the electrical system for the duration of the maneuver.

On two occasions he felt obliged to remove his prosthesis for a couple of hours because of skin irritation at the socket sensor port. This problem was found to be due to excessive sensor pressure and excessive wetting of the skin to ensure electrical contact. It responded to appropriate measures.

Unit #6—In March 1971 this unit was fitted to a 30-year-old long above-elbow amputee, high-pressure boiler welder and private part-time horse farmer. He had had over 5 years experience with BP prostheses and had developed superb skill. His amputation was performed for a job-related injury.

His EP unit is in configuration Type A. The motor is located in the elbow space and connected to provide either opening of a VO terminal device or elbow flexion. Serving as a selector switch, the lock on the external hinges is operated in the traditional manner with an elbow-locking strap attached to the front of the shoulder harness. The battery is hooked to the trouser belt. The single-site EMG sensor is mounted on the stump socket over the biceps muscle residual. Since this amputee depended heavily on the humeral rotation turntable in his work, and since his stump is fairly long, a special turntable was designed and constructed to occupy minimal longitudinal space.

Following delivery and training, this amputee's response to his EP prosthesis has been one of total rejection. He reports that it is because the limb is excessively tiring. He relates this both to the additional weight of the limb and to unaccustomed use of his biceps muscle residual to cause the terminal device to function and to flex the elbow. He explains that his work entails considerable physical labor and is performed while standing and without opportunities to rest. Under these circumstances he cannot tolerate the EP prosthesis more than 5 hours. He has stated that the additional weight would not be a problem for individuals in occupations permitting occasional opportunities to sit and support the prosthesis. Appliance fit did not seem to be a significant factor in his dissatisfaction since, after modification of the original harness to a shoulder saddle with cross-chest strap, he reported full satisfaction with both harness and socket. It is felt that a significant factor in this rejection may be one of habituation. As an extraordinarily vigorous, skilled, long-term BP user, this amputee may have developed such a strongly established habit of using his shoulders for prosthesis control and power that he is unable to convert easily to using his biceps muscle residual alone.
Seamone and Schmesser, Jr.: UE Externally Powered Prosthesis

In this situation, with his EP prosthesis, he exhausts himself by using both his shoulders and his biceps muscle.

*Unit #7*—In March 1971 this unit was fitted to a 56-year-old elbow-disarticulation amputee who had been a non-skilled laborer at the time of his injury. This prosthesis was delivered about 1 week after delivery of his BP limb and 9 months after amputation. The original injury also resulted in severe limitation of ipsilateral scapulo-humeral joint motion. In spite of special harnessing considerations and training efforts this amputee had great difficulty developing any useful function with the BP prosthesis.

His EP unit is in configuration Type B. The motor and battery are hard-mounted on a wide waistbelt. Force is transmitted from motor to terminal device by Bowden cable to provide either terminal-device opening or elbow flexion. Serving as a selector switch, the elbow lock is operated in the traditional manner with an elbow-locking strap attached to the front of the shoulder harness. In this case conventional outside elbow-locking hinges were used. The single-site EMG sensor is mounted in the stump socket over the proximal end of the biceps muscle.

This amputee’s reaction to his EP prosthesis has been strongly favorable. He wears it exclusively and full-time. He demonstrates excellent function and adapted to it immediately with negligible training.

*Unit #8*—In May 1971 this unit was fitted to a 17-year-old shoulder-disarticulation amputee, high school student, and part-time farm hand. His amputation was performed through the scapulo-humeral joint in October 1970 for a farm injury. He received his BP prosthesis in January 1971, but despite a satisfactory fit and training, he found it to be so functionless and encumbering that he soon stopped wearing it altogether.

His EP unit is in configuration Type A. The motor is located within the upper arm segment and connected to provide either opening of a VO terminal device or elbow flexion. Serving as a selector switch, the elbow lock is operated in the traditional manner with an elbow-locking cable and strap looped around the front of the shoulder cap and then routed down to the trouser belt. In this case a conventional Hosmer internal-locking elbow was used below the motor. Voluntary motion of the amputation scar where it adheres to the pectoralis muscle residual provides the motor-control signal. A piece of fine thread attached to a button cemented to the skin in this area transmits the skin motion to a low-friction displacement transducer.

This amputee’s response to his EP prosthesis has been highly favorable. He does not wear it full-time, but, because he finds it useful in his work activities, he wears it almost every day and has worn it as long as 10 hours at a time. Specific activities in which he finds it useful are: carrying buckets and other light one-hand objects, carrying two-hand
objects such as trash containers, and immobilizing small objects while he works on them with his remaining hand.

His unique control system permits an exceptionally quick, accurate, and reliable response. It has been completely trouble-free. The skin adherent button has not been troublesome. It has not required replacement in less than 1 week. The amputee has found that he can do this himself as well as apply and remove the prosthesis and adjust the control thread without assistance.

He favors reduction in battery time in order to reduce battery weight and bulk and permit its relocation from the belt to the prosthesis. These recommendations are being carried out.

In summary, during this report period, clinical evaluation was initiated on four new EXPAC units and continued on four which had been fitted previously. Amputation levels included one wrist disarticulation, two below elbows, two elbow disarticulations, two above elbows, and one shoulder disarticulation. Five of these were fitted with units of the Type B, belt-mounted, motor location. The remaining three were fitted with units of the Type A, prosthesis mounted, motor location. Amputees ranged in age from 17 to 56 years and represented a wide variety of occupations. All had been carefully fitted and trained with orthodox BP prostheses to facilitate comparison with their EP prostheses.

One above-elbow amputee rejected his EP prosthesis as "too tiring." He had had the longest experience (over 5 years) with a BP prosthesis of anyone in the series and was among the most highly skilled. The wrist-disarticulation amputee, who had had almost as long an experience with a BP prosthesis and was also very highly skilled, preferred his BP prosthesis for most activities, but preferred his EP one for certain activities. One below-elbow amputee who had had the next longest experience with a BP prosthesis remained undecided. Each of the remaining five amputees had a strong preference for the EP prosthesis and exhibited superior performance with this type of appliance.

During the test period the incidence of failure and malfunction of the nonelectrical conventional prosthetic components, though reasonable, exceeded that of the electrical components. Only minor electronic adjustments were required.

Clinical evaluation is being continued on all units with these amputees.