

Early Clinical Experience With The Johns Hopkins Externally Powered Modular System For Upper-Limb Prostheses¹

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Eight amputees were selected to help provide data for evaluation of the Johns Hopkins system. In order to determine the range of applicability of this externally powered system, amputees who represented a broad range of upper-limb amputation levels were selected. Included

in this program were one wrist-disarticulation amputee, two below-amputees, two elbow-disarticulation amputees, two above-elbow amputees, and one shoulder-disarticulation amputee. Following is a summary of the results of the evaluation program to date.

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Unit #1 was fitted to a left-wrist-disarticulation amputee in February 1970. It has a laminated forearm socket suspended only by a supra-condylar strap. The motor, electronic control unit, and battery pack are worn on the waist. The EMG sensor is built into the fore-

arm socket in a "floating" arrangement, and is located over the junction of the common extensor tendon and the extensor muscle bellies. Proportional opening of the terminal device is controlled by varying the EMG signal. The unit was evaluated in three phases.

During the first, or break-in-phase, which lasted for several weeks, the amputee wore the prosthesis for graduated periods while performing increasingly demanding manual skills. By practicing various manipulations the amputee attempted to develop maximum dexterity. The causes of wire breakage and other mechanical and functional problems were identified and the design was corrected.

In the second, or comparison, phase, various physical and functional measurements were made so that the new prosthesis could be compared to the amputee's pre-existing body-powered (BP) prosthesis. These include the span, force, velocity, and fine control characteristics of the terminal-device grasp, the range of terminal-device placement, the bimanual work envelope, and grasp-placement coordinations as well as stability, weight, comfort, and speed of application. Test activities were recorded on movie film for review and further analysis.

In the third and final phase, the amputee used the new device as his primary prosthesis for all of his activities for several months in order to reveal undiscovered problems and to determine mechanical endurance and ultimate amputee preference.

After wearing the unit for one year, the amputee reported: For

delicate work the body-powered prosthesis is superior to the externally powered (EP) one owing to (a) shoulder-muscle feedback, (b) the capability of setting the shoulders for steady force, (c) lack of lag time, and (d) higher speed. Because of the time lag and lower velocity, he is inclined to use his EP prosthesis primarily in a "bang-bang" mode. He dislikes battery and motor bulk and weight, especially at the end of the day. He has reported that the EP prosthesis is ideal for working above his head or within closely restricted space, such as when lubricating the underside of an automobile, or for conditions which render shoulder motion undesirable or difficult, such as when propped up to read in bed. The absence of a shoulder harness and lack of compression force on the end of the amputation stump are definite advantages of the EP system if and when the end of the amputation stump is tender. This amputee has been able to use a snugger socket with the EP system than with the BP system, because of this feature. He has no sensor skin-sensitivity problems despite a known sensitivity to nickel, the metal rivets in his lower-limb prosthetic socket, and his wrist watch. The net result of all factors is that he likes to have his externally powered system for special uses and for relief from his body-powered prosthesis, especially in hot weather. The average EP use is now two or three days per week.

Unit #2 (Fig. 1) was fitted to a right-above-elbow amputee in August 1970. One year prior to this time he had been fitted with a body-powered AE prosthesis with inter-

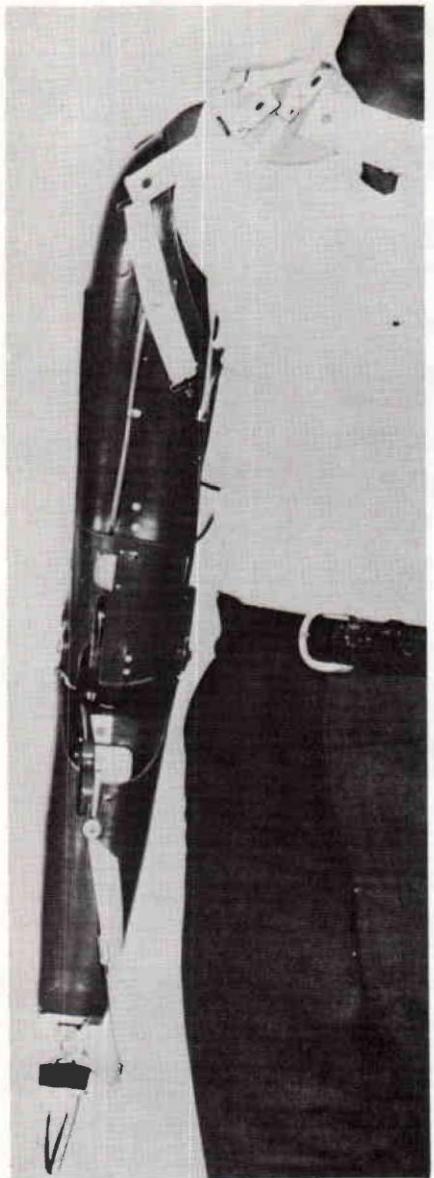


Fig. 1

Unit #2 fitted to an above-elbow case.

nal-locking elbow, AE figure-8 dual-control harness, quick-disconnect wrist, voluntary-opening (VO) hook, and an Army Prosthetics Research Laboratory (APRL) hand. He developed moderate facility with this equipment but never used the

hook. The EP power unit is located in the elbow space and controls either the terminal device (voluntary-opening function) or elbow flexion, using a routine external locking cable and strap to the shoulder saddle in order to select terminal-device vs. elbow function. The battery for this system is located on the belt. The single-site EMG sensor is mounted in the socket over the biceps muscle.

The amputee clearly prefers the externally powered prosthesis to his body-powered system and uses it all the time. Some harness adjustment, repair of the elbow-locking cable attachment, and replacement of the rubber band which closes the hook have been necessary, but these were not related to the power system. There have been no breakdowns or adjustment problems in the EP system.

Although the patient states that he actually preferred the additional weight of his EP prosthesis compared with that of the BP, he also states that the weight becomes objectionable if his activities require him to be standing or walking and without additional support for his prosthesis for more than three hours.

For this reason he feels that this type of limb might be too tiresome for certain kinds of outdoor employment. However, when he is able to sit down and rest the prosthesis in his lap or on a table for a few minutes every couple of hours, the externally powered prosthesis causes him less fatigue than the body-powered one; therefore, he feels that the limb is especially suited to persons doing office work or to persons whose work activities entail occa-

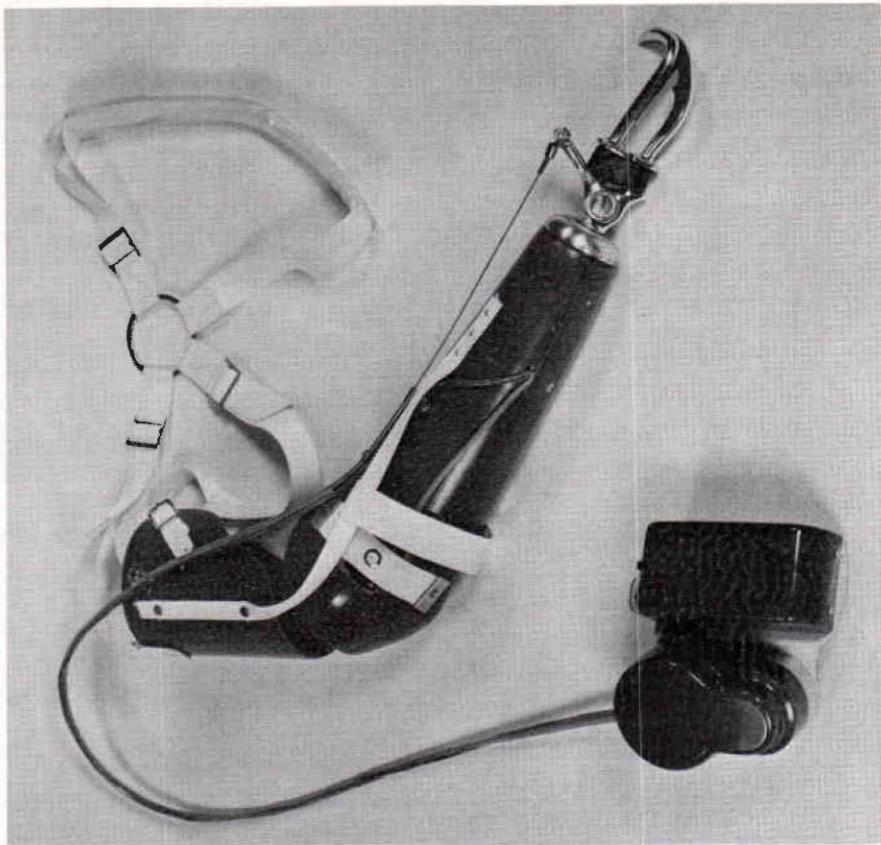


Fig. 2

Unit #3 for a right-mid-below-elbow amputee. In this case the power unit and battery case were designed to be clipped to the belt as a combined unit. A more convenient method is shown in Figure 3.

sional periods of sitting, as in driving a motor vehicle.

Preliminary analysis of experience with his EP system indicates that its advantages include ease of operation and an enlarged work envelope.

Unit #3 (Fig. 2) was fitted to a right, mid-below-elbow amputee during October 1970. His power unit and battery were initially designed to be clipped onto the belt with the power being transmitted to the prosthesis by a Bowden cable. A more permanent type of belt mounting, such as is illustrated in Figure

3, with the battery and motor on opposite sides, was subsequently found to be much more comfortable, secure, and less obstructive.

Reports by the patient of use time with the EP have varied from "most of the time" to "almost every day." This individual was fitted very snugly in order to obtain maximum stability of the socket on the stump, especially to facilitate playing the piano. It is not possible to fit the socket for his BP prosthesis as snugly as that for his EP without causing discomfort in the distal portion of the stump. This is believed to be

due to the development of comprehension forces in the end of the stump where the socket compresses it in reaction to the tension forces developed in the cable each time the terminal device is opened. In the EP prosthesis these compression forces are developed in the cable housing rather than in the soft tissues in the end of the amputation stump. This amputee has said that a significant reason for not wearing his EP prosthesis even more than he does is the extra time and effort required to apply the tightly fitting socket.

The subject had difficulty on some occasions with slow operation of the terminal device. He reported that it seemed to be dragging. The problem did not reappear when the prosthesis was examined and then

reapplied to him. Ultimately, it was discovered that he was inadvertently twisting the cable as many as several revolutions in the process of donning the belt and prosthesis. This problem was solved by teaching him to use color-coded wires attached to the cable as an indication of twisting.

He had a very weak EMG signal when he was fitted initially. After the first week of wear, the strength of the EMG signal became about three times as strong as it was initially and a readjustment in the electronic-system gain became necessary. His EMG output has remained constant at this high level since that time.

The amputee is a student of the piano. He has been able to continue his piano lessons, and is developing

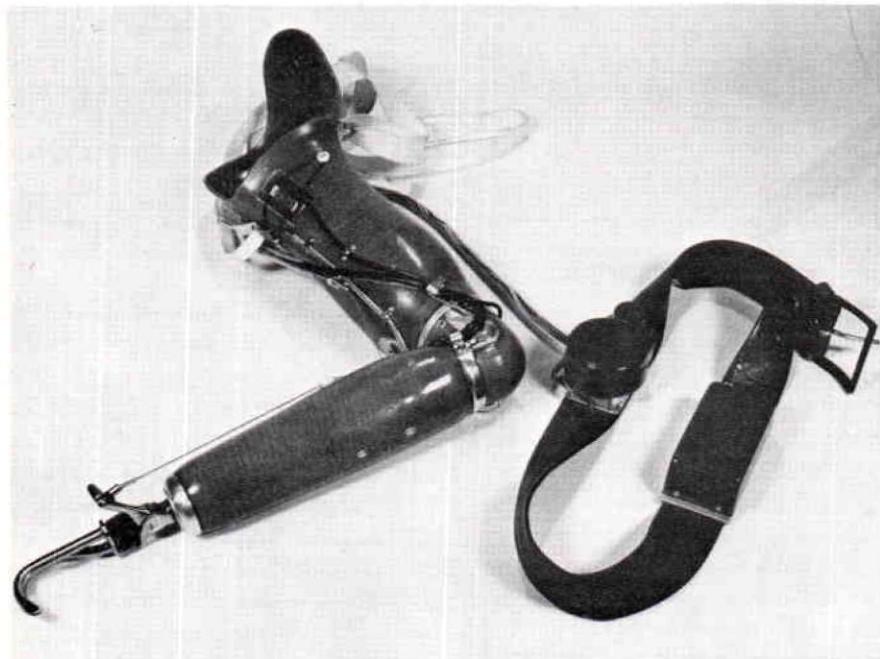


Fig. 3

Unit #4, for a right-elbow-disarticulation case. Note the location of power unit and battery pack on opposite parts of the belt. This arrangement was found to be more convenient than the initial design shown in Figure 2.



Fig. 4

Patient wearing Unit #4 playing the piano. Note the specially designed terminal device.

a good facility for the control of his EMG signal while playing the piano, using the specially designed terminal device shown in Figure 4.

Unit #4 (Fig. 3) was fitted in December 1970 to a right-elbow-disarticulation amputee who had only two months' experience with his body-powered prosthesis. A conventional Hosmer internal-locking elbow was used, the lock being activated in the traditional manner. The power unit and battery are mounted permanently on the belt in such a way that battery replacement is convenient. Force transmission between motor and terminal device is provided by a Bowden cable. The terminal device is of the voluntary-opening type.

This amputee's original injury was incurred while operating ma-

chinery used for processing soap. In January 1971 he returned to the same full-time job with the same employer.

The subject always uses his externally powered prosthesis from the time he gets up in the morning until he returns from work in the afternoon. Usually he takes the limb off at home, but puts it back on for any bimanual activities or to go out in the evening. He has worn the limb continuously as long as 14 hours.

On one occasion he dropped and broke the original battery case. Since delivery of his EP prosthesis, the only times he has worn his body-powered prosthesis was while this battery case was being replaced and on two other occasions when his EP prosthesis was in the laboratory for a check-out. The case was replaced

with one of a more durable material and no further breakage has occurred.

He has reported inadvertent openings of his terminal device in the washroom at his job when trying to hold wet toweling in order to wash and dry his remaining hand. In this situation he has resorted to switching off the power in order to maintain a grip on the toweling.

The sensor case was modified to improve electrode contact. He has had no other malfunction or mechanical or electrical breakdown. In reply to inquiry about speed he said that ideally he would like to have it a little faster. In reply to inquiry about the weight of his prosthesis he stated, "No problem. I guess I am used to it." Regarding the components on his belt he answered, "A little bulky, but they don't bother

me none." He stated that, "The arm is working beautifully. It will do anything you try to do with it."

Unit #5 (Fig. 5) was fitted to a short-below-elbow amputee who had already learned to use a body-powered prosthesis with a Muenster socket and an APRL hook or hand. The externally powered prosthesis has a Muenster socket. There is no additional suspension or harness. The power unit and battery are permanently belt-mounted but the battery mount permits convenient battery replacement. Force transmission between motor and terminal device is by Bowden cable; hook and hand are of the voluntary-opening type. Prior to fitting with the EP prosthesis the amputee had stated that he was bitterly disappointed with the functional capabilities of his BP prosthesis. Although he usu-

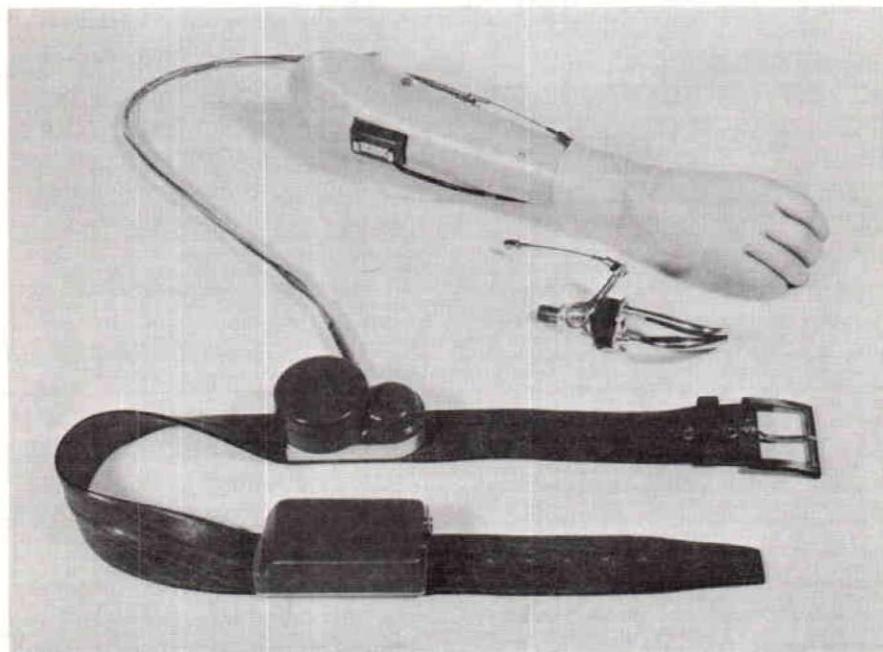


Fig. 5

Unit #5, for a short-below-elbow amputee. Note absence of harness.

ally wore this prosthesis, he did so almost entirely for appearance, and rarely used the hook.

This patient adapted immediately to the EP prosthesis without any special training. Since delivery of this system, he has used it exclusively, full-time, every day except on two occasions when he removed it for a few hours because of some skin irritation at the socket sensor port. It was felt that this problem was due at least in part to overzealous wetting of the skin in this area at the time of application of the prosthesis and to excessive pressure of the sensor. The condition improved with corrective action and no longer interferes with the use of the prosthesis. It is evident that this amputee is cycling his EP prosthesis more frequently than he formerly cycled his BP prosthesis. He reports that his battery lasts him about nine hours, and, in order to permit continuing function of his limb, he carries an extra battery with him when away from his house for the whole day.

The subject is a part-time farmer and mechanic. He likes to use the prosthetic hand in a work glove when working with farm hand tools. He prefers the hook when working with smaller metal objects. He reports that, although the belt-mounted components seemed annoying at first, he is no longer aware of them. When sitting, he rotates his belt slightly, thereby bringing the motor around to his side where it does not press against his back. The speed of operation is satisfactory, but he would like the hand to close a little faster. There have been no equipment breakdowns or malfunc-

tions. He denies having any trouble with inadvertent openings but says that occasionally when applying high force to an object he switches off his battery to maintain the grip. He states that it will be terrible for him if the system is retrieved when the evaluation is completed, and he complains that he does not know how he will get along when he no longer has it.

Unit #6 is fitted to an above-elbow amputee who lost his left upper limb in an industrial accident six years ago and has been using a body-powered prosthesis for approximately five years. He is a full-time employee of an industrial contracting company where he works as a high-pressure boiler welder. He also raises horses. His BP prosthesis is of heavy-duty construction and has an internal locking elbow and a farmer's hook. He is very skillful with his BP prosthesis, subjects it to heavy use, and has been wearing it full-time, all the time.

Since he depends heavily on the humeral rotation turntable in his work and since his stump is fairly long, a special turntable was designed and constructed that occupies minimal longitudinal space and still permits placing the motor in the elbow region without undesirable lowering of the elbow center. The sensor is placed in a socket port over the biceps muscle. The remaining electronic components are placed in the forearm unit and the battery is worn on the belt.

One week after the externally powered limb was delivered, the amputee reported that the above-elbow figure-8 harness was uncomfortable, owing to the increased

weight of the prosthesis. The harness was then converted to a shoulder-saddle type with a cross-chest strap. The patient reports that this new harness system is more comfortable. He also reports that his work requires him to be standing or walking almost all of the time. He finds that under these circumstances the externally powered prosthesis is very tiring and that he must switch to his BP prosthesis in order to continue working efficiently for periods longer than five hours. He reports relief from tiring if he is able to sit, and he states that the prosthesis would be ideal for work which permitted resting its weight occasionally on a supporting surface such as a desk top or in his lap. He believes that part of his fatigue might be due to unaccustomed use of his biceps muscle.

He has had no malfunctions or breakdowns and denies inadvertent openings. A fresh battery pack lasts him five hours of work time. He states that the response of the limb is good and he hopes to develop an increased fatigue tolerance. Until the weight problem is solved, this amputee shows a clear preference for his BP prosthesis.

Unit #7 was fitted to a 56-year-old left elbow-disarticulation amputee about one week after delivery of his first body-powered prosthesis and nine months after his amputation.

The original injury to his left upper limb also resulted in severe permanent limitation of motion in his left shoulder. Owing to the limited muscle power and excursion available, the harness selected for the BP prosthesis consists of a shoul-

der saddle and cross-chest strap for suspension and a separate axillary loop for transmission force from the right shoulder to the main cable. This loop is designed to encircle the upper arm near the belly of the deltoid in order to exploit some sound-side shoulder motion to obtain maximum cable excursion. In spite of these special considerations and daily special-training efforts, the amputee is having great difficulty developing any useful function with his (BP) prosthesis.

The externally powered unit has a socket, forearm unit, wrist unit, and voluntary-opening terminal device which are identical to those of the BP unit. An identical shoulder saddle and cross-chest harness are used, but the axillary loop was omitted from the EP unit. In the EP unit the main cable is routed around a pulley in the forearm unit. The power unit and battery are mounted on the belt similar to the one shown in Figure 5.

The subject was able to operate both the elbow and terminal device with good control immediately after delivery of the limb and without special training. Since delivery no further adjustments have been necessary. There have been no malfunctions or breakdowns. Thus far, the amputee reports that he is delighted with all aspects of his EP limb, but that he is very discouraged with his BP limb.

Unit #8 (Fig. 6) was fitted to an 18-year-old right-shoulder-disarticulation amputee to replace the limb lost in a traumatic amputation secondary to a corn-picker accident.

The patient was fitted with a conventional body-powered prosthesis

approximately 3½ months after the amputation. This device provided negligible function and he wore it on special occasions for appearance only. Prior to being fitted with the externally powered prosthesis he had, for all practical purposes, totally rejected the conventional system.

No myoelectric signals suitable for control of the prosthesis were found when a thorough exploration was made of the muscles of the injured side of the amputee's body.

However, more than one inch of transverse motion of the scar takes place when the pectoralis muscle is contracted. The patient has excellent voluntary control of the motion of the skin in this area.

A special transducer was developed to make use of this skin motion. The transducer utilizes a movable magnet and stationary semiconductor element that responds to changes in magnetic field strength. Approximately $\frac{3}{8}$ inch of motion of the small string, which can be

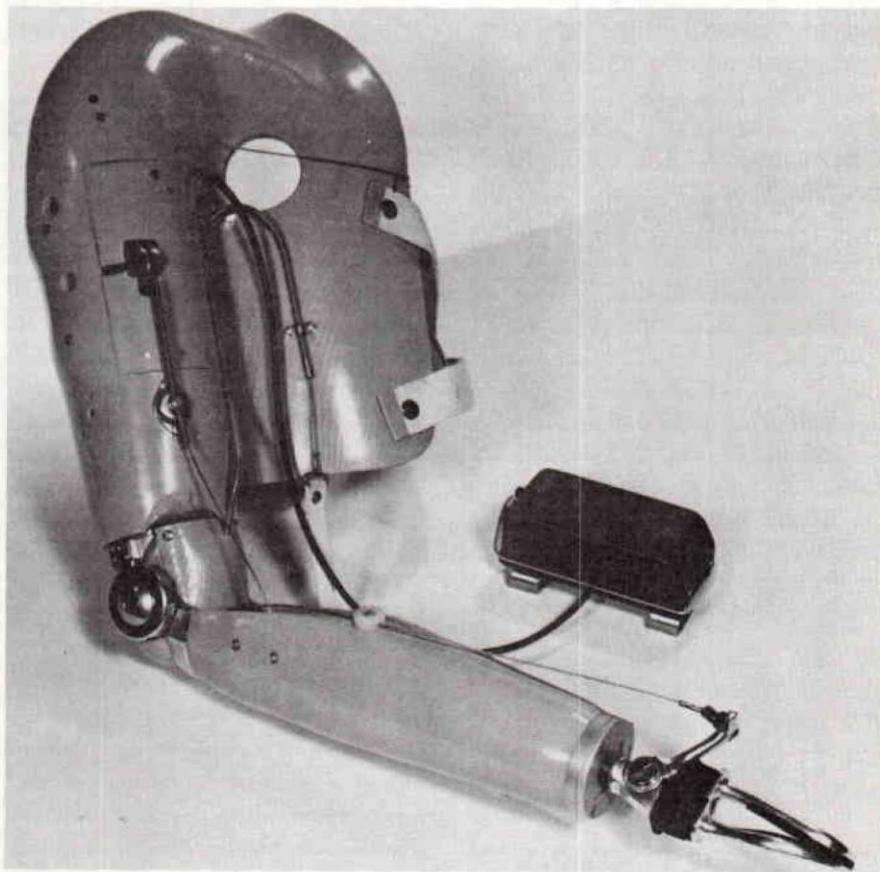


Fig. 6

Unit #8, for a shoulder-disarticulation amputee. The control of this prosthesis is provided by skin movement that provides relative motion between a magnet and a semi-conductor. A circular hole is provided in the socket over the pectoral area to permit connection between the skin and the string shown which is connected to the magnet portion of the transducer.

seen in Figure 6 emerging from the front of the shoulder of the prosthesis, controls the arm and terminal device. When the prosthesis is in use, the end of the string is passed through the large hole close to where it emerges from the prosthesis, and is attached to a button which is, in turn, attached to the skin with double-sided adhesive tape.

After using this prosthesis for approximately one month the amputee reports that he uses it 50% to 75% of the time. He uses it for bimanual operations, and for tasks like carrying empty buckets, but does not use it when he can do his work without it, such as when he drives a tractor. The adhesive attachment to the skin has remained intact up to two weeks without coming loose, and appears to be satisfactory for this evaluation. The battery is providing up to nine hours of operation on a single charge. The amputee has expressed a need for a "reach" capability, and is of the opinion that the prosthesis would be much more useful if the shoulder were movable.

Conclusions

Preliminary results of the evaluation of experimental models of the externally powered system on eight amputees indicated that this system has merit over body-powered systems in those cases where the following conditions exist:

1. The amputee is unable or unwilling to furnish the high force level and large excursions required to operate the body-powered prosthesis. Specific examples are: (a) high level of am-

putation; (b) tenderness in the end of the stump; (c) restriction of joint motion, especially in the shoulders; and (d) weakness of shoulder muscles.

2. The amputee needs a wider work envelope than is possible with a conventional body-powered prosthesis.

3. The amputee desires minimal harnessing for the prosthesis. As a trade off for this characteristic he must be willing to accommodate the additional weight/bulk of the electrical/mechanical subsystem of the powered system.

4. Training time must be minimal. Compared to other externally powered systems, the Johns Hopkins system offers advantages in that (a) it utilizes many standard, available prosthetic components, (b) it provides a powered elbow and/or powered terminal-device capability with a single motor and single EMG site, (c) it has demonstrated that proportional control is very "natural" and easy for the amputee to learn to use, (d) the system is versatile because powered components may be either located on the prosthesis or worn on the belt to suit the needs of the individual, and (e) donning is simplified by attachment of the sensor to the wall of the socket.

Versatility of component location is a particularly significant factor if the amputee is to be fitted in a manner consistent with his projected utilization of his prosthesis. The equipment-location criterion appears to be one of the critical factors in the ultimate acceptance or rejection of the powered system by

amputees. The Johns Hopkins concept allows maximum flexibility for equipment location.

This evaluation was based on the original experimental design to obtain data on the practicality of the basic concept. This initial design was limited in scope and did not include significant effort on miniaturization of components.

Further design refinements in packaging are planned to bring this design to a stage suitable for more extensive clinical testing and possible future availability to amputees.

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