A FIVE-YEAR REVIEW OF CLINICAL EXPERIENCE WITH JOHNS HOPKINS UNIVERSITY EXTERNALLY POWERED UPPER-LIMB PROSTHESES AND ORTHOSES [a]

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INTRODUCTION

Concurrent with the development at the Johns Hopkins University Applied Physics Laboratory of an external power and control system designed to power otherwise conventional upper-limb prostheses and orthoses, clinical evaluation of these composite devices has proceeded with amputees and paralytics, followed primarily through the Johns Hopkins Hospital Limb Prosthesis Clinic. Early results of this evaluation and details of specific applications have been reported periodically in this publication and in the Journal of Bone and Joint Surgery (Vol. 55-A(7), pp. 1493-1501). Adequate clinical experience has now been obtained to permit a more comprehensive report.

As itemized in Tables 1 and 2, 13 amputees and three paralytics have been fitted with 15 prostheses and three orthoses. The following amputation levels are included in this series: one wrist disarticulation, three below-elbow amputations, two elbow disarticulations, four above-elbow amputations, and four scapulohumeral disarticulations.

[a] Based on work performed under VA contract.

APL-MI External Power and Control Units (as of Feb. 1975)

ID	Sex	Age EP fitted	Occupation	Amp. level	EX-PAC	Con-trol	Amputee preference	EP still used	EP use (yrs.)
L.R.	M	27	Physician	WD	B	ME	BP most tasks EP specific tasks	Yes	5
J.C.	M	17	Music Student	BE	B	ME	BP exclusively	No	$3^{4}/_{12}$
D.D.	M	37	Electrician	BE	B	ME	EP exclusively	Yes	$2^{6}/_{12}$
J.P.	M	48	Farmer, Mech.	BE	B	ME	EP exclusively	Yes	$4^{2}/_{12}$
U.S.	M	54	Machine Operator	ED	B	ME	EP exclusively	Yes	$4^{3}/_{12}$
H.T.	M	56	Unskilled Laborer	ED	B	ME	BP most tasks EP specific tasks	Yes	$3^{11}/_{12}$
L.C.	M	30	Welder, Farmer	AE	A	ME	BP exclusively	No	$^{11}/_{12}$
L.B.	M	23	Business School Student	AE	A	ME	EP with ME	Yes	$4^{10}/_{12}$
S.S.	F	17	Nursing School Student	AE	A	BM	exclusively		
A.H.	M	12	High School Student	AE	A	BM	EP exclusively	Yes	$1^{10}/_{12}$
E.H.	M	44	Gardner, Horseman	SD	A	SKM	EP exclusively	Yes	$1^{2}/_{12}$
T.L.	M	18	Farmer, Welder	SD	A A(Sh)	SKM SKM	None	No	$^{6}/_{12}$
V.P.	F	19	College Student	Bilat. SD	A	SKM	EP with active shoulder EP exclusively	Yes Yes	$3^{9}/_{12}$ $2^{8}/_{12}$

Key:

AE = above elbow
BE = below elbow
BM = body motion
ED = elbow disarticulation
ME = myoelectric
SD = shoulder disarticulation
SKM = skin motion
WD = wrist disarticulation

One of the above-elbow amputees, L.B., was fitted concurrently with two externally powered (EP) prostheses, one of which is controlled by a single-site myoelectric (ME) sensor, the other of which is controlled by a body-motion (BM) sensor. The body-motion sensor consists of a transducer activated by low force shoulder motion. One of the shoulder-disarticulation amputees, T.L., was fitted concurrently with two exter-

TABLE 2.—*Clinical Experience: Paralytics Fitted with Upper-Limb Orthoses Powered with JH APL-MI External Power and Control Units (as of Feb. 1975)*

ID	Sex	Age EP fitted	Occupation	Diagnosis	Functional deficit	Function provided by orthosis	Result
J.M.	M	50	Office executive	Congenital C-spine anomaly	Bilateral flail scapulo-humeral and elbow joints	Unilateral active elbow flexion	Retrieved for improvements
W.I.	M	51	Business executive	Brachial plexus palsy trauma	Unilateral flail elbow joints	Unilateral active elbow flexion	Retrieved for improvements
D.S.	M	31	Computer programer	Poliomyelitis	Bilateral flail upper limbs, all joints	Unilateral grasp	Retrieved for improvements

nally powered prostheses, each of which is controlled by a skin-moti
(SKM) sensor. One prosthesis has no shoulder motion, whereas t
other provides active shoulder flexion-extension. V.P., a bilateral cc
genital shoulder-disarticulation amputee, was fitted with bilateral u

per-limb prostheses linked together in back. Both sides are powered by one External Power and Control Unit (EXPAC) located in the left above-elbow segment. This device provides bilateral active elbow flexion-extension, bilateral terminal-device function, and unilateral wrist pronation-supination. As a bilateral amelic, V.P. is listed in this series as one of the three shoulder-disarticulation amputees. Her double appliance is listed as a single prosthesis.

Two of the paralytics, J.M. and W.I., were fitted with simplified elbow orthoses powered with belt-mounted EXPAC units to provide active elbow flexion under myoelectric control. The remaining paralytic was fitted with a hand orthosis to provide active clasp-type grasp under myoelectric control.

SELECTION AND EVALUATION PROCESS

Each amputee in the early phase of this study was fitted with a functional, conventional body-powered (BP) prosthesis to facilitate comparison with his externally powered (EP) prosthesis. Amputees added since the report in the Bulletin of Prosthetics Research (BPR 10-17, pp. 33-37) have not been fitted with body-powered prostheses, because they had either abandoned the ones they already had or because the extent of their physical defects made body-powered prostheses inappropriate. D.D., a below-elbow amputee, could not be fitted with a body-powered prosthesis due to intensive fragile burn scar and skin grafts about his contralateral shoulder. A.H., an above-elbow amputee, had a limb remnant of inadequate length to stabilize an above-elbow prosthesis socket against displacement forces inherent in the function of an above-elbow body-powered prosthesis.

Amputees with an assortment of occupations and ages, and with a wide range of amputation levels were selected for this study to determine system versatility and reliability as well as other factors related to user acceptance. The paralytics chosen for the orthotics phase were similarly selected. None of these amputees or paralytics has had experience with any other type of externally powered prosthesis or orthosis or has participated in any other appliance evaluation program.

All test subjects were interviewed and examined periodically. Many were observed functioning in their home and work settings as well as in the laboratory and clinic. Additional information on performance was obtained by interviewing relatives, friends, and employers. Photographic studies were made of all cases. Motion picture film and/or video-tape studies were made of most. Detailed time-motion studies were made on L.R., a wrist disarticulation, and to a lesser extent on several others.

RESULTS

Eight of the 13 amputees are continuing to use their externally pow-ered prostheses exclusively more than 1 year after receiving them. Fou of these wear their prostheses full time. The other four wear thei prostheses frequently, although not necessarily every day. They insis that their prostheses are necessary for the performance of particula activities which have become significant or essential in their lives. In eac of these cases bimanual manipulations are involved which, because o the high level of amputation, would be difficult, if not impossible, t perform without an externally powered prosthesis.

An additional two of the 13 amputees prefer their externally powere prostheses for certain tasks, but they have concluded that they would no be greatly handicapped if restricted to using their body-powere prostheses exclusively.

After adequate trial, the three remaining amputees gave up thei externally powered prostheses. Two concluded that their body-powere prostheses were functionally superior. The third reverted to living with out any prosthesis, feeling that the weight and encumberance of eithe type is not commensurate with function derived.

The above-elbow amputee, who was fitted concurrently with tw externally powered prostheses featuring different control modes, con cluded that he preferred myoelectric control.

The shoulder-disarticulation amputee, who was fitted concurrentl with two externally powered prostheses, one of which provides shoulde flexion-extension, continues to maintain a strong preference for th prosthesis with this additional capability.

The orthosis designed to provide active elbow flexion-extension wa extensively modified with significant reduction in weight, and improve comfort and efficiency. Although the final design of the harness wa reasonably acceptable to the two paralytics who were each fitted with i use of myoelectric signals from the wrist extensor muscles for control c elbow flexion was found to be unsatisfactory due to inadvertent elbo flexion when manipulating objects on a work surface. These orthos have therefore been retrieved for appropriate control system improv ment. The paralytic fitted with an externally powered clasp-type han orthosis found this device satisfied design objectives for carrying objec but required modification to reduce weight and bulk and impro control. It has been retrieved for this purpose.

CONCLUSIONS

After a trial period long enough to exclude novelty appeal, externa powered prostheses may be favored over otherwise similar bod powered prostheses in a high proportion of upper-limb amputees.

ertain cases they increase the individual's functional capabilities, allowing him to perform bimanual tasks which may become significant to him nd not otherwise possible. Although externally powered prostheses are avored by some below-elbow amputees, their advantages are more npressive for higher level amputees and especially evident for very nort above-elbow or shoulder-disarticulation amputees. Among ower-and middle-level amputees relief of harness irritation and reduction in socket pressure may be significant enough to offset the disadvanages of increased weight and decreased speed which are characteristic f present externally powered prostheses.

After observing the impressive speed and dexterity of bilateral amutees with limb remnants long enough to provide function for bilateral ody-powered prostheses, it is evident that the externally powered sysem is not yet suitable for these individuals. However, experience with ne bilateral shoulder-disarticulation amputee in this series indicates nat an externally powered prosthesis can be useful to bilateral amputees ith limb remnants of inadequate length to operate body-powered rostheses efficiently.

Experience with a unit providing externally powered flexion and xtension at the shoulder joint of the shoulder-disarticulation prosthesis ndicates that this device greatly increases function and clearly merits ncreased clinical application.

Clinical experience in application of externally powered orthoses ndicates need for improving the ability of the paralytic to control the ppliance reliably, comfortably, and with minimum effort. Significant nprovement in harnessing for externally powered elbow flexion has een achieved.

UMMARY OF CLINICAL DETERMINANTS UTILIZED IN THE PRESCRIPTION OF APPROPRIATE JHU SENSOR AND POWER UNIT

Characteristics of the patient and his limb remnant determine the ppropriate power unit and sensor selection. As described in earlier sues of the Bulletin of Prosthetics Research, EXPAC units have been rranged in two different equipment configurations: an above-elbow A) configuration and a below-elbow (B) configuration. To satisfy indiidual needs, three different proportional control signal sensors, certain ower-assisted variations of conventional elbow locks, and a unit to rovide externally powered flexion-extension at the shoulder have been esigned and used.

Experience with this series of amputees and paralytics indicates:

1. The EXPAC combination of choice for a wrist-disarticulation or elow-elbow amputee is a Type B unit with myoelectric sensor placed

over the active remnant of finger and wrist extensor muscles on the posterolateral aspect of the proximal forearm. Although an otherwise similar body-powered prosthesis is functionally equivalent or superior, this externally powered prosthesis is preferable when reasonable socket pressure or harness chafe cannot be tolerated, as with painful neuromas, burn scars, and fragile skin grafts.

2. For the elbow-disarticulation amputee, the Type B unit with myoelectric sensor placed over the biceps muscle is indicated. External locking hinges are used to avoid lowering the elbow center. The power-assisted external locking elbow hinge is clearly preferable to the conventional body-powered type. In prescribing this externally powered prosthesis instead of an otherwise similar body-powered prosthesis, comfort is given priority over speed since elbow flexion-extension with the body-powered prosthesis is quicker but requires greater effort.

3. For an above-elbow amputee with stump length short enough that the elbow center will not be unduly lowered by using an internal elbow unit, the Type A unit is indicated. The power-assisted elbow lock control with this unit is recommended. For control signal acquisition a myoelectric sensor over the biceps muscle is recommended. If the biceps muscle offers an inadequate signal or is absent due to a high level of amputation, the body motion sensor should be used, permitting proportional control by low effort shoulder motion. In either case, the power-assisted elbow lock control is desirable.

4. For a shoulder-disarticulation amputee, the Type A unit is indicated, preferably in association with the externally powered shoulder flexion-extension unit. If, due to adherence of the surgical scar to the pectoralis muscle remnant, the patient can move the scar approximately 2 cm., this feature can be exploited for proportional control by using the skin-motion sensor. Otherwise, proportional control can be obtained with the body-motion sensor and a cross-chest strap or contralateral shoulder loop. A power-assisted elbow lock control activated by shoulder shrug is recommended. A chin nudge switch for control of the elbow lock is recommended.

5. The EXPAC system is not recommended for bilateral upper-limb amputees unless the limb remnants are inadequate to function the body-powered prostheses.

6. For flail elbows with functional hands the Type B EXPAC can be used to provide useful, active elbow flexion-extension with the harness described, provided the scapulohumeral joint can be controlled by remaining muscles or surgical arthrodesis. Depending upon the availability of adequate control motions or myoelectric potentials, a motion sensor or myoelectric sensor can be used, coupled with a dental-click-activated cable lock as described previously (BPR 10-21, pp. 128-136).