A FIVE-YEAR REVIEW OF CLINICAL EXPERIENCE WITH JOHNS HOPKINS UNIVERSITY EXTERNALLY POWERED UPPER-LIMB PROSTHESSES 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)

<table>
<thead>
<tr>
<th>ID</th>
<th>Sex</th>
<th>Age</th>
<th>Occupation</th>
<th>Amp.</th>
<th>EX-PAC</th>
<th>Control</th>
<th>Amputee preference</th>
<th>EP still used</th>
<th>EP use (yrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.R.</td>
<td>M</td>
<td>27</td>
<td>Physician</td>
<td>WD</td>
<td>B</td>
<td>ME</td>
<td>BP most tasks</td>
<td>Yes</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>EP specific tasks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J.C.</td>
<td>M</td>
<td>17</td>
<td>Music Student</td>
<td>BE</td>
<td>B</td>
<td>ME</td>
<td>BP exclusively</td>
<td>No</td>
<td>3½/12</td>
</tr>
<tr>
<td>D.D.</td>
<td>M</td>
<td>37</td>
<td>Electrician</td>
<td>BE</td>
<td>B</td>
<td>ME</td>
<td>EP exclusively</td>
<td>Yes</td>
<td>2⅞/12</td>
</tr>
<tr>
<td>J.P.</td>
<td>M</td>
<td>48</td>
<td>Farmer, Mech.</td>
<td>BE</td>
<td>B</td>
<td>ME</td>
<td>EP exclusively</td>
<td>Yes</td>
<td>4⅞/12</td>
</tr>
<tr>
<td>U.S.</td>
<td>M</td>
<td>54</td>
<td>Machine Operator</td>
<td>ED</td>
<td>B</td>
<td>ME</td>
<td>EP exclusively</td>
<td>Yes</td>
<td>4⅞/12</td>
</tr>
<tr>
<td>H.T.</td>
<td>M</td>
<td>56</td>
<td>Unskilled Laborer</td>
<td>ED</td>
<td>B</td>
<td>ME</td>
<td>BP most tasks</td>
<td>Yes</td>
<td>3½/12</td>
</tr>
<tr>
<td>L.C.</td>
<td>M</td>
<td>30</td>
<td>Welder, Farmer</td>
<td>AE</td>
<td>A</td>
<td>ME</td>
<td>EP specific tasks</td>
<td>No</td>
<td>1⅝/12</td>
</tr>
<tr>
<td>L.B.</td>
<td>M</td>
<td>23</td>
<td>Business School Student</td>
<td>AE</td>
<td>A</td>
<td>ME</td>
<td>EP with ME exclusively</td>
<td>Yes</td>
<td>4⅞/12</td>
</tr>
<tr>
<td>S.S.</td>
<td>F</td>
<td>17</td>
<td>Nursing School Student</td>
<td>AF</td>
<td>A</td>
<td>BM</td>
<td>EP exclusively</td>
<td>Yes</td>
<td>1⅞/12</td>
</tr>
<tr>
<td>A.H.</td>
<td>M</td>
<td>12</td>
<td>High School Student</td>
<td>AE</td>
<td>A</td>
<td>BM</td>
<td>EP exclusively</td>
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<td>1⅞/12</td>
</tr>
<tr>
<td>E.H.</td>
<td>M</td>
<td>44</td>
<td>Gardner, Horseman</td>
<td>SD</td>
<td>A</td>
<td>SKM</td>
<td>None</td>
<td>No</td>
<td>6/12</td>
</tr>
<tr>
<td>T.I.</td>
<td>M</td>
<td>18</td>
<td>Farmer, Welder</td>
<td>SD</td>
<td>A</td>
<td>SKM</td>
<td>EP with active</td>
<td>Yes</td>
<td>3⅝/12</td>
</tr>
<tr>
<td>V.P.</td>
<td>F</td>
<td>19</td>
<td>College Student</td>
<td>Bilat.</td>
<td>A</td>
<td>SKM</td>
<td>EP exclusively</td>
<td>Yes</td>
<td>2⅛/12</td>
</tr>
</tbody>
</table>

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

One of the above-elbow amputees, L.R., was fitted concurrently with two externally powered (EP) prostheses, one of which is controlled by a single-site myoelectric (ME) sensor, the other by a trans-site myoelectric (ME) sensor. The body-motion sensor consists of a trans-site shoulder disarticulation (SD) sensor.
Table 2—Clinical Experience: Paralytics Fitted with Upper-Limb Orthoses Powered with APR-MI External Power and Control Units (as of Feb. 1975)

<table>
<thead>
<tr>
<th>ID</th>
<th>Sex</th>
<th>Age</th>
<th>EP</th>
<th>Occupation</th>
<th>Diagnosis</th>
<th>Functional deficit</th>
<th>Function provided</th>
<th>Result</th>
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<tbody>
<tr>
<td>J.M.</td>
<td>M</td>
<td>50</td>
<td></td>
<td>Office executive</td>
<td>Congenital scapulohumeral and elbow joints</td>
<td>Unilateral active, retrieved for elbow flexion improvements</td>
<td></td>
<td></td>
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<tr>
<td>W.I.</td>
<td>M</td>
<td>51</td>
<td></td>
<td>Business executive</td>
<td>Trauma, Brachial plexus palsy</td>
<td>Unilateral active, retrieved for elbow flexion improvements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.S.</td>
<td>M</td>
<td>31</td>
<td></td>
<td>Computer programer</td>
<td>Poliomyelitis, bilateral upper limbs and all joints</td>
<td>Unilateral grasp, retrieved for improvements</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Revised shoulder disarticulation amputation was fitted with bilateral upper-limb powered prostheses, each of which is controlled by a skin-mounted sensor. One prosthesis has no shoulder motion, whereas the other provides active shoulder flexion-extension. Y.P.'s a bilateral co
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 powered prostheses exclusively more than 1 year after receiving them. Four of these wear their prostheses full time. The other four wear their prostheses frequently, although not necessarily every day. They insist that their prostheses are necessary for the performance of particular activities which have become significant or essential in their lives. In each of these cases bimanual manipulations are involved which, because of the high level of amputation, would be difficult, if not impossible, to perform without an externally powered prosthesis.

An additional two of the 13 amputees prefer their externally powered prostheses for certain tasks, but they have concluded that they would not be greatly handicapped if restricted to using their body-powered prostheses exclusively.

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

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

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

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

CONCLUSIONS

After a trial period long enough to exclude novelty appeal, externally powered prostheses may be favored over otherwise similar body powered prostheses in a high proportion of upper-limb amputees.
certain cases they increase the individual’s functional capabilities, allowing him to perform bimanual tasks which may become significant to him and not otherwise possible. Although externally powered prostheses are not favored by some below-elbow amputees, their advantages are more impressive for higher level amputees and especially evident for very short above-elbow or shoulder-disarticulation amputees. Among power-and middle-level amputees relief of harness irritation and reduction in socket pressure may be significant enough to offset the disadvantages of increased weight and decreased speed which are characteristic of present externally powered prostheses.

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

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

Clinical experience in application of externally powered orthoses indicates need for improving the ability of the paralytic to control the appliance reliably, comfortably, and with minimum effort. Significant improvement in harnessing for externally powered elbow flexion has been achieved.

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

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

Experience with this series of amputees and paralytics indicates:

1. The EXPAC combination of choice for a wrist-disarticulation or elbow-elbow amputee is a Type B unit with myoelectric sensor placed
over the active remnant of finger and wrist extensor muscles on the postolateral 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).