INTRODUCTION

The application of external power and advanced control system technology to artificial limbs has resulted in the development of an assortment of electrically powered hands, wrists, and elbows. Certain types of power units have been developed exclusively for elbow motion, whereas others have been developed exclusively for wrist motion and/or terminal-device function. Therefore, in order to actuate both elbow and terminal device, or elbow, wrist, and terminal device, more than one power unit is required. Furthermore, conventional prosthetic manufacturing techniques and components must be extensively modified in some cases to be compatible with some of these power control units.

As an alternative to the design of specialized externally powered devices, the Johns Hopkins approach has been to develop a basic power pack and control concept which has much versatility relative to application to upper-limb prostheses as well as possible application to orthoses. Two sizes of motor power packs and three types of sensors have been evaluated in selected experimental clinical testing. The sensor options are myoelectric, skin displacement, and body motion inputs. These basic components can be assembled in a number of ways to meet a particular requirement. The motor/electronics/battery pack may be located on the belt and power transmitted to the local area of need by means of a Bowden cable, or the power unit and battery unit may be located integral in the prosthesis.

The principal merits of this system are:
1. It utilizes many standard, available, prosthetic components.
2. It allows actuation of more than one joint, e.g., elbow, wrist, and terminal device, by a single motor and single myoelectric or skin displacement site.
3. Control is proportional and easily learned.
4. System has been shown to be durable and reliable.
5. Component placement is optional. Powered components may be located either on the prosthesis or worn on the belt to optimize the system to individually suit the amputee’s needs.
6. Full VO terminal-device interchange capability is retained.
7. It permits the patient to override the power unit manually without mechanical damage.

This system concept is currently undergoing clinical evaluation under the direction of Dr. G. Schmeisser, Chief of Orthopedic Surgery, Baltimore City Hospitals, on 10 amputees and two paralytics. Since the program was initiated in 1969, powered systems have been fitted to one wrist-disarticulation amputee, three below-elbow amputees, two elbow-disarticulation amputees, four above-elbow amputees, three shoulder-disarticulation amputees, two paralytics with flail elbows, and one paralytic requiring a hand orthosis. One of the shoulder-disarticulation amputees is a bilateral congenital amelic.

Preliminary results of clinical evaluation have been published in the Bulletin of Prosthetics Research in BPR issues 10-16 through 10-19 (Fall 1971 through Spring 1973). The results from this evaluation demonstrate the reliability and usefulness of this powered system approach, especially for amputees with higher level amputations.

**DESIGN CONCEPT**

A block diagram of the system concept is shown in Figure 1. Input signals can be provided by one of three means:

1. **Single-Site EMG Sensor**

   For those patients who have a suitable EMG site available, a packaged electrode assembly/electronic preamplifier may be utilized to provide proportional control of the power unit. This control mode was found to be most useful for amputation levels up to and including the above-elbow. A typical application of this sensor is shown for the below-elbow case in BPR 10-18, p. 264. The power unit for this system is worn on the waist. This particular patient cannot tolerate conventional harnessing on the opposite shoulder due to skin graft condition and is an ideal patient for this type system.

   The use of EMG control for an above-elbow prosthesis has been examined and found to be of merit, particularly for long above-elbow cases with good EMG signals. Extended work envelope and ease of control are two of the merits for this application.
2. Low Force Level Shoulder Control

Patients with a short above-elbow amputation appear to be prime candidates for the use of low force level shoulder control of a displacement transducer located within the prosthesis. The stump at this amputation level is generally too short for adequate contact surface in the conventional prosthesis, and the typical high force levels required for conventional prostheses cause additional unwanted motion of the upper portion of the prosthesis. Conventional systems fitted to amputees of this type are usually abandoned after little or no use.

EMG sites were explored on such patients and satisfactory sites could not be found. It was then decided to use gross body motion similar to body-powered systems but reduce the stroke requirement to 3/4 in. and force requirement to less than 2 lb. These requirements were met by using body motion to control a spring-loaded position transducer located within the prosthesis. External connections to this cable are identical to conventional practice for a figure-8 harness as shown in BPR 10-21, p. 131. Elbow unlocking was accomplished by means of an electromechanical arrangement that reduces the unlocking force level on the harness to an acceptable low value relatively independent of load on the prosthesis. The elbow is automatically locked approximately 2.5 sec. after first motion of the arm.

The control technique of using low force level shoulder control has been applied to two patients for a test period of several months. This
technique appears to provide a practical way of controlling the powered prosthesis for hard to fit cases.

3. Skin Motion Sensor

For higher level amputations, such as shoulder disarticulations, the harnessing of skin motion has been found to be practical and useful input command. A low force level motion 'transducer has been developed and is incorporated in the shoulder-disarticulation powered prosthesis shown in BPR 10-20, p. 264. Less than 3/4 in. of lateral skin motion over the pectoralis muscle allows proportional control of the motor to control elbow or terminal device opening. Control of shoulder motion (0 deg. and 45 deg.) is achieved by a chin nudge switch located on the shell of the prosthesis. The power unit for this prosthesis is located in the elbow space. Tests with the skin motion sensor input have been conducted over a 2-year period on one patient with highly satisfactory results. These tests are continuing to further evaluate the powered prosthesis.

MOTOR-ELECTRONIC COMPONENTS

The basic power and control components utilized in the Johns Hopkins system may be seen in BPR 10-19, p. 214. The motor is a direct-drive low-speed (15 to 20 r. p. s.) d. c. torque motor. It is coupled to a two-stage 15 to 1 gear reduction in the output stage. This system permits actuation in less than 1 sec. to torque levels of 13.6 kg: cable force and weighs less than 0.5 kg. It is so quiet that it is almost inaudible. The power units have no clutches, brakes, or mechanical stops and are very reliable; there have been no malfunctions or mechanical failures. They can be stalled at full power for short periods of time without internal damage of any kind. Hence, no current-limiting circuits are required.

The electronic control cards utilize discrete electronic components on printed boards. Reliability of these circuits has been excellent.

The removable nickel cadmium battery packs are conveniently sized and designed to allow the average user from 4 hours up to a full working day per charge. A diode was placed across each cell to minimize reverse polarity effects when the cells run down. A small charging unit recharges one or two packs simultaneously and shuts off automatically after 3 hours.

In addition to the basic development and evaluation program being conducted at Johns Hopkins, a complete set of drawings and specifications of the basic Mod 1 unit has been forwarded to the VA Prosthetics Center in New York. These drawings were submitted to industry for bids by the VA Prosthetics Center in New York for limited production. A
contract for six above-elbow units was awarded by the VA to the Pope Brace Company, Kankakee, Illinois. The system components include a myoelectric signal sensor or body motion input transducer, drive motor, control electronics, battery pack, and forearm pulley assembly.

The units have been delivered and are undergoing final engineering acceptance testing with preparation being made to fit these units to suitable above-elbow amputees (see BPR 10-19, p. 216).

POWERED ORTHOSES

In parallel with the development of powered systems for upper-limb prostheses, applicability of these concepts to orthoses is also being investigated.

One possible application is the use of the external power pack/cable arrangement to power a flail elbow. Our first patient, who had bilateral unstable flail shoulders and elbows, assisted in the early tests of basic system concepts but later withdrew from our evaluation program because he could achieve no useful function from the elbow flexion appliance. Part of the problem stemmed from the scapulohumeral joint hyperextending as the elbow flexed. Since the patient could not reach out in front of him, he could find no significant merit to the system. The progression of the design was from an initial complex harnessing arrangement with an external mechanical hinge, an intermediate design using lightweight cloth strap arrangement on both the forearm and upper arm, to a final arrangement which supports the cable housing by means of an attachment to a suspenders-type body harness and continues to use the lightweight cloth strap forearm arrangement (see BPR 10-20, p. 326).

A second paralytic patient, now in his 7th month of evaluating the elbow flexion device, had originally sustained a brachial plexus injury resulting in a flail scapulohumeral joint and total paralysis of elbow flexors. He had an adequate triceps, good scapulothoracic control, and good hand and wrist control. Surgical fusion of his scapulohumeral joint gave him good shoulder control; therefore, his residual disability was limited to lack of active elbow flexion. As anticipated, the improved powered elbow flexion device has operated well in this situation. Figure 2 shows this system fitted to the second patient. Proportional control of the elbow orthosis is achieved by use of the EMG sensor located near the elbow on the forearm.

A third paralytic patient undergoing evaluation has flail shoulders and elbows, bilaterally. He has no active muscle power in the left hand and wrist. Although his left biceps muscle lacks useful power, it generates a myoelectric signal. This patient's paralysis is a result of infantile poliomyelitis; hence, he has no sensory impairment. Furthermore, because of the underdevelopment of the digits and thumb web space of his
left hand, attempts to fit him with an orthosis designed to oppose the thumb and first two digits were unsuccessful. Careful analysis of his existing functional capabilities and needs revealed that he used the fingers of his right hand very capably for manipulating objects, but he needed some means of carrying objects in his left hand which did not depend on its digits. The clasping device was developed for this purpose (see BPR 10-21, p. 134). This patient uses his biceps myoelectric signal to control the power unit mounted on the forearm shell. The motor opens the appliance. When he relaxes, spring tension closes the palmar shell against his palm. He has now been using this device for about 4 months. It is easy for him to apply and is inconspicuous when covered by his shirt sleeve. It is performing as intended and is proving useful in his work activities. Evaluation of this device will be continued.

**CONTROL INPUT SENSOR DEVELOPMENT**

One of the key elements in a powered orthosis or prosthesis is the interface sensor between the patient and his machine. Three sensor techniques have been exploited in the Hopkins research program and were described earlier in this report.

During FY 1973, work was initiated on integrating a small magnetic diode within the frame of eyeglasses and placing a small high energy magnet on the skin near the eyebrow area. Tests in the laboratory on an experimental model have demonstrated that proportional control can be achieved with little training (Fig. 3). The technique looks sufficiently
promising to warrant further investigation for possible application to quadriplegics for control of power devices. A second sensor device (a small accelerometer) is also being investigated for use with the eyeglass frames. Preliminary tests indicate there may be signals related to audio sounds, such as teeth clicking or temporo mandibular joint motions, to provide on-off function control (see BPR 10-21, p. 135). Preliminary results from tests with these devices indicate that proportional control is achievable by locating the very small magnet over the eyebrow and using eyebrow motion for control. The second sensor, a small accelerometer located on the eyeglass frames, picks up the sharp vibration pulse caused by teeth clicking with the mouth closed. An electronic detector-filter circuit provides good rejection of unwanted signals. This technique is currently being evaluated on the patient wearing the powered elbow orthosis. It provides a means of turning the EMG signal on/off to allow the patient full use of his hand without inadvertent motion of the elbow.
A powered orthosis manipulator controlled by the eyeglass sensor is now under construction. This device is designed to provide the functions of hand grasping, elbow flexion, shoulder motion, and turntable motion for a highly disabled wheelchair or bedridden quadriplegic. The system employs two standard motors and control electronics utilizing mechanization techniques developed for the powered prosthetic systems described elsewhere in this report. Mode-select and on-off control is provided by means of the teeth-clicking joint motion as sensed by the accelerometer on the eyeglass frame. The patient can select any one of five modes of control by this means. Proportional motion of the output can be achieved by either an EMG signal on the side of the forehead or by eyebrow motion sensing using the magnetic motion sensor located on the eyeglass frame.

FUTURE PLANS

Engineering and development will be continued on the basic sensor interfaces in addition to total system integration of powered orthoses and prostheses. Clinical evaluation of experimental models will provide qualitative data on system performance and will aid in the identification of areas requiring further development.