MYOELECTRIC CONTROL OF UPPER-EXTREMITY JOINT MOTION

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Summary

Mucsles showing electrical activity under voluntary control may be used to control externally powered orthotic or prosthetic devices. Major problems include the elimination of electrical noise and interference, reduction or elimination of crosstalk from nearby muscles, and reduction of false signals from use of the control muscle in movements other than that being powered.

Circuits have been developed for on/off control from a pair of opposing muscles, for on/off control from a single muscle, and for proportional control from a single muscle. These circuits have been used primarily with hand splints to give pinch and release. Three recent applications for controlling powered elbow devices are described.

Sources of signals for controlling externally powered assistive equipment were discussed extensively at the Airlie House Conference [1]. Of these, we have been most concerned with the use of electrical signals from muscles. Such signals have been used to control orthotic as well as prosthetic devices, of a wide variety of electromechanical sophistication. We do not attempt here to review the extensive developments in this field which have occurred in a number of countries since others have given some indication of recent activities in this field [2], [3].

Our own emphasis has been on orthotic rather than prosthetic applications, and even here we differ from other groups in using when possible the severely paralyzed muscles of the individual rather than alternative muscles of normal or near normal strength. This choice has magnified the problems of signal pickup and processing, of electrical interference from power lines and other sources, and of crosstalk from nearby muscles which in some instances are stronger than the muscle selected for the control signal source. These problems of electrical noise and crosstalk, together with the synergistic use of muscles for a variety of motions (hence the con-

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trol source is not used solely to control a specific motion) constitute the technical barriers to a wider immediate use of such controls.

Progress in overcoming the noise problem has been described elsewhere [4]. Special electrodes and fitting procedures were developed, both for convenience and for reduction of noise. Special circuitry was developed and utilized. In summary, we now use three-in-line surface electrodes, with the center as reference. This electrode assembly is AC coupled to the differential amplifier. This amplifier must for our purposes have a high input impedance, both for common mode and for differential signals, so as to maximize signal transfer through the skin, and to reduce the conversion of a common mode signal to a differential one. It must also have a high effective common mode rejection ratio in order to minimize power frequency and other interference, most of which appears at the electrodes in common mode. The resulting signal from the differential amplifier is rectified, filtered, and processed so as to control the operation of a permanent magnet DC electric motor which drives the assistive device.

In the course of our work with a variety of patients, it has been important and useful to develop different signal processing schemes. In one, we use signals from two antagonist muscles one drives the motor in one direction and the other in the opposite direction. Each functions as an on/off control and an interlock arrangement prevents both from reaching the motor at once. This we call a two-muscle/two-level, or 2M/2L, circuit. In another scheme we use signals from a single muscle to control the bidirectional motor. A small effort drives it in one direction and a moderate one in the other; relaxation at any moment stops and holds it in position. This then is called a 1M/3L circuit, and is similar in function to that of Dorcas and Scott [5]. And as a third we developed a proportional control circuit whereby the voltage applied to the motor is controlled in each direction by the magnitude of effort made in the controlling muscle.

In each of these circuits we are using a solid state integrated circuit operational amplifier as the differential amplifier in the front end. We use a voltage regulated power supply in order to maintain stability of system sensitivity to the signals.

Selection of control sites and the plan of control is individual for each patient, and is made after examination for available signal magnitude, for elecrical crosstalk from nearby muscles, and for the synergistic use of the selected muscle in other movements.

Most of our applications of these circuits have been in controlling pinch and release in a hand split as used here at Rancho [6]. Eight patients have been fitted with myoelectrically controlled splints and have taken them home for use after discharge from the hospital; others are in the process of being fitted. We have also become interested in the control of elbow motion, and three recent examples of elbow control are summarized here as case histories.

Case 1. Mrs. S. S. suffered avulsion of her right forearm from the elbow in an accident. For a time she used a prosthesis with a two-cable control but this was not entirely satisfactory. It was decided to keep cable control for the terminal device, because of the sensory feedback, and apply electric power to the elbow. Examination for myoelectric activity nine months post injury showed very weak signals from the biceps and triceps areas, not separately controllable. Attempts to strengthen the muscles and to improve the separate control of each resulted in some gains in signal magnitude. But there remained too much correlation of the signals, and two-muscle, antagonist control seemed impractical.

The stronger signals were from the triceps area, hence this was used as the control muscle, and a 1M/3L logic was utilized, including the on-off switch to disconnect the motor. The electrode assembly was designed and fitted into the prosthesis shell so it is automatically positioned when the prosthesis is put on. The prosthesis including the motor weighs three pounds, and the battery and circuitry carried in a shoulder bag weigh an additional three pounds. She has been using this 5 to 10 hours daily for more than seven months, in her household activities. There seems to be no significant interference from other electrical signal generators such as her car, electric iron, or sewing machine. This case has been described in more detail elsewhere [7].

Case 2. Miss J. B., with onset of dermatomyositis at the age of 9. In the course of fifteen years, several disabilities developed secondary to this, including severe contractural deformities. As one step in relieving these, her left elbow was surgically released. It was then necessary to maintain the resulting range of elbow motion, and to strengthen the biceps and triceps muscles. She was given a powered splint with a cuff on the upper arm and one on the forearm: its motion was initially controlled by a switch near her right hand. This enabled her to move the elbow through its range of motion.

In order to strengthen the muscles by active use, signals from the biceps and triceps were utilized in a two-muscle, two-level myoelectric control system. Examination initially showed extremely weak signals from the biceps, with stronger signals from the triceps; the latter gave troublesome crosstalk at the biceps elecrodes, especially since high gain was needed for biceps signals.

The circuit system uses solid state integrated circuitry in the front end, and a voltage regulated power supply; it is otherwise similar to our earlier design [4]. In addition a safety switch was added so that if any trouble were encountered, from either electronic or physiological malfunctioning, she could switch off the myoelectric control and return to the hand switch control of the motor.

Since it was necessary to fit the elecrodes under the cuff on the upper arm, thinner electrodes than our usual ones had to be designed and fabricated. In addition, materials from the skin surface (fluids and ointments) tended to soak into the Silastic and interfere with pickup of the differential signal. This required repeated electrode construction, and led to new, more resistant, designs with impermeable plastic film next to the skin .

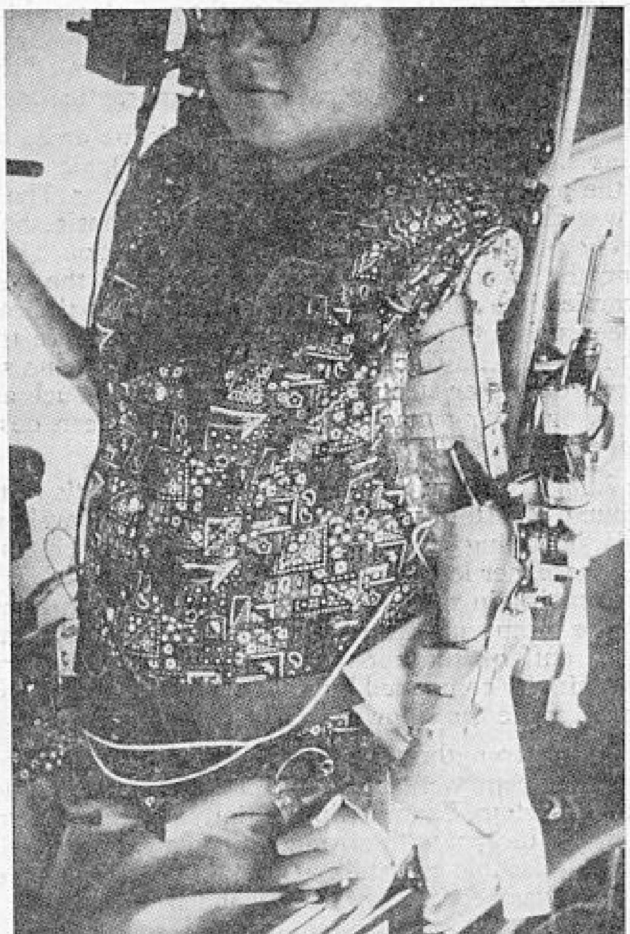

Fig. 1. Miss J. B. with 2M/2L muscle exerciser

Figure 1 shows the splint and motor, with the electrode strap just visible under the lower end of the cuff on her upper arm. She is also wearing a passive splint for hand positioning, not connected to the elbow orthosis. Circuitry and batteries are carried in a ladies' handbag on her wheelchair.

She exercises with the device frequently during the day and evening, and in the course of six months she has noticeably gained strength in these upper arm muscles.

Case 3. Mr. W. B. suffered traumatic spinal cord injury with bilateral loss below the C5 nerve root and damage at this level. On initial examination for possible use of a myoelectrically controlled, powered hand splint, no useful signals were found below the elbow. The splint was therefore controlled by the frontalis muscle, on the forehead above the right eyebrow.

About two years after the injury, distinct and useful signals were obtained from the supinator muscles in the forearm bilaterally and he was then able experimentally to control a bidirectional electric motor from either site. This raised the possibility of using one muscle to control pinch and release in the splint, and the other to aid in elbow flexion since his biceps was too weak to bring his hand quite to his mouth for eating and other near-face activities. Various designs for powering the elbow joint in a mobile arm support were tried, but a final satisfactory solution has not yet been established, partly because continuing pain in the shoulders and neck has seriously interfered with his use of assistive devices.

Thus, in two of these cases only the elbow motion was powered and myoelectrically controlled. In the third case, myoelectric control had been used for a hand splint, and with the appearance of signals from supinator muscles, both finger and elbow motion can be incorporated in a revised plan for the assistive system.

Conclusions

Our own experience, in agreement with that of investigators at other locations, confirms the feasibilitiy of using myoelectric activity for the control of externally powered assistive devices. Problems of electrical interference and noise have been reduced to acceptable proportions; the problems of crosstalk from nearby muscles and of use of the control muscle in other than the controlled movement can often be solved (or avoided!) by appropriate selection of the control site. Both on/off and proportional control have proved practical; control has been achieved using a single muscle and using a pair of opposing muscles. Such control has been applied to motions of pinch and release, and to elbow flexion and extension. Combinations of these, and of pinch-release with wrist motion or with forearm pronation-supination are being planned.

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