MYO-ELECTRIC CONTROL OF POWERED PROSTHESES

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The possibility of using myo-electric potentials for the control of powered prostheses is not a new one. It was probably first suggested as long ago as 1947 by the late Professor Norbert Weiner (1963), and was first achieved in Guy's Hospital in 1955 by Battye, Nightingale and Whillis. More recently the idea has received considerable publicity because of the introduction in Russia of an electric hand controlled in this way for mid-forearm amputations. Clearly the idea is one with considerable appeal, so that it is important to consider what are its possible advantages.

One of the most difficult problems in fitting a prosthesis to a patient, especially one equipped with external power, is to find sufficient independent control sites for each of the movements to be provided. However, there are nearly always muscles available in the stump which are no longer used but in which strong electrical signals can be detected. The advantage of using these signals to control a powered limb is that the control is entirely independent of other movements.

In poliomyelitis patients adequate signals can be detected even in muscles classified as 2 under the Medical Research Council grading. For these patients it should be possible to provide a magnified force from even a weak effort, rather like servo-assisted steering in a car.

It has also been suggested that myo-electric control might be of use to phocomelic and amelic patients, but where there is a limb remnant in which some movement occurs it is probably more realistic to use the movement as a signal rather than to try to interpret the electrical signals from the muscles producing it. If, however, the movement is hard to use because of poorly developed bones and joints in the limb it might be worth while trying myo-electric control.

DIFFICULTIES IN MEASURING MYO-ELECTRIC SIGNALS

The signal from surface electrodes over a strongly contracting normal muscle is an alternating current of up to a few millivolts and contains frequencies throughout most of the audible range. An estimate of the degree of stimulation of the muscle cells may be made by rectifying and smoothing these signals to obtain a direct current voltage proportional to the "loudness" of the myo-electric signal. Figure 1 shows a graph of this "loudness" level from electrodes over the biceps and triceps muscle plotted against the force at the wrist. A normal subject was asked gradually to increase a pushing force against a strain gauge, no movement being permitted at the elbow. The output from the strain gauge was the force produced and was plotted transversely, the intensity of the myo-electric signal vertically. It can be seen that the strength of the signal rose continuously with the force.

Two difficulties can also be seen from this graph. First, there is some apparent activity from the surface electrodes over the opposite muscle. Probably this is not real activity in the biceps but merely conduction of activity in the triceps through the flesh of the arm to the other pair of electrodes—what an engineer would call "crosstalk." Second, there seems to be some apparently random variation in the level of activity, which persists even when a steady load is maintained. The effect may be reduced by smoothing or averaging the signal over a longer time interval, but naturally this will introduce sluggishness in the response to sudden real changes in effort. Because a pair of surface electrodes over a muscle gets most of its signal from a fairly small group of muscle cells immediately beneath it, it only appreciates a sample of the total muscle activity. One would, therefore, expect the signal to show "sampling
error," which is probably the explanation of this random variation. It would also be reasonable to expect the variation to be a function—say perhaps 10 to 20 per cent—of the signal level rather than a constant absolute value, and this indeed is what is found in practice.

The other important difficulty is that normal or unprepared skin may have a resistance of 200 kilohms between a pair of silver electrodes one centimetre in diameter applied with saline jelly. In electrocardiography the skin is "prepared" by rubbing with jelly containing pumice powder. It is unlikely that the skin of an amputation stump would tolerate this daily abrasion for long. On the other hand the skin resistance cannot be relied upon to remain at a level of 150–200 kilohms during the whole day, nor can it be assumed that the skin under both electrodes will have the same resistance. Changes may occur from sweating, and even the slightest erythema will usually drop the resistance to about 5 kilohms. Amplifiers for myoelectric control must therefore be designed to give a consistent and interference-free signal in spite of these changes. This requires that their input impedance should be at least one megohm over the whole frequency spectrum used, and that their common mode input impedance should be considerably higher.

![Image of graph showing isometric contraction of normal triceps](image)

**Fig. 1**
Isometric contraction of normal triceps gradually increasing over about five seconds. Rectified and smoothed (time constant 100 milliseconds) voltages from surface electrodes over biceps and triceps plotted against force at the wrist. Three tracings have been superimposed. (E.M.G. (μV R.M.S.): Electromyograph (micro-volts root mean square).)

**PAST AND EXISTING MYO-ELECTRIC CONTROL SYSTEMS**

Technically it is fairly easy to arrange that when electrical activity rises above a certain level a switch is turned on, and several systems depending on this simple idea have been produced. The first working model using this on/off type of control was produced in 1955 by Battye et al. and more recently by Horn (1963) and Scott and Thompson (1964). A practical mid-forearm prosthesis using on/off control from an opposing pair of muscles is in use in Russia and was recently introduced into Britain (Polyan and Ezov 1963). Figure 2 shows a diagram of the control system. When the flexor muscles are contracted above a critical level the motor is turned on and begins to close the hand; when effort ceases the motor stops but the hand maintains its grip because the drive is through a non-reversible screw thread. To relax the grip or open the hand the extensor muscles must be contracted. No true proportional control is possible but the user can make some adjustment of the grip by varying the duration of his effort. When he has gripped an object he has no knowledge of the strength of his grip.
PROPORTIONAL CONTROL FROM MYO-ELECTRIC SIGNALS

It can be seen from Figure 1 that the signal intensity varies continuously with tension, so that to use the signal merely to achieve on/off control is to throw away some of the information it contains, and working models employing truly proportional control have been produced using both electric power (Bottomley, Kinnier Wilson and Nightingale 1963) and pneumatic power (Bottomley 1962). In collaboration with colleagues at St Thomas’s hospital it was decided, therefore, to produce a myo-electric control system with proportional control, and Figure 3 shows a block diagram of the system produced. For convenience a mid-forearm prosthesis has again been chosen.

The signals from two opposing muscles are first amplified, rectified and smoothed. Although there are spurious signals from the pair of electrodes over the opposite muscle, the signal from the muscle which is actually contracting always predominates: so by using the difference between their intensity as the control signal to the powered split hook, the “cross talk” referred to earlier is eliminated.

If a device is to be made that will feel natural to the user, and not require any new skill to be learnt before it can be used, it must behave in much the same way as the missing muscle. Muscles produce force in proportion to the stimulation reaching them, fairly independently of the velocity with which they are contracting. In this system, therefore, when an object is grasped the split hook exerts a force proportional to the subject’s effort, tightening up when he produces a greater signal and relaxing when he relaxes. The effect is achieved by measuring the force exerted by the hook and feeding this signal back to compare with the myo-electric signal. When this feedback signal is less than that which the subject seems to require, as judged by the myo-electric signal, current is fed to the motor so as to increase the force. Conversely,
when he relaxes, the feedback signal is greater than the myo-electric signal from the muscle, and the motor reduces the grasp once more. Since the user is deprived of the sensory impulses from the muscles which he normally uses to control his hand before an object is grasped and when it was moving freely, it was decided to make the speed of the free-moving hook proportional to the myo-electric signal. This is achieved in the same sort of way as the force control, by measuring the speed and feeding back this signal to the control system. It was arbitrarily decided to arrange that full speed (closing in about half a second) should be achieved by an effort equivalent to about one-third of the maximum possible force. This seems satisfactory in practice.

The overall effect of using these forms of feedback is that before the subject has grasped an object, he can control the speed of movement by varying his effort, and once he has grasped it he can control the strength of the grip. Drive is again by means of a non-reversible screw so that if the user wants to grasp an object for some considerable period the electronics may be switched off and the grip maintained without further effort. While the system is switched on, however, he does have some knowledge of how hard the prosthesis is gripping since this is directly related to the effort of his remaining muscles.

Without looking at the hook the user is not aware of its position. To remedy this, a light spring mimicking the elastic properties of the normal hand opposes opening of the hook. Thus, before the user has gripped an object, he has some knowledge of how far open the hook is, because he has had to increase the force in his extensors to make the hook open against the spring.

The component labelled "backlash generator" is used to allow for the random variations of the signal. No correction signal is applied to the motor unless the signal change exceeds preset limits which widen as the force feedback signal increases. (This allows for the greater variability of the signal with increased force which was mentioned above.)

Within a few minutes of wearing the apparatus all the amputees, and normal subjects on which it has so far been tried, have been able to control the hook in a graded manner.

CONCLUSIONS

All those concerned in prosthetics will realise that the substitution of myo-electric control for the normal cable-operated hand or hook for a mid-forearm amputation has disadvantages as well as advantages for the patient who, although he can operate the prosthesis completely independently of the strenuous shoulder effort associated with the ordinary cable system, loses the "feel" of the cable system which tells him not only the force but the position of the hook unit. The Medical Research Council/St Thomas's hand hook was designed purposely for mid-forearm amputations, to gain experience of the method with patients who would derive some advantage, but were not desperately in need of new control methods. The patients whose need is far greater are those who have amputations at higher levels; whereas they require more movements of the prosthesis there are fewer control sites to use. It is for these patients that myo-electric control will probably be found to be the most useful, particularly if it is skilfully combined with the use of orthodox methods.

FUTURE MYO-ELECTRIC CONTROL

So far only one independent control channel has been extracted from myo-electric signals, although some centres have experimented with the use of one channel for different movements by such manoeuvres as time sharing and sequential control. Ultimately it may be possible to extract more than one useful channel of control from multiple muscle groups either by a more sophisticated processing of surface signals or by indwelling electrodes.

There is also some evidence that, with suitable training, different parts of a muscle may be contracted independently. Some workers have even found that individual single motor
units may be voluntarily and independently contracted (Basmajian 1963). These facts open up great possibilities for the future of the patient with high bilateral arm amputations, always one of the most difficult problems for the prosthetist.

SUMMARY
1. A prosthesis under myo-electric control is described.
2. An advanced technique of proportional control of such a prosthesis is outlined.

This development stems from the work of the late Dr A. Nightingale of the Physics Department, St Thomas's Hospital, with whom the author studied the physiological problems involved. Mr T. K. Cowell and Mr P. Styles of the Department of Medical Electronics, St Thomas's Hospital, developed the amplifiers and logic circuits in collaboration with the author.

REFERENCES