THE USE OF MYO-ELECTRIC CURRENTS IN THE OPERATION OF PROSTHESES

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In patients who have lost part of the upper limb automatic reactions which have become patterned in the central nervous system over a period of years are not lost, but continue to be used in relation to the phantom limb. For example, a patient told to grasp with the phantom will fire off from the nervous system the complete set of impulses to prime movers and synergists which have been integrated by continued use into the pattern which in his sensorium stands for " grasp."

It has long been known that electrodes placed suitably on the skin over a contracting muscle can pick up electrical changes which vary from a few microvolts to a few hundred microvolts according to the force of contraction. It was therefore considered that it should be possible to use these potentials from the muscle bellies in the stump or one of the synergists

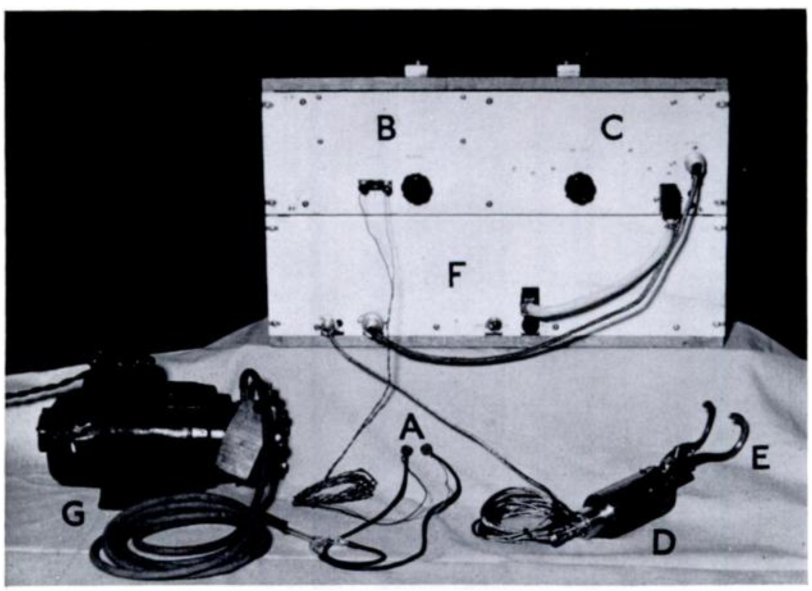

FIG. 1
The final apparatus.

to operate a prosthesis. The great advantage of such a system would be that the prosthesis would be directly controlled by the patient's cerebral cortex and no re-education would be required in the pattern of his muscular activity. This paper reports a preliminary investigation into the problem.

APPARATUS

We decided in the first place to restrict our aim to the construction of an apparatus capable of performing a simple open and close action when the subject made a light grasp with the fingers, and to concentrate on achieving reliability of action rather than complexity of movement or feats of strength. We also decided to give no attention to reducing the bulk of the apparatus, and standard components were used throughout.

The apparatus which we evolved is shown in Figures 1 and 2. The fluctuations of potential appear on the surface of the skin and are picked up by the electrodes (A). These are small brass cups which can be held to the skin by suction through a side tube. Leads are taken to the balanced amplifier (B) which is similar in many respects to those used in electrocardiography and electromyography. After amplification the signal is taken to the discriminator (C) which when operated switches power through to the solenoid (D). This is

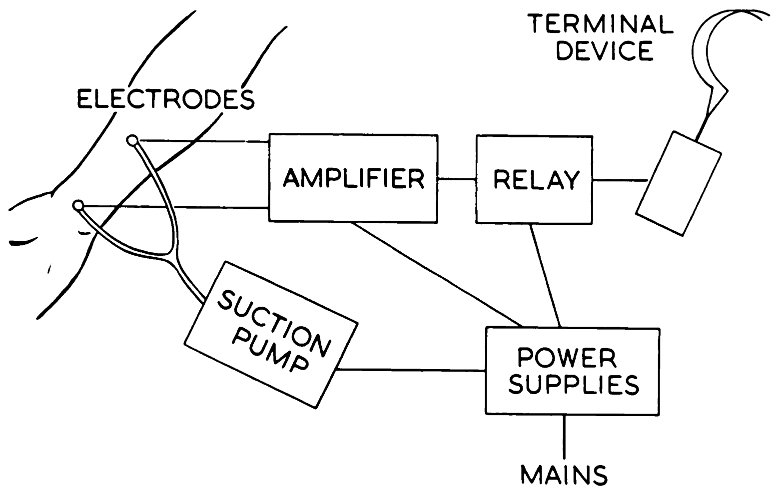

FIG. 2
Schematic diagram of the apparatus.

similar to an automobile " trafficator " and closes the split hook (E). The remaining apparatus consists of an electrical supply (F) connected to the mains, and a suction pump (G) for the electrodes.

As was expected, several difficulties were encountered in the design of the apparatus.

Thus electrical interference from the mains wiring and from electrical machines nearby was picked up by the subject and had to be reduced to a level well below that of the signal. This was achieved by the use of a balanced input in the amplifier and careful earthing of the subject.

Random electrical fluctuations in the amplifier itself and at the electrode-to-skin contact were reduced to a minimum by restricting the frequency range to which the amplifier responded. The most favourable range was found to be 100–1,000 c/s. Care was taken to ensure a good contact at the skin surface by cleaning with spirit and by the use of saline jelly under the electrodes.

Unwanted signals from muscles adjacent to the one selected to operate the device were reduced by careful placing of the electrodes in the optimum position, as found empirically.

It was found to be advantageous to introduce some " backlash " into the closing and opening of the switch (Fig. 3)—that is to say, to arrange that the signal required to close it was bigger than that at which it opened. In this way the strong contraction required for reliable closure of the terminal device could be considerably relaxed while the grasp was maintained, and the subject was not therefore required to maintain any excessive effort. The opening level was made considerably higher than the spurious signal level so that no difficulty was encountered in releasing the grasp when the contraction was relaxed.

Previous experiments had shown that the initiation of natural movements of the fingers always gives a large burst of signals which later dies down to a steady level as the contraction is maintained (Fig. 4). This may be due to the extra initial force required to overcome the inertia of the limb, and it has not yet been established whether this initial burst is produced by amputees.

Finally, it was found that the suction electrodes and commonly used saline pads were unsatisfactory for normal operation over long periods because the electrode jelly dried. Chlorided silver cups which are sealed to the skin with collodion were found to be quite satisfactory and can be worn comfortably for many hours.

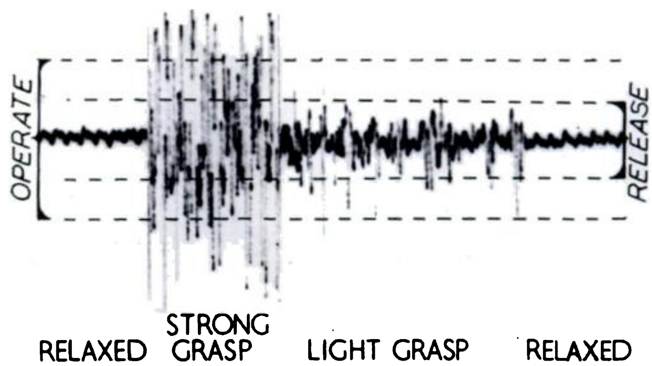

Fig. 3
Recording illustrating level of signal corresponding to different strengths of contraction.

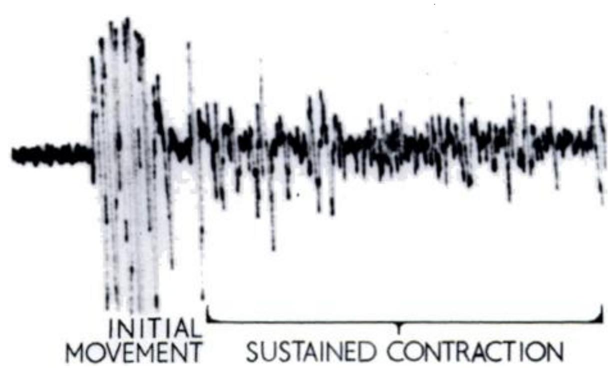

Fig. 4
Recording showing the "burst" of activity occurring on the initiation of a movement.

RESULTS

The apparatus described was tested on several normal subjects and was found to satisfy all the original conditions very well. It was sensitive enough to close, and remain closed, when a pencil was gripped lightly in the fingers, irrespective of movements of the wrist or arm. Similarly it was found that on relaxation the device opened immediately and remained open regardless of other movements not involving gripping with the fingers. This means that signals from other muscles than the required one had been successfully eliminated.

Rapid alternate contraction and relaxation of the finger flexors was followed faithfully by the device up to the speed of about three per second.

Most encouraging was the insensitivity of the apparatus to electrical machines working in the neighbourhood on the same mains supply. Commutator motors were run within two or three feet of the machine without any effect on its performance.

Obviously to operate the device it is best to pick up the changes in potential from one of the prime movers in the movement concerned, but experiments showed that if such were not available one of the synergists could be used provided it was not concerned in efforts directly antagonistic to the desired movement. In the latter case once grasp is achieved by the machine it is impossible to relax it, for in such efforts the synergist takes over the role of antagonist and the impulses continue to flow into the apparatus. A study of the movements of grasping with the whole hand or pinching between the finger and thumb disclosed that in both cases the flexor pollicis longus was the best muscle to use as a prime mover; of the synergists the brachioradialis was found most suitable.

Experiments on amputees showed that the pattern of use of muscles in this movement was persistent even after a period of years, although the best results were obtained when the amputation was recent.

DISCUSSION

An immediate possibility is the application of a pneumatic, rather than electric, drive to the terminal device. This would be more convenient in that it would avoid electrical interference at the very sensitive input connections which must be very close to the terminal device.

Having established that actions can be carried out reliably by myo-electric apparatus we had to consider whether such an apparatus could be made to give a graded response.

We believe this to be possible by the use of electro-mechanical servo-mechanisms, though the best system to use is not yet clear to us. There are many types of servo system common in electrical engineering, none of which compares in principle or subtlety with the human motor system. One way in which a graded grip might be obtained would be by means of a position control servo in which the position, or degree of closure, of the terminal device would be proportional to the strength of the muscular contraction. Such a device, if prevented from closing by the presence of an object between the claws, could be made to exert a force also depending on the strength of the contraction. This system would have two defects: in order to maintain the device closed a continuous strong grasp would be required; and the contraction required to exert a certain force would be dependent on the position of the claw.

A more perfect system from the mechanical point of view would be a velocity control servo, in which the velocity of the terminal device would be dependent on the signal. As in the position control servo the force exerted would also depend on the contraction. But unlike the position control servo no contraction need be made to keep the terminal device closed and motionless. Neither would the force exerted be dependent on the position of the claws. From a practical point of view, however, this system would suffer from the disadvantage that two signals would be required to control opening and closing speeds. These could be obtained only from a pair of muscles producing opposite movements, such as a flexor and extensor; but since one of this pair might also be used for the stabilisation of other joints the signal from it would be unreliable for operating an open and close device. Only in a prosthesis designed to carry out a large number of independent motions in a manner similar to that of the normal motor system would such a servo system be important.

The possibility of using signals from more muscles to perform more complex actions cannot be ignored, but would depend largely on the degree to which the apparatus can be reduced in size and complexity.

The sensory impressions from the skin and other tissues of the part that has been lost are, of course, missing in the amputee. Nevertheless it is conceivable that a " feedback " proportionate to the pressure exerted by the claw of a prosthesis could be used to stimulate an area of skin on the stump, and in this way a new conditioned response in the sensorium might be rapidly developed in the intelligent patient. This, in contradistinction to the movement of the claw, would need re-education.

There remains the problem of the child born without hands. Here, of course, the conditions are very different from those of the ordinary amputee who has developed in the years preceding amputation a pattern of hand consciousness and movement which can be used in relation to the prosthesis. The child born without hands can never develop a hand consciousness. But it is possible, provided there was no central nervous system deformity or agenesis, that such a child might develop in relation to a prosthesis a pattern similar to that which the ordinary person develops in relation to the hand if the process were begun early enough. Admittedly such a pattern would be a mere travesty of the wonderfully co-ordinated normal " hand consciousness," but it might be sufficient to enable such individuals to develop considerable skill.

CONCLUSION

Obviously these and other problems need much research, but the preliminary work already done is promising enough to indicate that a useful and dependable prosthesis could be developed to operate by the use of changes of muscle potential, and that such apparatus could be made light enough for practical use at the work-bench and in the home.