CLINICOPHYSIOLOGICAL CONDITIONS OF BIOELECTRIC CONTROL IN PROSTHESES

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The use of external sources of energy to control prosthetic appliances forms the object of researches of scientists and engineers in many countries. No one doubts the expediency of utilising external sources of energy in order to relieve the patient of unnecessary efforts when manipulating artificial limbs. However, the choice of these external sources of energy and the methods of control differ.

At present, the method of control by means of the bioelectric potentials of the muscles of the stump in combination with an external source of electric energy is being successfully applied in the Soviet Union. The choice of this method does not, however, exclude the possibility of others. We are now making use of artificial limbs with electric drives with contact control, the possibilities of pneumatic drives are being examined. Nevertheless, we give preference to bioelectric control.

It is the most functional, as it is nearest to the natural method of controlling a healthy limb. Compared to other methods it relieves the patient of the necessity of making compensatory movements of the segments of the limb above the amputation and of the body. Nor does it require special surgical preparation for a prosthesis. The method of bioelectric control restores to the muscles of the stump the function of contraction and slackening peculiar to this tissue, helps to restore the condition of other tissues of the stump to normal, reduces atrophy, improves metabolism, and protects the patient against trophic disturbances in the stump and, quite often, against phantom pains. This method of control also partially restores the conditioned-reflex relations lost after amputation. And this, in its turn, helps the patient to learn to control the prosthetic appliance, and enhances the feeling of fusion of the prosthesis with the stump.

Control of artificial limbs by means of the bioelectric potentials of the muscles of the stump leaves all the joints of the amputated limb free to carry out their natural functions, and ensures accuracy of the movements of the artificial limb, as it does not involve even the least displacement of the latter for the sake of control.

At the Central Research Institute of Orthopedics and Prosthesis, bioelectrically controlled prosthetic appliances are based on the principle of separate activity of the controlled muscles of the stump. In order to control the artificial limb, the patient must be able to contract each of the controlled muscles volitionally and, to a sufficient degree, separately. In doing this, he must develop the electric energy required for control of the prosthetic appliance without any considerable effort oı fatigue. The type of amplifier used requires bioelectrical activity of the controlled muscles of no less than 50 microvolts, i. e., slightly exceeding the threshold of control (30—40 microvolts), given lower activity of the antagonist. Therefore, before fitting patients with prosthetic appliances, the bioelectric activity of the muscles of the stump and the interaction of the antagonists are checked.

For controlled clenching and unclenching of the fingers of an artificial hand we use the bioelectric potentials of the truncated muscles of the stump, corresponding to the flexors and extensors of the hand and fingers. Many patients cannot learn to contract the antagonistic groups of muscles of the stump separately. This, however, is not regarded as a contraindication to use of the prosthesis, as the necessary habit can be actively developed in the patient by physiological methods. Our researches in this field were conducted jointly with Master of Biology Y. A. Shirokova, I. S. Goldberg and S. S. Smiles.

These methods of training include visual control by the patient of the activity of his muscles on the screen of a cathode oscillograph. The electric activity of the muscles is checked with lamp millivoltmeters.

As the necessary habit is developed, the need for visual control decreases. The training is completed by control of the muscular-articular response in a model of the prosthesis. Moreover, the effect of the training is reinforced by the psychological factor of realization of the contraction of the stump muscles in the movement of the fingers of the artificial hand.

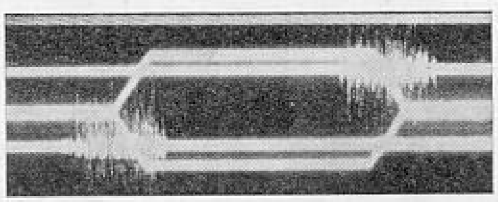

Figure 1.

Control of an artificial forearm with two movements (clenching and uncleanching the fingers of the artificial hand) can usually be learned in two or three lessons of 30—40 minutes each. Some cases need longer training.

The mechanism of the process of control of such an appliance is shown on the oscillogram (Fig. 1), from which it can be seen that activity of the controlled muscles is only required during movement of the artificial limb. The limb is kept stationary in any desired position with the help of a self-stopping mechanism, and no muscular energy is required here.

After an appropriate term of preliminary preparation and training in use of the prosthetic appliance, the movement of clenching and unclenching the fingers is easily controlled in any position of the artificial limb, both by the muscles of the forearm stump and by the muscles of the shoulder stump. In the latter case, the bicipital and tricipital shoulder muscles are used.

If the prosupinational movements of the stump of the forearm have been retained and can be used to rotate the artificial hand, training can ensure control of the function of the artificial hand by the bioelectric potentials of the flexors and extensors without their participation in the rotary movements of the stump.

Further research, aimed at functional improvement of prostheses, showed that longer training (5—10 lessons) could ensure isolated contraction of the four muscles of the stump of the forearm (Fig. 2) and, correspondingly, isolated tapping of the bioelectric potentials of these muscles, and their utilization as independent command signals for control of four separate functions of the experimental model of the artificial limb (flexing and extending the fingers of the hand, its pronation and supination). Moreover, here, different combinations of commands are possible and, hence, different combinations of controlled movements. The latter may be made consecutively or simultaneously, like the elementary and coordinated movements of a healthy hand (Fig. 2).

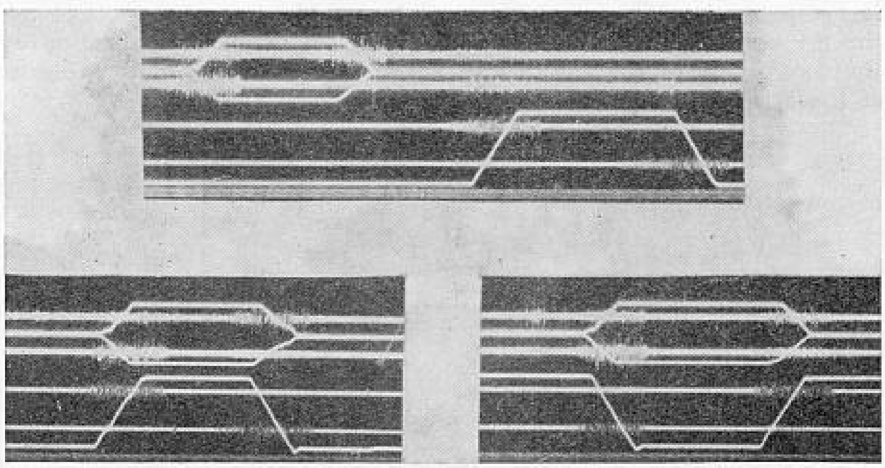

Figure 2.

The latest researches have shown that if the stump of the forearm is long enough (its middle and lower third), still longer training (10—15 lessons) makes it possible to achieve isolated contraction of even six muscles of the stump and independent control of six movements of the model of the artificial limb, both separately and jointly, in two or three joints of the model simultaneously.

These researches show that even the fairly complicated coordination of muscular contractions, necessary for bioelectric control, can be actively developed in the patient by appropriate training. This should not cause surprise, insofar as the mechanism of building up the habit of bioelectric control in principle resembles the mechanism of the movement habit built up in man.

This system of control, in which each movement of the artificial limb (or its model) is controlled by the bioelectric potentials of a separate muscle (or small group of closely adjacent muscles), thus ensuring the possibility of making two or even three movements simultaneously, is most justified from the clinical and physiological aspect.

However, the concentration of a large number of controling and driven devices and sources of energy in the artificial limb or the clothing of the patient may prove to be too heavy a load for him to carry. A certain technical economy can be gained by the use of the switch principle.

Therefore, the possibility of controlling four movements by two commands in turn is being studied. The most advantageous way of applying this principle is by using the activity of the controlled muscles themselves. This can be done, for instance, by using a switching device operated by simultaneous activity of two controlled muscles of the antagonists (Fig. 3). It may seem that such a system could cause difficulties of a physiological nature, insofar as the central innervation of the controlled muscles must switch over rapidly from the antagonistic to the synergetic, and vice versa. Our observations showed, however, that this habit can be developed in the muscles both of the forearm stump and of the shoulder stump (Fig. 3) by training with visual control (feedback) for five to ten lessons. We further established that control of movements in turn can also be achieved by changing the amplitude of the bioelectric potentials.

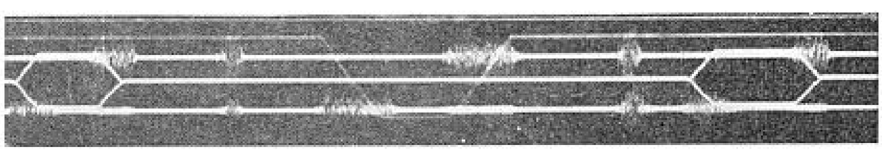

Figure 3.

The further development of a prosthesis with bioelectric control is proceeding along the lines of increasing the number of controlled movements with the aim of increasing the patient's functional possibilities. As we have already said, researches proved both the possibility of simultaneously picking up isolated bioelectric potentials of several muscles of the stump and of using them to control the movements of a model of the prosthetic appliance, and the possibility of controlling in turn different movements of the model of the prosthesis by one and the same muscles of the stump.

In order to make use of these clinicophysiological prerequisites in a prosthesis, work is proceeding simultaneously on the creation of small units which would facilitate the use of the principle of separate control, and also on the creation of switching devices and mechanisms which would ensure an increase of the functions carried out in turn. The possibility of separate control of several movements has created the prerequisites for the elaboration of a multifunctional artificial hand.

With the same aim of enriching the functional possibilities of prostheses, work is being carried out at the Institute with a view to providing artificial limbs with a device enabling the patient to feel the strength of the grip of the artificial hand. Frequency-impulse vibration irritations have been chosen as an information code to be used for analysis of the strength of the grip of bioelectrically controlled artificial limb. Owing to the intermittent nature of the irritant, practically no adaptation takes place and accurate perception is ensured.

The expediency of the principle of separate activity of the controlled muscles of the stump, chosen by the Institute, has been confirmed by researches and by the practical work of prosthetic-orthopedic enterprises in the Soviet Union. Training is feasible and takes very little time. The efficiency of training depends on several things. The magnitude of the bioelectric potential usually depends upon the condition of the muscles of the stump, i. e., when in good condition their activity is higher, when the tissues are atrophied it is lower. However, the condition of the stump muscles may also be determined by many other causes: by the nature of the amputation, the post-operation course of the wound, the patient's age, the time elapsing after the amputation, and the functions of the stump.

If, owing to the poor functional condition of the stump, the activity of its muscles is low and insufficient for control of the prosthetic appliance without considerable effort on the part of the patient, it can be actively increased by special gymnastics and other medical measures to improve the general condition of the stump.

Training in separate contraction of muscles depends to a great extent on the neuropsychic condition of the patient. Patients with an active nervous system acquire these habits sooner and without any great effort, patients with an inert nervous system need longer training and greater efforts on their own part and on that of the instructor.

At present, an artificial forearm with bioelectric control of the movements of flexing and extending the fingers of the artificial hand is being manufactured at 22 prosthetic-orthopedic enterprises in the Soviet Union. Special rooms have been fitted up there with training apparatuses, a stand for learning how to manipulate the artificial limb, and equipment for all stages of prosthesis. Exact medical recommendations for prostheses and methods of fitting the patient with the artificial limb have been elaborated. We attach very great importance to training in the use of the prosthetic appliance, given at the time of fitting the patient. The latter is taught how to control the artificial limb in different positions, incremented control, how to do simple work and make ordinary movements. This training helps the patient to understand the methods of control and memorise them.

Some patients are hospitalized for the period of training. Familiarity with the prosthetic appliance and perfect control of it come in the course of its everyday use.

The fact that this fundamentally new type of prosthesis has been mastered by a large number of practical prosthetists in a short time while attending special courses at the Central Research Institute of Orthopedics and Prosthesis and in the course of their practical work at prosthetic-orthopedic enterprises, as well as the considerable increase in the patients' functional possibilities, prove the efficiency of bioelectric control of artificial upper limbs. The clinicophysiological researches confirm the possibility of functional enrichment of bioelectrically controlled prosthesis.