MAIN PRINCIPLES OF CONSTRUCTION OF A BIOELECTRICALLY CONTROLLED ORTHOPEDIC BRACE

E.I. Plumm, V.I. Delov, and R.I. Kushnirov

Summary

Information is given about the merits of external sources of power for orthopedic braces. The advantages of a bioelectric control for actuation of the brace are noted.

The advantages of a method of frequency selection of information from a bioelectric signal derived from the muscles of different degrees of paresis are proved for the control purposes. The diagram of the system is described.

The main tasks of orthoses for patients after poliomyelitis is compensation for a motor defect and functional restoration of paretic muscles by means of functional bioelectric braces.

Orthopedic braces intended for compensation of a motor defect in the paralyzed muscles of upper limbs came into being comparatively recently /1, 2/. These were mechanical devices actuated by healthy muscles of different body parts with a help of traction, straps, and levers. Such braces differed only in minor ways and required great expenditure of energy during control.

Application of external sources of power eliminates the need for large amounts of energy. At present, different types of actuating mechanisms using electrical or pneumatical sources of energy are applied to braces /3-8/. The choice of type of actuating mechanism is one of the main technical problems in constructing a functional externally powered brace.

There are very many data in the literature dedicated to the question of a qualitative analysis of different types of drives applied in prosthetics. But the opinions available at present are contradictory /6-16/ because of the absence of criteria of an objective estimation of the quality of actuators according to their main characteristics.

Together with the choice of a type of drive to be used is the problem of a chioce of a type of control. To transfer information along the communication lines some type of code, or reproduction of the information in the some form of signals, is used. Accordingly the signals transferred from a man-operator to the system of control for an orthopedic brace are represented by a code that is introduced into the system as control information.

Depending upon the type of code system used, a "man - orthopedic brace" (which is considered to be included into a wide class of biotechnical "man-machine" systems) may be classified as the system with a sound and a bioparametric code. Both biomechanical and bioelectrical parameters may be referred to bioparametric parameters. The biomechanical code may characterize movements of body parts. A tension system of control may serve as an example. In addition, the biomechanical code may characterize the muscle state such as hardness and volume. A system of "myotonic control" /17/ may serve as a typical example.

Biomechanical codes are impossible to use if the source of the controlling signals are the muscles of a deeply paralyzed limb that is not able to perform both the movements and sufficient contraction of the muscles.

It is desirable to use an injured limb as the source of controlling signals for control of an actuator. Firstly, use of healthy muscles of a body or of the extremities which serve as a rule for vocational and everyday activities of a patient, decreases sufficiently his operative possibilities. Secondly, every volitional movement is more significant than a passive one as the impulses passing from the cortex to the motor apparatus help more rapid restoration of a function of injured muscles /18/.

Even when a very weakened electrical signal from the central nervous system is available to the muscles, it is possible to use a bioelectrical code. A bioelectrical system of control (BESC) allows the patient to perform perfect control of an orthopedic brace thus carry out a great number of different movements with his impaired extremity by using his own natural coordination habits.

This type of a system is essential for quality of control. By processing sophisticated bioelectrical signals, the system develops useful information about commands arrising from the central nervous system and passed along to the muscles. Therefore the circuit of separation of useful information from a command signal is one of the main elements in the control system. The structure of this circuit is defined to a great extent by the characteristics of a bioelectric signal, i.e. depends on the source of controlling command.

The structure of such a system of bioelectric control for a functional brace is defined by an input signal, i.e. by a biopotential parameter that can be adopted to be a controlling one. But the structure of the system is at the same time, defined by output data necessary for the control by an "executive" mechanism.

The question of a choice of a controlling biopotential parameter is in principle the question of a rational use of information from a muscle as a source of controlling signals.

Use of an electrical component of muscle contraction forms the foundation for the work of BESC. The electrical signals received by means of surface electrodes is characterized by amplitude, duration and pulsed frequency, integrated activity, and frequency spectrum. Definite correlation between value of biopotentials and tension of skeletal muscles are used in existing bioelectrical systems for control of prostheses and braces. An electrical signal from injured muscle has a number of features in comparison with an electrical signal from normal muscles /19, 20/. Its integrated activity is significantly less than is the case with normal muscle. Therefore in such a case BESC must possess high sensitivity that impedes to decide the problems of its interference - resistance. The system becomes intricate since any pair of movements (grasp-opening of the hand; pronation-supination of the forearm; flexion-extension in the elbow-joint, etc.) may be performed only under certain conditions by application a reversible actuating mechanism in the brace. In order to satisfy this condition two channels providing the movements in pairs are used.

Two muscles, at any rate are, necessary for the control by such a BESC. In this case the muscles must be capable of isolated activity. Increased physiological "crosstalk" and physical conductivity were observed visualy when paretic muscles were contracted. This has been confirmed by means of a cross-correlational analysis /21/. It is worth noting that increase of correlation between electromyographic signals of paretic muscle antagonists has been revealed not only in the case of a deep paresis but in the case of mild paresis when a visual analysis does not expose any pathological changes.

In connection with the difficulties mentioned above the specialists from Rancho Los Amigos Hospital (Los Angeles, California, USA) consider, for example, an idea of a bioelectric control from paralyzed muscles to be quite complicated for practical realization. As a consequence of this it is rarely used in orthopedic braces /22, 23/.

In our work, we proceeded on the assumption that as a controlling parameter it is possible to use insead of an integrated activity of a signal a pulsed frequency, provided the amplitude of impulses exceeds some threshold /24/. In this case the system is rather interference-resistant and simple. It is possible to provide discrete control by the reversible actuating mechanism with the help of a choice of the system thersholds on different channels. Such a system has been developed in the Laboratory of Bioelectric Systems of Control of a Central Research Institute for Prosthesis and Artificial Limb-Making.

Figure 1 shows a block diagram of the system.

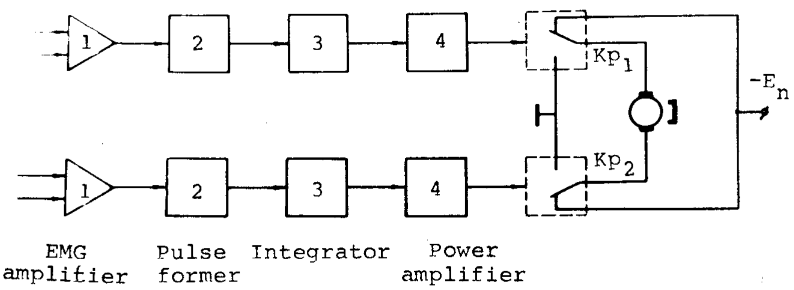

Fig. 1. Block-diagram of a bioelectrical control system.

A controlling parameter of a biosignal in this system is a pulsed frequency of its impulses. A special block of reading and transformation of impulses (BRT) has been introduced into the system.

The system operates in the following manner: a signal removed from the muscle by surface electrodes and amplified by a preamplifier of voltage AV arrives at the block of reading and transformation of impulses BRT which, as a response on each low-powered impulse of a biosignal, produces a square-wave impulse of a sufficient constant amplitude and constant duration.

These impulses are smoothed by the integrators and used to control the relays which provide reversing function to the electromotor rotation shaft.

Figure 2 shows oscillograms that demonstrate the control of the actuating mechanism with the help of deeply paretic muscles.

Use of a frequency parameter of a biosignal has made the system universal. It may be used with any form of an electric signal of the muscles with different deepness of injury.

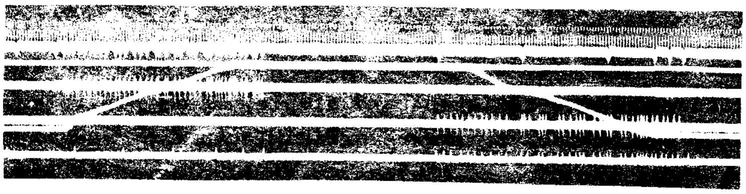

Fig. 2. Oscillograms of control of the brace with the help of signals from deeply paretic muscles.

1 - integrated EMG of an extensor;
2 - mechanogram;
3 - source EMG of an extensor;
4 - source EMG a flexor;
5 - integrated EMG of a flexor;
6 - time mark 0.02 sec.

An urgent task is the creation of functional braces with some pairs of controlled movements. Naturally the more the extremity is injured, the more number of controlled degrees of movability the brace must have. Nevertheless the number of preserved sources of controlling signals - muscles - will be less, the more the extremity is injured. Therefore when creating bioelectrical systems of control by multifunctional orthopedic braces the methods of control by several actuating mechanisms from the limited number of muscles may find application. No doubt logic devices will be used /25/.

At present at the CNIIPP the work on creating of upper-limb orthopedic braces is being carried out. These braces will have two pairs of bioelectrically controlled movements: grasp-opening of the hand and flexion-extension of the forearm /26, 27/.

Investigation and further improvements of the designs and the systems of control by functional orthopedic braces is an urgent task as a brace is an effective means of compensation of lost motor functions and in addition, is an important medical remedy in the rehabilitation of invalids.

References

/1/ Schanz A., Handbuch der orthopädischen Technik, Jena, 1923.

/2/ Stracker O., "Apparatotherapie der poliomielitischen Lähmungen", *Verhandlungen der Vereinigung der Orthopäden*, 1938.

/3/ Montgomery L.H., Stephenson S.E., "Muscle Potential Amplifiers and Their Application to Supportive Procedures", *Proceedings of the Second International Conference on Medical Electronics*, London, 3-8, 1960.

/4/ Lindemann, Marquardt, "Pneumatischer Lähmungsapparat", *Archiv für Orthopädische und Unfallchirurgie*, B.53, H.6, 508-523, 1962.

/5/ Шейнфинкель В.М., "Использование пневматических устройств в протезах верхних конечностей", Протезирование и протезостроение, сб. трудов, вып. VII /XI/, М., ЦНИИПП, стр. 24-27, 1962.

/6/ Davies R.M., and Lambert T.H., "Dynamic Characteristics of Pneumatic, Electric and Hydraulic Actuation of Prosthetic and Orthotic Devices", *The Proceedings of the International Symposium on External Control of Human Extremities*, Dubrovnik, 1966.

/7/ Fitzlaff G., "Gedanken über den Einsatz von [illegible] Antrieben bei elektronisch gesteuerten [illegible] *Technik*, H.?, 144-148, 1966.

/8/ Sell G., "Stand der Entwicklung von myo-elektrisch gesteuerten Armprothesen in der Bundesrepublik", *Orthopädie Technik*, H.3, 61-63, 1967.

/9/ McLaurin C.A., "On the Use of Electricity in Upper Extremity Prostheses", *The Journal of Bone and Joint Surgery*, V. 47-B, 448-452, 1965.

/10/ Karchak A., Nickel V.L., [illegible] "Application of External Power in Upper Extremity Orthotics", *Product Engineering*, V.36, No. 21, 107, 1965.

/11/ Godden A.K., "Powered Artificial Limbs for Thalidomide Casaulties and Other Aids for the Handicapped", First Annual Report, No. 1, 018, Engineering Laboratory, University of Oxford, 1967.

/12/ Sell G., Merten H., "Bericht über den Stand der Entwicklung von myo-elektrisch gesteuerten Armprothesen in der Bundesrepublik", *Orthopädie Technik*, H.7., 170-172, 1967.

/13/ Karchak A., Allen J., Nickel V., "Applications of External Power to Orthotic and Prosthetic Devices", *Archives of Physical Medicine and Rehabilitation*, V.48, No. 7, 341-34?, 1967.

/14/ Lambert T.H., Davies R.M., "The Place of Hydraulics in the Design of Powered Prostheses", *Digest of the 7th International Conference on Medical and Biological Engineering*, Stockholm, August 1967, 449.

/15/ Hohf J.O., Engel W.H., Siebens A.A., "A Hydraulic System for Powering Orthotic Devices", *Archives of Physical Medicine and Rehabilitation*, V.48, No. 8, 424-428, 1967.

/16/ Montgomery S.R., "Pneumatic Power for Arm Splints", *Digest of the 7th International Conference on Medical and Biological Engineering*, Stockholm, 1967, 455.

/17/ Groth H., Lyman J., Weltman G., "Electrical and Mechanical Properties of New Body Control Sites for Externally Powered Prostheses", *Proceedings of the International Symposium on the Application of Automatic Control in Prosthetics Design*, 46-64, Opatija, 1962.

/18/ Ухтомский А.А., Физиология двигательного аппарата, Собрание сочинений, т.3, АН СССР, 1950.

/19/ Славуцкий А.Л., "Физиологические предпосылки к построению функциональных аппаратов для верхних конечностей", Шестая научная сессия ЦНИИПП, М, 145-153, 1958.

/20/ Витензон А.С., "Управление дозированными движениями макета биоэлектричиского аппарата от паретичных мышц", Протезирование и протезостроение, сб. трудов, вып VIII, М, ЦНИИПП, 16-21, 1963.

/21/ Кудина Л.П., "Исследование соотношений во времени разрядов двигательвых единиц у человека", Канд. диссертация, М., 1968.

/22/ Antonelli D., Waring W.,"Myoelectric Control of Powered Devices", *Archives of Physical Medicine and Rehabilitation*, V.48, No. 7, 345-349, 1967.

/23/ Antonelli D.G., Waring W., "Circuit for a One Degree of Freedom Myoelectric Control", *Medical Research Engineering*, Fourth Quarter, 35-38, 1967.

/24/ Пламм Э.И., "Особенности построения биоэлектрических систем управления функциональными аппаратами", Протезирование и протезостроение, сб. трудов, вып. XXI, М., ЦНИИПП, 47-54.

/25/ Полян Е.П., Шнейдер А.Ю., Пламм Э.И., "Принципы сокращения источников командных сигналов в многофункциовальных биоэлектрических системах управления", II Симпозиум по теории и принципам устройств манипуляторов.

/26/ Делов В.И., Кушниров Р.И., Шенк Н.А., "Биоэлектрический ортопедический аппарат при распространенном параличе верхней конечности", Протезирование и протезостроение, сб. трудов, вып. XIX, М., ЦНИИПП, 50-53, 1968.

/27/ Делов В.И., Кушниров Р.И., "Определение мощности привода локтя биоэлектрического аппарата при переменной скорости", Протезирование и протезостроение, сб. трудов, вып. XX, М., ЦНИИПП, 119-123, 1968.