WALK CORRECTION OF PATIENTS AFFECTED WITH FLACCID PARESIS OF LOWER LIMBS USING MULTICHANNEL MUSCLE ELECTRICAL STIMULATION

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Clinico-physiological foundation of artificial correction of pathological walk by means of multichannel muscle electrical stimulation is presented based on complex studies of 52 patients with flaccid pareses of lower limbs (results of poliomyelitis and spinal trauma). Medical indications and contra-indications for prescription of this treatment method have been established. Main principles of artificial correction of movements have been determined: selection of controllable elements of the walk; the ways of synchronization of the muscle electrical stimulation with phases of a locomotor cycle; amplitude and temporal programs of muscle stimulation as well as its mode while walking. Walk correction has been carried out with a help of a four-channeled corrector of movements worked out at the Institute.

As a result of application of many days correction course of movements in patients with flaccid pareses of lower limbs of different etiology the following positive changes have been revealed: significant increase of functional properties of paretic muscles, improvement of the main characteristics of the walking (rate, length of a step, velocity), normalization of its biomechanical structure accompanied by complex rearrangement of the muscles of both legs. Observations of a number of catamneses indicate a prolonged character of these changes.

Rehabilitation of patients with flaccid pareses of lower limbs (the results of poliomyelitis and spinal trauma) as before keeps its actual meaning: I) the contingent of such patients is rather large, 2) it is characterized by considerable affection of supporting-motor functions, 3) in the general, it is represented by people of able-bodied age, 4) disability of a motor sphere in the most part of the patients progresses with age, 5) possibilities of treatment of patients in the residual period are extremely limited.

At present new methods of restorative therapy of motor disorders have been developed based on application of a method and means of artificial correction of movements (ACM) by means of electrical stimulation (ES) of muscles at certain phases of a locomotor cycle (I-5).

The aim of this article is representation of the following aspects of work: I) clinical, biomechanical and physiological foundations of walk correction in patients with flaccid paresis of lower limbs by means of ES of paretic muscles; 2) determination of medical indications and contra-indications for prescription of this treatment method; 3) formulation of the main principles of ACM while patients' walking; 4) analysis of results of application of ACM.

I. The foundation for correction of walk in patients with flaccid pareses of lower limbs by means of ES of paretic muscles.

A clinical picture of results of poliomyelitis, spinal cord injuries is characterized by considerable variety of motor disorders that is conditioned by different localization and severity of affection of a supporting-motor apparatus, by peculiarities of deformations and compensatory mechanisms.

Clinico-biomechanical analysis makes it possible to determine those muscle complexes that have a function deficiency during walking and therefore must be electrically stimulated.

Based on the study of about 5 thousand muscles by a five-mark grading system* in 90 patients with the results of poliomyelitis and IIO patients with spinal cord injuries in the lumbar-sacral spine the following picture of paresis distribution has been revealed.

At the poliomyelitis consequences mostly often affected are the muscles of a hip and shank where the number of paralized and deeply paretic muscles (0-2 points) comprises respectively 68% and 73% of cases. The pelvic muscles, mainly gluteal ones, are considered to be more intact muscles where the number of muscles with an identic evaluation mark decreases to 58% of cases.

At the results of a spinal cord injury paralysis and deep paresis of a foot and shank muscles is observed in about 80% of cases, deep paresis of m.quadriceps femoris - in 35% of cases; m.semitendinosus and m.biceps femoris - in 58% of cases; m.gluteus maximus and m.gluteus medius - respectively, in 7I% and 64% of cases. More severe affection of a supporting-motor

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* According to a five-mark grading system 0-I point means absence of the force of muscles and movements; 2 points means the force of muscles by a value 5-IO% from maximum, capability for movements while unloading the weight of a limb; 3 points means the force of muscles by a value of IO-30% from maximum, capability for movements against the weight of a limb; 4 points means the force of muscles above 30% from maximal value, capability for movements against loads exceeding the weight of a limb; 5 points means a norm.

system in this contingent of patients as a rule is combined with sensory, vegetative and trophic disorders, disturbance of function of pelvic organs.

Imbalance of the muscles-antagonists and sharply changed load on the separate segments of the limb sometimes cause development of deformations, the most distributed from which are flexion contractures in the hip joint (HJ) and knee joint (KJ), recurvature and valgus in the KJ, pathological movability and ankylosis in consequence of arthrodesis in the ankle joint (AJ).

These data on the degree of muscle paresis is of a principal value for realization of ACM because the muscles having a clinical mark above two points can be used as " an actuator" in the correction systems.

The other important foundation for the correction system building is the data on a biomechanical and innervation structure of a locomotor act in patients with flaccid pareses of lower limbs. These data have been obtained by means of a complex quantitative study of biomechanical and electrophysiological gait parameters in 32 patients with consequences of poliomyelitis and 20 patients following a spinal trauma. The results of the study have depended on a unilateral or bilateral nature of a pathological process.

In case of a unilateral flaccid paresis of lower limbs rough temporal, kinematic and dynamic asymmetries were of primary importance. They were manifested in decrease of a supporting time, reduction of value of inter-link angles and maxima of supporting reaction, decrease of electrical activity of muscles (EAM) on the side of a paretic limb and an increase of above-said parameters on the side of an intact limb. Simultaneously with quantitative changes of the parameters qualitative changes have been marked, i.e. a loss of separate elements of a stance phase, prolapsus of some phases of a locomotor cycle (for example, plantar flexion in the AJ during rolling over the forefoot or flexion in the KJ at the stance phase), deformation of dynamograms of components of a supporting reaction, change of a distribution character of EAM during a locomotor act.

All above-mentioned asymmetries have a dual genesis as they reflect decrease of supporting and push-off functions of a paretic leg with simultaneous compensatory increase of the same functions in an intact leg. It is worthy of note that compensatory mechanisms of pathological walking as well as of normal walking were aimed at the decision of the main locomotor tasks: provision of a body stability, its propulsion and swing of a limb. Nevertheless of these tasks in pathological walking differed from normal walking. Thus stability of a paretic limb was achieved for account of participating of practically all of the rest muscles of the leg; body propulsion was achieved mainly owing to a forced back push-off of an intact limb; in swinging of the limb not only dorsal flexors of the AJ and flexors of the HJ participated but the flexors of the KJ usually not functioning during this phase of a step. Not only increase but distinct prolongation of activity of the muscles-extensors of the KJ and HJ at the second third of a stance phase was characteristic for the work of muscles of an intact limb. Evidently it served as compensation of insufficiency of a back push-off by a paretic limb.

In bilateral affection of lower limbs the same disorders of locomotor functions were observed inherent in a paretic limb: temporal, kinematic and dynamic asymmetries were smoothed down, however less affected limb took a role of a leading leg. Besides, in consequence of support on crutches or canes an anthropomorphous character of walk was significantly damaged.

Such are the studies on the basis of which indications and contra-indications have been worked out for prescription of an ACM method, the main principles of its organization have determined.

2. Indications and contra-indications for walk correction of patients with flaccid pareses of lower limbs by means of ES of muscles

The principal indication for prescription of ACM to the patients with consequences of poliomyelitis and spinal cord injuries is deficiency of a muscle function (DMF) resulting in distortion of a biomechanical structure of walking. In these diseases DMF by its origin is first of all an absolute one as it is connected with affection of a neural and muscular systems: destruction of spinal motoneurons, their axons, disturbance of neuromuscular synapses, atrophy of muscle fibers. In addition to the absolute DMF, in walking of such patients a relative DMF is always present conditioned by the change of current afferentation from the limb. The relative DMF is explained by the decrease of supporting capability of paretic limbs, by the change of their postural characteristics because of development of contractures or pathological habits, by insufficient tension of muscles after their grafting, by limitation of movements in the joints or in the artificial joints of an orthopedic brace.

A necessary requirement for application of ACM is a preserved capability of the muscles to react to electrical irritation by a contraction sufficient for achievement of correcting effect in walking. As usual those muscles exert such contraction which have a clinical mark above 2 points.

The most meaningful one for disturbance of the walking structure is a deficiency of the muscles-extensors: m.triceps surae, m.quadriceps femoris, gluteal and sacralspinalis muscles. This principle comprises the base of a clinical classification of patients in which the function of the muscles-extensors of the HJ,KJ and AJ is presented in a dual code. A function insufficient for performing an active movement and providing stability in the joint is designated by the minus sign (-) in this classification and a sufficient function (usually, above 2 points) is designated by the plus sign (+).

As it is evident from Table I the patients with flaccid pareses of lower limbs in dependence of intactness of muscles-extensors may be divided into 8 clinical groups.

Table I. Clinical classification for determination of indications for ACM in patients with flaccid pareses of lower limbs

Clinical group of patients	Evaluation of extensors function			Rate of cases in % (patients with CP)	Rate of cases in % (patients with CSCJ)	Indications for ACM
	HJ	KJ	AJ			
0	-	-	-	24.3	36.4	Not recommended
I	-	-	+	0.7	0	Not recommended
II	-	+	-	2.I	24.4	Recommended in separate cases
III	-	+	+	0.7	I.3	Recommended in separate cases
IY	+	-	+	16.I	2.I	Recommended
Y	+	-	+	7.6	0	Recommended
YI	+	+	-	I8.6	25.0	Recommended
YII	+	+	+	29.9	I0.7	Recommended

Legend: CP - consequence of poliomyelitis; CSCJ - consequence of spinal cord injuries (in the lumbar- sacral spine). By the data of the study 90 patients suffer from consequences of poliomyelitis, II0 patients - from consequences of spinal cord injuries.

Groups IY, Y, YI and YII, comprising 72% of all cases, are the most prospective ones for ACM in patients with consequences of poliomyelitis, and in patients with consequences of a spinam trauma - groups II,YI and YII comprising 62% of all cases as far as in these groups of patients a capability for strengthening the extensors of HJ and KJ exists meanwhile the function of the extensor of the AJ may be compensated partially with a help of an orthopedic brace.

Contraindications for ACM in this contingent of patients are divided into absolute and relative ones. Malignant tumours, deficiency of cardiovascular system at the stage of subcompensation and decompensation, all forms of epilepsy, renal and urinary tract diseases, pregnancy, intolerance of minimal electrical irritations are related to the first group; to the second group - deformities or pathological movability in the joints, poor tolerance of electrostimulation, diseases and extensive scarred damages of skin integuments at the place of electrode application.

3. The main principles of realization of ACM during walking of patients with flaccid pareses of lower limbs.

Realization of ACM supposes the decision of the following problems: I) selection of movements capable of correction and the muscles capable of stimulation; 2) determination of an amplitude program of ES of muscles; 3) establishing the temporal program of ES of muscles during the gait cycle; 4) ascertaining a type, form and size of electrodes and their localization in relation to a motor area of the muscle; 5) the search for an adequate mode of ES of muscles during walking.

Selection of movements amenable to correction and the muscles amenable to stimulation in the patients with flaccid pareses is based on the three main principles: a) achievement of the maximal biomechanical effect during walking by means of correction of the least number of movements; b) use of synonymous methods of correction in the identical character of motor disorders; c) preferential correction of extension movements and ES of extensors as far as their function is aimed at performance of the primary locomotor mechanism - displacement of a human body and provision of stability.

Based on these assumptions the following types of correction effects have been applied: in unilateral affection - correction of extension and abduction in the HJ by means of simultaneous ES of m.gluteus maximus and gluteus medius. This type of correction has been combined more often with correction of extension in the KJ by means of ES of the m. quadriceps femoris, not so often - with correction of plantar flexion in the AJ by means of ES of the m.triceps surae. In bilateral affection the same types of correction effects have been applied but on both legs. In the cases when strong swaying of the body in the frontal and sagittal planes were revealed, correction was carried out by means of simultaneous ES of m.sacrospinalis and m.obliquus externus abdominis. In separate cases correction of dorsal flexion in the AJ was carried out by means of ES of m. tibialis anterior; and correction of flexion in the KJ - by means of ES of m.semitendinosus.

An amplitude program of ES supposed the use of a sequence of square-wave form electrical pulses with a frequency from 40 to 80 Hz, voltage to 60 Volt, duration from 20 to 300 s. Intensity of ES was set up by means of change of two parameters: voltage amplitude and duration of a pulse. Usually such intensity of ES was selected which provided correction of movements at usage for a short time (not more than 0.5 s.)

A temporal program of ES during the cycle coincided with a natural program of excitation and contraction of muscles in walking. The last third of a swing phase and the first half of a stance phase were the phases of ES for the extensors of the HJ and KJ; for the m.triceps surae - the second third of a stance phase; for the m.tibialis anterior, m.semitendinosus, m.sacrospinalis the end of a stance phase and the third(first third) of a swing phase were the phases of ES. Synchronization of ES with phases of a step was carried out with a help of a potentiometer angular transducer, placed in the area of the KJ of a paretic limb or an artificial knee joint of an orthosis. Switching on the potentiometer at the extension phase in the KJ was a common act for excitation of the muscles functioning at the end of a swing phase and in the first half of a stance phase (gluteal muscles, quadriceps femoris, etc.) For excitation of muscles working at the end of a stance phase and in the first half of a swing phase switching on an angular transducer, placed on the other leg, was used, also at the extension phase. For more delicate tuning of ES to the proper phases of a step time delay was used from the moment of switch on by duration of 0.I - 0.3 s. Duration of ES fluctuated in the limits 0.4-0.7 s in dependence on a type of the muscle and the walk rate.

Pliable skin electrodes containing current-conducting textile were applied for ES of muscles. The electrodes had a rectangular form and the size equal to transversal section of the stimulated muscles. The electrodes were fixed by means of elastic cuffs. An active, with the minus sign (-), electrode was attached over the motional area of the muscle, an indifferent, with the plus sign (+), electrode was attached at the distance of 4-8 cm from an active one.

A four-channel corrector of movements developed at the CRIP, Moscow, was used for ES of muscles during walking. The device is capable of simultaneous or sequential independent ES of the four muscular groups of a man at the different phases of a locomotor cycle (4). A course of correction training including 20 sessions has been carried out for all patients. During the session the patient walked along the path a distance of I-2 km, with this receiving about I,000 - 2,000 stimulation pulses by an average duration 0.4 - 0.7 s for every stimulated muscle.

4. The results of ACM application during walking of the patients with flaccid pareses of lower limbs.

52 patients have been investigated (32 patients with consequences of poliomyelitis, 20 - following spinal cord injuries in the lumbar-sacral spine). The most part of the patients with consequences of poliomyelitis used orthoses in walking. All the patients with consequences of a spinal trauma wore orthopedic shoes leaning on the crutches or canes in walking.

The following investigations have been carried out for objective estimation of a correction training course: I) measurement of the muscle force and their electrical activity during exertion of a maximal effort; 2) registration of a number of biomechanical parameters (podograms, angular displacements in the joints, ground reactions) and an electrical activity of the main muscles of a limb and pelvis during walking.

These investigations have shown that a functional state of the muscles improved significantly after a training course: the force of muscles and their maximal electrical activity increases. Increase of the force of muscles in patients with consequences of poliomyelitis comprises at an average 60-70%, in the patients with the results of a spinal trauma - about 40%; an increase of a maximal electrical activity of muscles respectively 24% and 40%.

Together with improvement of functional properties of the muscles positive changes in a biomechanical gait structure were fixed observed in the process of a correction training: I) stability in walking is increased (a vertical and longitudinal components of a ground reaction at the phase of the heel strike rise); 2) kinematics of a paretic limb is improved, a pattern of movements in the joints becomes more normal, their amplitude rises, asymmetry of movements in both legs is decreased, an amplitude of frontal and sagittal swayings of the trunk is decreased; 3) a form of dynamograms of ground reactions is normalized, a value of a toe-off rises that indicates the strengthening of a motional function of lower extremities.

Such positive changes in the gait structure result in an increase of the step length, rate and speed of locomotion, in capability to walk for a larger distance (with a faster speed and lesser fatigue). In consequence of significant improvement of supporting-motor functions of lower limbs the patients in a lesser degree use by an additional support of crutches and canes. It makes possible to substitute more functional orthoses for less functional to a number of patients.

In spite of increase of the locomotion speed the energy consumptions of the patients in walking decrease after a training course. But not only biomechanical structure of the walk changes, an innervation structure of the walk also changes. In one cases rearrangement of the muscle work consists in redistribution of activity between the limbs: the activity of muscles of more affected limb, especially, activity of muscles-extensors increases and the activity of muscles of less affected, more intact limb, decreases. By the way, redistribution of activity quite often takes place between the muscles of the same limb as well. All this shows an extremely complex compensatory process taking place in a motor sphere of a patient under the influence of continious correction effects.

The regularities of change of a biomechanical structure of the walk considered above may be shown taking the examples of the two patients.

Patient L-va , consequences of poliomyelitis, paresis of lower limbs, more sharply expressed on the left side. Does not use any orthopedic devices. Was treated by a course of correction training (20 sessions), during which correction of movements was carried out in the both HJ by means of ES of the m. gluteus maximus and m.gluteus medius in combination with correction of movements in both KJ by means of ES of ms. quadriceps femoris; the latter was alternated with correction in the AJ by means of ES of the gastrocnemius muscles.

As can be seen from Fig.I under the influence of a correction course on the side of a more affected limb a recurvature in the KJ at the stance phase has appeared to be removed, extension in the HJ has improved, a form of dynamogram R_z has normalized, an amplitude of the impacts on the dynamogram R_x has increased. On the less affected limb an amplitude of movements in all the joints has increased at the phase following the strengthened toe-off. Fig.2 shows complex redistribution of activity in a number of muscles of lower extremities following the course.

Patient N-ov. Diagnosis:compression fracture of a lumbar spine at the LI level three years ago, deep lower paraparesis. Up to the moment of the investigation moved with a great difficulty, extremely slowly, using an additional support of the crutches. Could walk not more than for 20 m. The patient had a typical gait with legs almost straightened in the KJ. His walking was very unstable. His supporting base comprised 80% of the cycle dutation , an amplitude of flexion in both KJ comprised about 20°, an amplitude of movements in both HJ was of decreased value. A vertical component of a supporting reaction R_z did not reach the level of a body weight even during the impacts because of a partial unloading of the body weight on the crutches, a longitudinal component R_x was negligible (Fig.3) Following 20 sessions of a correction training the force of the muscles being stimulated has increased more than two times.The patient could walk for a distance about 2km without difficulty, leaning on the crutch and the cane, the walking speed has increased two times. Biomechanical structure of a locomotor act has also significantly changed: duration of a stance phase has decreased, an amplitude of movements in the KJ and HJ has increased, the impacts on dynamograms R_z and R_x have become more distinct. Electrical activity of most of the muscles of both legs has increased at the corresponding phases of the step(Fig.4)

The data obtained evidence that a method of ACM not only stipulates an increase of a fuction of weakened muscles but does contribute to formation of a more normal locomotor stereotype in patients with flaccid pareses of lower limbs.

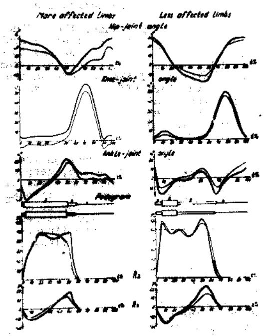

Fig.1 Biomechanical parameters of Patient **L-va** gait with consequences of poliomyelitis. Thin line - before the correction course, solid line - following **the correction course.** Symbols α° angular displacement **(degrees),** P- body **weight,** R_x - longitudinal component of supporting reaction (P%), R_z - vertical component of supporting reaction (P%), t - duration of gait cycle (%).
1 - heel-support; 2 - foot-flat-support;
3 - forefoot-support; 4 - swing phase .

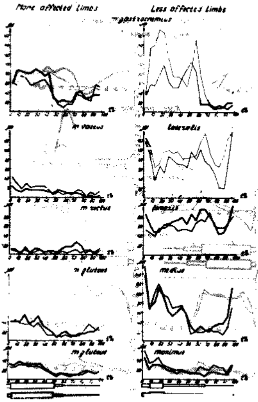

Fig.2 Change of muscle electrical activity during gait cycle of Patient L-va with consequences of poliomyelitis. Symbols μV - value of integrated electrical activity in microvolts, t - duration of gait cycle (%). Thin line - before correction course, solid line - following correction course.

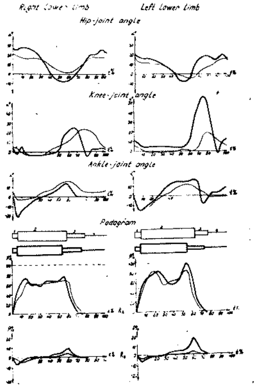

Fig.3 Biomechanical parameters of Patient N-ov gait with consequences of spinal cord lesion in the lumbar-sacral spine. The same designations as in Fig.1.

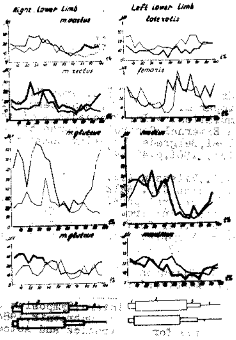

Fig.4 Change of electrical activity of muscles **during** gate cycle of Patient N-ov with **consequences of spinal cord injury in** the **lumbar-sacral spine.**
The r--- designations as in Fig.2.

REFERENCES

I. Liberson W.T., Holmquest H.J., Scot D., Dew M. Functional electrotherapy. Stimulation of the peroneal nerve synchronized with the swing phase of the gait of Hemiplegic Patients. - Arch.Phys.Med.Rehabil., I96I, 42,p.IOI-I05.

2. Stanić U., Aćimović-Janežić R., Gros N., Trnkoczy A., Baid T., Kljajić M. Multichannel electrical stimulation for correction of hemiplegic gait.- Methodology and preliminary results. - Scand.J.Rehabil.Med., I978, No.IO,p.75-92.

3. Maležić M., Krajnik J., Stanić U., Gros N., Aćimović R., Pirnat P., Stopar M., Kljajić M. Long term effects of multichannel stimulation. - In: Proceedings of the 7th Intern. Symposium on External Control of Human Extremities, Dubrovnik, I98I, Belgrade, Yugoslav Committee for Electronics and Automation, I98I,p.409-4I9.

4. Kondrashin N.I., Vitenson A.S., Spivak B.G., Zarezankov V.G., Roifman G.D., Iljina J.P. Walk correction of patients affected with infantile cerebral paralysis using multichannel electrical stimulation. In: Proceedings of the 7th Internat. Symposium on External Control of Human Extremities, Dubrovnik, I98I, Belgrade, Yugoslav Committee for Electronics and Automation, I98I,p.305-3I5.

5. Kondrashin N.I., Vitenson A.S., Konovalova N.G., Spivak B.G., Dubrovsky J.V. Amputees' prosthetic gait correction by means of multichannel electrical muscle stimulation. In: Proceedings of the Eighth Intern.Symposium on External Control of Human Extremities, Dubrovnik, I984, Belgrade, Yugoslav Committee for Electronics and Automation, I984, p.365-372.

6. Витензон А.С. Физиологические предпосылки искусственного управления работой мышц при патологической ходьбе. - "Протезирование и протезостроение", I98I, сб.тр., вып.59, М., ЦНИИПП, с.3I-44.