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AMPUTEES´PROSTHETIC GAIT CORRECTION BY MEANS OF MULTICHANNEL ELECTRICAL MUSCLE STIMULATION

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Abstract

Clinical, biomechanical and physiological prerequisites of motional correction during walking on below-knee and above-knee prostheses by means of electrical stimulation of muscles in certain phases of a locomotor cycle are given in the paper on the basis of complex studies of 57 amputees. An indication for this method of amputees´rehabilitation is a relative or absolute deficit of a muscular function at performance of the motor act. With this the basic principles of artificial correction of motions during walking on prostheses are determined, i.e. selection of controllable elements of gait, methods of synchronization of electrical muscle stimulation with the phases of the cycle, amplitude and temporal programs of muscle stimulation as well as its range during walking. A stationary 4-channel corrector of motions and a method of motional correction have been carried out at the Institute.
As a result of application of electrical muscle stimulation of the amputees´gait on prostheses increase of functional properties of weakened muscles of a truncated limb has been noted, decrease of the temporal, kinematic and dynamic asymmetry in walking has been revealed. At the same time a tendency has been marked towards equalizing the muscles work of prosthetic and intact legs during walking as well as decrease of energy expenditures during walking, especially after the course of motional correction carried out for many days.

Up to this time a problem of walk improving in ambulation of the amputees on prostheses was carried out mainly by means of developing more advanced prosthetic constructions and more effective means of preprosthetic preparation and amputees´gait training.
At present for the first time a possibility of making use of quite new principles of this problem decision has appeared , based on application of a method and systems of artificial correction of movements (ACM) by means of electrical stimulation (ES) of muscles in the certain phases of a gait cycle.
The purpose of the paper is a statement of the following aspects:
1) clinical, biomechanical and physiological foundations of gait correction in ambulation on prostheses by means of ES of muscles:,

2. Determination of medical indications and contraindications for this method prescription; 3) formation of the main principles of ACM in walking on prostheses; 4) analysys of the results of ACM application.

1. The foundation of walk correction by means of ES of muscles during walking on prostheses.

The principal indication for application of ES of muscles for gait correction in ambulation on prostheses is a deficit of a muscular function (DMF). The latter is expressed in reduction of the muscle force and their maximal electrical activity. Reduction of these indices in the below-knee amputees comprises 60-70% for the truncated below-knee stump muscles, 30-40%- for the thigh muscles, 15-20%-for the pelvic muscles; in above-knee amputees the truncated muscles have been weakened up to 60%, the rest ones- by27-45% in comparison with the muscles of a normal limb. With this a biomechanical structure of prosthetic walking is significantly disturbed: I) the gait rate is reduced, the step length and locomotional speed are diminished; 2) extention at the hip joint (HJ) is decreased in the stance phase, flexion at the knee joint is reduced or completely disappears in the stance phase, plantar flexion at the heel-strike at the ankle joint of a prosthetic limb is sharply decreased; 3) an asymmetry of temporal, kinematic, dynamic and electrophysiological parameters of walking arises; 4) phase characteristic of the muscle work changes during a locomotor cycle.

The asymmetry of temporal parameters is characterized by the increase of the swing step phase for the prosthetic limb and its decrease for the normal leg. In connection with this a rhythm coefficient is diminished to 0.94 at prosthetic below-knee walking and is diminished to 0.74 at prosthetic above-knee walking (in norm it is equal to 1.0). The asymmetry of kinematic parameters consists in different values and manner of movements at the articulations of prosthetic and normal lower limbs. The asymmetry of dynamic parameters is characterized by diminishing value of vertical and longitudinal components of weight-bearing reaction at the heel-strike and toe-off phases of a prosthetic limb especially. Finally, the asymmetry of electrophysiological parameters consists in reduction of the muscle work of a prosthetic limb and in the increase of work of the normal limb muscles during walking. At the same time phase characteristics of the muscle work during the cy-

cle are changed significantly: levelling or sharp decreasing of electrical activity peaks of the truncated limb muscles takes place and just the oposite, the increase of electrical activity peaks is marked on the background of its total increase in the normal leg muscles.

The data given above show exclusive urgency of the problem of the muscle work activization of the truncated limb for normalization of prosthetic gait.

2. Indications and contraindications for motional correction by means of ES of muscles at walking of the amputees on prostheses.

A total indication for artificial correction of movements (ACM) is as a rule a deficit of a function of some muscles of a truncated limb resulting in disturbance of a biomechanical structure of the gait. In walking on below-knee prosthesis insufficiency of a function of truncated musculus gastrocnemius, quadriceps femoris and gluteus maximus arises, and in walking on above-knee prosthesis insufficiency of a function of the two latter muscles is marked. The above-mentioned muscles are the object of electrical stimulation in this connection.

The absolute contraindication for application of artificial correction of movements are intolerance by the patient of minimal electrical irritiations, sub- and decompen ated cardiovascular diseases, benign and malignant neoplasms. The relative contraindications are diseases and deficiencies of the stump, fixed joint deformations, prosthetic fitting of a poor quality.

3. Main principles of artificial correction of movements (ACM) at prosthetic gait.

Realization of ACM supposes carrying out a number of preliminary operations the most important of which are the following: 1) selection of the movements needing correction and the muscles for stimulation.; 2) determination of the amplitude parameters of the muscle ES, 3) setting of the temporal parameters of the muscle ES during the gait cycle, 4) determination of the electrode type, form and sizes and their localization on the motional area of the muscles, 5) search for an adequate mode of the muscle ES at gait.

Selection of the movements for correction and the muscles for stimulation is based on three main principles:

a) achievement of the maximal biomechanical effect at gait by means of correction of the minimal number of movements, b) using of identical methods of correction at a similar character of motional disturbances, c) initial restoration of the force elements of walking, after that-restoration of correctional elements of gait. Consequently, the major object of ES are the extensors, the work of which helps to displace the body and create balance at gait, and the main phase for correction is a stance phase of the cycle. Only after normalization of these muscles activity it is necessary to improve the work of the flexors in a swing phase of the cycle.

According to medical indications three types of correction may be realized for the below-knee amputees: one-channeled-ES of a truncated musculus triceps surae; two-channeled-ES of a musculus quadriceps femoris on the amputation side; three-channelled-ES of m. triceps surae, m. quadriceps femoris and m. gluteus maximus on the amputation side, one-channelled ES being the main type of correction.

At above-knee prosthetic gait the main correctional influence is achieved by simultaneous ES of the muscular complex: m.gluteus maximus and m.gluteus medius, truncated muscles-m.semitendinosus, m.biceps femoris and abductors. An additional correctional influence is achieved by means of ES of the hip flexors. In a method of artificial correction of movements developed by us a sequence of electrical stimuli is applied with 40-80 Hz frequency, an amplitude to 60V, duration of 20 to 300 ns. Intensity of electrostimulation is set up by means of change of two parameters:voltage amplitude and duration of a stimulus. As a rule such intensity of ES is chosen which helps to create correction of movements during not a long time (not more than 0.5 s).

The temporal program of ES of muscles must provide phase correlation of the artificial and natural programs of the muscle excitation during the gait cycle. Such phases for the extensors of the hip and knee joints are the last third of a swing phase and the first half of a stance phase; for the m.triceps surae-the second third of a stance phase; for the flexors of the hip and the knee-the past part of a stance phase and first part of a swing phase. The temporal program of ES of the muscles during the cycle is carried out by means of a synchronization sensor measuring the angles of flexion and extension at the knee joint or at the arti-

ficial knee joint. When a sensor of the knee angle is used the moment of its triggering off in the extension phase of the knee joint or artificial knee joint is the common one for excitation of the muscles functioning at the end of the swing phase and at the first part of, the stance phase (gluteal muscles, posterior group of the hip muscles, m. quadriceps femoris). The moment of triggering off the sensor in the flexion phase is a common one for excitation of the muscles working at the end of the stance phase and first half of the swing phase (flexors of the hip and knee joints). The use of the knee angle sensor allows to carry out ES of the muscles with a small time delay (0.1-0.15 s); great time delay (0.3-0.4 s) is necessary only for excitation of the m. tricepts surae. Duration of ES is equal to 0.4 s on the average but varies depending on a type of the muscle and gait rate within the limits of 0.2-0.6 s.

For electrostimulation of muscles transcutaneous electrodes are applied containing current-conducting tissue. The electrodes have a rectangular form and the sizes according to the crosscut of the muscles subjected to stimulation. An active (-) electrode is applied over the motional site of the muscle, an indifferent one (+) is applied on the distance of 4-8 cm. from the active electrode.

The modes of muscle ES at amputees´gait depend on the severety of muscle affection and locomotional characteristics connected with it very closely, i.e. the rate and the length of a step. As a rule duration of an ES phase must not exceed a half of the duration of the gait cycle. This means that while walking for a distance 1km (at duration of electrostimulation 0.4s and the step length equal to 0.6 m) the invalid receives 800 stimulating impulses with a total time of 320 s for every muscle.The patients are recommended to walk with correction not more than 2 kms a day with rhythmical periods of rest (in the first days not more than 0.5 km). In total the course consists of 20every day sessions, after that prophylactic treatment (1-2 sessions a week) or repeated course are desirable (the latter not earlier than after 6 months).

4. The results of artificial correction of movements (ACM)during amputees´prosthetic gait.

57 amputees (28- with below-knee amputation stump at the mid-third level and 29-with above-knee amputation stump at the mid-third level) were studied. The patients with below-knee stump were given mainly ES of the truncated m.triceps surae and m.quadriceps femoris; the patients with above-knee stumps were given ES of the m. gluteus maximus and m.gluteus medius and posterior group of the thigh muscles.

For objective assessment of motional correction by means of ES of muscles at prosthetic gait registration of a number of biomechanical parameters has been carried out(podogram, angular displacements at natural or artificial joints, electrical activity of 10 major muscles of the leg and pelvis). By means of the indirect calorimetering method measuring of energy expenditures has been realized.

The studies showed that correction of movements at below-knee prosthetic gait resulted in the following changes of walk structure; the movements at the knee joints of both the limbs in swing and stance phase became more symmetrical; extension at the hip joint of the prosthetic limb was increased; asymmetry of stance phases of both limbs decreased because of increase of the toe-offs and heel-strikes of the prosthetic limb and weakening of the impact of the normal leg.

These biomechanical data correlate with subjective feelings of the amputees who mark increase of stability, more tight fitting of the socket on the stump, less fatiguability at the gait.

Analogical changes in the structure of locomotion are observed at correction of above-knee prosthetic gait: the gait becomes more rhythmical, asymmetry of movements at the artificial and natural knee joints of both legs is decreased; plantar flexion at the ankle-joint of the normal leg is increased at the heel-strike; the leanings of the body relative to frontal plane are decreased; an amplitude of dynamograms of the normal leg is slightly decreased; an amplitude of dynamograms of prosthetic limb is increased to some extent.

Realization of many days course of correctional training at gait has three main effects: 1) increase of functional properties of the weakened muscles of a truncated limb that is shown by the increment of the muscle force and electrical activity on the average 1.3-1.5 times in comparison with initial state; 2) fixing of positive changes in the biomechanical and innervation structure of

the gait, i.e. decrease of kinematic and dynamic asymmetries; levelling of the work of muscles of prosthetic and normal limbs; 3) decrease of energy expenditures comprising 32% at prosthetic below-knee gait and - 29% at prosthetic above-knee gait, in comparison with the level before the course of correction.

The most important is that after the course of correction a pattern of muscular activity during the cycle is changed significantly the maxima of muscular activity of the normal leg are reduced and, on the contrary, the maxima of the muscular activity of the prosthetic limb grow up. All these factors show that influenced by correctional training a new stereotype of gait is being formed, this new being more adequate to the norm.

Such are some results of application of the method of artificial correction of movements during walking on prostheses.