ELECTROSTIMULATION OF MUSCLES DURING THE GAIT WITH AN ABOVE-KNEE PROSTHESIS IN PRIMARY PROSTHETICS

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ABSTRACT

We studied the muscle electrostimulation in primary prosthetics of above-knee amputee using comparative clinical and experimental methods. We proved that the muscle deficit is the main indication for prescribing this method for the motor restoration. We considered different patterns of stimulation for gait corrections. We determined which muscles has to be stimulated, and what are stimulation amplitudes and temporal patterns. Our studies include biomechanical and innervation structures. We applied a four channel corrector of gait developed at out Institute. We concluded that the electrostimulation improves the gait performance due to the better stabilization of the stump, increased strength of preserved muscles and faster habituation to the gait with an above-knee prosthesis. This procedure increased the symmetry of the gait and partly equalized the work in ipsilateral and contralateral thigh muscles. This study pointed that stimulation during the gait cycle has many advantages in comparison with the stimulation in rest.

KEY WORDS: Electrostimulation, gait, above-knee prosthesis, amputee, primary prosthetics

INTRODUCTION

Primary prosthetics management of above-knee amputees after trauma is an urgent medico-social problem up to the present. In spite of undeniable importance of this problem several questions remains to be cleared up to some extent. These questions are:

1) When to begin fitting of the prosthesis ?
2) How to change the balance in the new gait pattern and what method to use for this ?
3) How to increase the stability of the stump ?
4) How to increase the habituation to the new locomotor pattern ?

Many of these questions are not resolved. The main reason is that the use of primary prosthetics is parallel to reparative and degenerative processes in the stump [1,2]. Before, two methods of amputee training for the gait were used, a traditional one based on physiotherapy [3] and physiotherapy combined with electrostimulation in rest [4].

We introduced the new method of artificial correction of movements (ACM) by electrical stimulation (ES) of muscles during certain phases of the gait cycle. This methods, clearly, makes possible to solve above mentioned problems. An ES of muscles will improve the blood circulation and metabolism of the stump, and its later functional restoration. An ES of stump muscles will prevent atrophic processes in a muscular tissue. An ES of muscles, applied in combination with known physiotherapeutical methods for gait correction facilitates habituation to the new biomechanical and neurophysiological situation after amputation.

METHODS OF ES DURING THE GAIT IN PRIMARY PROSTHETICS

The proposed method is evaluated in 25 amputees in our Institute. The amputees age were from 17 to 52, and there were 19 male and 6 female subjects. Traffic accidents were the most frequent cause for the amputation. The fitting process of the socket was done between 1 and 8 months after the injury (average is 2.5 months). The level of amputation was: above and at the upper border of the middle third of a thigh - 2 subjects, in the middle third - 10 subjects, on the border of middle and lower third of the thigh - 7 subjects and in the lower third - 6 subjects.

We used reinforcing and phantom impulsive gymnastics, massage and physiotherapy for preparation of the stump for the socket.

After one to three weeks in our Institute (this is the average time for reduction of edema) patients were fitted with primary-definitive prostheses. We used uniform prostheses: a metal socket, a single-axis knee joint, a metal below-knee tube, metal ankle and a polyurethane foam foot. The individual alignment was done using CRIP principles. The load bearing on an ischial tuberosity was provided through socket manufacturing. Good contact of the stump and socket was provided. We corrected the prosthesis alignment according principles of levelled hip epicondyles of intact and prosthetic leg.

The prosthesis suspension consisted initially of a leather swivel fastened to the belt; after finishing the course of ACM most of subjects rejected the suspension.

After two to four weeks we divided our group in 15 subjects using the ES method and 10 patients as a control group. The control group received the stimulation of stump and gluteal muscles at rest.

A deficit of muscular function (DMF) caused by the loss of muscles, their weakening and pathological functioning sharply changed the locomotion pattern and served us a general indication for the use of ES during walking. We observed the weakness of gluteus medius and gluteus maximus in primary prosthetics in addition to weakness of posterior and anterior thigh muscle groups.

DMP of gluteal muscles was revealed during the walk as an increase of swaying of a body relatively the sagittal and frontal planes, a decrease of resistance to banding of a prothetic leg, a small angle of extension at the hip joint, asymmetry of movements in legs, and weakness in supporting and push-off during prosthetic stance phase.

DMP of posterior group of thigh muscles was characterized by deterioration of dynamic adaptation of the stump to the prosthetic socket, an increase of pump movements on the stump, insufficient resistance to bending of a prosthetic limb, a small extension angle at the hip joint, kinematic and dynamic asymmetry of the gait.

DMP of anterior group of thigh muscles was manifested as deterioration of dynamic adaptation of the stump to the prosthetic socket, decrease of a flexion angle at the hip joint (the stump is brought forward as a result of a circumduction).

Contraindications for ES and ACM application were divided into absolute and relative ones. The first are neoplasms, cardio-vascular diseases, intolerance of the minimal electrical irritations, pregnancy, while the second are diseases and deformities of the stump, deformation of the joints, unqualified prosthetics.

Following method for the ES was developed. Additional flexion moment at the hip joint during first two thirds of a stance phase was selected as the main correction. ES was applied to gluteus maximus and medius, semitendinosus m., biceps femoris and thigh adductor. Different results are obtained when this ES paradigm was applied: stability while standing on a prosthesis, frontal and sagittal swaying is decreased, a roll over a foot is easier and the swing of the prosthesis is improved. Due to the better prosthetic performance, the sound leg have more natural movement, closer to the pattern of normal bipedal gait.

We realized following corrections: 1) hip flexion at the end of a stance phase and beginning of the swing phase; 2) better symmetry of sacrospinal and oblique external abdominal muscles in both sides during the same phase of the gait; 3) activity of the triceps surae in intact leg during the middle third of a stance phase. The thigh muscles were used for hip flexion and on the side of flexion facilitation the increase of the step length and speed of progression are achieved. Better symmetry of sacrospinal and abdomina movements decrease swaying of the body, specifically toward the prosthetic leg. Triceps surae muscles in intact leg contributes to a faster swing of the prosthesis and back push allowing shorter stance phase on the sound side and longer stance phase on prosthesis.

During the training. in most patients we applied first two of above mentioned corrections, while the triceps surae stimulation was optional.

We used four channel corrector of movements [5]. This device consists of electro-stimulator, synchronization transducers, electrodes and elements for fixation of electrodes. The electronic stimulator delivers four independent channel of current pulses during desired phases of the gait cycle.

We applied surface rectangular conductive rubber electrodes. Multilayer structure of conductive rubber was used. Fixing cuffs were used for fixation of electrodes. We localized the position of electrodes in rest. Active electrode was close to the motor point, and the neutral anode 6 to 8 cm from the cathode.

We used a train of pulses with amplitudes up to 60 V, with pulse durations ranging from 20 to 200 μs and 40 to 50 pulses per second. The amplitude was determined individually and usually it ranged from 30 to 60 V. The pulse width control was used for fine tuning. ES was applied for periods shorter than 0.6 seconds while walking.

The stimulation paradigm was created according to natural firing of corresponding muscles in normal locomotion. We used potentiometer transducers as a feed-back for the temporal pattern of stimulation. Both knee angle were equipped with transducers. A trigger for excitation of the thigh muscles at the end of a stance phase and initiation of the swing phase the data from prosthesis were used. Triggering of thigh flexors, sacrospinal muscles and external oblique abdominal muscles was obtained from the sound leg. Similarly, we stimulated triceps surae muscles. The delay time before trigger and stimulation varied between 0.1 and 0.3 seconds, and duration of stimulation between 0.4 and 0.6 seconds, depending on the gait speed and stimulated muscles.

ES muscle temporal regime during the gait was determined using amputee cardiac-vascular system stage and special characteristics of his ambulation. Before an ACM training, all our subjects walked slow in comparison with their performane after the procedure. The stimulation time decreased from 0.6 to 0.4 seconds with the increase of the gait speed. The distance of the walk at the beginning was between 0.5 and 1 km, increasing during the program to 2 km. Total training program included 20 sequences daily.

The stimulation of the gluteal muscles and stump muscles at rest was performed with a help of Stimul-1 apparatus. Stimulation parameters were: f = 2500 Hz (sinusoidal), modulated with square-wave form of 50 pulse per second. The ES was applied for 10 seconds and rest intervals of 1 minute. The session consisted of 10 minutes of stimulation. Total number of session was 20.

RESULTS WITH THE USE OF ACM PARADIGM IN PRIMARY PROSTHETICS

We used clinical and instrumental methods to compare efficacy of the ES applied during the gait and applied while resting. The changes in the stump and in the gait performances were compared.

Change in the functional status of the stump

We used two methods to evaluate the state of the stump: 1) measurements of the circumference, and 2) recording of the force generated my thigh muscles.

In patients receiving ES during the gait the thigh perimeter was increased by less than 2 cm which allowed us to use the same socket during the treatment. The ES in patients while resting increased the perimeter for 3 cm, in average, which forced us to produce a new socket for the final prosthesis.

Dynamographic and electromyographic studies of the stump, showed that ES during gait is more effective in comparison to the ES in rest.

The average increment in force, in patients stimulated during gait reached 39%, while the increase in control group was 22%. The thigh extensor muscles forces increased for 52%, which is much more than in control group, 21%. The ES in intact leg produced the rise of force for 14% (gait) and 10% (rest).

The maximal electrical activity of muscles raised up for 37% which is significantly more that in our control group (16%).

The gait pattern with ES during the gait

Electropodography, electrogoniography, electrodynamography and quantitative electromyography were used for complex biomechanical and electrophysiological studies of gait performance in primary prosthetics with ES.

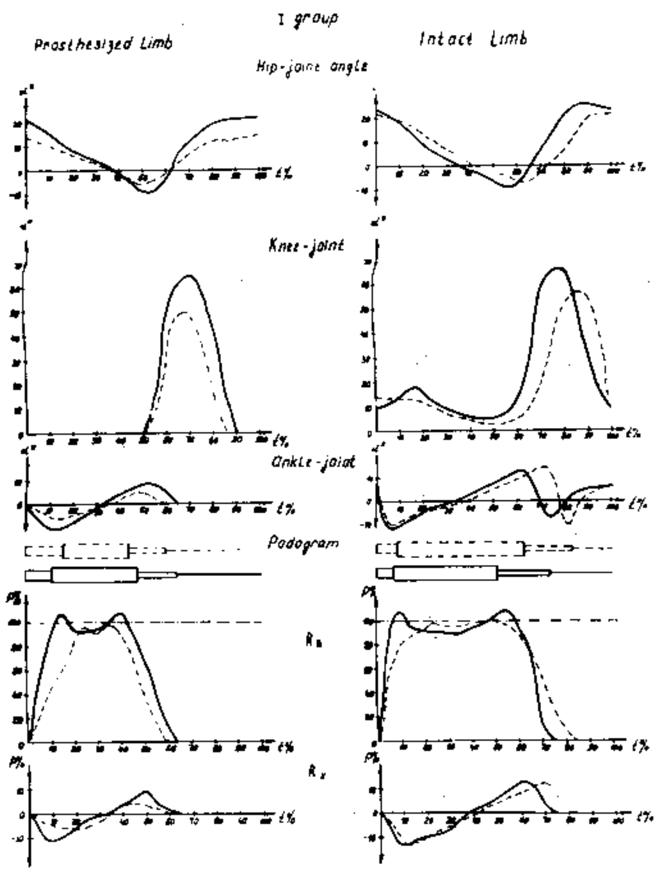

Figure 1. Biomechanical parameters during the gait of above-knee amputee. Electrical stimulation was applied to thigh and abdominal muscles in affected side while walking. The dash line corresponds to the performance before the treatment and solid to the obtained pattern after the program.

An significant change in gait pattern is recorded with the use of ES during this cyclic motion, even in subjects who started their walking for the first time with an above-knee prosthesis. Three elements were considered in this study: temporal pattern, kinematic and dynamic asymmetry.

Data from literature [6] suggests that the speed of an amputee sharply decreases (0.4 m/s); a coefficient of rhythm reflecting the correlation between corresponding gait phases in prosthesis and a sound leg is low (0.44); the articulation of the prosthesis and the sound leg differs very much; the ground reaction vector has a dramatic change in amplitude, temporal pattern and position of its activity (center of pressure spatial pattern). We will mention that: the minimum in ground reaction in prosthesis is lacking,

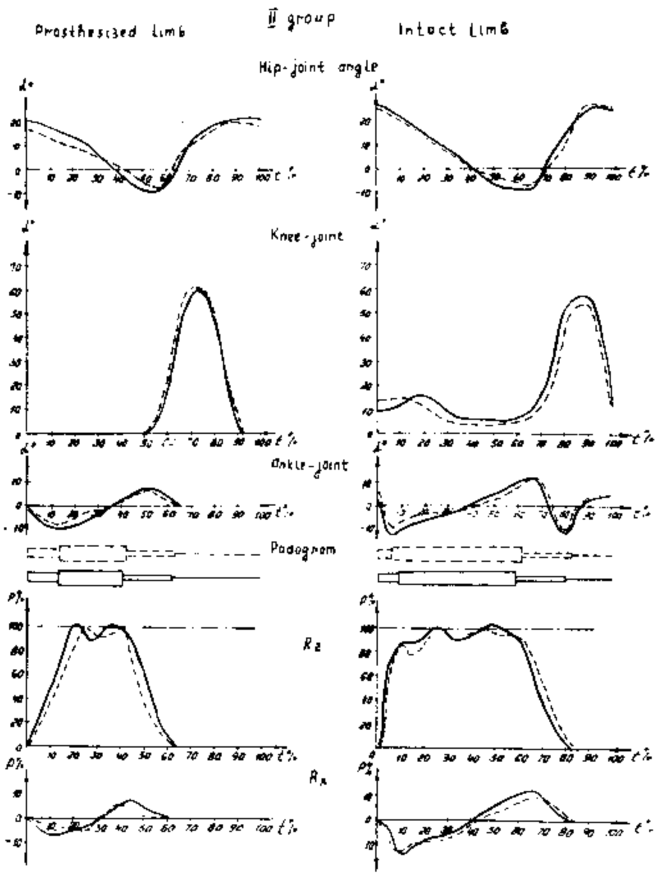

Figure 2. Biomechanical parameters during the gait of above-knee amputee. Electrical stimulation was applied to thigh and abdominal muscles in affected side in rest. The dash line corresponds to the performance before the treatment and solid to the obtained pattern after the program.

the force hardly reaches the body weight, the pattern is delayed in comparison with the sound leg and the like (Figures 1 - 4).

It is clear that some of the changes are the result of neurophysiological effects: a decrease and diffusion of maximal electrical activity in the stump has been marked, while markedly expressed is the increased activity in most of muscles in the intact leg.

Starting from the presented data, we introduced the ES during the gait and demonstrated some very favourable effects of this treatment.

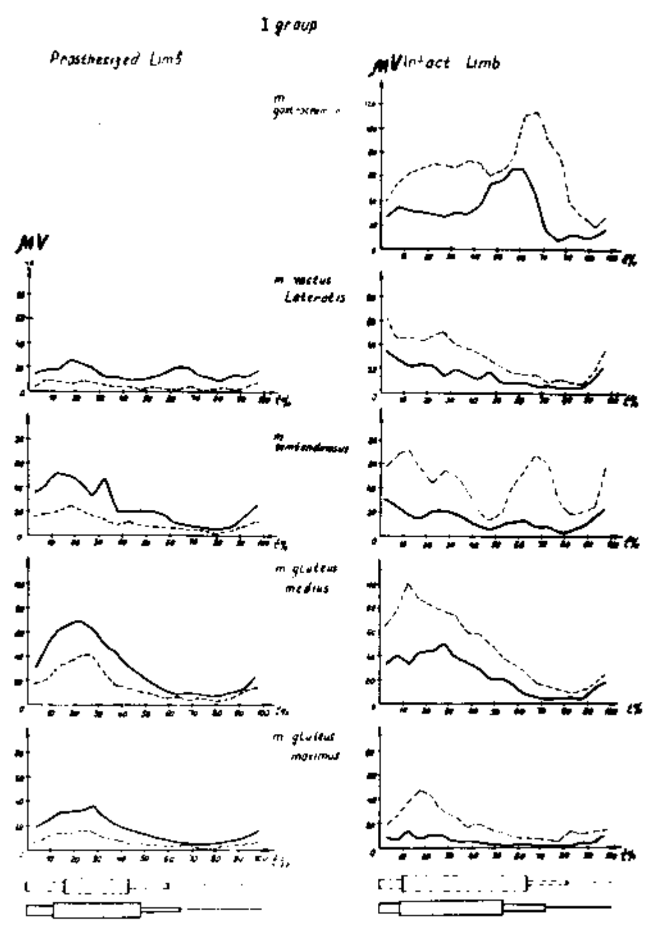

Figure 3. EMG activity recorded in muscles of above-knee amputees walking on the level floor. Electrical stimulation was applied to thigh and abdominal muscles in affected side while walking. The dash line corresponds to the performance before the treatment and solid to the obtained pattern after the program.

After the training protocol following results are recorded. We recorded average increase of:

ELECTRICAL STIMULATION		
	in gait	in rest
gait speed	88%	35%
step length	61%	19%
rate	35%	17%
rhythm coefficient	97%	77%

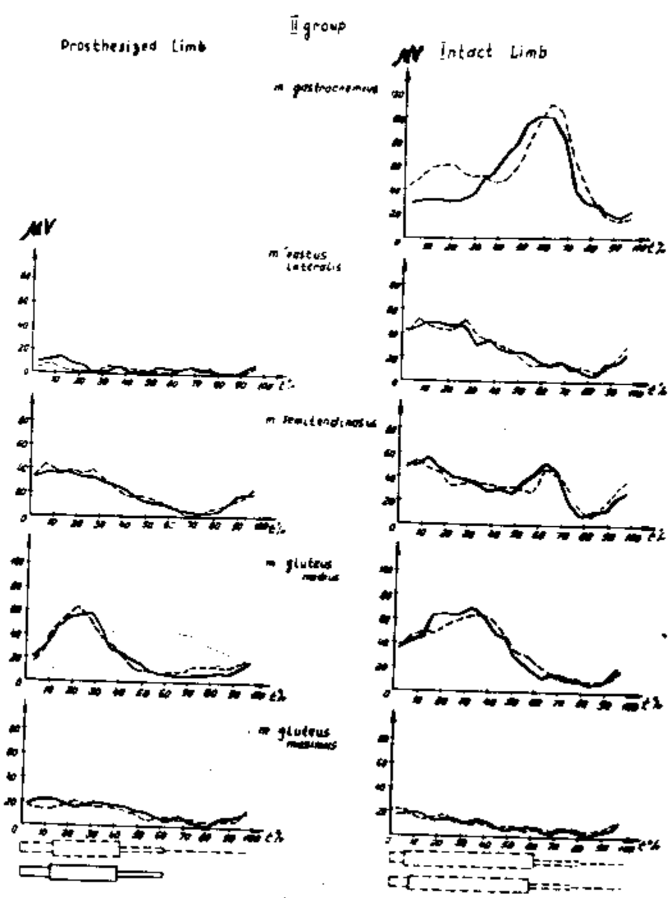

Figure 4. EMG activity recorded in muscles of above-knee amputees walking on the level floor. Electrical stimulation was applied to thigh and abdominal muscles in affected side at rest. The dash line corresponds to the performance before the treatment and solid to the obtained pattern after the program.

The amplitude of the knee flexion in a swing phase increased for 16° in prosthesis and for 9° in intact limb due to much better gait symmetry. IN control group these increments were 1° and 3° respectively. This small increment didn't change the gait pattern.

In case of ES, while walking, the change in ground reaction forces is recorded. The amplitude was larger at the heel-strike and push-off phased, in average fro 17% and 11% respectively in prosthesis and 11% and 10% in the sound leg. The ES in rest allowed the increase of ground reaction forces for a smaller amount. The change in the force in the sound leg may be explained with the increase of the gait speed, which holds for the increase in our control group.

EMG activity after the program showed dramatic change, and became much more symmetric, decreasing in the sound side and increasing in the affected one. The correlation of muscles increase from 39% to 96%. In the same time, the ES in rest didn't change the correlation almost at all (Figures 3 and 4).

CONCLUSION

It is clear, from above-mentioned and described material, that the ACM method is an efficient way for gait restoration of above-knee amputees during primary prosthetics. This method accelerates the rehabilitation course at a whole because of the better stabilization of the stump and development of a much more appropriate gait pattern with a definitive prosthesis.

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