INITIATION OF GAIT DURING TWO TO THREE WEEKS THERAPY WITH MULTICHANNEL ELECTRICAL STIMULATION

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Abstract

Multichannel electrical stimulation was applied in 20 hemiplegics after stroke or head injury using a six-channel microprocessor stimulator/stride analyzer. It was expected to initiate gait and to restore the gait pattern in two to three weeks therapy up to the degree where the patient could walk independently. Therapy was followed-up in every session by stride analyzer. At the beginning and at the end of therapy, the gait was measured by the ground reaction measuring system and recorded by video. The results show improvement in gait in all cases with and without stimulation. At the end of therapy all patients acchieved more or less independent gait.

I. Introduction

Soon after introduction of the first single channel stimulators for correction of drop-foot there appeared tendencies to stimulate, besides the muscles for dorsal flexion of foot, also other muscle groups of the hemiplegic leg, which also play an important role in gait. So Vodovnik et al. (1) in 1965 suggested a six-channel stimulator for stimulation of six main antagonistic muscle groups on affected leg. It started a preiod, when numerous multichannel devices were developed, control principles were studied hoping for closed loop control, stimulation sequences were studied as well as improvement of gait and therapeutic effects of stimulation (2-6). Clinical assessment and kinesiological studies demonstrated that application of cutaneous stimulation to the six main antagonistic muscle groups of the lower limb could considerably restore pathological gait. Multichannel functional electrical stimulation (FES) acchieved a higher correction level, faster recovery rate and better endurance than standard approaches in motor disabled patients (7-10). In spite of good correction of gait, multichannel surface FES has not got widely used as an orthotic aid, because of its complexity and the size of stimulator and because of the large number of electrodes, which positioning is already unsurmountable problem for the hemiplegic patient. In therapy it was shown, that there are considerable therapeutic effects during the therapy, which are fading after the therapy during a six months periode, when no significant difference could be shown between them and the control group, which followed clasical course of therapy (7,8). These are probably the major reasons that there are currently no reports on use of multichannel surface FES in rehabilitation of hemiplegic patients.

Due to the fact that patients treated in previous studies by multichannel electrical stimulation had less severe motor disabilities, and the results of this therapy were promising, we decided to apply multichannel stimulation to a group of severely involved patients after cerebrovascular insult, tumour or craniocerebral trauma. They were disabled to the degree that they could not walk or even lift themselves up from the wheelchair without the help of a physiotherapist. It was expected that multichannel stimulation would help them to establish an initial gait pattern and antigravity support.

The purpose of this paper is to present an approach employing intensive initial multichannel therapy in severely involved patients and to evaluate its effects with the stride analyzer included in the stimulator. Additionally, measurements by the ground reaction measuring sistem at the beginning and at the end of therapy were performed to evaluate changes in the gait pattern of the patient.

II. Methods

A. Instrumentation

The stimulator used in therapy had six independent galvanically separated channels with intermittent stimulation pulses, each optionally triggered by a left or right heel switch. The stimulation sequence was set for each channel by 16 switches, 8 for the stance and 8 for the swing phase (Fig. 1). The sequences automatically adapted to the walking rate of the patient, permitting a stride time up to 7 seconds. Detailed description of the stimulator was published elsewhere (11).

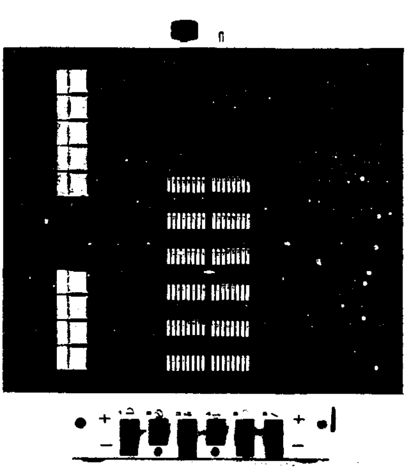

Fig. 1. Six-channel microprocessor stimulator used in therapy: six arrays of sixteen switches in the middle provide selection of the stimulation sequences, on the right next to them are switches for selecting whether each channel is triggered by left or right heel-switch and amplitude knobs. Measured statistical data are displayed in the top right corner by the pushbuttons on the left of the LC display. Six polarity switches are next to the electrode connectors on the bottom.

The stride analyzer part of the stimulator enabled us to measure the following statistical parameters of gait: the number of steps, average stride time, temporal symmetry of gait (heel-on time left / right) and average heel-on times with their standard deviations for both legs. The distance that the patient walked was also measured, which provided the average stride length (distance / number of steps) and average velocity (average stride length / average stride time). All these parameters are available immediately after the session, which enables us a qualitative follow-up and analysis of the patient's gait and by that simulataneus planning and modification of the course of therapy (12-15).

At the beginning and at the end of therapy the patient's gait was recorded by video for visual documentation and measured by the ground reaction measuring sistem which gave a graphic representation of ground reaction force and the spatial distribution of its point of action (16,17). The measuring system has five pairs of measuring shoes with eight or nine force transducers inlayed in each sole (18). The shoes are connected by cable through amplifiers to HP2100 computer, where the data are recorded and later processed.

For stimulation silicon conductive rubber 5 cm x 10 cm electrodes with karaya pads for larger muscles and 5 cm x 5 cm for smaller muscles were used, while 2.5 cm gauze button electrodes were used for peroneal nerve stimulation.

B. Selection of the patients

For the selection of patients, neurological, internist, physiatric and psychological examinations were made. The level and nature of the lesion were considered together, with the compensation of the cardiovascular system, the passive range of motion in leg joints, proprioception, response to electrical stimulation in individual muscle groups, intactness of the skin, and peripheral circulation.

Besides general tests, more specific ones included the manual muscle test, test of motor functions, clinical kinesiological analysis of gait, and the test of daily living activities. Together with the patient's informed consent, adequate psychosocial condition, communicativness, and motivation were also required. Patients with contraindications such as ademand pacemaker, pains in joints, dizziness, changes on skin, rejection of stimulation, etc. were excluded.

Twenty stroke or head injury patients, 5 females and 15 males, with ages from 14 to 74 (mean 48, standard deviation 16), were included in the study. There were 7 right and 13 left hemiplegic patients with severe motor deficits. At the beginning of stimulation therapy, they could mostly walk only with the support of an accompanying physiotherapist. Patients in the early and later phase of rehabilitation after the onset of injury were candidates for multichannel stimulation. The treatment started from 1.5 to 72 months post-onset (average 9.5, std. dev. 16.5). The therapy varied according to the contition of the patient and lasted from 7 to 21 days (average 14, std. dev. 3.5).

C. Treatment

Trains of 0 to 120 volt stimulation pulses of 30 hertz frequency and 0.2 milliseconds pulse duration were applied in most cases to the common peroneal nerve for ankle dorsal flexion, soleus muscle for plantar flexion, quadriceps muscle for knee extension, hamstring muscles for knee flexion, gluteus maximus muscle for hip extension and triceps brachii muscle for reciprocal arm swing during the swing phase of the ipsilateral leg (19). In patients with bilateral impairment, the common peroneal nerve or quadriceps or hamstring muscles on the contralateral leg were stimulated instead of the triceps brachii or soleus muscles. Stimulated muscles on the contralateral side were selected according to the kinesiological deficiencies of the patient. In one case we also stimulated the romboideus muscle to correct crooked bearing of the patient. Exact stimulation sites were found with cyclic stimulation. In the patient in sitting or in prone position, the electrodes were shifted along each muscle, which we wanted to stimulate, as long as the optimal functional response has been acchieved. When found, the sites were marked on the skin with a pen, which was hard to erase, and not conductive. Amplitude was raised until a good functional response was obtained, or up to the pain threshold if the contraction was not satisfactory. In some cases, where the muscles on the contralateral side were stimulated, amplitudes were set below the contraction level for providing sensory information when the stimulated muscle should be activated.

Stimulation timing was determined for every patient, starting with an initial pattern and modifying it during the first couple of stimulation sessions untill an optimal gait was achieved.

The patients walked on a 50 or 90 metre walkway. They started with the support of a physiotherapist on the shorter distance, repeating it after a rest. The initial distance depended on the ability of the patient, or was determined by the internist, to avoid overexertion by the patient. During the progression of treatment the distance was increased. However the patient was not instructed to prolong it over 600 metres per session, because our primary goal was to correct the gait pattern and not to increase the accomplished distance.

III. Results

In Figure 2 average stride time, average stride length and average velocity of gait at the beginning and at the end of therapy with their standard deviations for the group of 20 patients are presented. All the gait parameters were measured over a couple of hundred steps, which provided very reliable statistics. On average, stride time shortened by 20% (std. dev. 12%) at the end of therapy in all but one patient. In that particular patient the longer average stride time was caused by considerably longer steps with electrical stimulation, which was also an improvement. The gait velocity increased on average by 61.6% (std. dev. 47.5%) and the stride length by 46.3% (std. dev. 32.5%). The data before and after therapy have been compared by t-test. It showed a highly significant difference ($p < 0.005$) in

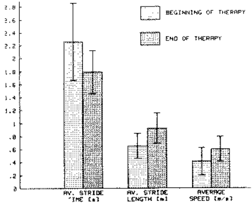

Fig. 2. Diagram of average stride time, average stride length and average velocity with their standard deviations at the beginning ant at the end of therapy with multichannel stimulation, for the group of 20 hemiplegic patients.

all three parameters. All these data were measured during stimulation. Measurements with the ground reaction measuring shoes in the gait laboratory also showed changes in gait without stimulation after finishing the therapy. Average stride time was considerably shorter in all patients, gait was more consistent, loading of the impaired leg was longer and higher, loading of the crutch, if used, was lesser, and the trajectory of the point of action looked closer to normal, when compared to those at the beginning of therapy. Three phase gait (crutch - impaired leg - healthy leg) spontaneously changed into two phase gait (crutch and impaired leg - healthy leg) in all the patients. According to the qualitative measurements and to subjective observations it can be said, that there was no case where the quality of gait and the gait pattern or the condition of the patient stagnated or got worse during the therapy. There appeared more or less improvement in all patients.

The right hemiplegic patient M.D. (age 45), after a head injury in a car accident, made 136 steps with the help of physiotherapist during the first stimulation session, and achieved about 500 steps after five days of therapy. He maintained this number of steps per session, and concluded his 12 day therapy with the left crutch and minor assistance from the physiotherapist. As shown in Figure 3, his average stride time (plot 1) shortened from 3.36 seconds to 2.09 seconds, average heel-on times for both legs (plot 2-left, 3-right) shortened by about 40%, while dispersion (plot 4-left, 5-right), defined as the standard deviation / mean, remained constantly 20% for both legs.

As shown in Figure 4, the symmetry of gait (plot 1) varied between 0.71 and 1.46, while the average velocity (plot 2) increased from 0.12 m/s to 0.41 m/s and the average stride length (plot 3) from 0.41 m to 0.86 m.

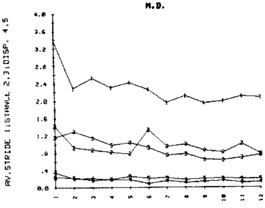

Fig. 3. Patient M.D. during therapy: average stride time [s](1), average heel-on times for both legs [s](2-left, 3-right) and dispersions (4-left, 5-right).

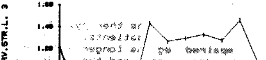

Fig. 4. Patient M.D. during therapy: symmetry of gait (1), average velocity [m/s](2) and average stride length [m](3).

Results of ground reaction force measurements (Fig. 5 to 7) show the average vertical component of force (full line), with its standard deviation (dotted line), and body weight (bw) of the patient in the upper diagram. The lower two diagrams show the spatial distribution of the force point of action on the shoe soles with standard deviations in the X and Y directions represented by rectangles at preselected time intervals (TI). Average stride duration (100%), its standard deviation (SD) and the number of steps (NS) are given in the text attached to the figure.

Comparing the forces during gait of the right hemiplegic patient M.D. without stimulation at the beginning and at the end of therapy (Fig. 5 and Fig. 6) revealed considerable improvements. Average stride time shortened from 5.24 seconds to 3.58 seconds and standard deviaton was reduced from 1.34 seconds to 0.42 seconds. Average velocity and stride length improved from 0.075 m/s and 0.43 m at the beginning to 0.15 m/s and 0.57 m at the end of therapy. The stance time of the impaired leg increased from 45% to 65% of the stride time and its loading was 25% higher, because the patient walked without the support of a physiotherapist. The loading of the impaired leg was still lower than that of the healthy one, partly because the patient was using a crutch; however, the stance times of both legs were almost equal. The slope of the ground reaction force showed that the patient was slowly shifting weight from the healthy to the

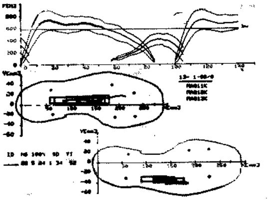

Fig. 5. Ground reaction forces of patient M.D. without stimulation at the begining of therapy.

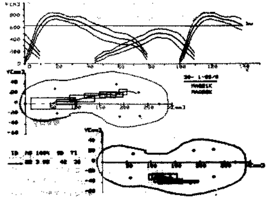

Fig. 6. Ground reaction forces of patient M.D. without stimulation at the end of therapy.

impaired leg, because he felt insecure. The lower, force distribution diagrams showed that the patient was still loading his left foot on the middle lateral edge during the whole stance phase, with a slight shift toward the toes at the end of therapy. It was obvious that the patient still suffered from drop foot during the swing phase. The trajectory of the force point of action for the right leg changed more. At the beginning of therapy it started 80 mm from the heel and ended 70 mm from the toe tips, which meant that the loading and push off were performed with a flat foot. At the end of therapy, we can see considerable improvement in the loading and somewhat less in the push off.

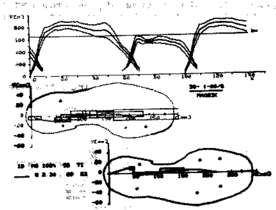

Fig. 7. Ground reaction forces of the patient M.D. with stimulation at the end of therapy.

Gait with stimulation (Fig. 7) showed greater improvement. The stride time was 2.3 seconds with 0.09 second standard deviation. The stance time of the impaired leg was still shorter by 20% of the stride time, but the force pattern was closer to normal. The patient loaded his impaired leg as fast as the unimpaired one, since he felt more secure. The amplitude of the force was still lower in the impaired leg, because the patient was using a crutch. Spatial distributions of the point of action showed greater improvement, especially on the affected side. With heel loadings on both legs and the distributions in the centre of the soles toward the toes, the trajectories aproached a healthy pattern, while the standard deviations for the impaired left leg were still larger than in a healthy person.

IV. Discussion

Previous studies were based on patients with less severe motor disabilities and some sort of already developed gait pattern at the beginning of therapy. It was shown that a pathological gait pattern was corrected through therapy with multichannel electrical stimulation. With the present approach we tried to initiate a new, correct gait pattern in patients who could not walk at all. The course of therapy has been followed-up by data provided by the stride analyzer included in the stimulator, which required no additional measuring equipment.

Measurements were not restricted to the gait laboratory, so the patients remained in their everyday areas which was not disturbing for them. The measured data were averaged over hundreds of steps and gave reliable statistics. However, these data were available only for the stimulated gait. The ground reaction measuring system was used to evaluate the changes in gait pattern without stimulation, which also appeared to be significant.

The non-invasive surface approach restricts multichannel stimulation to the clinical environment and requires skilled personnel, which increases the costs and reduces the number of treated patients. The approach presented with multichannel therapy during the first couple of weeks can initiate independent gait in severely motor disabled patients, who can then continue with less demanding treatment and use single or dual channel stimulation for correction of gait (20).

The most important fact is that patients who were not able to walk or did not dare to, due to the self-confidence, or were not included in the gait training from different reasons, or this kind of program lasted for months, achieved their own gait, and thereby independence in their everyday life, in 2 to 3 weeks of therapy. In addition, higher recovery rates also reduced the costs of rehabilitation. The question here is, what is the real value of this therapy comparing to the clasical methods for rehabilitation of gait, but it can not be answered untill some detailed comparative study is carried out.

Usually when it is discussed about the effects of FES, terms like "long-term effects" or "short-term effects" are used. In this case neither of them is appropriate, because the effect of the described therapy is more or less independent gait and by that acquired possibility of including such a patient in clasical program of gait rehabilitation. The lasting of this effects depends on motivation of the patient and his environment, for the gait. If the patient keeps walking, the effects are permanent, if not the effects will probably fade away and the patient will end on a wheelchair. Disregarding the objective effectiveness of this method we have to be aware, that it has its limitations and that all of the presented results were acchieved also by including all of the clasical methods of rehabilitation. This method is supposed to be only an integral part of complex program of rehabilitation of the hemiplegic patients.

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