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The use of a treadmill with biofeedback function in assessment of relearning walking skills in post-stroke hemiplegic patients – a preliminary report

Wykorzystanie bieżni ruchomej z funkcją biologicznego sprzężenia zwrotnego w nauce chodu u chorych z niedowładem połowiczym po udarze mózgu – doniesienie wstępne

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Abstract

Background and purpose: One of the most important goals of rehabilitation of post-stroke hemiplegic patients is the recovery of their locomotion function. The aim of the study was to assess walking function recovery by means of in-patient rehabilitation procedures, as well as the effectiveness of treadmill gait training with the use of biological feedback.
Material and methods: The research involved groups of chronic post-stroke hemiplegic patients receiving treatment in the rehabilitation ward. Factors under scrutiny included walking speed and capacity, number of steps, weight bearing symmetry for lower extremities while standing, lower limb mobility on the Brunnström scale, and muscle tone on the Ashworth Scale. The study group patients followed a rehabilitation regime that included treadmill training aided with biofeedback function. Each study group participant exercised every day (a total of 15 times), with a single practice time ranging from 5 to 20 minutes. Control patients followed a rehabilitation regime without the additional treadmill exercises.
Results: Patients in both groups demonstrated improvement in locomotion abilities. In the group following the physiotherapy regime supplemented with treadmill training with the use of biofeedback, the measures of walking speed, weight bearing symmetry for lower extremities, and number of steps were better than in controls.
Conclusions: Treadmill gait training with the use of biofeedback is effective for relearning locomotion functions in post-

Streszczenie

Wstęp i cel pracy: W rehabilitacji chorych z niedowładem połowiczym po udarze mózgu jedną z najważniejszych potrzeb jest odzyskanie funkcji chodu. Celem pracy była ocena efektów nauki chodu w warunkach rehabilitacji szpitalnej oraz określenie przydatności stosowania treningu chodu na bieżni ruchomej z wykorzystaniem biologicznego sprzężenia zwrotnego.
Materiał i metody: Badanie przeprowadzono w grupach chorych z niedowładem połowiczym po udarze mózgu w okresie przewlekłym, leczonych na oddziale rehabilitacji. Oceniano prędkość i dystans chodu, liczbę kroków, symetrię obciążenia kończyn dolnych podczas stania, sprawność ruchową kończyny dolnej w skali Brunnström i napięcie mięśniowe w skali Ashworth. Chorzy z grupy badanej realizowali program rehabilitacji z treningiem na bieżni ruchomej wyposażonej w funkcję biologicznego sprzężenia zwrotnego (BSZ). Każdy z badanych ćwiczył codziennie (łącznie 15 razy), czas pojedynczego ćwiczenia wynosił od 5 do 20 minut. W grupie kontrolnej chorzy realizowali podobny program rehabilitacji, ale bez dodatkowych ćwiczeń na bieżni.
Wyniki: U chorych z obu grup uzyskano poprawę badanych parametrów chodu. W grupie chorych realizujących program fizjoterapii uzupełniony o treningi na bieżni ruchomej z wykorzystaniem BSZ, poprawa prędkości i dystansu chodu oraz symetrii obciążenia kończyn dolnych była istotnie większa w porównaniu z grupą kontrolną.

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stroke hemiplegic patients and can constitute a significant type of exercise in a physiotherapy regime.

Key words: stroke, physiotherapy, gait, biofeedback, treadmill.

Wnioski: Trening chodu na bieżni ruchomej z wykorzystaniem BSZ daje lepsze efekty poprawy funkcji chodu u chorych z niedowładem połowiczym po udarze mózgu w okresie przewlekłym niż program fizjoterapii bez wykorzystania bieżni z informacją zwrotną.

Słowa kluczowe: udar mózgu, fizjoterapia, chód, biologiczne sprzężenie zwrotne, bieżnia.

Introduction

Stroke as a complication of cardiovascular diseases poses a great health problem in modern societies. It is the third most common cause of death and the most common cause of disability in the elderly population [1-3]. Limb paresis with increased or decreased muscle tone, and loss of body balance are major obstacles in relearning independent standing and walking. Loss of walking skills and major impairment of gait seriously limit the ability to perform activities of daily living and prevent patients from returning to a normal social life. Gait in hemiplegic patients is often non-efficient, asymmetric and non-aesthetic; it is slow and requires great expenditure of energy [4,5]. The goals of rehabilitation in patients after stroke include the restoration of lost function, to the best possible extent, according to the real abilities and skills of the individual, or compensation of function that is definitely lost. It is assumed that the greatest improvement in functional recovery may be expected within the first three months after stroke onset. It is greatly related to the restoration of gait function.

The improvement of gait is also possible in chronic post-stroke patients. The central nervous system has some capacity for learning and adaptation due to the brain plasticity mechanisms. Brain plasticity in chronic post-stroke patients can be increased with exercises, including motor ones, and the effect of motor training depends on its intensity and systematic application [6-8].

Integrated sensorimotor stimulation should be provided directly by the therapist, and the use of specialized equipment might be considered as a helpful addition only [9]. The variety of methods involved in relearning and improving the gait in hemiplegic patients after stroke include biofeedback methods with the use of dynamometric platforms, rotors for passive and active exercises within lower limbs, signalling crutches and the treadmill. A crucial element of relearning of the patient's locomotor function using a treadmill with biofeedback option is the real-time feedback. In the case of gait relearning, the feedback includes information on the appropriate pattern of gait and its parameters, including stride length and velocity, as well as the symmetry of the particular phases of gait.

The velocity of gait forced with the velocity of the treadmill and adjusted to the patient's abilities, as well as additional acoustic and visual stimuli, affects not only the improving gait pattern, but also better balance, coordination, muscle strength and endurance [10-12].

The aim of the study was to assess the walking function recovery in patients with chronic post-stroke hemiplegia involved in in-patient rehabilitation procedures using a treadmill with biofeedback. We evaluated the effects of gait relearning in patients of a rehabilitation ward, as well as the effectiveness of treadmill gait training with the use of biological feedback.

Material and methods

The study involved patients with post-stroke hemiparesis who were treated in the Clinical Department of Rehabilitation with the Subdivision of Early Neurological Rehabilitation (Voivodship Hospital No. 2 in Rzeszów). The study included all consecutive patients who were admitted to that ward before and after implementation of a treadmill with biofeedback function. Inclusion criteria consisted of history of stroke, time since the onset of stroke > 6 months, ability to walk independently, lower limb motricity between 3 and 5 on the Brunnström scale, disability score between 1 and 3 on the Rankin scale, spasticity of paretic lower limb not greater than 1+ on the modified Ashworth scale, and altered weight-bearing symmetry in lower limbs while standing (symmetry index > 1.15). Exclusion criteria consisted of disturbed higher mental functions that limited comprehension and ability to fulfil the tasks during the training sessions, visual field defects, concomitant orthopaedic disorders (coxarthritis, gonarthritis), flexion contracture at the ankle, periodic cardiac or pulmonary insufficiency preventing participation in additional exercise with the treadmill, or lack of consent to additional exercise.

Thirty patients were qualified for the study. The study group comprised 15 patients (12 men and 3 women) admitted consecutively, who satisfied the inclusion criteria and completed the rehabilitation programme with the addition of the treadmill exercises. The control group consisted of 15 patients (12 men and 3 women) admitted consecutively to the ward. Mean age of patients was 62 years (range: 50-71) in the study group and 59.5 years (range: 54-70) in the control group. Mean time since the onset of stroke was 3 years (range: 1-13) in the study group and 4 years (range: 1-13) in controls. The two groups were similar regarding the type of stroke and the side of the paresis (Table 1).

Patients were evaluated twice. The first assessment was performed during the second day of the hospital stay, and the second assessment was performed on discharge. The assessment included velocity and distance of walking, number of steps in the walkway test and time required to complete the 'get up and go' test. Velocity of gait was assessed with an attempt to perform a 10-m march. Patients walked at self-adopted velocity and were allowed to use orthopaedic aids (sticks, crutches, AFO or DAFO braces). Walking distance was assessed with the 2-minute walking test. Patients walked with a self-adopted velocity between two points 30 m apart. The walking lasted 2 minutes and the distance was measured in metres. The 'get up and go' test measured the time required to get up independently from a chair, walk 3 m, come back and sit down independently on the chair.

The motricity of the paretic lower limb was assessed according to the Brunnström scale, the muscle tone in the lower limb was assessed with the modified Ashworth scale, and the weight-bearing symmetry of the lower limbs was evaluated with a dynamometric platform and measured with the symmetry index [13-15].

The dynamometric platform applied for the assessment of the weight-bearing symmetry of the lower limbs is a self-made construction equipped with two complex tensometric sensors that enable the recording of the load independently for each limb. Mean values of the load were used to calculate the symmetry index. The normal values of the symmetry index were assumed to be 1.0-1.15 [16,17].

All patients participated in a rehabilitation programme focused on the regaining of lost motor skills, including functional gait. Patients received individual and group exercises, training with rehabilitation devices, occupational therapy, physiotherapy, and psychotherapy. The goal of the individual exercises, including passive, assisted, guided, active and neurodevelopmental exercises (NDT, Bobath, PNF), was to regain the

Table 1. Baseline characteristics of both studied groups

	Study group	Control group
Sex		
men, *n* (%)	12 (80%)	12 (80%)
women	3 (20%)	3 (20%)
Age, mean (range) [years]	62 (50–71)	59.2 (54–70)
Type of stroke		
haemorrhagic	5 (33%)	6 (40%)
ischaemic	10 (67%)	9 (60%)
Paretic side		
left	10 (67%)	9 (60%)
right	5 (33%)	6 (40%)

ability to load the paretic limb, to recover the appropriate pattern of swing movement of the paretic limb, and to relearn the appropriate postural reactions of the trunk. The mean total time spent on exercise in both groups was about 2 hours daily per patient. Patients enrolled in the study group had additional training with the treadmill with biofeedback function (Gait Trainer 2, Biodex).

The biofeedback function implemented in the treadmill uses real-time visualization of the location of both feet and the suggested area where the foot stepping forward should be placed. During the exercise, the patient receives additional visual data that illustrate the task (restoration of symmetry and increase of stride length) and acoustic information after successful completion of the task.

Treadmill training was provided during the 3-week rehabilitation course, five days a week, once daily (15 sessions in total). Duration of the training session was related to the clinical status of the patient and varied from 5 to 20 minutes. The tread speed was between 0.34 and 1.0 m/s. The training load, duration of the exercise and the tread speed were increased according to the patient's subjective assessment of the effort and to the results of the task, i.e. performing strides of the set length. Stride length was 50-75 cm (Fig. 1).

The protocol of the pilot study reported in this paper was not presented to the bioethical committee (there was no interference with the usual rehabilitation programme). The planned major study with the use of randomization was approved by the bioethical committee.

Statistical analysis was performed with Statistica v. 9. Non-parametric tests, including Mann-Whitney *U*-test for small groups and Wilcoxon test, were used to assess the significance of differences between the two

Fig. 1. Training of walking skills on the treadmill

studied groups. A p-value < 0.05 was considered significant.

Results

Table 2 provides data on the assessed measures of motricity. Differences between groups were evaluated with Mann-Whitney U-test. The two studied groups did not differ in terms of the assessed measures of motricity at the beginning of the rehabilitation course.

Physiotherapy improved gait in both studied groups. All evaluated features of gait function improved in the study group, and the differences between baseline values and those assessed at the end of treatment were significant. An improvement of gait function was noted in all patients in the study group; in three of them, however, the walking speed did not improve. Patients who served as controls also improved, but to a lesser extent. Significant differences between baseline and final assessment were noted for the 'get up and go' test, as well as for the number of steps in the walkway test. More controls than patients from the study group did not experience an improvement (Table 3).

Table 2. Comparison of baseline gait motricity between study group and controls

Variables	Study group		Control group		*p*-value
	Median (range)	Mean ± SD	Median (range)	Mean ± SD	
Gait velocity [m/s]	0.5 (0.2-0.9)	0.5 ± 0.2	0.5 (0.1-0.9)	0.5 ± 0.2	0.77
Number of steps	24.0 (18-38)	25.5 ± 5.2	25.0 (14-40)	25.7 ± 6.8	0.93
Two-minute walking distance [m]	60.0 (41-93)	62.8 ± 15.8	55.0 (20-105)	60.3 ± 26.4	0.62
Get up and go test [s]	18.0 (11-31)	19.4 ± 6.7	18.0 (11-31)	19.3 ± 6.9	0.93
Symmetry index	1.6 (1.0-3.6)	1.8 ± 0.8	1.6 (1.1-3.8)	1.8 ± 0.7	0.84

Table 3. Descriptive statistics and comparison of differences between first and second assessment in study group and controls

Measures of gait performance (change during the rehabilitation)	Study group			Control group		
	Mean change for the whole group	*n*	*p*-value*	Mean change for the whole group	*n*	*p*-value*
Gait velocity [m/s]	0.1	12	0.0047	0.0	10	0.16
Number of steps	–3.8	14	0.0010	–2.5	11	0.0229
Two-minute walking distance [m]	13.3	15	0.0007	4.7	9	0.0505
Get up and go test [s]	–2.8	14	0.0022	–3.3	15	0.0007
Symmetry index	–0.5	14	0.0010	–0.2	12	0.0258

N – number of persons who improved after the rehabilitation
**Wilcoxon test for the difference between first and second assessmen*

Table 4. Measures of gait performance and their changes during the rehabilitation – comparison between study group and controls

Measures of gait performance (change during the rehabilitation)	Study group		Control group		*p*-value
	Median (range)	Mean ± SD	Median (range)	Mean ± SD	
Gait velocity [m/s]	0.1 (–0.1-0.2)	0.1 ± 0.1	0.0 (–0.1-0.1)	0.0 ± 0.1	0.033
Number of steps	–3.0 (–15.0-0.0)	–3.8 ± 3.4	–3.0 (–10.0-8.0)	–2.5 ± 4.1	0.44
Two-minute walking distance [m]	10.0 (1.0-30.0)	13.3 ± 10.3	5.0 (–10.0-20.0)	4.7 ± 7.9	0.019
Get up and go test [s]	–2.0 (–10.0-2.0)	–2.8 ± 2.8	–3.0 (–10.0- –1.0)	–3.3 ± 2.3	0.39
Symmetry index	–0.3 (–1.5-0.0)	-0.5 ± 0.5	–0.1 (–0.7-0.3)	–0.2 ± 0.3	0.033

The major goal of the study was to establish whether any difference exists in terms of relearning walking ability between the studied groups. Table 4 shows the descriptive statistics of the assessed measures of the dexterity (i.e. their values at the beginning and at the end of the study) and the comparison of those results between groups with the Mann-Whitney *U*-test. Although the studied groups were small, significant differences between groups were found in three measures of dexterity (increased velocity of walking, longer distance in the march test and better weight-bearing symmetry of the lower limbs in the standing position, as reflected by normalization of the symmetry index).

Discussion

Patients after stroke require individual, continuous and complex rehabilitation, aimed at the restoration of lost function to the best possible extent, or the compensation of definitely lost function, and then adaptation to functioning in the patient's own environment. Regaining of locomotor independence, including safe and effective gait, is one of the most important needs of the hemiparetic patient. The gait of the hemiparetic patient after stroke is characterized by marked asymmetry of the phases of gait, stride length and weight-bearing load of the lower limbs (greater in the non-paretic limb). Taken together, all these abnormalities lead to significant slowing of walking and markedly decreased activities of daily living.

Treadmill training improves the parameters of gait and provides good results in both the acute and the chronic phase of stroke. According to Visintin *et al*. [18], treadmill training is a specific task that enables training of the whole cycle of gait with multiple repetitions instead of single movements. Wernig, Nanassy and Muller suggest that treadmill exercises stimulate the repeatability and rhythmicity of gait, and these, in turn, improve strength, coordination and endurance. Hesse believes that treadmill training in hemiparetic patients provides the opportunity to train the appropriate pattern of gait due to the reproduction of the movements in conditions similar to normal ones [19,20]. Similar results of treadmill training, suggesting improved kinematic parameters of gait, were obtained by Harris-Love [21].

Rehabilitation of patients after stroke uses methods based on broad, multidirectional stimulation of the nervous system, which enables relearning of the motor skills due to the brain's plasticity. Those methods often include internal biofeedback, aimed at compensation of the lost or altered afferent impulsation required for the appropriate gait analysis and planning [22-24]. Biofeedback provides a continuous flow of information through vision, hearing and proprioception to the central nervous system; it is essential for the appropriate control of voluntary motor acts.

Additional external information provided to the patient during the training session enables better central programming and planning of movement in patterns similar to the normal ones.

Kinalski states that post-stroke patients who have lost their motor function can activate movement through training with biofeedback. This is due to the fact that the motion of the impaired limb can be visualized with a visual signal displayed on the monitor; thus the kinaesthetic signal can be replaced with a visual one.

Visualization also increases the patient's motivation for further training because it provides an assessment of the results and makes them more objective [25,26]. Magill believes that biofeedback related to information on the wrong and appropriate efforts is very useful in training of particular skills. The information provided enables patients to improve their performance [27]. It should be noted that Teasell and Woodford analysed published reports on the efficacy of several methods used to facilitate relearning of walking, including EMG biofeedback, treadmill, partial body weight support and functional electrostimulation, and did not find unequivocal evidence for the superiority of those methods over conventional ones [29,30].

The results of our study suggest that the in-patient rehabilitation even in the chronic phase after stroke improved the gait. Patients with additional training on the treadmill with the use of biofeedback had a greater increase in gait velocity, better improvement in weight-bearing symmetry of lower limbs and significantly longer walking distance in the march test when compared with controls. It may be stated, therefore, that the enrichment of the rehabilitation programme with the treadmill training with biofeedback provided better improvement of gait in hemiparetic post-stroke patients than the routine rehabilitation schedule without treadmill training. Similar effects were reported by Sullivan, Knowlton and Dobkin. Post-stroke patients who trained with the treadmill with the gait speed faster than the patient walking on the ground obtained a greater increase of gait speed (by 28.6%) than patients who walked on the ground [31].

Our results cannot unequivocally determine whether the biofeedback function used during the treadmill training had a significant effect on the results. It might be suspected that the visual and acoustic information on accuracy of the task set to the patient brought the positive effect. Visualization of the real position of the patient's feet and the information of the desirable position are clear and understandable. They motivate the patient to perform conscious correction of the abnormal symmetry of the stride length.

Our results suggest that gait training with a treadmill coupled with biofeedback is useful in relearning locomotor function in hemiparetic patients, even in the chronic phase of stroke. It seems to be an efficient means of expanding and enriching methods used in gait training and rehabilitation programmes for patients after stroke.

Conclusion

Gait training with a treadmill coupled with biofeedback function significantly improves velocity of gait, walking distance and weight-bearing symmetry of lower limbs in hemiparetic patients after stroke.

Disclosure

The authors report no conflict of interest.

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