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Original Article

The Effects of Stair Gait Exercise on Static Balance Ability of Stroke Patients

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Abstract. [Purpose] This study examined the effects of stair gait exercise on the static balance ability of chronic stroke patients. [Subjects and Methods] The thirty stroke patients who participated in this experiment were randomly assigned to an experimental (n=15) or control (n=15) group. The experimental group performed stair gait exercise for 30 minutes, while the control group performed flat surface gait exercise for 30 minutes. The programs lasted four weeks, with both groups performing the exercises three times per week for 30 minutes each time. The stability balance ability of subjects was measured and compared before and after the interventions. [Results] The results of the experimental group showed a significantly different values, but those of the control group did not. Between-group comparison of changes in the anterior/posterior length in the limit of stability revealed significant increases in the experimental group but no significant increase in the control group. Only the surface area ellipse of Romberg, the length of Romberg, and length/area of Romberg showed significant differences between the two groups after the interventions. [Conclusion] The static balance ability improved in the group that performed the stair gait exercise. This study provides important data for identifying the recovery of balance ability through rehabilitation exercises in patients with nervous system diseases.
Key words: Strokes, Balance ability, Stair gait

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INTRODUCTION

In hemiplegia patients, the lower extremity of the affected side supports only 25 to 43% of the patient's body weight in standing postures, leading to asymmetric postures[1)]. This reduces the ability of the body to maintain its center of gravity and affects equilibrium reactions and orientation responses, thereby seriously hampering postural control ability[2)]. The reduced balance ability induces flaccidity and spasticity in the lower extremities of hemiplegia patients, and sensory function disorders of the affected side hinder independent walking[3)]. Poor balance increases the risk of falls and serious complications in stroke patients[4, 5)]. Thus, preventing falls and enhancing the ability of stroke patients to perform daily living activities independently is the most basic aim in stroke rehabilitation[6)].

Stairs are used frequently in daily life, and differences between stair gaits and flat surface gaits have been reported as follows: In stair gaits, each step starts from the toes or the sole rather than the heel. Force is required to push the body upward and forward, and control of the body against falls is required when descending stairs[7)]. More dynamic effort is required in stair gaits than flat surface gaits because an awareness of body balance and lower extremity force is necessary[8)]. Patients with hemiplegia resulting from lesions in the central nervous system perform flat surface gait exercise first, followed by gait exercise on sloped areas and ascent and descent of stairs. These exercises are indispensable not only for conducting activities of daily living but also for self-reliance that enables the patients to be independent from others and should be emphasized in the process of treatment without fail[9)].

In a review of stair gait-related studies, Eun et al.[10)] stated that much larger extension moments than flexion moments occurred in the lower extremity joints of healthy individuals and that larger extension moments occurred in the knee and hip joints than in the ankle joints. Kim et al.[11)] examined the contact force applied to knee joints during flat surface gaits and during slope-way or stair gaits. They reported that the contact force was greater during stair gaits, approximately 4.25 times that of the body weight. Andracchi et al.[12)] reported that the moments generated by the flexors and the extensors during ascent and descent of stairs were much larger than those during flat surface gaits.

Improving balance is an important goal in the treatment of patients with hemiplegia caused by stroke. Most studies of balance in stroke patients conducted thus far have examined general gaits, and most studies on stairs have not

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included stroke patients. Thus, this study examined the effects of stair exercise on the balance ability of stroke patients. The results provide basic data on gaits useful for the treatment of individuals who have suffered a stroke.

SUBJECTS AND METHODS

Subjects

This study was conducted at K Hospital located in Daegu from March 1, 2014, to March 30, 2014. The inclusion criteria were hemiplegia patients who had been diagnosed with stroke by computed tomography (CT) or magnetic resonance imaging (MRI) at least six months earlier, could maintain independent standing postures for at least 30 seconds, could walk independently for at least 30 m indoors, could communicate to the extent that they could understand therapists' verbal commands, could walk using walking aids or independently, were not taking drugs to relieve spasticity, had no lower motor nerve lesion, had no orthopedic disease in their lower extremities, and voluntarily agreed to participate in this study after receiving an explanation of the study's aims. This study was approved by the University Institutional Review Board and was conducted in accordance with the ethical standards of the Declaration of Helsinki. Thirty subjects took part in the study. The subjects were randomly assigned to a flat surface gait group of 15 subjects or a stair gait group of 15 subjects. The general characteristics of the study subjects who participated in this study are summarized in Table 1.

Table 1. General characteristics of subjects

	CG	EG
Sex (M/F)	8/7	10/5
Age (yrs)	59.3 ± 3.2	61.7 ± 3.6
Height (cm)	167.2 ± 3.7	165.1 ± 4.6
Weight (kg)	64.3 ± 3.2	61.3 ± 3.4
Paretic side (R/L)	8/7	9/6
Onset duration (mo)	37.3 ± 6.4	28.4 ± 5.3

Values are means ± SD, CG: control group; EG: exeprimental group

Each group performed the exercise for 30 minutes per time, five times per week for four weeks. Before the experiment, all the subjects received general physical therapy consisting of joint motion exercises, muscle strengthening exercises, and stretching exercises from physical therapists with a clinical career of at least five years.

The experimental group performed gait exercise by ascending and descending wooden stairs, which had a width of 0.8 m, high of 10 cm, and tread depth of 28 cm thread. In the gait exercise program, the experimenter helped the patients to climb the stairs by holding the ischium of the patients' affected side, assisting the flexion of the popliteus, and supporting the ankle when the ankle joint was unstable. While the patients descended the stairs, the physical therapist supported the region above the patient's knee joint with their left hand (in cases of left hemiplegia). The physical therapist also aided stability by holding the patient's waist with his hands. When the patient's feet touched the stairs, the forefoot came into contact with the stairs first to stably assist weight bearing by the knee. The patients were allowed to hold a safety bar to prevent falls. Use of the safety bar and the therapist's assistance gradually decreased as the patients' gait abilities improved[13].

The control group performed flat surface gait exercise by walking 10 m back and forth on a hard, stable indoor surface, which was free of obstacles. During the exercise, the therapist watched the patients continuously to reduce the risk of falls.

A balance ability measuring and training system with biofeedback (AP1153 BioRescue, France) was used to measure static balance ability of the subjects. The balance ability measuring and training system is suitable for static and dynamic measurements of the balance ability of patients, healthy individuals, and athletes. It records the moving path line of the center of pressure during certain movements to determine the length (mm) of the moving path line, the average speed (cm/s), and the area of the movements. The patients were instructed to spread their legs to approximately 30° in an upright standing posture and keep their eyes forward. Before the measurements, the method was explained and demonstrated on a monitor. To measure the distribution of weight bearing between the paretic and nonparetic sides and the total distance and area of movement of the center of gravity of the body, the patients were instructed to maintain their balance and posture for one minute while keeping their eyes forward. The patients were instructed by the monitor on how to use ankle strategies to maintain their balance. To determine their static balance, the limit of stability was measured in a static standing posture while the patients maximally moved their center of gravity without losing their balance.

SPSS 17.0 for Windows was used for statistical processing of the data obtained in this study, and paired t-tests were conducted to test the significance of differences before and after the experiment in each group. The significance of between-group differences was tested by conducting one-way ANOVAs and LSD ex post facto tests. The statistical significance level α was set to 0.05.

RESULTS

The results regarding the ability of the patients to maintain balance during gait exercises showed that the weight-bearing footprint on the paretic side of the experimental group increased significantly ($p<0.05$) and that of the nonparetic side decreased significantly ($p<0.05$) after the experiment. In contrast, the weight-bearing footprint of the control group did not decrease significantly on either the paretic or nonparetic side ($p>0.05$). The anterior length in the limit of stability increased significantly on both the paretic and nonparetic sides in the experimental group ($p<0.05$) but not in the control group ($p>0.05$). Likewise, the posterior length in the limit of stability increased significantly on both the paretic and nonparetic sides in the experimental group ($p<0.05$) but not in the control group ($p>0.05$). Moreover, the surface area ellipse of Romberg decreased

Table 2. A comparison of balance between before and after the interventions for the CG and EG

		CG (n=15)		EG (n=15)	
		Before	After	Before	After
Weight bearing of foot print (%)	A	51.6 ± 14.4	51.0 ± 15.2	41.0 ± 6.1	46.0 ± 7.7*
	N	48.4 ± 14.0	49.0 ± 15.2	59.0 ± 5.5	52.0 ± 12.5*
Anterior length in limit of stability (cm^2)	A	20.5 ± 1.6	17.8 ± 1.7	19.2 ± 1.6	24.1 ± 1.3*
	N	25.1 ± 1.1	25.8 ± 1.8	21.5 ± 1.6	44.9 ± 1.1*
Posterior length in limit of stability (cm^2)	A	30.3 ± 3.1	28.2 ± 1.7	23.9 ± 1.8	29.1 ± 2.0*
	N	26.5 ± 2.8	27.9 ± 2.5	29.2 ± 2.0	33.4 ± 2.0*
Surface area ellipse of Romberg (mm^2)		184.7 ± 27.0	188.6 ± 25.8	179.1 ± 41.9	102.2 ± 24.6*[a]
Length of Romberg (cm)		30.5 ± 2.4	29.0 ± 2.0	38.6 ± 4.9	30.0 ± 4.0*[a]
Average speed of Romberg (cm/s)		0.5 ± 0.0	0.4 ± 0.0	0.6 ± 0.0	0.4 ± 0.0*
Length/area of Romberg (cm/cm^2)		47.0 ± 10.5	48.7 ± 11.0	49.2 ± 12.6	26.9 ± 4.8*[a]

Mean±SE. *Significant difference compared with before therapy at <0.05. [a]Significant difference in gains between the two groups at p<0.05. A: affected side; N: normal side

significantly in the experimental group (p<0.05) but not in the control group (p>0.05). With respect to the length of Romberg (p<0.05), it increased significantly in the experimental group but not in the control group (p>0.05). The average speed of Romberg decreased significantly in the experimental group (p<0.05), but the control group showed no significant decrease (p>0.05). Although the length/area of Romberg decreased significantly in the experimental group (p<0.05), it did not in the control group (p>0.05). In the analysis of between-group differences before and after the experiment, only the surface area ellipse of Romberg and the length/area of Romberg showed significant differences (p<0.05) (Table 2).

DISCUSSION

Evaluation of the speed and accuracy of movements of the center of gravity and the degree of weight bearing and movements in stroke patients is the only means of obtaining information on the recovery of balance ability in stroke patients. Such information has been used to establish new treatment plans to increase the degree of weight bearing associated with functional activities in stroke patients[14]. Efficient forms of gaits are indispensable for patients with hemiplegia due to stroke to achieve functional independence in daily activities of living[15].

One study of balance exercises for stroke patients indicated that the movements of the upper/lower extremities decreased and postural shake increased in static standing postures because the patients could not control their movements due to reduced muscle strength, abnormal muscle tone, and abnormal movement patterns[16]. Another reported that stroke patients' body sways decreased following the application of an ankle joint proprioceptive exercise program[17]. Lee compared the balance ability of an experimental group with chronic stroke of at least six months who took part in traditional physical therapy and task-based exercise programs and a control group who received only traditional physical therapy[18]. The study reported that the body stability of the experimental group increased greatly. Declines in balance ability in stroke patients lead to decreased gait velocity, placing additional stress on patients and eventually making social functions more difficult[19].

In reviews of the correlation between the balance ability of stroke patients and their gait ability, Keenan et al.[20] and Kim and Lee[21] reported that gait ability was correlated with balance-related senses, and Bohannon and Leary[22] reported that balance in standing postures was significantly correlated with gait ability in many studies.

The findings of the abovementioned studies illustrate that the gait and balance abilities of stroke patients are very closely related. Thus, only gait exercise performed in daily living can have important effects on locomotion in stroke patient. Therefore, in this study, the stroke patients were divided into a flat surface gait (control) group and a stair gait group. The effects of the stair gait exercise on the following parameters were then studied: static balance, changes in the weight-bearing footprint of the paretic and nonparetic sides in static standing postures, the surface area ellipse of Romberg, the length of Romberg, the average speed of Romberg, the length/area of Romberg, and the anterior/posterior length in the limit of stability.

In this study, when the weight-bearing footprints in static standing postures were compared before and after the experiment, they were significantly decreased on the nonparetic side and significantly increased on the paretic side in the experimental group. In the case of the surface area ellipse of Romberg and the length of Romberg in static standing postures, the experimental group showed significant decreases, but the control group did not. With regard to the length of Romberg and the average speed of Romberg, these decreased significantly in the experimental group but not in the control group. Comparison of the changes in the anterior/posterior length in the limit of stability in static standing postures showed that they increased significantly in the experimental group but not in the control group. In the tests for between-group differences before and after the experiment, significant differences were observed only in the surface area ellipse of Romberg and the length/area of Romberg.

The fact that the experimental group moved the distribution of weight bearing on the paretic and nonparetic sides to the center of gravity for balance is likely due to the patients moving their bodies as their weight moved from their nonparetic side to their paretic side. They used ankle strategies in static standing postures until they achieved the maximum degree of voluntary weight bearing. The former is like due to improvements in the proprioceptive senses for the ankle joint or improvements in the ability to distribute their body weight appropriately during the performance of gait motions. The increases in the anterior/posterior length in the limit of stability of the stroke patients indicate that the stair gait exercise improved the postural stability and balance ability of stroke patients.

Eng et al.[23] stated that weight-bearing ability in stroke patients was correlated with functional ability and that the ability of stroke patients to asymmetrically move their body weight to the left/right in static standing postures was closely related to motor functions and the level of independent living, as well as the length of stay in the hospital. They further noted that gaits directly affected the ability of the patient to transfer weight bearing forward, backward, leftward, rightward from the paretic side in standing postures. Therefore, difficulties in the control of postural balance not only cause asymmetrical standing postures but also lead to postural sway, resulting in the repeated concentration of weight bearing on the unaffected side and declines in postural balance ability[24]. However, in studies by Leroux et al.[25] and Lay et al.[26], the activities of the gluteus maximus, rectus femoris, vastus medialis, and gastrocnemius increased during slope-way ascents. Kim[9] compared electromyograms of stair gaits of patients with hemiplegia due to stroke and found that the activities of the rectus femoris, biceps femoris, and gastrocnemius were high when subjects were ascending a stairs. Therefore, stair gait exercise appears to increase the activities of the muscles necessary for maintaining postures to reduce diverse postural sway in static standing postures. This enables the maintenance of standing postures by consuming a minimal amount of energy in these postures.

In this study, the static balance of patients with hemiplegia due to stroke improved significantly following stair gait exercise. The results of this study provide important data for identifying the recovery of balance in stroke patients during rehabilitation training. Continuous stair gait exercise can improve the balance functions not only of stroke patients but also of patients with other nervous system diseases.

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