

Comparison of Two Treadmill Gait Training Techniques on the Gait and Respiratory Function in Stroke Patients

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| Abstract |

PURPOSE: This study compared two different techniques of treadmill gait training, and evaluated the outcomes on gait and respiratory function in patients with hemiplegic stroke.

METHODS: This was a single-blinded, randomized, controlled, comparative study, enrolling a total of 21 stroke patients in a rehabilitation hospital. Subjects were randomly assigned to either the treadmill walking training group with gradual speed increase (GSI group, n = 10), or treadmill walking training group with random speed changing (RSC group, n = 11). All participants performed 60 min of comprehensive rehabilitation therapy (5 × / week for 6 weeks). In addition, each group received either GSI or RSC treadmill walking training for 20 min (5 × / week for 6 weeks, total 30 sessions). Gait and respiratory function were measured before and after the 6-week training.

RESULTS: Both groups showed significant improvements

in the 10-m walking test, 6-minute walking test, timed up and go test, forced vital capacity (FVC), forced expiratory volume in 1 second, and maximal voluntary ventilation after training ($p < .05$). The GSI group showed a significantly greater increase in the FVC than the RSC group (+14.8 L vs. +12.5 L, $p < .05$).

CONCLUSION: Both training methods can be effective for improving the walking and respiratory functions of stroke patients. However, our results indicate that treadmill walking training with gradual speed increase might be a more effective method for improving the respiratory function (FVC) than treadmill walking training with random speed changing.

Key Words: Exercise, Gait, Respiration, Stroke

I. Introduction

Ischemic or hemorrhagic cerebrovascular disease damages the brain tissue, affecting not only motor functions, but also sensory functions and psychological disorders, thereby making it difficult to perform daily activities [1]. Stroke patients require special attention due to impaired walking function, which is a necessity for maintaining an independent life [2]. Gait impairment in stroke patients results in decreased gait stability and gait speed [3]. In addition, motor and sensory paralysis due to stroke weakens

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the muscular strength of the diaphragm, intercostal muscles, and abdominal muscles of stroke patients. This limits the breathing function of stroke patients, which in turn reduces gait endurance [4].

Treadmill gait training is excellent in improving gait function due to the application of appropriate timing to the gait cycle of both lower extremities, and the possibility of increasing the hip joint extension and adjusting gait intensity when walking [5-7]. In addition, since it is effective in reducing energy consumption and cardiovascular burden, and increasing maximum oxygen intake, it is widely used as an effective intervention method for improving walking endurance [8,9].

Previous reports indicate that improving walking speed in the gait training program has an excellent effect on improving muscle strength, endurance, coordination, and postural control [10,11]. Treadmill gait training is therefore being actively implemented as an intervention method to increase gait speed during gait training for stroke patients. By applying speed change during treadmill gait training for stroke patients, Lee and Oh [12] compared the effects of treadmill gait training at a comfortable speed and at a high speed. Lee [13] also compared the effects of treadmill walking training with progressively increasing speed, and continuous treadmill walking training without changing the speed. To date, studies on treadmill speed change have mainly focused on continuous speed and gradual increase in speed. In particular, it is reported that compared to variable speed, treadmill gait training at a constant speed decreases the degree of exercise concentration or interest in the process of learning gait movements [14].

This study was therefore undertaken to examine and propose a more effective treadmill speed control training protocol for improving the function of stroke patients, by comparing the effects of treadmill walking training with gradually increasing speed, and treadmill walking training with random changing of speed. We hypothesized that treadmill gait training with a gradual speed change would

be more effective in improving gait and respiratory function, as compared to treadmill gait training with randomly changing speed.

II. Methods

1. Participants

The participant of this study were patients diagnosed with hemiplegic stroke and receiving inpatient treatment at the Bonifacio Rehabilitation Hospital in Daejeon Metropolitan City. The inclusion criteria for the participants were: stroke of more than 6 months, score greater than 24 on the Korean Mini-Mental Status Examination (MMSE-K), and could walk for more than 20 minutes on a treadmill speed of 0.8 km/h or more [15]. Exclusion criteria included history of fractures on the paralyzed or non-paralytic lower extremity, and history of heart and lung surgery within the last 3 months [9]. Totally, 86 patients with stroke were initially considered, and represented 70% of all patients with stroke admitted to our inpatient rehabilitation center; 65 patients were unable to participate in the study as they did not fulfill the inclusion criteria or met exclusion criteria. Finally, 21 patients who met the criteria for selection and exclusion in this study were enrolled. The 21 participants were assigned to either a gradual speed increase treadmill walking training group (GSI group, n = 10, mean age = 59.20 years) or a randomized controlled speed treadmill walking training group (RSC group, n = 11, mean age = 61.27 years); grouping was decided after lots were drawn by a 7-year experienced clinical therapist, who had no information about the study. All subjects were fully explained the purpose and method of this study, and voluntarily agreed to participate in the experiment. The study was performed in accordance with the Declaration of Helsinki (1975). This study was conducted after receiving approval of the Research Ethics Review Committee at Daejeon University (IRB: 1040647-201312-HR-052-03).

2. Intervention

A treadmill (TRAK K-200T, Lift gear, Seoul, Korea) with easy speed control was used for gait training, with gradual speed increase or random speed change. All subjects underwent comprehensive rehabilitation which included joint range of motion exercise, muscle strength exercise, balance training, and gait training, 60 minutes, 5 times a week, for 6 weeks. In addition, gradual speed increasing treadmill walking training or random speed changing treadmill walking training was imparted for 20 minutes, 5 times a week, for a total of 6 weeks. The treadmill walking training was supervised by a physical therapist having 7 years clinical experience, who was blinded to the study.

1) Gradual speed increasing treadmill gait training

To apply the gradual speed increasing treadmill gait training, a heart rate monitor (PM-45, Beurer, Germany) was used to measure the resting heart rate and the maximum heart rate ($220 - \text{age}$) [16]. Karvonen's formula [$\text{target heart rate} = \text{exercise intensity (\%)} \times [(\text{maximum heart rate} - \text{resting heart rate}) + \text{resting heart rate}]$] was used to apply the 40-70% exercise intensity of the maximum heart rate reserve presented by the American Society of Sports Medicine [17,18]. The treadmill speed, corresponding to each subject's maximum heart rate reserve of 40%, 50%, 60%, and 70%, was subsequently calculated. The starting walking speed of the treadmill was adjusted to 40% of the initial reserve heart rate, with gradual increase of speed every 5 minutes [19]. In the case of any complaints of difficulties with the increased speed, the speed was maintained at the previous stage.

2) Random speed changing treadmill gait training

For the application of random speed changing treadmill gait training, the treadmill speed corresponding to each participant's maximum heart rate reserve 40%, 50%, 60%, and 70% was calculated, similar to gradual speed increase

treadmill gait training. Walking training was performed for 20 minutes, by changing the calculated four treadmill speeds in a random order every 5 minutes. The random sequence speed was changed by the physical therapist every 5 minutes, according to the order in which the subject drew lots before training. In case of difficulty in maintaining continuous walking due to sudden increase or decrease in speed, the speed was maintained at the previous stage.

3. Outcome measures

1) Primary outcome measures

In order to evaluate gait function, a 10-m walking test, a timed up and go test, and a 6-minute walking test were performed. The 10-m walking test is a measure used to evaluate gait performance [20]. Barring the initial acceleration section and the end deceleration section of 2 m each, the walking speed in the middle 10 m, in a total 14 m flat walking path, was measured using a stopwatch. No feedback, such as instructions or encouragement, was provided during the test. A timed up and go test measures the functional mobility and balancing ability [21]. The time taken when the participant sits in a chair with armrests and walks a distance of 3 m from the chair with a start signal, and subsequently returns and sits back again, was measured. The 6-minute walking test determines the endurance of the walk [22]. It is a test that measures the walking distance for 6 minutes, and was measured by walking around a 20 m distance. There was no warm-up exercise before the test, and the walking speed and rest time during the measurement were self-adjusted according to the patient's ability. All gait functions were measured three times, and the average value was used.

2) Secondary outcome measures

A spirometer (Spirometer HI-801, CHEST MI INC, Japan) was used to evaluate respiratory functions. In this study, we measured the forced vital capacity (FVC), forced

expiratory volume in one second (FEV1), and maximum voluntary ventilation (MVV). All measurements were performed three times in total, and the maximum value was used for analysis [23]. FVC and FEV1 are general indicators that assess respiratory function [24], and MVV is an indicator that assesses endurance of inspiratory muscles [25].

For the measurement of FVC, participants were asked to sit in a chair, tilt their upper body forward about 15 degrees, and wear nose tongs for the use of closed circuit. After biting the mouthpiece and wrapping it with lips, they were induced to exhale air with maximum force after maximum inhalation, and the subject was encouraged to exhale until the end. The examiner made sure that the subject's lips were completely covered, and nothing was blocking the mouthpiece to prevent air leakage as much as possible. FEV1 was recorded after maximum inspiration in the same posture and conditions as for the FVC. In order to check whether FEV1 is the value obtained from the maximum curve, the FVC was set to be less than 5%, and the time to reach the peak expiratory flow rate was set to be less than 120 ms. The MVV was measured in the same posture and conditions as the FVC test. Inhalation and exhalation were repeated 15 to 20 times for 12 seconds, and the maximum amount of ventilation that the subject could perform was measured.

4. Data analysis

The demographic variables were analyzed at the baseline using appropriately an independent t-test or Chi-Square test. The Shapiro-Wilk test was used to assess the normality. To determine the source of significant differences between pre- and post-training, simple contrasts were conducted for each significant time for the main effects. Two-way repeated measures analysis of the variance (ANOVA) was applied to compare the mean differences between the two groups (GSI group and RSC group) as the first factor, and time (pre training and post training) as the second factor. SPSS ver. 25.0 (IBM Corp, Armonk, NY, USA) was used for the analysis, and statistical significance was accepted for p values $< .05$.

III. Results

Demographic characteristics of the groups are presented in Table 1. No significant intergroup difference was observed for sex, age, weight, height, and paretic side ($p > .05$).

Table 2 shows the changes in walking functions (primary outcomes: 10-m walking test, timed up and go test, and 6-minute walking test) and respiratory functions (secondary outcomes: FVC, FEV1, and MVV) after subjecting the groups to respective intervention. Significant improvements

Table 1. General Characteristics of the Participants at Baseline

Demographic Features	GSI Group	RSC Group	χ^2/t	P
Sex (male / female)	6 / 4	6 / 5	.064	.801
Age (years)	59.20 \pm 9.30	61.27 \pm 10.88	.467	.646
Height (cm)	160.50 \pm 11.26	166.09 \pm 8.44	1.296	.211
Weight (kg)	63.30 \pm 10.70	67.00 \pm 8.96	.862	.399
Paretic Side (right / left)	3 / 7	5 / 6	.531	.466
Onset Duration (months)	50.50 \pm 29.17	61.09 \pm 35.36	.744	.466
Stroke Type (infarction / hemorrhage)	6 / 4	5 / 6	.444	.505

Values are expressed as frequency or mean \pm SD.

GSI group, treadmill walking training with gradual speed increase; RSC group, treadmill walking training with random speed changing.

Table 2. Pre- to Post-training Changes in the Walking and Respiratory Variables in the Two Groups

	GSI Group (n = 10)			RSC Group (n = 11)			F (time × group)	I ²
	pre	post	% Change	Pre	post	% Change		
10-m Walking Test (sec)	13.84 ± 7.11	12.43 ± 6.68	-10.19 [†]	19.99 ± 10.56	19.11 ± 10.84	-4.41 [†]	2.851	.130
6 MWT (meter)	290.40 ± 126.90	308.10 ± 131.93	+6.10 [†]	207.55 ± 96.85	222.27 ± 97.77	+7.09 [†]	.956	.048
TUG (sec)	17.43 ± 9.93	15.42 ± 8.56	-11.54 [†]	20.54 ± 10.25	18.94 ± 9.12	-7.79 [†]	.490	.025
FVC (L)	2.70 ± 1.19	3.10 ± 1.08	+14.81 [†]	2.42 ± .65	2.66 ± .68	+9.92 [†]	.790*	.263
FEV1 (L)	2.02 ± .90	2.21 ± .84	+9.41 [†]	1.92 ± .39	2.18 ± .38	+13.54 [†]	.706	.036
MVV (L)	71.26 ± 33.22	76.86 ± 31.01	+7.86 [†]	85.98 ± 25.89	92.54 ± 27.24	+7.63 [†]	.580	.030

Values are expressed as mean ± SD.

GSI group, treadmill walking training with gradual speed increase; RSC group, treadmill walking training with random speed changing; 6 MWT, 6 minutes walking test; TUG, timed up and go; FVC, forced vital capacity; FEV1, forced expiratory volume at one second; MVV, maximal voluntary ventilation.

*Significant difference ($p < .05$) between the GSI group and RSC group.

[†]Significant difference ($p < .05$) from pre-intervention.

in the 10-m walking test, timed up and go test, 6-minute walking test, FVC, FEV1, and MVV were observed after training in both groups ($p < .05$). The GSI group showed a larger increase in the FVC than the RSC group (+ .4 L vs. + .3 L, $F(1, 19) = 6.790$, $p = .017$, $I^2 = .263$). However, values obtained for the 10-m walking test, timed up and go test, 6-minute walking test, FEV1, and MVV after training in the GSI and RSC groups were not significantly different ($p > .05$).

IV. Discussion

This study was undertaken to compare the effects of treadmill gait training with gradually increasing speed, and gait training with randomly changing speeds, on the gait and respiratory function changes in stroke patients. Evaluation of gait function revealed significant improvement after intervention in both groups, when considering the 10-m walking test, timed up and go test, and 6-minute walking test; however, no significant intergroup difference was observed for the amount of change. Munari et al. [9] compared the effects of treadmill gait training at slow and high speeds on gait function in stroke patients. They

reported that in the 6-minute walking test, the treadmill gait training at high speed increased 58 m more than training at slow speed. In the 10-m walking test, the treadmill gait training at high speed was reduced by 1.7 seconds. These results indicate that treadmill gait training conducted at a high speed is more effective in improving the gait function of stroke patients, as compared to walking training at a slow speed. The two methods of treadmill training conducted in this study also showed improved gait function. Both techniques were ascertained to show similar results because they were applied at a high speed of up to 70% of the maximum heart rate. In addition, Jang [26] compared exercise concentration in stroke patients with and without changes in walking speed, and reported that walking training in which the walking speed is changed was more effective in inducing the concentration of exercise in stroke patients than in the case where the speed remained constant. It was therefore considered that improvement of gait function of the two training methods in the current study is due to improved exercise concentration during gait training.

When comparing the respiratory function, significant changes were determined for FVC, FEV1, and MVV after

intervention in both groups. In the FVC, the group subjected to gradual speed increasing treadmill gait training showed a more significant increase of 2.3 L, as compared to random speed changing treadmill gait training. In both training methods, the result of improved respiratory function in stroke patients after intervention compared to before intervention is thought to be due to the improved excessive energy consumption while walking [27]. Munari et al. [9] compared the effects on VO₂ max and walking energy cost of treadmill gait training at high and slow speeds in stroke patients. They reported that the faster speed increased VO₂ max by 3.73 mL/kg/min more than the slow speed, and walking energy consumption decreased by 10.9 mL/kg/km. These results are similar to the results obtained in this study, which shows improved respiratory function at high speed of up to 70% of the maximum heart rate reserve in both training methods. Seethapathi et al. [28] reported that changing the walking speed on a treadmill consumes 6-20% more calories than walking at a constant speed. They reasoned increased calorie consumption and energy metabolism in the process of adapting to the changing walking speed. Therefore, as determined in the current study, the result of increasing lung function in stroke patients subjected to changing treadmill speed, in either a gradual or random order, could be due to an increase in energy metabolism. In this study, the gradual speed increasing treadmill gait training showed a greater improvement in FVC than random speed changing treadmill gait training. These results are possibly because gait training, in which the treadmill speed is gradually increased, provides a more favorable environment for lung function adaptation, than training conditions in which the treadmill speed is randomly increased or decreased [29]. FVC, along with FEV₁, is a useful measurement variable for diagnosing patients with respiratory problems and determining their recovery [30]. In addition, the VO₂max, walking speed, and walking endurance of stroke patients correspond to about 50%, compared to normal people [31]. Therefore,

our results indicate that gradual speed increasing treadmill gait training is a more effective intervention method for the recovery of lung function in stroke patients, as compared to random speed changing treadmill gait training.

Since this study was not conducted with many subjects, there is a limitation in that it cannot provide results with high power. This study compared the effects of interventions for a relatively short intervention period of 6 weeks. These results are unable to generalize and interpret the effect of the intervention since it is difficult to completely control psychological variables when measuring the heart rate. However, this study has promising clinical significance, in that it investigates the effects of treadmill gait training program conducted in a more difficult environment, by applying gradual increase in speed and randomly changing speed. Further studies that complement the limitations of this study need to be performed in future, and current study results can be used as basic data for application of an intervention method that can be generalized to improve gait and respiratory function in stroke patients.

V. Conclusion

This study was conducted to compare the effects of gradual speed increasing treadmill gait training, and random speed changing treadmill gait training, on gait and respiratory function in stroke patients. Both groups showed effective improvements in the gait function and respiratory function of stroke patients, with the gradual speed increasing treadmill gait training group being more efficacious in improving the respiratory function. Therefore, in the case of treadmill walking training to improve respiratory function in stroke patients, it is considered more effective to gradually increase the speed rather than apply randomly changing speeds.

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