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Original Article

Lower limb muscle activities and gain in balancing ability following two types of stair gait intervention in adult post-chronic stroke patients: A preliminary, randomized-controlled study

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ABSTRACT

Objectives: This study aims to compare the changes in lower limb muscle activities after stair ascending and descending training at two different heights of stairs in patients with chronic stroke and to suggest a stair height which is more effective in improving the strength and balancing ability of these patients.

Patients and methods: Between November 2016 and February 2017, a total of 20 patients (14 males, 6 females; mean age 56 years; range, 52 to 61 years) with hemiparesis were included in this randomized-controlled study. The patients were randomly assigned to the 10- or 15-cm stair height group (10- and 15-cm groups, respectively; n=10 in each). Both groups received comprehensive rehabilitation therapy and additionally performed stair gait training for 30 min four times per week for a total of six weeks. Balancing abilities and the activities of the paralyzed lower limb's rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius during stair ascending were measured before and after the stair gait training.

Results: During stair ascent, the 15-cm group showed significantly greater muscle activities of the rectus femoris, biceps femoris, and tibialis anterior than the 10-cm group ($p<0.001$, $\eta^2=0.115$; $p=0.001$, $\eta^2=0.022$; and $p=0.001$, $\eta^2=0.036$, respectively).

Conclusion: Our study results suggest that ascending stairs with 15-cm step height results in a greater muscle activity than with a 10-cm step height.

Keywords: Balance, chronic stroke, muscle activity, stair gait training, stair height.

Stroke is a disease in which cerebral function is lost due to blockage of blood supply or bleeding of brain tissue.[1,2] It is associated with various neurological dysfunctions that affect movement, sensation, postural control, language, cognition, and perception depending on the location of the brain lesion and degree of damage.[3,4]

The reduction in the walking ability of patients with hemiplegia is mainly caused by weakness of the lower limbs,[5] which occurs in the flexor muscles of the ankle, knee, and hip joints;[6,7] hence, strengthening of the leg muscles and improvement of function through effective management, such as strength and coordination,[8] are the mainstays of the management.

Stairway walking is a functional activity which is frequently encountered in activities of daily living.[9] Stairway walking is similar to walking on a flat ground in that there is a reciprocal movement of both legs and a double stance phase.[10] However, since stairway ascending moves the center of gravity of the body in the anterior and vertical directions, more strength and postural control ability of the lower limb is needed than while walking on a level surface.[11] A previous study has reported that knee joint extension moments

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are up to two times greater during stair ascending than during level-ground walking.[12,13] Therefore, stair walking training is a representative task-oriented training method for improving leg strength and postural control of patients with hemiparetic stroke in indoor and outdoor environments.[14]

Rehabilitation training for improving the stair-climbing function of patients with stroke is usually performed through the corner exercise staircase.[15] However, some stairway walkers have different heights of 10 or 15 cm,[15,16] and the regulation of the Welfare for the Disabled Law for stairway height of less than 18 cm is also vague, making it difficult to produce a consistent stairway walker.[17,18] Therefore, the height of the stairway walker that would an opportunity to improve the function of the stroke patient should be proposed. Thus far, studies have been conducted on the effects of stair walking training to improve the function of patients with stroke. Comparative studies on the muscle activity of leg muscles during gait on the ground and on the stairs,[19] lower limb muscle activity according to various foot contact areas during ascending the stairs,[16] and muscle activity of the lower extremity muscles while walking on ramps versus stairs have been conducted.[15,20] However, no study has examined the balancing ability and muscle activity of the lower extremity muscles during stair ascending according to different stair heights.

In the present study, we hypothesized that stair walking training at stair heights of 10 and 15 cm would produce greater balance and muscle activity in the paretic lower limb, compared to the baseline variables and that there would be a difference in functional recovery between the two heights. Therefore, the aim of this study was to compare the lower limb muscles' activities and balancing ability using two different stairway heights for the walking training of patients with hemiparetic chronic stroke and to identify a stair height that is more effective in improving strength and balancing ability.

PATIENTS AND METHODS

This preliminary, randomized-controlled study was conducted in a tertiary hospital between November 2016 and February 2017. A total of 58 patients hospitalized with hemiparetic stroke were screened for the study. *Inclusion criteria were as follows:* having a diagnosis of hemiparesis for more than six months, being able to walk more than 10 meters independently on a flat ground without an assistive walking device such as a cane, being able to go up and down stairs independently with or without handrail support, being able to climb two stairs within five sec without using the handrails, and having a Mini Mental State Examination (MMSE)-Korean version score of ≥24 points who could understand and follow the instructions given by the researcher. Those with other neurological or orthopedic conditions other than stroke and those whose paralyzed dorsiflexor had a muscle tone of Grade ≥2 according to the modified Ashworth scale[21] were excluded. A total of 35 patients did not meet the inclusion criteria and three patients refused to participate. Finally, 20 patients (14 males, 6 females; mean age 56 years; range, 52 to 61 years) with hemiparesis were included in the study. The study was conducted using a randomized design. For randomization, 20 sealed envelopes were prepared in advance and marked inside with 1 (n=10) or 2 (n=10), which indicated the 10-cm group (stair walking training with stair height of 10 cm) or the 15-cm group (stair walking training with stair height of 15 cm), respectively. An independent therapist not involved in the study performed the randomization.

A written informed consent was obtained from each patient. The study protocol was approved by Daejeon University Research Ethics Committee (1040647-201608-HR-002-03). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Interventions

All patients underwent neurodevelopmental treatment consisting of joint mobilization, muscle stretching, and strengthening, and functional training for 30 min per day for five times per week. In addition, stairway walking training was performed for 30 min, four times per week for a total of six weeks.

The stairway gait training was performed on a specially-made staircase with a width of 150 cm, length of 28 cm, and height of either 10 or 15 cm. The stairway walk training was conducted with the following instruction: "Go up and down the stairs comfortably." When climbing the stairs, all patients were asked to walk in the order of affected foot followed by the lesser affected foot and to walk barefoot at a self-selected comfortable speed on a four-step wooden staircase.[16,22] For safety purposes, the staircase was positioned with the patient's non-affected side next to a wall. The patients were instructed to walk in steps on the staircase without using the handrails. The therapist always supervised or minimally assisted the patient to prevent accidents such as falls. During stair climbing, the patients walked on level ground for 3 meters before stepping onto the staircase and continued walking to the end of an elevated walkway. When descending the stairs, the patients walked from the end of the elevated walkway and continued walking on level ground to the starting position.[4,22,23]

Outcome measures

Outcome measures were performed by an examiner who did not participate in the randomization and blinded to the patient groups. All tests were performed in a separate space in the physical therapy room.

The Berg balance scale (BBS) and Timed Up and Go (TUG) tests were performed to measure the patients' balancing ability.[24,25]

The MP150 surface electromyography (EMG) system (Biopac System Inc., CA, USA), which has a good reliability and validity, was used to measure the activities of the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius during stair ascending.[26,27] To minimize skin resistance to the EMG signal of the muscle area, the hairs around the attachment area were removed. The skin stratum was, then, rubbed three or four times with a thin sandpaper, and finally, the skin was wiped with alcohol-soaked cotton. The Ag-Ag/Cl surface electrode mode (Biopac System Inc., CA, USA; diameter 2 cm) was used for EMG signal acquisition. Each electrode was attached parallel to the muscle belly of the attachment muscle.[28] The samples were secured at 1,000 Hz using a personal computer. The raw surface EMG signals were band-pass filtered between 30 and 500 Hz to minimize noise. The collected EMG signals were analyzed using the Acqknowledge 3.8.1 software (Biopac System Inc., CA, USA). For normalization of the EMG signal, the collected EMG signals were converted to root mean square (RMS), and for normalization of the RMS values, the percentage of maximum isometric contraction (% MVIC) values, ranging from 0 to 100%, were obtained by dividing the RMS values by the MVIC. For acquisition of MVIC data, the EMG electrodes were placed on the muscles and the patients were asked to perform four MVIC exercises against manual resistance provided by the researcher: *(i)* knee extension while sitting with hip and knee at 90° of flexion, *(ii)* knee flexion in prone with knee at 90° of flexion, *(iii)* ankle dorsiflexion while sitting with hip and knee at 90° of flexion and ankle touching the floor, and *(iv)* ankle plantar flexion while standing on the affected leg.[29] Joint angles in these positions were verified with a manual goniometer. The patients completed one or two warm-up isometric muscle contractions at 50 and 75% of their perceived maximal effort with one min of rest in between each muscle contraction. After each warm-up isometric muscle contraction, the patients completed five sec maximal

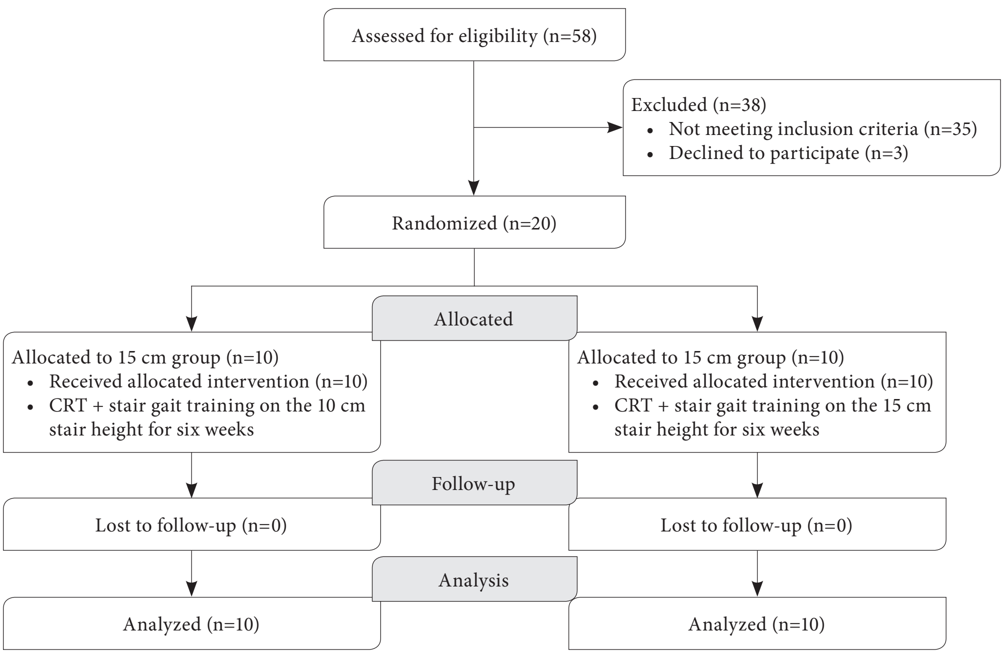

Figure 1. CONSORT diagram showing study flow.

CRT: Comprehensive rehabilitation therapy.

isometric leg (e.g., knee extension, knee flexion, ankle dorsiflexion, and plantar flexion, respectively) three times with one min of rest between the attempts to avoid fatigue.[30] The mean value was calculated, and EMG data were excluded for one sec before and one sec after the completion of each attempt.

In this study, the time required for the two-step climbing was approximately five sec. Considering this, we measured the muscle activity for stance and swing phase for seven sec during stair ascending on usually used stairs (width: 150 cm; length: 25 cm; height: 12 cm), and the data for five sec, except the first and last seconds, were used for data analysis.

All variables were measured before and after stair walking training for six weeks. All data measured before and after six weeks of training were collected three times for each measurement variable, and the mean value was finally calculated. To minimize fatigue induced by several measurements, an adequate rest time was given between the measurements. If the patient complained of fatigue during the measurement or asked for more breaks, the measurement was discontinued and additional rest was given.

Statistical analysis

Statistical analysis was performed using the IBM SPSS for Windows version 23.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were expressed in mean ± standard deviation (SD) or number and frequency. The Shapiro-Wilk test was used to test the data for normality. To compare the general characteristics at baseline between the two groups, independent t-test was used to analyze continuous variables and the Fisher's exact test was used to analyze dichotomous variables. Paired t-tests were conducted for each significant time for the main effects to identify the source of the significant difference between pre- and post-training. Two-way repeated measures analysis of the variance (ANOVA) was carried out to compare the mean differences of BBS and TUG between the two groups (10- and 15-cm groups) as the first factor and time (pre- and post-training) as the second factor. For variables with a significant difference at baseline test between the two groups, analysis of covariance (ANCOVA), i.e., controlling for the pretest difference, was used to examine which group showed a significant better post-test performance when there was a statistical significance in the pretest of each outcome variable

TABLE 1
Baseline demographic and clinical characteristics of patients

	10-cm group		15-cm group		
	n	Mean±SD	n	Mean±SD	*p*
Sex					1.000
Male	7		7		
Female	3		3		
Age (years)		57.4±10.4		56.0±10.0	0.752
Height (cm)		162.9±7.7		164.5±9.2	0.679
Weight (kg)		60.8±7.3		63.1±9.2	0.545
Paretic side					1.000
Right	6		6		
Left	4		4		
Onset duration (month)		30.5±9.9		33.3±9.9	0.535
Stroke type (infarction/hemorrhage)	6/4		7/3		1.000
Berg balance scale (score)		29.8±4.7		33.2±4.4	0.114
Timed up and go (sec)		17.6±3.3		16.2±2.0	0.281
Muscle activity					
Rectus femoris		35.8±0.96		38.8±0.5	0.012
Biceps femoris		26.2±1.2		32.0±1.0	0.002
Tibialis anterior		16.4±0.96		27.3±1.0	<0.001
Gastrocnemius		38.5±0.83		49.9±0.9	<0.001

SD: Standard deviation; Muscle activity (% of maximal voluntary isometric contraction). For comparison between groups, Fisher's exact test was used for dichotomous variables or independent t-test for continuous variables.

TABLE 2
Comparison of functional evaluation results between the two groups

	10-cm group (n=10)		15-cm group (n=10)				
	Preoperative	Postoperative	Preoperative	Postoperative			
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	F (time × group)	F (ANCOVA)	*p*
Berg balance scale (score)	29.8±4.7	32.9±3.6†	33.2±4.4	36.0±4.0†	0.134	-	0.007
Timed Up and Go (sec)	17.6±3.3	15.1±2.4†	16.2±2.0	14.8±1.9†	2.151	-	0.107
Muscle activity							
Rectus femoris	35.8±1.0	34.5±1.0	38.8±0.5	40.5±0.8†	-	29.544*	0.115
Biceps femoris	26.2±1.2	27.8±1.0	32.0±1.0	34.9±0.9†	-	16.481*	0.022
Tibialis anterior	16.4±1.0	17.1±1.1	27.3±1.0	29.6±0.8	-	16.716*	0.036
Gastrocnemius	38.5±0.8	44.0±0.8†	49.9±0.9	51.5±0.9	-	3.286	0.255

SD: Standard deviation; Muscle activity (% of maximal voluntary isometric contraction); * Significantly different as controlling for the pretest difference (p<0.05); † Significantly different compared to baseline (p<0.05).

between the two groups. A *p* value of <0.05 was considered statistically significant. An eta-squared (η^2) was calculated to identify the magnitude of the effect sizes, and it was interpreted as small (0.02), medium (0.13), or large (0.26).[31,32]

RESULTS

The study flow chart is shown in Figure 1. All patients, 10 in the 10-cm group and 10 in the 15-cm group, completed the six-week intervention. No significant differences in the pretest demographic and clinical characteristics were found between the two groups, except for the muscle activities (Table 1).

Table 2 provides a summary of the balance and muscle activity parameters before and after training in the two groups. A significant improvement in the BBS and TUG was observed after stair walking training in the two groups ($p<0.05$); however, there were no significant difference in the time × group interaction. The ANCOVA for the muscle activities showed significant and large effects. After the intervention, the 15-cm group had significantly greater rectus femoris, biceps femoris, and tibialis anterior activities ($F[1, 18]=29.544$, $p<0.001$, $\eta^2=0.115$; $F[1, 18]=16.481$, $p=0.001$, $\eta^2=0.022$; and $F[1, 18]=16.716$, $p=0.001$, $\eta^2=0.036$, respectively) than the 10-cm stairway walking training group, but not on the gastrocnemius.

DISCUSSION

In the present study, we found that the group with stair walking training at 15-cm high had higher rectus femoris, biceps femoris, and tibialis anterior activities than the group with stair walking training at 10-cm high. This finding possibly indicates that the step height of 15 cm is more effective than the step height of 10 cm for improving the muscle strength of paralyzed lower leg muscles.

Roh and Park[17] analyzed body movements during stair climbing of elderly. The 18-cm step height required an excessive force while ascending and descending the stairs, and reported that it was difficult to maintain body balance due to the weakness of the body's core muscle. They strongly advocated designing the height of stairs for elderly individuals to be 15-cm or less. In another study, Kim[33] reported that vertical movements of 9.7 to 12.4-cm in the ankle joint were observed in normal adults while climbing stairs. Nadeau et al.[12] also reported that knee joint extensor moments were up to two times greater during stair ascending than during level-ground walking. Reeves et al.[34] showed that ankle plantar flexor and knee extensor played a pivotal role in moving the body's mass upward and forward toward the next step during stair ascending. During stair climbing, the rectus femoris and tibialis anterior showed a higher muscle activity than the medial part of the gastrocnemius, which is the posterior muscle, and the biceps femoris showed the highest activity in the one-legged stance phase during stair walking.[19] In addition, previous studies demonstrated that, while stair ascending, a strong knee extensor force was generated to lift the body upward.[11] Considering the results of these studies,[11,12,19,34] 15-cm stair walking training was more effective in increasing the rectus femoris muscle activity than 10-cm stair walking training, and the 15-cm stair height was possibly considered the height that facilitates normalization of the muscle contraction mechanism of the paralyzed lower limb and supports postural control of the one-legged stance phase. Therefore, the 15-cm stair height could be considered a more convenient height for moving the body upward than a 10-cm stair height.

Furthermore, stair walking training was effective in increasing the activity of the rectus femoris in individuals in their twenties, and it was effective in increasing the muscle activity of the biceps femoris in elderly individuals.[35,36] These previous studies showed that the knee joint flexor and extensor activities are active while walking on the stairs, which support the results of our study that a 15-cm stair height is more effective for lower limb muscle activation than the 10-cm stair height.

Paralyzed leg due to a stroke makes the dorsiflexion inadequate in the swing phase of gait. Therefore, it is important to induce tibialis anterior muscle contraction in rehabilitation training program for improvement of the gait function.[37] Hemiplegia due to stroke changes the normal balance of cortical excitability of the cerebral hemisphere. Therefore, it needs to improve walking speed to improve cortical excitability, and tibialis anterior muscle activation is needed to improve walking speed.[38] The results of the study comparing the TA muscle activity according to the gait condition for normal adults suggested that the training to increase the TA muscle activity during the stair climbing had a positive effect on making the stair walking more efficient.[39] Therefore, these previous studies positively support the results of this study that a 15-cm stair height is more effective for tibialis anterior muscle activation than the 10-cm stair height.[37-39]

Nonetheless, this study has some limitations. First, it failed to identify the effects of continuous intervention after the six-week intervention. In this study, the effect sizes for the main variables (step height) were 0.12, 0.02, and 0.04, respectively, indicating medium or small explanatory power.[31] These results can be attributed to the small sample size and increasing the explanatory power of the main effect by obtaining more subjects is necessary. In addition, the EMG results of the lower limb muscles measured during stair climbing is a variable which includes the active contraction of lower extremity muscle in addition to the activities of a spastic muscle. Therefore, careful attention should be paid to the clinical implementation of the EMG results in the study. Thus, it is early to apply the results of our study to a general rehabilitation program for patients with hemiparetic stroke. However, this study is clinically valuable, as it describes the training effect according to the height of stairs in stair walking training.

In conclusion, our study results suggest that stair walking training at a stair height of 15-cm is more effective for increasing the muscle activity of the paralyzed lower limb than at a stair height of 10-cm. Therefore, stair walking training at a stair height of 15-cm may be an effective intervention to improve the paralyzed leg strength of patients with stroke.

Declaration of conflicting interests

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