Original Article

Effects of Progressive Body Weight Support Treadmill Forward and Backward Walking Training on Stroke Patients' Affected Side Lower Extremity's Walking Ability

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Abstract. [Purpose] The purpose of the present study was to examine the effects of progressive body weight supported treadmill forward and backward walking training (PBWSTFBWT), progressive body weight supported treadmill forward walking training (PBWSTFWT), progressive body weight supported treadmill backward walking training (PBWSTBWT), on stroke patients' affected side lower extremity's walking ability. [Subjects and Methods] A total of 36 chronic stroke patients were divided into three groups with 12 subjects in each group. Each of the groups performed one of the progressive body weight supported treadmill training methods for 30 minute, six times per week for three weeks, and then received general physical therapy without any other intervention until the follow-up tests. For the assessment of the affected side lower extremity's walking ability, step length of the affected side, stance phase of the affected side, swing phase of the affected side, single support of the affected side, and step time of the affected side were measured using optogait and the symmetry index. [Results] In the within group comparisons, all the three groups showed significant differences between before and after the intervention and in the comparison of the three groups, the PBWSTFBWT group showed more significant differences in all of the assessed items than the other two groups. [Conclusion] In the present study progressive body weight supported treadmill training was performed in an environment in which the subjects were actually walked, and PBWSTFBWT was more effective at efficiently training stroke patients' affected side lower extremity's walking ability.
Key words: Support treadmill training, Forward walking, Backward walking

INTRODUCTION

Stroke patients have characteristic walking patterns showing long gait cycles, low walking speeds, differences in stride length between the affected side step length and the unaffected side step length, and short stance phases and relatively long swing phases on the affected side[1]. The recovery of walking ability is an important element for the improvement of quality of life and the achievement of functional independence in daily life, and is one of the most important goals not only for patients, but also for therapists[2].

For the walking rehabilitation training of stroke patients, body weight supported treadmill walking training is widely used in clinics[3].

Previous studies have stated that body weight supported treadmill training is more helpful for walking ability than walking training on the ground, because it extends the affected side lower extremity's body weight support periods, enhances symmetric postures, and induces constant activity patterns in the calf muscles[4, 5]. Body weight supported treadmill walking training helps maintain proper postures, and these postures play a role in increasing body weight support by the damaged lower extremity while providing more proprioceptive sense information input[6].

In general, although forward walking is widely performed as a method of walking training, some studies have recently investigated the effects on stroke patients of backward walking[7]. In an exercise physiological study, Nadeau et al.[8] reported that backward walking and forward walking had different exercise physiological characteristics and that the temporospatial characteristics of backward walking could increase the frequency of, and endurance for walking.

Among the stroke patient-related studies of body weight supported treadmill walking training, clinical studies have been conducted comparing treadmill walking training and walking on the ground[1, 4, 9], increasing walking speeds[10], intervention methods that gradually increase the gradients of the treadmill to increase the intensity of training[11], whether treadmills should be used or not[12], and speed-dependent treadmill training methods[13].

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These studies have reported that treadmill walking training is effective at improving walking. However, studies of body weight support, walking speeds, and walking directions related to body weight supported treadmill walking training for improving stroke patients' walking are still insufficient. To improve the effects of body weight supported treadmill walking training, gradual increases in the degree of body weight support[14] and walking directions[7, 15] are important. In particular, with regard to the improvement of stroke patients' walking, existing body weight supported treadmill walking training is conducted with uniform training parameters, such as forward walking and speed, making it difficult to change the stroke patients' walking patterns, and no studies have conducted body weight supported treadmill training and forward and backward walking training simultaneously to investigate the improvement of walking ability.

Therefore, the purpose of this study was to examine the effects of progressive body weight supported treadmill forward and backward walking training on changes in the stroke patients' affected side lower extremity's walking ability, and to examine the differences between progressive body weight supported treadmill forward and backward walking training groups in order to present diverse therapeutic protocols for improving stroke patients' walking and enhancing their functionality.

SUBJECTS AND METHODS

This study was conducted with 36 stroke patients in the rehabilitation center of a general hospital located in Korea as subjects. To minimize selection bias, the patients were randomly assigned to three groups. The selection criteria were: patients who medically had had stroke for at least six months; had no joint contracture, pain, or fractures in their musculoskeletal system, or hemianopia based on their medical records; and had functional gait index scores exceeding three points. All subjects understood the content of the study and voluntarily participated in the study. This study was approved by Institutional Human Research Review Board of Sahmyook University.

Walking tests were conducted using a walking analyzer (OptoGait, MicrogateS.r.l, Italy, 2010) to collect data for the quantitative walking analysis of the patients' walking characteristics. The temporospatial characteristics of walking that comprise affected side step length, affected side stance phase, affected side swing phase, and affected side walking time were analyzed. To remove inter-tester differences, all measurements were performed by one skilled physical therapist. The temporal symmetry index was calculated using the formula: 2×[(affected single-limb support − unaffected single-limb support) / (affected single-limb support + unaffected single-limb support)]×100[7, 16, 17]

The study was conducted over of six weeks from June to August 2013. Progressive body weight supported treadmill walking training was performed for three weeks, and the subjects were evaluated after the three weeks of training. As a follow-up test, the subjects were evaluated six weeks after the beginning of the training to examine the persis-

tency of the exercise effects. The subjects were randomly divided into a PBWSTFBWT group of 12 subjects, a PBWSTFWT group of 12 subjects, and a PBWSTBWT group of 12 subjects, which performed their respective regimes 30 minutes, six times per week.

The PBWSTFBWT group performed forward and backward walking on treadmill while wearing a suspension system, the degree of body weight support was progressively decreased from 40% of body weight in the first week of the training program to 30% in the second week and 20% in the third week[4, 18, 19]. The participants' average forward walking speeds ranged from 0.6 to 1.0 km/hr, and their average backward walking speeds ranged from 0.4 to 0.9 km/hr. The mean walking speeds of the PBWSTFWT, PBWSTBWT, and PBWSTFBWT groups were 0.71±0.20, 0.75±0.31, and 0.67±0.16 km/h, respectively, and there were no significant differences among the groups. The mean speed of forward walking in the PBWSTFWT group started at 0.71±0.20 km/h and ended at 0.85±0.22 km/h, and in PBWSTBWT group the mean speed of backward walking started at 0.57±0.17 km/h and ended at 0.67±0.16 km/h, and in PBWSTFBWT group the mean speed of forward and backward walking started at 0.67±0.16 and 0.53±0.09 km/h, respectively, and ended at 0.86±0.22 and 0.63±0.09 km/h, respectively. The mean weight support during the intervention was progressively reduced from 40 to 20%, decreasing 10% weekly. For the exercise intensity, individual gait speeds were changed at the same changes of body weight support. The patients initially selected a treadmill walking speeds that they considered appropriate while walking on the ground, and when each patient could stably walk for 20 seconds or longer[20], the treadmill walking speed was increased by 0.1 km/hr each time[21]. Two physical therapists participated in the training to help the subjects with the walking training. One physical therapist took a position right behind the subject to help the subject with proper body weight support, and the other physical therapist took a position on the side of the subject's affected leg to assist the subject's steps and control the lower extremity movements during the swing and stance phases. They manually corrected the subject's forward walking patterns for 15 minutes and backward walking patterns for 15 minutes. When a patient showed fatigue, signs of pain, abnormality of breathing, or change in complexion after beginning the walking training, a rest of five minutes was allowed[22].

The PBWSTFWT group and the PBWSTBWT group performed forward walking training for 30 minutes and backward walking training for 30 minutes, respectively, and the other parts of their training were implemented in the same way as for the PBWSTFBWT group.

All statistical analyses in this study were conducted using PASW Statistics 18.0 for Windows. Among the general characteristics of the three groups, sex, diagnoses, paretic side, ankylosis, and whether walking aids were used were tested using the χ^2 test. The homogeneity of the dependent variables, such as age, height, weight, and Korean Mini-Mental State Examination scores, among the three groups were tested using one-way analysis of variance (ANOVAs) before the training. Repeated measures ANOVA was con-

ducted to compare the differences between the first three weeks of the training and the three weeks of follow up within each of the groups, and to compare the differences between pairs of groups before the training, three weeks after the beginning of training, and six weeks after the beginning of training. The Bonferroni test was used as a post-hoc test of the differences between the groups, as analyses of covariance (ANCOVAs) for the variables that showed significant differences during the treatment period. The statistical significance level of all data was chosen as $\alpha = 0.05$.

RESULTS

The general characteristics of the study subjects are shown in Table 1.

According to the results of this study, all three groups showed significant changes in the characteristics of the affected side lower extremity after the 3 weeks of training ($p<0.05$). In the comparison of the three groups, while the affected side stance phase, affected side swing phase, affected side single support, and symmetry index did not show significant differences, the affected side step length and affected side step time of the PBWSTFBWP group showed significant differences compared with the PBWSTFWT and the PBWSTBWT group after the 3 weeks of training ($p<0.05$). Additionally, there were only significant improvement of the affected side step length for all three groups during the follow-up period and was a significant

difference between the PBWSTFBWTP and the PBWST-BWT groups (Table 2).

Table 1. The general characteristics of the subjects (N=36)

	PBWSTFB-WT (n=12)	PBWSTFWT (n=12)	PBWSTBWT (n=12)
Age (year)	51.00 ± 14.60	52.75 ± 9.21	50.25 ± 16.69
Onset (months)	11.33 ± 3.76	11.00 ± 4.22	11.83 ± 3.46
Gender			
Male	8 (66.7%)	8 (66.7%)	9 (75.0%)
Brain lesion location			
Cortex level	1 (8.3%)	1 (8.3%)	
Subcortex level	6 (50.0%)	7 (58.3%)	7 (58.3%)
Mixed	5 (41.7%)	4 (33.3%)	5 (41.7%)
Affected side			
Left	6 (50.0%)	6 (50.0%)	4 (33.3%)
Right	6 (50.0%)	6 (50.0%)	8 (66.7%)

Values are N (%) or Mean ± SD, ns = not significant, PBWST-FBWT: Progressive Body Weight Supported Treadmill Forward and Backward Walking Training, PBWSTFWT: Progressive Body Weight Supported Treadmill Forward Walking Training, PBWSTBWT: Progressive Body Weight Supported Treadmill Backward Walking Training, Mixed= cortex level + subcortex level

Table 2. Comparison of walking ability among the three groups (N=36)

Group		PBWSTFBWTP Mean ± SD	PBWSTFWT Mean ± SD	PBWSTBWT Mean ± SD
ASL (cm)	0 week	41.67 ± 5.97	41.44 ± 8.57	41.72 ± 7.81
	3 weeks	48.64 ± 5.06[*,†,2,3]	44.33 ± 8.70[*,†,1]	44.88 ± 9.72[*,†,1]
	6 weeks	50.33 ± 5.25[*,‡,3]	46.62 ± 7.95[*,‡]	48.88 ± 10.25[*,‡,1]
AStP (%)	0 week	68.43 ± 5.53	68.56 ± 4.76	68.60 ± 6.79
	3 weeks	65.93 ± 3.58[*,†]	64.96 ± 5.11[*,†]	65.19 ± 6.47[*,†]
	6 weeks	65.02 ± 4.29	64.87 ± 5.31	64.69 ± 8.65
ASwP (%)	0 week	31.58 ± 5.53	31.44 ± 4.76	31.39 ± 6.79
	3 weeks	34.07 ± 3.58[*,†]	35.04 ± 5.11[*,†]	34.81 ± 6.47[*,†]
	6 weeks	34.98 ± 4.29	35.13 ± 5.31	35.31 ± 8.65
ASS (%)	0 week	32.23 ± 7.21	33.61 ± 7.19	32.66 ± 5.91
	3 weeks	36.10 ± 4.41[*,†]	36.76 ± 7.18[*,†]	37.19 ± 3.98[*,†]
	6 weeks	39.26 ± 5.85	37.37 ± 6.36	38.74 ± 4.80
AST (sec)	0 week	1.26 ± 0.33	1.25 ± 0.28	1.27 ± 0.31
	3 weeks	0.91 ± 0.12[*,†,2,3]	1.10 ± 0.30[*,†,1]	1.07 ± 0.17[*,†,1]
	6 weeks	0.90 ± 0.09	1.09 ± 0.29	1.05 ± 0.16
Symmetry Index	0 week	−16.26 ± 13.50	−16.06 ± 12.09	−16.40 ± 9.36
	3 weeks	−8.51 ± 5.10[*,†]	−10.77 ± 5.09[*,†]	−10.73 ± 11.37[*,†]
	6 weeks	−7.56 ± 7.21	−9.05 ± 3.15	−9.02 ± 11.53

[*]$p<0.05$, [†]significantly different from 0–3 weeks, [‡]significantly different from 3–6 weeks, ASL: Affected side Step Length, AStP: Affected side Stance Phase, ASwP: Affected side Swing Phase, ASS: Affected side Single Support, AST: Affected side Step Time
Post-hoc tests comparison was calculated using Bonferroni's method
[1] significantly different from PBWSTFBWT
[2] significantly different from PBWSTFWT
[3] significantly different from PBWSTBWT

DISCUSSION

In this study, progressive body weight supported forward walking training and backward walking training were performed by stroke patients, and we examined the effects of the training programs on the patients' walking abilities. According to the results, all three groups showed significant changes at the end of the training period, and comparisons among the three groups showed significant differences in the affected side step length and affected side walking time.

The affected side step length increased in all three groups. In the comparisons of the three groups, the PBWSTFBWT group showed more significant improvement than the other two groups at the end of the three weeks of the treadmill training, and the PBWSTFBWT and the PBWSTBWT groups showed more significant improvements than the PBWSTFWT group at the end of the follow-up period, six weeks after the beginning of the experiment. These results are consistent with the results of a study conducted by Verma et al.[23] who reported that 30 stroke patients, divided into two groups for circuit task-oriented gait training, showed improvements in walking-related parameters, such as stride length. Our results are also consistent with those of the study conducted by Yang et al.[7], in which 25 stroke patients were divided into an experimental group that performed general walking training plus backward walking training for 30 minutes at a time, three times per week for three weeks, and a control group that performed only general walking training. The experimental group's stride length increased from 0.78 m before the intervention to 0.88 m after the intervention. Sousa et al.[14] reported that when 12 chronic stroke patients performed walking training on the ground without any body weight support or partial body weight support at self-selected speeds, the walking speeds and symmetric stride length of the individual patients increased, a result which is agreement with the results of our present study. We think patients' walking speeds increased, because the patients' muscle activities were increased by the movements of their affected side lower extremity, and their mental states or self-confidence in walking improved as a result the repeated walking training on a treadmill in a stable walking environment. Also, we found a significant difference in affected side step length at the end of the follow-up phase, possibly because a variety of tasks on the treadmill induced a higher activation of the cortex. Accordingly, we think that the activation of the flexors and extensors of lower limb through PBWSTFBWT would elicit a higher center of gravity, which would improve the step length. Although the affected side stance phase, affected side swing phase, and affected side single support increased in all three groups, comparisons among the three groups showed there were no significant differences. These results are consistent with the results of the study conducted by DeVita and Stribling[24] who was reported that when the quadriceps muscles of the thigh undergo eccentric contractions they require relatively more metabolism during backward walking because of longer stance phase duration compared to forward walking. Also, in the study conducted by Lam et al.[25], stroke patients performed body weight sup-

ported treadmill walking training with sandbags attached to the affected side ankle weighing 5% of the patients' body weight for 30 minutes per day for 4 weeks. The swing phase ratio of the affected side lower extremity increased from 34.2 to 39.4% and the ratio of the unaffected side stance phases improved from 75.4 to 69%. The repeated performance of body weight supported treadmill walking training increased proprioceptive feedback through the sensory receptors on the sole, thereby improving lower extremity extensor muscle strength and the central pattern generators.

The affected side walking time showed significant improvement at the end of the 3 weeks of training in each of the three groups. In comparisons among the three groups, the PBWSTFBWT group showed a more significant improvement than the other two groups at the end of the three weeks of training. These results are consistent with the results of a study conducted by Roerdink et al.[26] who reported that when the frequency of auditory stimuli was increased during treadmill walking, stride time and walking time decreased. In the study of Yang et al.[7], 25 stroke patients were divided into an experimental group that performed general walking training plus backward walking training for 30 minutes at a time, three times per week for three weeks, and a control group that performed only general walking training. The experimental group's stride time decreased from 1.96 sec before the experiment to 1.62 sec after the experiment. Therefore, we consider that progressive body weight supported walking training is an appropriate method for improving motor control ability and reinforcing newly learned walking training, because it reduces the phenomenon of foot dragging during the swing phase, thereby reducing the time that the affected side of the lower extremity needs to stay in the air for the body weight to be moved, and it induces repeated use of the muscles necessary for walking while the body's weight is supported.

The symmetry indexes increased in all three groups, but comparisons among the three groups did not find any significant differences. These results are consistent with the results of a study conducted by Combs et al.[27] who reported that when nine stroke patients and 22 healthy individuals performed body weight supported treadmill walking training for eight weeks, the stroke patients' group showed larger changes in walking symmetry after the training. Based on these results, we consider that body weight supported treadmill walking training is a meaningful training method for improving walking ability, because it reduces and adjusts the weight that must be borne by the patient and supports the patient's trunk, so the patients can feel less fear while trying to improve their ability to control their lower extremity movements.

The limitations of this study include the fact that the experimental groups' daily lives could not be completely controlled, the size of the experimental sample was small, and the subjects were limited to stroke patients who could walk, making it difficult to generalize the results.

In summary, this study demonstrated that progressive body weight supported treadmill walking training had a positive effect on stroke patients' walking abilities, and that implementing progressive body weight supported forward

and backward walking training is more effective at improving stroke patients' affected side lower extremity walking abilities.

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REFERENCES

1) Eich HJ, Mach H, Werner C, et al.: Aerobic treadmill plus Bobath walking training improves walking in subacute stroke: a randomized controlled trial. Clin Rehabil, 2004, 18: 640–651. [Medline] [CrossRef]

2) Kelly-Hayes M, Beiser A, Kase CS, et al.: The influence of gender and age on disability following ischemic stroke: the Framingham study. J Stroke Cerebrovasc Dis, 2003, 12: 119–126. [Medline] [CrossRef]

3) Miller EW, Quinn ME, Seddon PG: Body weight support treadmill and overground ambulation training for two patients with chronic disability secondary to stroke. Phys Ther, 2002, 82: 53–61. [Medline]

4) Hesse S, Konrad M, Uhlenbrock D: Treadmill walking with partial body weight support versus floor walking in hemiparetic subjects. Arch Phys Med Rehabil, 1999, 80: 421–427. [Medline] [CrossRef]

5) Hesse S, Werner C, Bardeleben A, et al.: Body weight-supported treadmill training after stroke. Curr Atheroscler Rep, 2001, 3: 287–294. [Medline] [CrossRef]

6) Mudge S, Rochester L, Recordon A: The effect of treadmill training on gait, balance and trunk control in a hemiplegic subject: a single system design. Disabil Rehabil, 2003, 25: 1000–1007. [Medline] [CrossRef]

7) Yang YR, Yen JG, Wang RY, et al.: Gait outcomes after additional backward walking training in patients with stroke: a randomized controlled trial. Clin Rehabil, 2005, 19: 264–273. [Medline] [CrossRef]

8) Nadeau S, Amblard B, Mesure S, et al.: Head and trunk stabilization strategies during forward and backward walking in healthy adults. Gait Posture, 2003, 18: 134–142. [Medline] [CrossRef]

9) Hesse S, Bertelt C, Jahnke MT, et al.: Treadmill training with partial body weight support compared with physiotherapy in nonambulatory hemiparetic patients. Stroke, 1995, 26: 976–981. [Medline] [CrossRef]

10) Ada L, Dean CM, Hall JM, et al.: A treadmill and overground walking program improves walking in persons residing in the community after stroke: a placebo-controlled, randomized trial. Arch Phys Med Rehabil, 2003, 84: 1486–1491. [Medline] [CrossRef]

11) Phadke CP: Immediate effects of a single inclined treadmill walking session on level ground walking in individuals after stroke. Am J Phys Med Rehabil, 2012, 91: 337–345. [Medline] [CrossRef]

12) Polese JC, Ada L, Dean CM, et al.: Treadmill training is effective for ambulatory adults with stroke: a systematic review. J Physiother, 2013, 59: 73–80. [Medline] [CrossRef]

13) Pohl M, Mehrholz J, Ritschel C, et al.: Speed-dependent treadmill training in ambulatory hemiparetic stroke patients: a randomized controlled trial. Stroke, 2002, 33: 553–558. [Medline] [CrossRef]

14) Sousa CO, Barela JA, Prado-Medeiros CL, et al.: Gait training with partial body weight support during overground walking for individuals with chronic stroke: a pilot study. J Neuroeng Rehabil, 2011, 8: 48. [Medline] [CrossRef]

15) Takami A, Wakayama S: Effects of partial body weight support while training acute stroke patients to walk backwards on a treadmill —A controlled clinical trial using randomized allocation—. J Phys Ther Sci, 2010, 22: 177–187. [CrossRef]

16) Giakas G, Baltzopoulos V: Time and frequency domain analysis of ground reaction forces during walking: an investigation of variability and symmetry. Gait Posture, 1997, 5: 189–197. [CrossRef]

17) Pomeroy VM, Evans B, Falconer M, et al.: An exploration of the effects of weighted garments on balance and gait of stroke patients with residual disability. Clin Rehabil, 2001, 15: 390–397. [Medline] [CrossRef]

18) Chen HY, Wing AM, Pratt D: The synchronisation of lower limb responses with a variable metronome: the effect of biomechanical constraints on timing. Gait Posture, 2006, 23: 307–314. [Medline] [CrossRef]

19) Schwartz I, Sajin A, Moreh E, et al.: Robot-assisted gait training in multiple sclerosis patients: a randomized trial. Mult Scler, 2012, 18: 881–890. [Medline] [CrossRef]

20) Yang YR, Chen YC, Lee CS, et al.: Dual-task-related gait changes in individuals with stroke. Gait Posture, 2007, 25: 185–190. [Medline] [Cross-Ref]

21) Ditor DS, Macdonald MJ, Kamath MV, et al.: The effects of body-weight supported treadmill training on cardiovascular regulation in individuals with motor-complete SCI. Spinal Cord, 2005, 43: 664–673. [Medline] [CrossRef]

22) Kesar TM, Reisman DS, Perumal R, et al.: Combined effects of fast treadmill walking and functional electrical stimulation on post-stroke gait. Gait Posture, 2011, 33: 309–313. [Medline] [CrossRef]

23) Verma R, Arya KN, Garg RK, et al.: Task-oriented circuit class training program with motor imagery for gait rehabilitation in poststroke patients: a randomized controlled trial. Top Stroke Rehabil, 2011, 18: 620–632. [Medline] [CrossRef]

24) DeVita P, Stribling J: Lower extremity joint kinetics and energetics during backward running. Med Sci Sports Exerc, 1991, 23: 602–610. [Medline] [CrossRef]

25) Lam T, Luttmann K, Houldin A, et al.: Treadmill-based locomotor training with leg weights to enhance functional ambulation in people with chronic stroke: a pilot study. J Neurol Phys Ther, 2009, 33: 129–135. [Medline] [CrossRef]

26) Roerdink M, Lamoth CJ, Kwakkel G, et al.: Gait coordination after stroke: benefits of acoustically paced treadmill walking. Phys Ther, 2007, 87: 1009–1022. [Medline] [CrossRef]

27) Combs SA, Dugan EL, Ozimek EN, et al.: Bilateral coordination and gait symmetry after body-weight supported treadmill training for persons with chronic stroke. Clin Biomech (Bristol, Avon), 2013, 28: 448–453. [Medline] [CrossRef]