J. Phys. Ther. Sci.
27: 1603–1607, 2015

Original Article

Effects of conventional overground gait training and a gait trainer with partial body weight support on spatiotemporal gait parameters of patients after stroke

Byoung-Sun Park, PT, MS[1)a], Mee-Young Kim, PT, PhD[1)a], Lim-Kyu Lee, PT, MS[1, 2)], Seung-Min Yang, PT, MS[1)], Won-Deok Lee, PT, MS[1)], Ji-Woong Noh, PT, MS[1)], Yong-Sub Shin, PT, MS[1)], Ju-Hyun Kim, PT, PhD[3)], Jeong-Uk Lee, PT, PhD[4)], Taek-Yong Kwak, PhD[5)], Tae-Hyun Lee, PhD[6)], Ju-Young Kim, PhD[6)], Junghwan Kim, PT, PhD[7)]*

[1)] *Laboratory of Health Science and Nanophysiotherapy, Department of Physical Therapy, Graduate School, Yongin University, Republic of Korea*
[2)] *Commercializations Promotion Agency for R&D Outcomes, Republic of Korea*
[3)] *Department of Physical Therapy, College of Health Welfare, Wonkwang Health Science University, Republic of Korea*
[4)] *Department of Physical Therapy, College of Health Science, Honam University, Republic of Korea*
[5)] *Department of Taekwondo Instructor Education, College of Martial Arts, Yongin University, Republic of Korea*
[6)] *Department of Combative Martial Arts Training, College of Martial Arts, Yongin University, Republic of Korea*
[7)] *Department of Physical Therapy, College of Public Health & Welfare, Yongin University: 470 Samga-dong, Cheoin-gu, Yongin-si, Gyeonggi-do 449-714, Republic of Korea*

Abstract. [Purpose] The purpose of this study was to confirm the effects of both conventional overground gait training (CGT) and a gait trainer with partial body weight support (GTBWS) on spatiotemporal gait parameters of patients with hemiparesis following chronic stroke. [Subjects and Methods] Thirty stroke patients were alternately assigned to one of two treatment groups, and both groups underwent CGT and GTBWS. [Results] The functional ambulation classification on the affected side improved significantly in the CGT and GTBWS groups. Walking speed also improved significantly in both groups. [Conclusion] These results suggest that the GTBWS in company with CGT may be, in part, an effective method of gait training for restoring gait ability in patients after a stroke.
Key words: Gait training, Spatiotemporal gait parameters, Stroke patients

(This article was submitted Jan. 8, 2015, and was accepted Jan. 31, 2015)

INTRODUCTION

Most hemiplegic patients who have suffered from stroke experience a restriction of their mobility in the home and in the community, particularly in terms of walking independently[1)]. The restoration of gait ability is an important goal in the process of therapy for stroke patients because gait is such a significant element in achievement of functional independence[2)]. Characteristically, stroke patients suffer from deficits in their functional ambulation capacity, balance, walking velocity, cadence, stride length, temporal gait pattern, and muscular activity pattern[3)]. Generally, stroke patients show decreased walking velocity, which results in a decreased paretic stance phase and an increased paretic swing phase. In addition, stroke results in an asymmetric spatiotemporal gait pattern. An increase in gait velocity without improvements in symmetry suggests that compensatory strategies are retained and amplified[4)]. In this regard, Mumman noted that the biggest loss after a stroke is gait ability and that a hemiplegic patient shows selective ability to regulate and coordinate the movement disorder, which results in a slow gait velocity and lower extremity compensation movement on the non-affected side[5)]. Perry suggested that a hemiplegic patient manifests a short stride length and slow gait velocity as a result of damage to the joints and the regulation function of the muscles, both of which are necessary for normal gait. Among the several indicators relating to gait, gait velocity is a useful indicator representing clinical trends, the quality of the gait, and the degree to which the gait velocity function

[a]The first 2 authors (Park BS and Kim MY) contributed equally to this work.
*Corresponding author. Junghwan Kim (E-mail: junghwankim3@yongin.ac.kr)

is abnormal in both hemiplegic and normal patients. Also, velocity is easy to measure and is closely related to the patient's clinical condition[6]. Specifically, stroke patients suffer from deficits in their functional ambulation capacity, balance, walking velocity, cadence, stride length, temporal gait pattern, and muscular activity pattern. Normal gait is smooth and symmetric, but the hemiplegic gait has been described as slow and asymmetric[7]. Among the assessment methods commonly used to characterize walking in patients with hemiplegia, measurement of temporal and spatial parameters is generally considered the easiest to perform and the most clinically relevant[4, 8–10]. Temporal gait measures include velocity, cadence, step length, stride length, individual phase durations and proportions, and symmetry ratios[3, 4, 11]. Recent investigations have shown that walking speed is linked to a greater extent with non-hemiplegic limb stance and swing than with hemiplegic limb stance and swing[3]. This correlation is not surprising, given the significant change in the gait cycle of the weight-bearing non-hemiplegic leg as a result of weakness in the hemiplegic leg[7]. Training with a gait trainer and partial body weight support is relatively effective for repetitive practice of the gait cycle and restoration of gait ability in acute, subacute, and chronic hemiparesis patients and healthy adults[7, 12, 13]. Stroke patients treated using this training method have exhibited improvements in walking ability, and a newly developed gait trainer is as effective as treadmill therapy with partial body weight support (BWS), while also requiring less input from a therapist[1]. According to a recent study by Werner et al., treadmill training with body weight support resulted in improvements in functional ambulation classification (FAC), gait velocity, and Rivermead scores in subacute, non-ambulatory stroke survivors[12]. In another study, subjects with chronic stroke symptoms showed an increase in their 10 m walking time, Berg Balance Scale score, and step length as a result of either BWS treadmill or overground ambulation training[14]. A similar study conducted recently on 25 subjects including both healthy patients and stroke patients involved a three-week program to compare the effects of treadmill training on the ambulation of stroke survivors in the early stages of rehabilitation. It was found that treadmill training was more effective than conventional gait training for improving some gait parameters such as functional ambulation, stride length, percentage of the paretic single stance period, and gastrocnemius muscular activity[3]. An electromechanical gait trainer is an effective alternative to treadmill therapy, as it provides weight support on both sides and intense gait rehabilitation after stroke[1]. The machine can simulate the stance and swing phases in a highly physiological manner, and ropes attached to the harness control the movement of the center of mass in a phase-dependent manner[12]. However, the gait trainer also offers severely disabled hemiparetic subjects the possibility of training with a highly symmetrical gait-like movement involving favorable facilitation of the relevant anti-gravity muscles; the effort required by therapists is simultaneously reduced[15]. In this study, we investigated to confirm the effects of conventional overground gait training (CGT) and the effects of a gait trainer with partial body weight support (GTBWS) in stroke patients.

SUBJECTS AND METHODS

The participants of this study include 30 hemiplegic patients (twenty-two males and eight females) who had a stroke diagnosis and were receiving admission or outpatient treatment in P rehabilitation center. The subjects were alternately assigned to either the conventional overground gait training (CGT) group or the electrical gait training group using the gait trainer with partial body weight support (GTBWS). As part of a four-week gait training intervention, the CGT group and GTBWS group received a 30-minute conventional overground gait training session and five daily physical therapy treatments per week. During this intervention, the GTBWS group received a total of 30 gait training sessions using an electromechanical gait trainer, each session lasting 20 minutes. The GTBWS group involved ambulating on a motor-driven treadmill (Gait Trainer 2™ analysis system, Biodex Medical Systems, Inc., Shirley, NY, USA) adjusted to the subject's comfortable walking speed. Gait trainer training (harness-supported treadmill walking training) focuses on straight trunk and limb alignment with proper weight shifting and weight bearing on to the hemiplegic limb during the loading phases of gait, as well as stepping to advance the limb forward[16]. Treadmill velocity was adjusted to a comfortable cadence and stride length. The vertical and horizontal movements of the center of mass in the pelvis were controlled by ropes attached to the harness, and these varied depending on the phase of gait[13, 15]. The physiotherapist sat in front of the patient and gently shifted the paretic knee into extension during the stance phase, thus preventing knee hyperextension thrust or knee collapse. Physical assistance with tasks such as setting the paretic limb, controlling the knee, helping with hip and trunk erection, and shifting body weight was provided according to individual needs[3, 12–15]. The body weight support (BWS) group was provided with up to 30–40% BWS at the beginning of training, and the percentage of BWS was progressively increased or decreased according to the subjects' gait pattern and ability to walk[14, 17]. In order to figure out the clinical outcomes, ambulation ability was assessed using the functional ambulation classification (FAC) and walking speed to quantify the changes. In addition, the gait trainer analysis system was used to quantify the changes in spatiotemporal gait parameters such as walking speed, walking cycle, stance phase on the affected side, stride length on the affected side, and symmetry index of stance phase and stride length. The 10-m walking velocity test was used to quantify changes in gait ability. Each of the following measures was carried out three times to evaluate variations: 1) FAC and walking speed, 2) spatiotemporal gait parameters, 3) symmetry index of the stance phase and stride length, and 4) 10-m walking velocity test. In this way, the average study values were measured and evaluated before and after the research. Pre- and post-intervention assessments were carried out by physiotherapists, who were blind to the group placement of the subjects. The FAC distinguishes six levels of required support during gait training. It was performed using the walking aid recommended by the treating therapists and without orthoses[11]. The FAC has been reported by many previous research studies to be valid, reliable, and capable of

Table 1. Clinical characteristics of the hemiplegic stroke patients

Variable	CGT group	GTBWS group
Age (yrs)	37.7 ± 4.5	44.2 ± 3.9
Gender		
Male (%)	12 (80.0)	10 (66.7)
Female (%)	3 (20.0)	5 (33.3)
Height (cm)	170.1 ± 2.2	168.5 ± 2.1
Weight (kg)	65.1 ± 2.4	68.0 ± 3.5
Caused of disease		
Infarction (%)	11 (73.3)	12 (80.0)
Hemorrhage (%)	4 (26.7)	3 (20.0)
Affected side		
Right (%)	9 (60.0)	7 (46.7)
Left (%)	6 (40.0)	8 (53.3)
Time post stroke (mo)	19.9 ± 3.3	20.5 ± 6.2
K-MMSE (score)	26.3 ± 3.7	27.3 ± 3.2

All data are presented as the mean±SE. CGT: conventional overground gait training; GTBWS: gait trainer with partial body weight support; K-MMSE: Korean version of the mini-mental state examination

offering valuable measures of hemiplegic gait quality[3, 14, 17]. While the subject walked 13 m, the researcher measured a 10-m section using a stopwatch, omitting 1.5 m at both the start and end points[16]. To determine walking velocity and assess safety and stability, the patients were asked to walk 10 m at their maximum speeds. Measurement of gait velocity is a highly valid and reliable test method in that it shows the gait ability and functional training ability of a stroke patient[18]. Patients used a quadripod or walking cane during measurements. In this study, the average of three values measured consecutively was used as the measurement value to determine gait ability before and after the study. The gait trainer used in the study helped the participants observe their feet touching the ground in real time on a monitor through shadow images. This device is able to compare the gait velocity (meters/sec), gait cycle (cycles/sec), and symmetric index (%) of the stance phase and the swing phase through a histogram using normal category values. The gait trainer was designed by Werner et al. to stimulate gait phases in a symmetric manner with stance and swing phase ratios of 60% to 40%, respectively. These ratios are based on a normal walking speed, and gait training is aimed at training patients after a stroke to attain as close to a normal gait pattern as possible by the end of their rehabilitation programs[19]. The vertical and horizontal movements of the center of mass are controlled in a phase-dependent manner by a rope attached to a harness and connected to a gear system. A pulley can relieve part of the body weight. Body weight is partially supported to compensate for paresis of the affected lower limb, and this support is reduced as soon as the patient can take his or her full weight. The clinical criteria for this are the ability of the patient to extend his/her hips and the ability to carry weight sufficiently on the affected lower limbs[12]. The gait training personnel using the system must read a set of instructions concerning data processing and should be knowledgeable about gait mechanics and stroke rehabilitation. Spatiotemporal measures are calculated for each patient using the GAITRite software, which allows velocity, step time, step length, and step width to be measured. Step time, length, and width are averaged for the left and right limbs separately. Values are then averaged across all steps for each patient[20]. In this study, the participants were allowed to observe the training process on the monitor with the shadow image removed for accurate measurement. The collected data were tested in a Kolmogorov-Smirnov examination using SPSS version 20.0. In the results, the assumption of a normal distribution was satisfied, and outcomes were expressed as the mean ± standard error. An independent t-test was used to compare participants between the groups, and a paired t-test was conducted to compare the participants before and after the treatment. The statistical significance level was set at $\alpha=0.05$. The protocol for the study was approved by the Committee of Ethics in Research of the University of Yongin, in accordance with the terms of Resolution 5-1-20, December 2006. Furthermore, all volunteers or their next of kin provided informed consent for participation in the study.

RESULTS

Table 1 summarizes the clinical characteristics of the stroke patients that participated in the present study. A group comparison of functional ambulation classification showed that the patients in the CGT group and the GTBWS group attained a significantly better gait ability level by the end of the study (Table 2). Walking speed also improved significantly in both groups by the end of the study, respectively (Table 2). Furthermore, in the CGT group, there was no significant increase in the walking cycle, stance phase on the affected side, symmetry index of the stance phase, symmetry index of the stride phase, or 10-m walking velocity; only the stride length on the affected side showed a significant improvement (Table 2). However, significant increases in the stance phase on the affected side, the stride length on the affected side, and the symmetry index of the stance phase were found in the GTBWS group (Table 2).

DISCUSSION

The aim of this study was to determine the effects of hemiplegic walking aids on key ambulation abilities, spatiotemporal gait parameters, and symmetry index when they are used for gait training in chronic stroke patients. This study is a valuable guide to gait parameter assessment, and treadmill training with partial body weight support is a promising new approach to gait rehabilitation after stroke[21]. Ambulation ability, walking speed, and gait parameters in chronic stroke patients were improved following the use of a gait trainer with partial body weight support and conventional overground gait training as measured using the FAC, walking speed, spatiotemporal gait parameters, symmetry index of the stance and stride phases, and 10-m walking velocity test. Recent studies have reported interrelationships in terms of these parameters[12–14, 19]. Hesse and Werner noted that patients should try to walk fast on a treadmill, thereby facilitating the relevant weight-bearing muscles and

Table 2. Effects of gait training on spatiotemporal gait parameters of patients after stroke

Variable	CGT group		GTBWS group	
	Pre-T	Post-T	Pre-T	Post-T
Walking speed (m/sec)	0.49 ± 0.02	0.56 ± 0.02*	0.52 ± 0.03	0.57 ± 0.03*
FAC (score)	1.7 ± 0.4	3.1 ± 0.2*	1.7 ± 0.4	2.8 ± 0.3*
Walking cycle (cycles/sec)	0.65 ± 0.12	0.66 ± 0.02	0.63 ± 0.03	0.63 ± 0.02
Affected side stance phase (sec/%)	46.7 ± 1.8	46.5 ± 1.5	47.0 ± 1.2	48.5 ± 1.1*
Affected side stride length (cm)	0.37 ± 0.02	0.42 ± 0.03*	0.38 ± 0.03	0.42 ± 0.03*
Symmetry index of stance phase (%)	90.4 ± 6.4	88.8 ± 5.2	89.9 ± 4.2	94.0 ± 4.0*
Symmetry index of stride phase (%)	99.1 ± 7.7	96.1 ± 4.7	90.6 ± 6.4	93.1 ± 5.7
10-m walking velocity (m/sec)	22.9 ± 4.7	22.6 ± 4.6	29.8 ± 11.8	29.2 ± 11.6

All data are presented as the mean±SE. CGT: conventional overground gait training; GTBWS: gait trainer with partial body weight support; FAC: functional ambulation classification; Pre- and post-T: before and after treatment. $^{*}p < 0.05$

improving gait efficieney[21]. It has also been asserted that speed alone is an effective indicator of the degree of gait abnormality and that no element is more important than velocity in measuring hemiplegic gait[7]. Other studies not only emphasize the nature of the relationship between gait speed and other temporal and spatial gait parameters but also the association between walking speed and symmetry in patients with stroke-induced hemiplegia[3, 7–9]. Many studies have indicated that these assessments represent an adequate analysis of hemiplegic gait parameters and that the assessment results concur with those of previous studies evaluating gait trainer systems as a means of restoring gait ability and its related parameters in patients with chronic stroke effects[7–9, 11–13]. In the present study, FAC and walking velocity were employed as useful indicators for making decisions regarding comprehensive gait parameters in chronic hemiplegic patients. It was found that FAC and walking speed correlate with improvements in the gait parameters. In a group comparison, both the CGT and GTBWS groups showed significant improvement in terms of stride length on the affected side. The present study examined the effects of treadmill training on the ambulation of stroke survivors in the early stages of rehabilitation. The results of recent studies indicate that treadmill training without weight support is feasible and well tolerated by subjects with hemiparesis, even in the early stages of gait rehabilitation[3]. Hesse and Werner studied four weeks of physiotherapy and gait trainer therapy and showed that they resulted in a relevant improvement of gait ability in all subjects. Velocity, cadence, and stride length improved significantly[13]. A study of Frankenberg et al. showed that walking velocity improved significantly over time in both their groups and that gait ability improved[12]. In the present study, the group comparison revealed that patients in both groups attained a significantly higher gait ability level. In another study, gait training of 50 subjects using treadmill gait training with body weight support (BWS) was compared with gait training of 50 subjects using treadmill gait training without body weight support (no-BWS) to assess clinical outcome measures for stroke patients[16]. The results showed that after six weeks, the BWS group scored significantly higher than the no-BWS group for functional balance, motor recovery, overground walking speed, and overground walking endurance[16]. It should be noted that gait trainer training is no more time-consuming than conventional overground gait training[3]. The limitation of conventional overground gait training as a daily routine in the present study was the effort required by therapists in assisting the gait of severely affected subjects by controlling paretic knee, hip, and trunk movement. A physiotherapist was required to assist patients with movement on the gait trainer. Therefore, a gait trainer with BWS may supplement gait therapy by enabling repetitive practice of gait-like movement without excessive effort on the part of therapists[15]. Also, the gait trainer in the present study was more effective with regard to restoration of functional ambulation ability, walking speed, and the gait spatiotemporal variables and symmetry index of the stance phase and stride length. The gait trainer with BWS training applied in the present study is more significant in terms of FAC, walking speed, and spatiotemporal gait parameters compared with conventional overground gait training. According to recent studies, treadmill training is easy to incorporate during conventional treatment, since unlike a weight support system, it is no more time-consuming or taxing for the therapist than overground training. Other studies have suggested that the gait trainer enables repetitive practice of a gait-like movement by nonambulatory or ambulatory subjects without excessive work on the part of therapists[12, 13, 19]. In this study, the major advantage of the gait trainer with BWS is that it requires less effort by a therapist than conventional therapy. Further scientific studies should be carried out focusing on improvement of gait characteristics and ambulation ability in hemiplegic patients[22–25]. In addition, greater numbers of participants and longer treatment times, including a follow-up, should be used to validate the results of this study.

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) Turnbull GI, Charteris J, Wall JC: Deficiencies in standing weight shifts by ambulant hemiplegic subjects. Arch Phys Med Rehabil, 1996, 77: 356–362. [Medline] [CrossRef]
3) Laufer Y, Dickstein R, Chefez Y, et al.: The effect of treadmill training on the ambulation of stroke survivors in the early stages of rehabilitation: a randomized study. J Rehabil Res Dev, 2001, 38: 69–78. [Medline]
4) Patterson SL, Rodgers MM, Macko RF, et al.: Effect of treadmill exercise

training on spatial and temporal gait parameters in subjects with chronic stroke: a preliminary report. J Rehabil Res Dev, 2008, 45: 221–228. [Medline] [CrossRef]

5) Mumma CM: Perceived losses following stroke. Rehabil Nurs, 1986, 11: 19–24. [Medline] [CrossRef]
6) Perry J: Kinesiology of lower extremity bracing. Clin Orthop Relat Res, 1974, (102): 18–31. [Medline] [CrossRef]
7) Roth EJ, Merbitz C, Mroczek K, et al.: Hemiplegic gait. Relationships between walking speed and other temporal parameters. Am J Phys Med Rehabil, 1997, 76: 128–133. [Medline] [CrossRef]
8) Jayakaran P, DeSouza L, Cossar J, et al.: Influence of a walking aid on temporal and spatial parameters of gait in healthy adults. PM R, 2014, 6: 796–801. [Medline] [CrossRef]
9) Youdas JW, Hollman JH, Aalbers MJ, et al.: Agreement between the GAITRite walkway system and a stopwatch-footfall count method for measurement of temporal and spatial gait parameters. Arch Phys Med Rehabil, 2006, 87: 1648–1652. [Medline] [CrossRef]
10) Wong JS, Jasani H, Poon V, et al.: Inter- and intra-rater reliability of the GAITRite system among individuals with sub-acute stroke. Gait Posture, 2014, 40: 259–261. [Medline] [CrossRef]
11) Holden MK, Gill KM, Magliozzi MR, et al.: Clinical gait assessment in the neurologically impaired. Reliability and meaningfulness. Phys Ther, 1984, 64: 35–40. [Medline]
12) Werner C, Von Frankenberg S, Treig T, et al.: Treadmill training with partial body weight support and an electromechanical gait trainer for restoration of gait in subacute stroke patients: a randomized crossover study. Stroke, 2002, 33: 2895–2901. [Medline] [CrossRef]
13) Hesse S, Werner C, Uhlenbrock D, et al.: An electromechanical gait trainer for restoration of gait in hemiparetic stroke patients: preliminary results. Neurorehabil Neural Repair, 2001, 15: 39–50. [Medline] [CrossRef]
14) 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]
15) Hesse S, Uhlenbrock D, Sarkodie-Gyan T: Gait pattern of severely disabled hemiparetic subjects on a new controlled gait trainer as compared to assisted treadmill walking with partial body weight support. Clin Rehabil, 1999, 13: 401–410. [Medline] [CrossRef]
16) Visintin M, Barbeau H, Korner-Bitensky N, et al.: A new approach to retrain gait in stroke patients through body weight support and treadmill stimulation. Stroke, 1998, 29: 1122–1128. [Medline] [CrossRef]
17) 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]
18) Dobkin BH: Short-distance walking speed and timed walking distance: redundant measures for clinical trials? Neurology, 2006, 66: 584–586. [Medline] [CrossRef]
19) Tong RK, Ng MF, Li LS, et al.: Gait training of patients after stroke using an electromechanical gait trainer combined with simultaneous functional electrical stimulation. Phys Ther, 2006, 86: 1282–1294. [Medline] [CrossRef]
20) Shrout PE, Fleiss JL: Intraclass correlations: uses in assessing rater reliability. Psychol Bull, 1979, 86: 420–428. [Medline] [CrossRef]
21) Hesse S, Werner C, Paul T, et al.: Influence of walking speed on lower limb muscle activity and energy consumption during treadmill walking of hemiparetic patients. Arch Phys Med Rehabil, 2001, 82: 1547–1550. [Medline] [CrossRef]
22) Kim MY, Kim JH, Lee JU, et al.: The effects of functional electrical stimulation on balance of stroke patients in the standing posture. J Phys Ther Sci, 2012, 24: 77–81. [CrossRef]
23) Jeon HJ, Kim MY, Lee JU, et al.: Differences in leg length discrepancy and weight distribution between the healthy and unhealthy sides of hemiplegic stroke patients. Toxicol Environ Health Sci, 2013, 5: 221–226. [CrossRef]
24) Lee WD, Lee JU, Kim J: Differences in amplitude of functional electrical stimulation between the paretic and nonparetic sides of hemiplegic stroke patients. Toxicol Environ Health Sci, 2013, 5: 82–85. [CrossRef]
25) Lee WD, Kim JH, Lee JU, et al.: Differences in rheobase and chronaxie between the paretic and non-paretic sides of hemiplegic stroke patients: a pilot study. J Phys Ther Sci, 2013, 25: 717–719. [Medline] [CrossRef]