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Effects of Slope Changes During Body Weight-Supported Treadmill Training on Gait Characteristics in Patients With Hemiplegia

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Abstract

The purpose of this study was to determine the therapeutic effect of slope changes of the treadmill with body weight-supported training on gait characteristics in patients with hemiplegia. The volunteered subjects were divided into 3 groups based upon slope changes: control group (0° incline), 7° group (7° incline), 12° group (12° incline). They were trained the body weight-supported treadmill training (BWSTT) for 8 weeks. All subjects were supported up to 40% of their body weight on the treadmill training and the support was gradually decreased to 0~10% as the subjects were adapted to the training. There were significant improvements of walking velocity, step length of the affected side, the asymmetry ratio of step length in 7° group (57.80 ㎝/s, 67.25 ㎝, .14), 12° group (71.00 ㎝/s, 71.00 ㎝, .11) than control group (40.62 ㎝/s, 55.00 ㎝, .74) ($p<.05$); there were no differences between 7° group and 12° group in the all outcomes ($p>.05$). Both 7° group and 12° group scored higher than the control group in those outcomes and finally the effects of slopes changes of the treadmill were effective on gait characteristics of patients. But it still remains undetermined what degree on the treadmill might be better to train the hemiparetic patients. Therefore, more studies are required to look into minutely the changes of slopes of the treadmill influencing on gait characteristics.

Key Words: Body weight-support treadmill training; Chronic stroke patients; Slope of the treadmill.

Introduction

Stroke is the most common cause of adult disability, including loss of motor, sensory and cognitive function. The impairment of walking is the one of the major disabilities after stroke (Barbeau and Vinsitin, 2003). Those disabled in such a way suffer from by slow walking speed and limited endurance (Jorgensen et al, 1995). Finch et al (1991) reported that hemiplegic gait patterns have loss of the smoothness and amplitude of normal joint rotational movements. Perry et al (1995) also found that slow walking speed, different step length between the affected and unaffected limb and short stance phase of affected limb compared with the unaffected limb during walking were common in hemiparetic patient. To support a percentage of body weight with a harness system is a way to regain walking ability, thereby decreasing the load on the lower extremities while the patient is being trained on a treadmill. This approach is suitable not only for spinal cord injury but also hemiparetic patients (Finch et al, 1991; Perry et al, 1995; Visintin et al, 1998).

Visintin and Barbeau (1989) attempted to compare the locomotic patterns between 40% and 0% unloading of the lower extremities in spastic patients. A total of 40% unloading of the lower extremities resulted in a straighter trunk and knee alignment during the loading phase. Furthermore, a decrease in double support time and an increase in single support time, stride length and speed were seen, as compared to 0% body weight support. Hassid et al

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(1997) also revealed greater symmetry of single limb stance during body weight-supported treadmill training (BWSTT).

Recently, new training paradigms incorporating fast walking and intensive training regimens were proposed (Dean et al, 2000; Pohl et al, 2002; Sullivan et al, 2002). These principles were applied to stroke patients, and this combination of the BWSTT and fast speed produced the greatest increments of walking speed compared with a BWSTT group or a fast walking group alone (Lamontagne and Fung, 2004). Sullivan et al (2002) studied 24 subjects with chronic hemiparesis arranged randomly according to locomotion severity.

The ability to control the joints in the lower limb enables a stable gait pattern on inclines; with an impairment, however, there may be an increased risk of slipping on an incline (McIntosh et al, 2006). The knee and ankle joint muscles are much more stabilized in slope walking than on the horizontal level (Tokuhiro et al, 1985). Many researchers have reported that gait patterns are influenced by the incline of the walkway in healthy subjects (Goswami, 1998; Kawamura et al, 1991; McIntosh et al, 2006). The pedestrian's step and stride length decreased during ramp descent due to reduction of the counteracting friction (Sun et al, 1996). Leroux et al (2002) reported that 5° uphill walking led to increased hip flexion at the end of the swing phase, and that stride length was increased in healthy subjects. However, there have been few studies of its effects according to slope changes of the treadmill with BWSTT in patients with hemiplegia. Therefore, the purpose of this study was to determine the effects of slope changes with BWSTT on gait characteristics in chronic stroke patients.

Methods

Subjects

Twelve chronic stroke patients were recruited voluntarily from D hospital and P hospital located at Busan city, Korea. The inclusion criteria for this study were categorized at 1) a diagnosis of unilateral stroke or intracerebral hemorrhage shown by magnetic resonance imaging or computed tomography more than 6 months after the onset of stroke, 2) sufficient cognition to follow simple instructions and understand the content and purpose of the study (MMSE-K score>24 point), and 3) the ability to ambulate 10 m with or without an assistive device and walking speed reported to be slower than before the stroke. The Mini-Mental Status Examination-Korea provides a valid and reliable quick screen of cognitive function, and it had been used to select experimental category for stroke patient (O'Sullivan, 2001; Won, 2006).

Table 1. Demographic and clinical features of patients with stroke (N=12)

	Training groups			
	Control group (n_1=4)	7° group (n_2=4)	12° group (n_3=4)	p
Age (yrs)	64.5±4.4[a]	61.5±15.8	65.0±20.3	.93
Gender (M/F)	1/3	3/1	3/1	
Side of hemiplegia (R/L)	0/4	1/3	3/1	
Type of stroke (CI[b]/CH[c])	4/0	3/1	4/0	
Assistive device (each)	3	2	3	
Stroke onset (yrs)	4.8±.8	4.4±.7	3.8±1.4	.19
MMSE-K[d] (max. 30)	26.6±2.5	26.3±2.1	26.0±2.0	.91

[a] Mean±SD.
[b] CI: Cerebral infarct.
[c] CH: Cerebral hemorrhage.
[d] MMSE-K: Mini-Mental State Examination-Korea.

Patients were excluded if they had 1) other neurological deficits that would affect ambulation ability, 2) any additional medical or psychological condition that would affect their ability to comply with the study protocol, 3) cognitive deficit or aphasia with an inability to follow 2 consecutive step commands, and 4) severe hip, knee, or ankle contracture that would prevent passive range of motion of the leg. There were 12 patients with chronic stroke who participated in this study for 8-week. Four subjects were randomized to each training group (Table 1).

Intervention

Participants were fitted in a harness, which was then connected to an overhead suspension system positioned over a treadmill[1], Walker Traction[2] By using the walker traction provided initially and progressive when decreasing the amount of body weight support, the subject increased activity tolerance and could maintain proper limb kinematics throughout stance and swing with the assistance of a physical therapist (Figure 1).

A physical therapist was positioned behind the patient to provide proximal stability at the hips. The physical therapist should monitor the patient about upright posture, pelvic position, and weight shift. An assistant stood beside the patient to control the treadmill and also to monitor stride characteristics (Pohl et al, 2002). Subjects were encouraged to hold a handrail because the slopes were not a familiar environment for them, intensifying their need for a feeling of security (Dean et al, 2000).

The angle of slopes were provided with several boards was measured by a goniometer (Figure 2). The height of each board was 1.2 ㎝, and 10 boards provided an 7° incline at the treadmill. Placing 18 boards under the treadmill created an incline of 12°. The width of this treadmill was about 100 ㎝ that we measured between the forward and backward wheels. Kawamura et al (1991) observed that walking speed, which is the product of step length and cadence, significantly decreased in both up and downslope walking at 12° compared with 3°, 6°, and 9° in healthy subjects. The other angle that adopted 7° because the phasic activity of the lower extremity muscles was seen to change at an inclination over 6° in upslope walking by Tokuhiro et al (1985). For this reason, these were critical inclinations it selected to define in patients with hemiplegia.

During all assessments of this study, neither par-

Figure 1. Training equipment.
A: walker traction, B: harness,
C: treadmill.

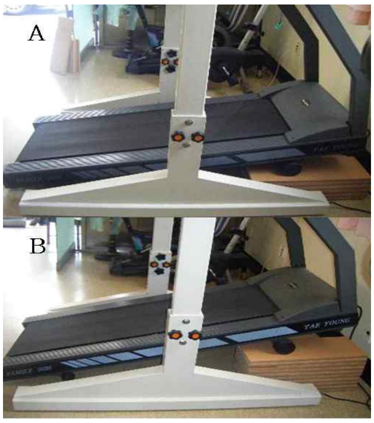

Figure 2. Slopes of a treadmill.
A: 7° slope (using 10 boards),
B: 12° slope (using 18 boards).

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1) Family 2020, Tae Young System, Korea.
2) Walker Traction, Sae Han Trade, Korea.

ticipants nor the research physical therapist were blinded to their treatment because it was not practical. Ambulatory ability was measured by Gaitrite Electronic Walkway[3].

The control group was tested at a 0° incline on the treadmill, and 7° group was tested at a 7° incline. 12° group used a 12° incline on the treadmill with BWSTT. The three groups had the same speed (80 ㎝/s) (Sullivan et al, 2002). Initially, 40% of subjects′ body weight was supported (Barbeau and Vinsitin, 2003); this was decreased to 0∼10% as the subjects adapted to the training (Lamontagne and Fung, 2004; Sullivan et al, 2002).

All subjects received 8-week (24-session) of the BWSTT according to slopes (0°, 7°, 12°) over an 8-week training phase. Each session included four 2.5-minute bouts for a total of 10 minutes of this training 3 times per week. Each resting time was 2∼3 minutes, but when patients needed more rest, we had to allow it. Including resting time, this experiment was taken almost 20∼25 minutes for each patient. In the pretest, subjects were trained with BWSTT and fast speed (80 ㎝/s) for 2 minutes in order to allow them to adapt to the training procedure. During the training phase, all individuals also received physical therapy for 30 minutes, three times per week.

Statistical Analysis

All data was performed by using SPSS Professional Statistics software for Windows version 12.0. For statistical analyses of demographic data in the three groups (control group, 7° group, 12° group), we used analysis of variance (ANOVA). A Bonferroni correction for post-hoc was done. Statistical significance was set at p-value less than .05.

Results

Walking Velocity, Cadence and Step Length

Both 7° group and 12° group of the pre-test (control group, 36.57±26.51 ㎝/s; 7° group, 25.75±4.52 ㎝/s; 12° group, 48.92±17.73 ㎝/s) increased velocity after 8-week (control group, 40.62±31.01 ㎝/s; 7° group, 57.80±21.85 ㎝/s; 12° group, 71.00±26.26 ㎝/s) according to the measures, but control group was less increased (Table 2). The cadence of the groups (before training: control group, 65.62±15.92 steps/min; 7° group, 65.62±14.27 steps/min; 12° group, 78.95±21.00 steps/min) was increased after 8-week training (control group, 84.18±11.94 steps/min; 7° group, 92.02±27.51 steps/min; 12° group, 95.05±22.37 steps/min) but there were no significant differences in the groups (Table 2).

Step length of the affected side was increased in the groups of post-test ($p<.05$). Both 7° group and 12° group of the pre-test (control group, 55.00±19.47 ㎝; 7° group, 49.75±4.19 ㎝; 12° group, 54.75±12.68 ㎝) increased step length of the affected side after 8-week (control group, 55.00±18.85 ㎝; 7° group, 67.25±15.92 ㎝; 12° group, 71.00±15.29 ㎝), but control group was a small amount of increase.

Asymmetry Ratio of Step Length

The asymmetry ratio of step length in three groups (before training: control group, .81±.98; 7° group, .39±.31; 12° group, .65±.07) were decreased after 8-week training (control group, .74±.87; 7° group, .14±.11; 12° group, .11±.01), and there were significant differences ($p<.05$). It indicated that 7° group and 12° group decreased the asymmetry ratio more than control group (Table 3).

Discussion

We hypothesized that using the slopes (7°, 12°) of the BWSTT and a fast speed (80 ㎝/s) might be more beneficial than simply supporting body weight during BWSTT in chronic stroke patients. In addition, a higher velocity increased the activation of many muscles of the paretic side (Hesse et al, 2001).

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[3] GAITRite, MAP/CIR Systems Inc., U.S.A.

Table 2. Differences of walking velocity, cadence and step length of the affected side between three groups in various training phases (N=12)

Variable		Control	7°	12°	p
Walking velocity (㎝/s)	Pre-test (before training)	36.57±26.51[a]	25.75±4.52	48.92±17.73	.262
	Mid-test (4-week)	36.70±32.94	39.20±20.28	55.47±19.13	.535
	Post-test (8-week)	40.62±31.01	57.80±21.85	71.00±26.26	.041*
Cadence (steps/min)	Pre-test (before training)	65.62±15.92	65.62±14.27	78.95±21.00	.604
	Mid-test (4-week)	79.67±12.61	80.50±24.21	84.27±20.79	.916
	Post-test (8-week)	84.18±11.94	92.02±27.51	95.05±22.37	.324
Step length of the affected side (㎝)	Pre-test (before training)	55.00±19.47	49.75±4.19	54.75±12.68	.542
	Mid-test (4-week)	53.75±21.70	57.25±16.04	61.75±15.92	.233
	Post-test (8-week)	55.00±18.85	67.25±15.92	71.00±15.29	.032*

[a]Mean±SD.
*p<.05.

Table 3. Differences of the asymmetry ratio of step length between three groups in various training phases (N=12)

Asymmetry ratio of step length	Control	7°	12°	p
Pre-test (before training)	.81±.98[a]	.39±.31	.65±.07	.426
Mid-test (4-week)	.76±.85	.28±.29	.39±.06	.811
Post-test (8-week)	.74±.87	.14±.11	.11±.01	.030*

[a]Mean±SD.
*p<.05.

Our study revealed improved walking velocity and step length of the affected side on an increased slope (p<.05). Sullivan et al (2002) also suggested the BWSTT with fast speed (89 ㎝/s) to chronic stroke patients was more effective in improving over-ground walking velocity than slow speed (22 ㎝/s) and variable speed (22 ㎝/s, 45 ㎝/s, 67 ㎝/s, 89 ㎝/s) groups. Fast walking induces marked speed-related improvements in body and limb kinematics and muscle activation patterns (Lamontagne and Fung, 2004).

Previous studies about application of human slope walking compared with uphill slopes such as 3°, 6°, 9° and 12° (Kawamura et al, 1991), or 5° and 10° (Yamasaki et al, 1984). The ratio of stance phase to swing phase was about 6:4 at most inclinations. However, an exception at 12° was observed, as the stance phase increased (Murray et al, 1984). We tried a 12° slope to find changes and the result revealed a significant decrease of asymmetry of the step length. The other angle we used was 7° because the phasic activity of the lower extremity muscles changed at an inclination exceeding 6° in upslope walking. Thus, it follows that the muscles stabilize the knee and ankle joints much more in slope walking than in level walking (Tokuhiro et al, 1985). These could facilitate much more proprioceptive inputs and an improved gait pattern was revealed, but it was not significant.

McIntosh et al (2006) also found that the ankle plantar flexion moment and power in a +5° incline was less than for walking on the horizontal level in healthy subjects. Also, the most characteristic feature in the evolution of orientation with ground slope was the discrete jump that occurs around the +5° slope (Goswami, 1998). A possibility is that the leg is being lifted off the ground on a +5° incline, without push off. It means that the plantar flexor is not used as much on inclined treadmill walking in patients with hemiplegia. The result of our study using a 7° and 12° slope was also significant with regard to some gait characteristics.

A progressive increase in stride length reflects that momentum is generated greatly as the treadmill slope becomes steeper in uphill walking (Leroux et al, 1999). Incline walking required important adaptations in lower limbs patterns of movement in healthy subjects when adapting to uphill walking is to lift up the swinging leg by performing a simultaneous increase in hip and knee flexion of that limb. This period of the gait cycle corresponds to the period where the pelvic tilt toward the swinging limb was decreased. By decreasing this lateral tilt, the pelvis would permit a greater lift up of the swinging limb (Cavagna and Margaria, 1966). This would be one of the reasons that the asymmetry ratio of step length was a significant decrease in the experimental groups, which means the gait pattern is better than before through the BWSTT on the slopes (7° and 12°). It means that inclined treadmill exercise led to a recovery of right and left symmetry through movement of the affected side. However, one of the studies with BWSTT (0° incline) found that there was greater symmetry of single limb stance time in hemiparetic patients (Hassid et al, 1997).

Both the experimental groups indicated better improvements compared with the control group in the most outcomes so that 7° and 12° slopes of the BWSTT might have influence on the improvement of gait patterns of patients. Even though it remains to disclose that which degree of slope on the treadmill might be better to train hemiparetic patients. We should conduct more studies with the divided slopes of a treadmill to train subjects.

Sullivan et al (2002) showed that gait velocity and cadence and stride length improved with BWSTT (0° incline) with fast speed, but the control group of this study was not greatly improved in velocity, cadence and step length of the affected side. Firstly it might be effected by short training time, 10 minutes which is not enough for them. Previous studies (Lamontagne and Fung, 2004; Sullivan et al, 2002) applied the BWSTT to individuals with chronic stroke at least for 15 minutes or much more than this to treat patients. Although this study was limited by training time, it showed to be effective in the experiment groups.

It was difficult to compare this study with other studies because they are mostly related to kinematic changes of gait pattern in healthy subjects according to slope changes (Kawamura et al, 1991; Leroux et al, 1999; McIntosh et al, 2006; Yamasaki et al, 1984). The relatively small group size is also one of the weaknesses. However, this may be somewhat compensated for by the homogeneity of the groups. In addition, a different ratio between right and left hemiparetic side in the subjects exists. It still needs more studies to verify that changes of slopes of the treadmill could have influence on gait characteristics. We also suggest we need observation of the follow-up in those subjects how the gait pattern might change.

Conclusion

The purpose of this study was to know that slope changes with BWSTT adapted with chronic stroke patients were an effective way to change gait characteristics and to offer more efficient way for individuals to regain better gait performance. Walking velocity and step length of the affected side significantly increased in both experimental groups (7° and 12°), and asymmetry ratio of step length significantly decreased. There is a possible modification to gradually reduce the power of hands in use of a handrail to increase the postural control training demand with application of not only incline and decline grade but also side-slope of the treadmill. More researches are necessary to further out understanding of the use of slopes in the BWSTT on rehabilitative process of stroke patients.

References

Barbeau H, Vinsitin M. Optimal outcomes obtained with body-weight support combined with treadmill training in stroke subjects. Arch Phys Med Rehabil. 2003;84(10):1458-1465.

Cavagna GA, Margaria R. Mechanics of walking. J Appl Physiol. 1966;21(1):271-278.

Dean CM, Richards CL, Malouin F. Task-related circuit training improves performance of locomotor tasks in chronic stroke: A randomized, controlled pilot trial. Arch Phys Med Rehabil, 2000;81(4):409-417.

Finch L, Barbeau H, Arsenault B. Influence of body weight support on normal human gait: Development of a gait retraining strategy. Phys Ther. 1991;71(11):842-855.

Goswami A. A new gait parameterization technique by means of cyclogram moments: Application to human slope walking. Gait Posture. 1998;8(1):15-36.

Hassid E, Rose D, Commisarow J, et al. Improved gait symmetry in hemiparetic stroke patients induced during body weight-supported treadmill stepping. Neurorehabil Repair. 1997;11(1):21-26.

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(11):1547-1550.

Jorgensen HS, Nakayama H, Raaschou HO, et al. Recovery of walking function in stroke patients: The copenhagen stroke study. Arch Phys Med Rehabil. 1995;76(1):27-32.

Kawamura K, Tokuhiro A, Takechi H. Gait analysis of slope walking: A study on step length, stride width, time factors, and deviation in the center of pressure. Acta Med Okayama. 1991;45(3):179-184.

Lamontagne A, Fung J. Faster is better: Implications for speed-intensive gait training after stroke. Stroke. 2004;35(11):2543-2548.

Leroux A, Fung J, Barbeau H. Adaptation of the walking pattern to uphill walking in normal and spinal-cord injured subjects. Exp Brain Res. 1999;126(3):359-368.

Leroux A, Fung J, Barbeau H. Postural adaptation to walking on inclined surfaces: I. Normal strategies. Gait Posture. 2002;15(1):64-74.

McIntosh AS, Beatty KT, Dwan LN, et al. Gait dynamics on an inclined walkway. J Biomech. 2006;39(13):2491-2502.

Murray MP, Mollinger LA, Gardner GM et al. Kinematic and EMG patterns during slow, free, and fast walking. J Orthop Res. 1984;2(3):272-280.

O'Sullivan SB. Assessment of motor function. In: O'Sullivan SB, Schmitz TJ, eds. Physical Rehabilitation: Assessment and treatment. 4th ed. F.A. Davis Co., 2001:181.

Perry J, Garrett M, Gronley JK, et al. Classification of walking handicap in the stroke population. Stroke. 1995;26(6):982-989.

Pohl M, Mehrholz J, Ritschel C, et al. Speed-dependent treadmill training in ambulatory hemiparetic stroke patients: A randomized controlled trial. Stroke. 2002;33(2):553-558.

Sullivan KJ, Knowlton BJ, Dobkin BH. Step training with body weight support: Effect of treadmill speed and practice paradigms on poststroke locomotor recovery. Arch Phys Med Rehabil. 2002;83(5):683-691.

Sun J, Walters M, Svensson N, et al. The influence of surface slope on human gait characteristics: A study of urban pedestrians walking on an inclined surface. Ergonomics. 1996;39(4):677-692.

Tokuhiro A, Nagashima H, Takechi H. Electromyographic kinesiology of lower extremity muscles during slope walking. Arch Phys Med Rehabil. 1985;66(9):610-613.

Visintin M, Barbeau H. The effects of body weight support on the locomotor pattern of spastic paretic patients. Can J Neurol Sci. 1989;16(3):315-325.

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(6):1122-1128.

Won JM. The effect of muscle strengthening exercise and gait training for stroke persons in a community. Physical Therapy Korea. 2006;13(3):18-23.

Yamasaki M, Sasaki T, Tsuzuki S, et al. Stereotyped pattern of lower limb movement during level and grade walking on the treadmill. Ann Physiol Anthropol. 1984;3(4):291-296.

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