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Immediate effects of single-leg stance exercise on dynamic balance, weight bearing and gait cycle in stroke patients

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Objective: This study aimed to identify how various applications of weight bearing on the affected side of hemiplegia patients affect the ability of balance keeping of the affected leg and the gait parameters.
Design: Cross-sectional study.
Methods: Eighteen patients with hemiplegia participated in this study. There were twelve males and six females. This study investigated the effects of the single-leg stance exercise on dynamic balance, weight bearing, and gait ability compared with four conditions. Dynamic balance and weight bearing were measured using the step test (ST) of the affected side in stroke patients. In addition, gait parameters were measured using the optogait system for analysis of the spatial and temporal parameters of walking in stroke patients.
Results: This study investigated the effect of the single leg stance exercise on the paralysis side. The ST showed significant findings for all conditions ($p<0.05$). Therefore, knee extension and flexion exercise on the affected side single-leg stance (condition 4) significantly improved dynamic balance and weight bearing on the affected side ($p<0.05$). In the condition of moving the knee joint in a single-leg stance was discovered that the stance phase time significantly increased more than in the condition of supporting the maximal voluntary weight on the affected side ($p<0.05$).
Conclusions: Single-leg stance on the paralysis side with knee flexion and extension increased symmetry in weight bearing during stance phase time. This study suggests that single-leg stance exercises augments improved gait function through sufficient weight bearing in the stance phase of the affected side.

Key Words: Balance, Single-leg stance, Stroke, Weight-bearing

Introduction

Stroke patients have various disorders, including muscle atrophy, decreased muscle strength, sensory disability, and reduced balance ability. As part of the sensory disorders, the proprioceptive sense of these patients is sometimes damaged. Among the lower-extremity problems that most hemiplegia patients experience, decrease of proprioceptive sense and muscle strength in the damaged joints lead to asymmetry of the lower extremity [1,2]. Decreased sensory makes it difficult to support weight on the affected side and causes asymmetric weight bearing on both lower extremity [3]. Also, in quiet standing, postural sway occurs more severely because of decreased stability of the affected leg compared with the unaffected leg [4]. While in the standing position, weight bearing increases on the less-affected side and the center of pressure (COP) is shifted onto the less-affected side. Many hemiplegia patients tend to stand with the weight more on the unaffected side, which can become a risk factor for musculoskeletal degeneration or pain in the unaffected side, as well as for decrease in bone density in the affected side [5,6].

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Previous studies reported that maximal voluntary weight bearing on the affected side decreased the ability to support weight on the outer and forward direction more on the affected side than on the unaffected side [7]. Asymmetric weight bearing on the affected side leads to a balance control disorder in the affected leg and asymmetry of gait [8].

The asymmetric gait cycle of stroke patients also affects their gait symmetry. The speed and the symmetry of gait are correlated with motor recovery, lower-extremity muscle strength, peak torque, total work, and spasticity [8]. If the gait symmetry is reduced, gait speed is also reduced, and these are related to problems such as asymmetric weight bearing, inefficiency, and change in balance control [9]. Previous studies reported that the COP of the body is focused backward in the asymmetric stance phase during the low-speed gait of a stroke patient [10], and that this is related to balanced standing and asymmetry of gait [8].

To achieve symmetric gait, symmetrical weight bearing should first be achieved. Symmetric weight bearing can be achieved by consistent training for proper weight bearing on the affected side. In previous studies, for symmetric weight bearing on the affected side, muscle strengthening through sit-to-stand exercises [11], weight movement training by using visual feedback [12], and single-leg exercises on the affected side with use of a tool to control the angle of the hip joint were implemented [13]. Among them, muscle strengthening exercises and single-leg exercises, which are easily applied in the clinic, are simple and efficient methods to improve the sensorimotor system of hemiplegia patients with sensory damage. Also, O'Sullivan and Schmitz [14] reported that patients with problems in the sensorimotor system refuse to use the affected side, and therefore, that this behavior could be learned; however, repeated stimulation of the senses affects sensory function and the sensory recovery capacity, which indicates that using the affected side helps patients with sensory disorders.

In this study, movement of joint with muscle activity was applied to increase weight bearing on the affected side to produce a more symmetrical weight bearing. This provides sensory stimuli into the sensory receptors of the joints and muscles, and the input of proprioceptive sense information contributes to the stability of joints [15]. Accordingly, in this study, we intended to apply movement of the knee joint during a single-leg stance to increase the patient's ability to weight bear on the affected side and promote symmetric weight bearing. This study has the following hypotheses: (1) the single-leg stance affects weight bearing on the affected side more so than quiet standing, leading to symmetric weight bearing and enhanced gait ability; (2) when knee joint movement is applied in the single-leg stance, the sensory input and muscle activation will be increased more than without this movement, leading to symmetric weight bearing and enhanced gait ability.

Methods

Subjects

The subjects were 18 patients (12 men and 6 women) with left hemiplegia who were admitted to H Hospital in Seoul, Korea. The inclusion criteria of this study were as follows: (1) a score of ≥25 on the Korean version of the Mini-Mental State Examination (MMSE-K), (2) ability to do 10-m independent gait or independent gait with a cane, (3) reduced proprioceptive sense in the affected leg, and (4) absence of musculoskeletal disorders in the lower extremities.

Procedures

To evaluate the weight bearing and gait ability of the affected side, four conditions were implemented and then measured: (1) quiet standing position, (2) holding the position after shifting the weight to the affected side maximally and voluntarily, (3) raising the unaffected leg and holding the standing position on the affected leg, and (4) repeated flexion/extension movements of the knee joints for 30 s while in a single-leg stance (Figure 1). In the second condition, the time for weight bearing after weight shifting to the affected side was 30 s. When implementing the third condition, the time was also 30 s like in the second condition, but the flexion of the hip joint had to be kept at 5^{o} and the knee joint flexion at 10^{o}. In the fourth condition, flexion and extension movements of the knee joint in the third condition were applied with no hyperextension of the knee joint, and the hip joint was maintained at 5^{o} flexion and the knee joint at 10^{o} flexion.

Additionally, in the single-leg stance, the therapist could provide verbal cues to help the patient maintain balance, and if necessary, a cane could be also used. To evaluate the gait ability after the implementation of each condition, an OptoGait system (Microgate S.R.L, Bolzano, Italy, 2010) was used and the subject was requested to walk at a comfortable speed. When necessary, minimal assistance was provided through a cane to eliminate the subjects' anxiety during gait performance. Additionally, a step-test measurement was conducted three times after the implementation of the

Figure 1. Positioning to each conditions. (A) Quiet standing, (B) maximal weight bearing on affected side, (C) single-leg stance on affected side.

conditions. Each condition was measured with OptoGait and the step test, and subjects took enough rest before moving to the next condition.

Outcome measures

Step test

Step test is a measurement method in which the action of raising the unaffected foot to a 7.5-cm height and then bringing the foot down again on the floor is repeated for 15 s, with each action counted [16]. The measurement was conducted a total of three times, and the subjects took a 1-min rest between each measurement. Before the measurement, the subjects stood on the front step without any aid. The step was placed 5 cm in front of the patient. Only complete steps were recorded while the action was being repeated for 15 s. During the test, the subjects were not provided with any aid or help. If any help was necessary for keeping balance or if the subject requested for help, the test was stopped and only complete steps were recorded. In previous studies, the reliability of the test-retest intraclass correlation coefficient (ICC) was 0.99, when the subjects were 21 stroke patients, the reliability was $>$0.88 [16]. For inter-rater reliability, the ICC was 0.996-0.999, and the intra-rater reliability was 0.981-0.995 [17].

OptoGait

To measure gait ability, the OptoGait system was used. OptoGait consists of two 3-m transmitting bars and a web cam (Logitech Webcam Pro 9000) (Figure 2). Bars on both sides were installed with 1 m width between each other. Each bar was equipped with a total of 96 light-emitting diodes placed at 1-cm intervals, and communicated through direct infrared light. An optical sensor transmitted at 100 Hz was used and collected information about the time and space gait parameters while a subject walked between two parallel bars. Video information was saved and the web cam was

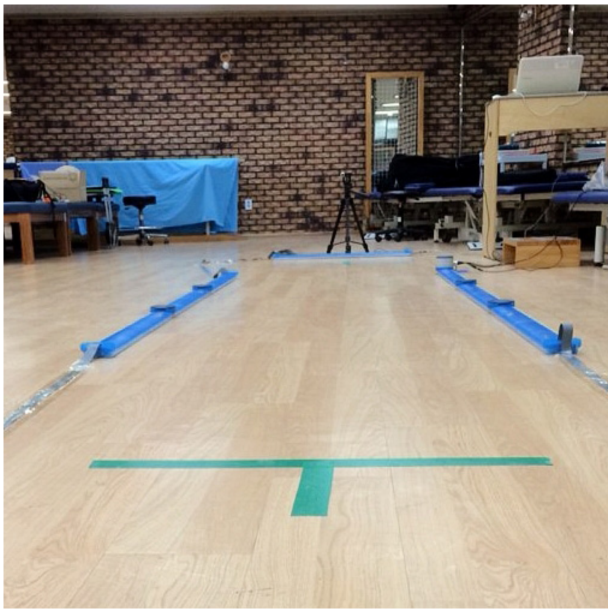

Figure 2. OptoGait system (Microgate S.R.L, Bolzano, Italy, 2010).

synchronized for measurement accuracy, including the starting foot for the walk of the subject and recognition of error due to foot overlap. The collected information about the time and space parameters was processed by using OptoGait ver. 1.5.0.0 (Microgate S.R.L) software [18]. For accuracy of data collection, the system was calibrated to 0 before taking measurements.

Data analysis

In this study, PASW Statistics 18.0 (IBM Co., Armonk, NY, USA) was used for statistical analysis. The general characteristics of subjects were analyzed by using descriptive statistics (Table 1). Additionally, the effects of the step test and gait cycle of the four conditions were repeatedly measured to validate the immediate effects. The significance level was set at 0.05 for all analyses.

Results

This study applied the four conditions to stroke patients to measure dynamic balance and weight bearing of the affected lower extremity and gait parameters. Positioning of each condition was as follows: condition 1 was quiet standing position for 30 s, condition 2 was holding the position after maximal voluntary shifting the weight to the affected side, condition 3 was holding the single leg standing position on the affected leg, and condition 4 was repeating flexion/extension movements of the knee joints for 30 s while in a single-leg stance.

The step test showed a significant difference in condition 4 depending on the repeated measurement point ($p<0.05$). Additionally, in paired comparison, condition 2 showed a significant difference from condition 1. Condition 3 showed a significant difference from condition 1 and condition 2 ($p<0.05$). Also, condition 4 showed a significant difference from condition 1, condition 2, and condition 3 ($p<0.05$; Table 2).

The OptoGait system was used to compare and analyze the stance phase and the swing phase of the affected and unaffected sides during the gait cycle. The results showed a significant difference in the stance phase of the affected side in condition 4 depending on the repeated measurement point ($p<0.05$). According to the paired comparison of the stance phase, conditions 1 and 4 ($p<0.05$) and conditions 2 and 4 ($p<0.05$) showed a significant difference (Table 3).

Table 1. General characteristics of the subjects (N=18)

Characteristic	
Age (y)	50.89 (9.779)
Sex (male:female)	12:6
Affected side of stroke (right:left)	0:18
Weight (kg)	63.78 (7.026)
Height (cm)	164.11 (7.722)
After shock (mo)	12.00 (4.256)

Values are presented as n or mean (SD).

Discussion

In this study, four conditions in standing (standing still, maximal voluntary shifting of weight to the affected side

Table 2. Effect of the step-test (conditional) (N=18)

	Condition 1	Condition 2	Condition 3	Condition 4	F	p
Step test (steps)	7.074 (1.870)	7.851 (2.344)[a]	8.407 (2.560)[a,b]	9.111 (2.647)[a-c]	14.919	<0.001

Values are presented as mean (SD).
[a]Significant of condition 1 ($p<0.05$). [b]Significant of condition 2 ($p<0.05$). [c]Significant of condition 3 ($p<0.05$).

Table 3. Effect of gait variables (conditional) (N=18)

	Condition 1	Condition 2	Condition 3	Condition 4	F	p
Affected, stance phase (sec)	1.893 (1.032)	1.968 (1.217)	1.991 (1.139)	2.190 (1.196)[a,b]	4.298	0.009
Affected, swing phase (sec)	1.229 (0.654)	1.213 (0.818)	1.291 (0.714)	1.166 (0.904)	0.172	0.915
Less affected, stance phase (sec)	1.918 (1.044)	1.962 (1.233)	1.996 (0.969)	2.006 (1.149)	1.093	0.382
Less affected, swing phase (sec)	1.452 (0.680)	1.745 (1.323)	0.546 (2.999)	1.442 (0.587)	1.271	0.320
Stride (cm)	76.500 (14.608)	70.185 (13.258)	76.370 (18.166)	67.981 (11.570)	0.651	0.594

Values are presented as mean (SD).
[a]Significant of condition 1 ($p<0.05$). [b]Significant of condition 2 ($p<0.05$).

and holding for 30 s, single-leg stance on the affected leg for 30 s, and repeatedly flexing/extending the knee joint for 30 s while in a single-leg stance on the affected leg) were implemented, and their effects on weight-bearing ability and gait were immediately compared. To measure the weight-bearing ability of the affected side and dynamic standing balance, a step test was used. An OptoGait system was used to measure the time of the stance and swing phases during the gait cycle. A paired comparison of each condition in the step test showed that the step count significantly increased in every condition. The step test in this study is the ability to support the weight of the contralateral step test. This is used to measure the ground reaction forces as force plate validity in stroke patients based on the results of previous studies were applied [19]. Therefore, the step test can be a simple tool used in the clinic to measure weight bearing capacity. Additionally, the OptoGait system results demonstrated that conditions 1 and 4 and conditions 2 and 4 showed a significant difference in the stance phase of the affected side ($p < 0.05$).

In previous studies, maximal voluntary weight bearing on the affected side was more effective than quiet standing, and there was a positive correlation in the gait cycle [7]. A study by You *et al.* [13] showed that when the affected side single-leg stance, timed up and go test (TUG), and berg balance scale (BBS) was applied for eight weeks, it significantly increased the subjects' ability to walk and improvement in balance could be seen.

The step-test position for stroke patients is stepping on the unaffected side while keeping balance with the affected lower extremity [20]. The significant results of the step test in all conditions was attributed to the fact that the foot used for the single-leg stance and the weight-bearing foot on the step test was the same. Furthermore, the significant results are attributed to weight bearing by the affected leg and its measurement in the two conditions of shifting the maximal voluntary weight and the single-leg stance. However, a significant difference was found only in the OptoGait measurement in this study, and this is probably because the focus of the conditions applied to subjects was placed on muscle activity and sensory input of the affected side in the standing position. Gait uses various muscles, including lower-extremity muscles for weight bearing, as well as trunk muscles. Furthermore, the gait cycle of the unaffected side should be also considered. Therefore, significant differences seemed to appear only in the stance phase similar to the conditions that were implemented in this study.

For hemiplegia patients who have abnormal gait patterns, exercises that increase the activity of the gluteus maximus and hamstring muscles, as well as activate the quadriceps around the knee joint, and the coordinated movement of soleus are known to be important [21]. For the single-leg stance applied in this study, the stance was set to maintain 5^{o} flexion at the hip joint and a 10^{o} flexion of the knee joint, at best, based on previous studies [13] for lower-extremity muscle activation. Additionally, the reason why knee joint movement was applied after the single-stance on the affected side in the fourth condition was that repeated movement of the joint inputs sense stimuli to sense receptors of the joints and muscles.

Lower-extremity muscles consist of muscle spindles or proprioceptive sensory receptors that have sensitive receptors, such as the Golgi tendon organ [22]. Also, proprioceptive sensory stimuli provide stance information and necessary segmental movements for the motor control system, and when movement of a single joint occurs, the strength of the activated muscles also changes according to that angle [23]. Changes in the joint angle affect the activity of all muscles related to that joint, and many movements can be made when joint movements overlap [23]. In other words, movement of a joint affects the movements of other joints. In this study, the activity of the more effective muscles around the joints and make sense of the receptor activity in single-leg stance was applied to the movement of the knee joint.

The results of this study show that applying the single-leg stance in hemiplegia patients will increase sensory input and muscles activation of the affected lower extremity and improve the asymmetric weight bearing toward a more symmetric distribution. Additionally, it was demonstrated that voluntary movement of lower-extremity muscles to increase sensory input is more effective. Furthermore, concerning the gait cycle, it was found that the short stance phase time due to the unstable weight bearing of the affected leg improved through the single-leg stance. However, it was not sufficient to affect the symmetry of gait because of the complex mechanism of gait. In addition, this study was conducted on left hemiplegia patients who have sensory recovery problems involving the disorder of improper recognition of the body due to right brain damage, and the effect was not clearly demonstrated as the measurement was performed only once. Furthermore, because study was aimed only at left hemiplegia patients, the results could not be compared between left hemiplegia patients and right hemiplegia patients. In future studies, more concrete and systematic protocols of the single-leg stance should be applied to many subjects, and the effects need to be clearly demonstrated.

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