

Original Article

# Repetitive sit-to-stand training with the step-foot position on the non-paretic side, and its effects on the balance and foot pressure of chronic stroke subjects

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**Abstract.** [Purpose] This study aimed to improve the asymmetrical weight-bearing ratio by applying repetitive sit-to-stand training methods that feature a step-foot position to the paretic-side foot of hemiplegic patients; it sought also to provide the information needed to apply weight-bearing and balance training to hemiplegic patients. [Subjects and Methods] The subjects were divided into two groups: a spontaneous group and a step group. They all performed repetitive sit-to-stand training five times per week for a total of six weeks. The Biodex Balance System, TUG, and 5XSST were used to measure the static and dynamic standing balance of each patient. A foot mat system was used to measure foot pressure. [Results] In the balance measurements, differences in the Overall index, Ant-post index, Med-lat index, Fall risk index, TUG, and 5XSST after training was significantly different between the two study groups. In evaluating foot pressure measurements, we found that the COP (Ant-post), Peak pressure: hind foot, and Contact area: hind foot measurements significantly differed between the groups after the training. [Conclusion] Repetitive sit-to-stand training that involves positioning the non-paretic leg upward can be considered a significant form of training that improves the symmetric posture adjustment and balance of hemiplegic patients following a stroke.

**Key words:** Step-foot position, Balance, Foot pressure

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## INTRODUCTION

The most common mobility problem among stroke patients is muscular weakness contralateral to the injury side<sup>1)</sup>. Persons with hemiparesis scarcely use their affected foot for weight-bearing while executing trunk movement and reaching tasks<sup>2)</sup>; this may lead to difficulties in performing daily activities, such as rising from a chair without assistance<sup>3, 4)</sup>.

Stroke patients use their weight on their non-paretic side when moving their hip or trying to stand up, by positioning the non-paretic side of their foot to the rear instead of the paretic side of their foot, or by using an arm to compensate for the unsuitable sit-to-stand position<sup>5)</sup>. If this compensatory mechanism becomes habitual, it will exacerbate the non-use of the paretic-side leg<sup>4)</sup>. According to the results of previous studies, even the learned non-use of the paretic side in chronic stroke patients who repetitively used the paretic

side of their limbs has been reported to improve the use and function of the paretic limbs<sup>6)</sup>, and these repetitive training tasks have been found to improve the ability to assume the sit-to-stand position<sup>7)</sup>. Shumway-Cook et al.<sup>8)</sup> recommend that stroke patients perform their tasks in fast-moving training and in a variety of environments, along with sit-to-stand training. According to other studies that focused on seat height<sup>9)</sup>, results from the use of foot placement<sup>10, 11)</sup> and stepping on the non-paretic-side leg<sup>11)</sup> suggest that even the weight-bearing ratio of the non-paretic side leg of chronic stroke patients can vary, depending on their sit-to-stand position. The results of applying a lateral step to the elderly population and patients with hip disorders or balance problems may enhance our understanding of the mechanisms that underlie dysfunctions in postural control<sup>12)</sup>. However, most changes in the measured parameters have been evaluated in the absence of an intervention period. The most prevalent characteristic among hemiplegic patients due to stroke is imbalance between their paretic and non-paretic legs, which limits their daily activities. Thus, hemiplegic patients must perform sit-to-stand training in order to do independent walking and return to their daily lives. In this study, we look for ways to improve the asymmetrical weight-bearing ratio by applying different repetitive sit-to-stand training to the non-paretic-side foot of hemiplegic patients, and provide the

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information needed to offer balance training to hemiplegic patients.

## SUBJECTS AND METHODS

A total of 23 subjects participated in the study, with 12 subjects in the experimental group and 11 in the control group. There was no significant difference among them in terms of height, weight, age, time since stroke, and the like. The mean ( $\pm$ standard deviation)  $\pm$  height, weight, age, and time since stroke in the spontaneous (SPO) control group were  $161.43 \pm 8.49$  cm,  $61.21 \pm 13.10$  kg,  $61.29 \pm 10.76$  years, and  $33.36 \pm 21.09$  months, respectively; those figures in the step (STP) experimental group were  $164.67 \pm 9.54$  cm,  $61.53 \pm 9.45$  kg,  $57.47 \pm 9.47$  years, and  $26.6 \pm 14.61$  months, respectively.

The subject inclusion criteria were more than six months having passed since their injury, the ability to walk 10 m independently and without aid, and the ability to rise from a chair without the use of the hands and with the non-paretic lower limb supported on a step. All the patients had a modified Ashworth Scale (MAS) score of below grade 2 spasticity and a Mini Mental State Examination (MMSE) score of 24 or higher. Individuals were excluded if they had less than 15-degree passive ankle dorsiflexion, any orthopedic disorder that might interfere with the experiment, neglect of space on the affected side, or any other neurological disease or auditory or visual deficit that could prevent data collection. The University Research Ethics Board approved the study protocol, and all subjects gave informed consent. The experiment subjects underwent neurological physical therapy five times per week under the guidance of a physical therapist with more than three years of experience, and they were divided into two groups—namely, the SPO group and the STP group. Additionally, all subjects underwent repetitive sit-to-stand training five times per week for a total of six weeks.

For the evaluation of the balance position, the Biodex balance system SD (Biodex Medical System, Inc., USA) was used. The test was run for 20 s, and the test application levels of the mat were 1–8, wherein 1 was the most common movement, and 8, the least common movement. Because this study targeted patients with central nervous system injuries, the test was conducted at the lowest level, 8, which represents the least amount of movement and the lowest risk factor. Balance ability was captured as a balance index value, and the better an individual's balance ability was, the lower the balance index would be. As part of the assessment program, we also undertook the postural stability test (PST) and the limits of the stability test (LST). Before the test, the patient stood on a fixed mat on his or her two feet and exercised three times to adjust to the equipment, after which time the test was started. The subjects were measured at the position at which their feet were comfortably opened and both their hands were on the equipment. Three measurements were taken and their results were averaged.

The timed up and go test (TUG) is a simple way of assessing a patient's standing ability and movement ability. The patient sits on a chair that features arm rests, and the length of time is measured from when the tester signals the

patient and the patient stands up and walks for 3 m, passes the predetermined turning point, and returns to the chair. The intraclass correlation was 0.99, and the interclass correlation was 0.98; these values have been reported with high levels of confidence<sup>13</sup>. In recent years, this method has been used to evaluate the balance ability and functional movement of the elderly and fragile elderly, and of stroke, Parkinson's disease, and arthritic disease patients, to predict their risk of a fall<sup>14</sup>.

To measure leg strength, we used the five times sit-to-stand test (5XSST). This test measures the time required to assume the sit-to-stand position on a stool five times without using a hand. The interclass correlation was 0.87<sup>15</sup>.

The pressure measurement system evaluates the pressure applied to the sole of the foot during the standing position, using the mat form of a resistance-type pressure sensor called F-Mat (Tekscan Inc., USA). The size of the pressure sensor is 8,382 mm  $\times$  8,382 mm, and it is composed of 44 horizontal sensors and 52 vertical sensors. The pressure distribution was used with a commercial Tekscan program (Ver. 5.83) and analyzed by collecting the data at 30 frames/s. The foot pressure measurement equipment was used to measure, from the stationary state, the distribution of foot pressure on the mat equipped with a pressure sensor; it also measures the pressure in real time, so as to analyze the symmetry and asymmetry weight distribution and any selection bias. The subjects assumed the static standing position on the mat and maintained it for 30 s; we then analyzed the middle 5-s interval. The foot pressure measurement was taken three times, and the results were averaged.

Sit-to-stand training was performed as per Roy (2007) and Rocha Ade et al<sup>11</sup>. It was divided into the following two conditions, while taking into account the conditions of use and patient fatigue.

- (1) SPO group: No instructions were given regarding the initial foot position.
- (2) STP group: The non-paretic foot was constrained by supporting it on a step, and the paretic foot was kept at ground level. Both feet had 10-degree ankle dorsiflexion (step height: 25% of the knee height).

The configuration of the training was as follows:

- (1) Move the cup from the non-paretic side to the paretic side 10 times, while sitting.
- (2) Carry out the sit-to-stand position 10 times by aligning the body center while looking in the mirror in front.
- (3) Carry out the sit-to-stand position 10 times while picking up the goods in front of the paretic foot with the non-paretic hand.
- (4) Carry out the sit-to-stand position 10 times and put the weight on the paretic side, with the aid of a therapist.
- (5) Carry out the sit-to-stand position 10 times as directed by the therapist, without looking in the mirror. A 1-min rest was allowed after each set, across all training sets. Considering the intensity of the training, 12-times sit-to-stand training was conducted at weeks 3–4, and 15 times at weeks 5–6.

The descriptive statistics and the results of tests for normality (i.e., Shapiro-Wilk) and homogeneity of variance were calculated as outcome variables, using the SPSS 20.0 for Windows software package (SPSS Inc., Chicago, IL, USA). An independent two-sample t-test was used, given

**Table 1.** A comparison of balance and foot pressure pre/post-test, in each group

	SPO group (n=11)	STP group (n=12)
Balance	Overall index* (m/s)	0.16±0.38
	Ant-post index* (m/s)	0.07±0.25
	Med-lat index* (m/s)	0.12±0.31
	Fall risk index* (m/s)	-0.33±1.08
	TUG* (s)	0.43±4.47
	5XSST* (s)	0.11±3.88
	COP(Med-lat) (cm)	-0.64±1.43
Foot pressure	COP(Ant-post)* (cm)	-0.65±1.76
	Peak pressure-forefoot (kPa)	-18.16±23.78
	Peak pressure-hindfoot* (kPa)	-7.21±34.04
	Contact area-forefoot (cm <sup>2</sup> )	-12.54±25.26
	Contact area-hindfoot* (cm <sup>2</sup> )	-14.65±33.05

Mean±SD.

SPO group: Spontaneous group, STP group: Step group

\*p&lt;0.05

the homogenous nature of the subject; the difference before and after training was calculated and comparisons were made using an independent two-sample t-test. The statistical significance level was set at  $\alpha = 0.05$ .

## RESULTS

In the balance measurement, the changes to the Overall index, Ant-post index, Med-lat index, Fall risk index, TUG, and 5XSST values after training significantly differed between the STP and SPO groups ( $p < 0.05$ ). In evaluating the foot pressure measurement, the COP (Ant-post), Peak pressure: hind foot, and Contact area: hind foot values were found to significantly differ between the groups after the training ( $p < 0.05$ ). In the evaluation of the plantar pressure measurement, the COP (Med-lat), Peak pressure: fore foot, and Contact area: fore foot values did not significantly differ between the STP and SPO groups after the training ( $p > 0.05$ ). The balance and foot pressure measurements of the subjects are outlined in Table 1.

## DISCUSSION

The average person, in terms of mobility, can adjust his or her body weight relatively easily through the use of his or her own dynamic balance ability and a symmetrical weight support on either side of the leg in the standing position. Stroke patients, however, are more likely to stand by using more weight support on their non-paretic leg and less weight support on their paretic leg. This creates a tendency wherein the patient may fall upon movement, and thus it restricts daily activities, making it difficult to return to independent living. To increase weight support on the paretic leg, the effects of foot pressure and balance in stroke patients were examined by conducting repetitive sit-to-stand training with the non-paretic foot on the mat. In the current study, a statistically significant and dynamic reduction in balance ability appeared among those patients in the group training

that made use of the mat. Leroux et al.<sup>16</sup> report that a stroke patient showed a significant increase in balance, mobility, and stability in his posed body upon undertaking a task-oriented program. Tung et al.<sup>17</sup>, in their study of 32 stroke patients, applied 30 min of general physical therapy in their control and experimental groups three times per week for four weeks, and additional repetitive sit-to-stand training in the experimental group, which improved the dynamic balance ability and the extension muscle ability of the patients therein. In this study, the group that used the mat showed improved balance ability and foot pressure; this enabled them to elevate their non-paretic leg and shift the center of gravity in their non-paretic leg to that in their paretic leg, and to move more slowly. It might also have brought about quick recovery in their position adjustment by reducing their learned non-use of the paretic leg. There was a significance decrease in COP (Ant-post) in the foot pressure test, and the peak pressure of the hind foot and the contact surface of the hind foot each showed significant increases. Cheng et al.<sup>18</sup> report that after repetitive sit-to-stand training with a symmetrical foot posture, the total distance from the center of pressure in every direction—front and rear, and left and right—in the static standing position decreased after training. In the current study, the total distance from the center of pressure in the front and rear decreased.

Chaudhuri and Aruin<sup>19</sup> report that elevating the non-paretic-side foot forcibly loads more weight on the paretic leg, improves the weight support symmetrically while increasing muscle activity in the paretic leg, provides strong stimulation, and finally, increases the weight load on the paretic leg. Laufer et al.<sup>20</sup> report that in their study of hemiplegic patients while using steps of various heights (10 cm and 17 cm) on the non-paretic side of the leg and forced weight-bearing induction on the paretic side, the weight support on the paretic leg increased. However, there was no significant difference in the weight distribution of the paretic-side leg between the 10-cm and 17-cm steps. Rodriguez and Aruin<sup>21</sup> reported that when they used varying degrees on the outer

apparatus and varying mat heights on the non-paretic-side leg to increase weight-bearing on the paretic side, there was a symmetrical improvement in the standing position. In particular, the use of a 5-degree outer apparatus and a 9 × 12-mm mat derived the greatest improvement in the symmetry of the position.

The benefits of sit-to-stand training that features greater loading on the affected limb may include increased muscle strength in the affected limb—something that is made possible by maximizing joint compression and augmenting the sensory awareness of the limb. Increased muscle strength and confidence-placing weight through the affected limb may reduce fall risk during sit-to-stand activities. Greater use of the affected limb through the use of CIM strategies may provide a functional training method for muscle strength and joint position sense, and may reverse the effect of learned non-use<sup>22)</sup>.

In hemiplegic patients, due to the reduction of feedback through the soles of the foot, foot pressure transfer through the lateral mid-foot to the fore foot and toe area has been reported<sup>23)</sup>. This is caused by reduced weight-bearing on the paretic side, inadequate mobilization of the paretic leg upon balancing, and imbalance of the foot and ankle muscles. These findings were relatively less prevalent among stroke patients than the normal group in the pressure and the contact area of the hind foot<sup>24)</sup>. In the current study, in the STP group, the maximum pressure of the hind foot increased the contact area of the rear foot, as it continuously provided pressure on the ankle and the paretic-side leg during repetitive sit-to-stand training. Thus, it increased body cognition and weight-bearing, and was thought to have activated the extension muscle on the paretic side. Moreover, the increase in the surface area of the hind foot contact area supports the surface and increases the weight-bearing ability on the paretic side. This intervention can be especially useful for individuals with ankle range-of-motion limitations who could experience difficulties in positioning their paretic foot backward<sup>11)</sup>.

Based on the results of previous studies and those of this study on measured posture symmetry and balance, repetitive sit-to-stand training that positions the non-paretic leg upward can be considered a significant form of training that helps improve symmetric posture adjustment and balance in hemiplegic patients following a stroke. One should bear in mind, however, that as this study did target only partially hemiplegic patients, its results have limited generalizability with regard to all hemiplegic patients.

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