



Original Article

The effects of upper and lower limb position on symmetry of vertical ground reaction force during sit-to-stand in chronic stroke subjects

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Abstract. [Purpose] The purpose of this study was to evaluate the influence of arm and leg posture elements on symmetrical weight bearing during Sit to Stand tasks in chronic stroke patients. [Subjects and Methods] The subjects were diagnosed with stroke and 22 patients (15 males and 7 females) participated in this study. All participants performed Sit to Stand tasks on three foot postures and two arm postures. Two force plates were used to measure peak of vertical ground reaction force and symmetrical ratio to peak Fz. The data were analyzed using independent t-test and two-way repeated ANOVA. [Results] The results of this study are as follows: 1) Peak Fz placed more weight in non-paretic leg during Sit to Stand. 2) A symmetrical ratio to Peak Fz indicated significant difference between foot and arm posture, and had non-paretic limb supported on a step and paretic at ground level (STP) and grasped arm posture that lock fingers together with shoulder flexion by 90°(GA) (0.79 ± 0.09). [Conclusion] These results suggest that STP posture of the legs and GA posture of the arms should be able to increase the use of the paretic side during Sit to Stand behavior and induce normal Sit to Stand mechanism through the anterior tilt of the hip in clinical practices, by which loads onto the knee joint and the ankle joint can be reduced, and the trunk righting response can be promoted by making the back fully stretched. The outcome of this study is expected to be a reference for exercise or prognosis of Sit to Stand in stroke patients.

Key words: Stroke, Sit to Stand, Ground reaction force

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INTRODUCTION

The onset of a stroke leads to various symptoms, such as sensory, motor, cognitive, speech, and emotional disabilities¹⁾ and damage to the motor²⁾, balance ability of not only the upper and lower limbs, but also the trunk. In particular, the decrease of balance ability causes a lot of difficulty in performing activities of daily living³⁾.

Patients with hemiplegia after stroke have balance-control problems, such as postural sway, asymmetrical weight support, damaged weight-transfer ability, and postural standing-control degradation. Since most of their daily lives are spent sitting in wheelchairs during the early stages of rehabilitation, their exercise levels are very low compared to normal healthy individuals, and their selective trunk movements and balance abilities are significantly lower in the sitting position⁴⁾. This is essential for optimal performance in activities of daily living⁵⁾.

Some patients have asymmetrical posture of the head and neck due to the imbalance between muscle activity and stability and the changes in movement and stability between the head, trunk, and pelvis, as well as dominant use of the nonparetic side

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due to the lack of balance control, thereby inducing asymmetrical body-weight support⁶). Therefore, balance on changing support-surfaces⁷) during the rehabilitation of stroke patients and improvement of gait function, which is the most important factor in determining functional disability in stroke patients, are two of the most important goals during the rehabilitation process for all stroke patients⁸).

Consequently, these patients are at increased risk for falls, which frequently occur during Sit to Stand.

During the acute recovery period, when Sit to Stand is most difficult, stroke patients tend to develop habits and strategies to compensate for impairment on their paralyzed side⁹), including weight-bearing asymmetry. Many patients continue to exhibit weight-bearing asymmetry even after regaining strength and function in the paretic limbs. Prolonged asymmetry can lead to secondary muscle weaknesses in both the upper and lower body of the paretic side¹⁰). To compensate for the impairment of the paretic side, patients tend to shift their center of mass to their non-paretic side. This motor pattern requires increased energy expenditure and may lead to other orthopedic issues, which can worsen motor control and accelerate muscle weakness¹¹). In these patients, as much as 80% of the body weight is placed on the non-paretic side, which threatens postural stability and increases the risk of falls¹²).

During Sit to Stand and stand-to-sit, healthy individuals load their legs more or less symmetrically¹³). However, stroke patients exhibit asymmetrical weight bearing during the movement, placing approximately 41.5% less load on the paretic leg¹⁴). According to Cheng et al., stroke patients tend to put only 24–29% of the load on the paretic leg¹⁵). In order to compensate for compromised strength and coordination during Sit to Stand, stroke patients often shift their weight to the non-paretic leg as they start lifting themselves from the seated position; they may also place the non-paretic foot behind the paretic foot and use their arms¹⁶). Asymmetrical motor patterns result from the dominant use of the non-paretic side during Sit to Stand. Furthermore, fossilization of these compensation strategies reinforces underuse of the paretic leg.

Gait disability among stroke patients is a very common symptom that is observed in 80% of all patients¹⁷). The management of gait ability is an important goal in the process of therapy for stroke rehabilitation because gait is such a significant element in achievement of functional independence^{18, 19}). In order to recover a symmetrical gait various therapeutic approaches have been used to help stroke patients to overcome asymmetrical weight bearing²⁰). Biofeedback training related to weight distribution has been shown to be effective at restoring symmetrical stance following stroke²¹). Also elevating the non-paretic limb to suppress its use promoted greater weight bearing symmetry²²).

Sit to Stand is a complex movement that integrates upper and lower body movement. Neurological recovery in the upper body happens at a slower pace than in the lower body. Moreover, neurological damage in the upper body often leads to permanent disabilities, a fact that should be considered for motor skill recovery in stroke patients²³). Davies²⁴) reported that specific arm positions during neurodevelopmental techniques promote symmetrical movement in stroke patients. Carr et al.²⁵) reported that arm movements could help the lower body to generate more power. Therefore, we need a basis for assessing the effectiveness of various arm positions and movements for rehabilitation of stroke patients.

Several studies have explored various ways to encourage symmetrical weight bearing in stroke patients during Sit to Stand^{6, 22}). However, research on the relationship between various foot and arm placements and load bearing of the paretic lower limbs is lacking. The current study investigated the effects of various arm and leg positions on load-bearing symmetry during Sit to Stand in chronic stroke patients. The purpose of this study was to evaluate the influence of arm and leg posture elements on symmetrical weight bearing during Sit to Stand tasks in chronic stroke patients.

SUBJECTS AND METHODS

The study subjects consisted of 22 patients diagnosed with stroke via computed tomography (CT) scan or magnetic resonance imaging (MRI), who met other selection criteria, and who consented to participate in the study. Subjects' diagnosis, age, gender, and incident date were obtained through medical record review and interviews. The selection criteria included: patients with hemiparesis for a minimum of six months following incident of stroke; patients able to walk 10 m unassisted; patients with a Korean small-scale psychology test score of 24 or above, who were able to communicate and understand the tasks required by the study; patients with a minimum ankle range of motion (ROM) of 10°; and patients with Modified Ashworth Scale spasticity scores of 2 or less (0: no resistance, 5: affected parts rigid in flexion or extension). Additional patient evaluations were performed using the Fugl-Meyer assessment of motor recovery after stroke (FMA) (total possible score:34) for quantitative measurement of function recovery, as well as a timed get up and go (TUG) test to assess active balance (Table 1). The study was performed according to the principles of the Declaration of Helsinki, and ethical approval was granted by local committee of the Institution Review Board of university hospital.

Two force plates (AMTI, USA) were used to measure Fz during the experiments. Three different foot placements were tested in this study, including symmetrical placement (SYM), asymmetrical placement (AYM), and placement of the non-paretic limb on a step with the paretic limb at ground level (STP). SYM involved posterior placement of both feet with the ankle flexed at 15°. AYM involved anterior placement of the non-paretic limb with a neutral ankle (flexed at 0°) and knee bent at 90°, and posterior placement of the paretic limb with ankle flexed at 10°. STP involved placement of the non-paretic and paretic limbs on the plate and floor, respectively, with both ankles flexed at 15°. The plate height was set at 25% of subject's knee height. The two arm positions tested in this study included symmetrical arms (SA) and grasped arms (GA). SA involved relaxed and natural placement of the arms on each side of body, while GA involved clasping of fingers with shoulders bent

Table 1. Demographic and clinical characteristics of the subjects

Variable	Mean	SD
Age (years)	57.75	7.82
Height (cm)	163.38	4.31
Weight (kg)	67.58	2.72
Time since stroke (months)	13.19	6.13
Type (ischemic/hemorrhagic)	16/6	
Side (R/L)	11/11	
Gender (M/F)	15/7	
Ankle ROM (°)	24.82	8.71
Ashworth scale		
Adductors	1	1
Knee extensors	1	1
Soleus	2	1
Gastrocnemius	2	1
Fugl-Meyer Motor Assessment Score (/34)	27.67	2.42
TUG (s)	19.48	6.96
Knee height (cm)	42.92	4.45

at 90° to grasp arms²⁶).

The Sit to Stand experiments were conducted on a Bobath table (Bobath table NT-5000, Nteck, Korea) whose height was set according to each subject's knee height. Subjects were instructed to bend their hips and knees at 90° in order to measure their ankle ROM with a Goniometer (Goniometer PVC, Anymedi, Korea). Subjects were instructed to place their feet hip-width apart and parallel to their knees. The depth of the seat (table) was set at half the length of subjects' thighs (from the femur head to the knee joint). Subjects were instructed to perform each task while maintaining foot placement. In order to ensure the accuracy of the positioning, fluorescent-colored tape was used to mark where the subjects should be seated as well as where their feet and thighs should be placed²².

From the initial seated position, subjects were instructed to fix their gaze at a spot 3 m ahead at eye level and stand up at a natural pace upon the test administrator's prompt: 'Please stand up.' Each subject repeated the move five times on command, during which the ground reaction force was measured. The average of three measurements was used in the analysis.

The peak vertical ground reaction force (peak Fz) during Sit to Stand was measured between the points at which the subjects initiated and finished the movements; the measurements were generalized as percentage of bodyweight (%BW). The sampling rate of the force plates was set at 200 Hz, and the results were stored in ASCII for analysis by the Matlab software program. The center of pressure (COP) and the frequencies of ground reaction force calculated via the Fast Fourier Transform (FFT) process were used to measure and evaluate the balance required for posture control, and peak Fz was used to assess weight-bearing symmetry²⁷⁻²⁹.

Symmetry ratios to peak Fz provide a simple measure of the kinematic symmetry between the paretic and non-paretic sides. A symmetry ratio of 1 represents perfect symmetry; and increasing deviation from this ratio indicates severe asymmetry. A symmetry ratio greater than 1 implies that the paretic side's ratio is greater than the non-paretic side. Conversely, a symmetry ratio less than 1 implies that the non-paretic side's ratio is greater than the paretic side. The variables' extracted values were applied to the symmetry ratio equation shown below²⁹.

$$\text{Symmetry ratio} = 100 \times \frac{\text{Paretic side (parameter value)}}{\text{Non-paretic side (parameter value)}}$$

Experiment results were statistically analyzed with PASW Statistics for Windows, version 18.0. Independent sample t-tests were performed to compare the average peak Fz of the paretic and non-paretic limbs under each condition and the symmetry ratios of the two arm placements combined with the three leg positions. A two-way repeated analysis of variance (ANOVA) was performed to examine differences in symmetry ratios for each peak Fz according to the positional elements. Finally, the Bonferroni method was used for post-hoc testing of the ANOVA results.

RESULTS

Comparison of peak Fz between paretic and non-paretic legs under each condition revealed that the peak Fz of the paretic side was significantly greater than that of the non-paretic side ($p < 0.05$) (Table 2).

Comparison of the symmetry ratios of the peak Fz of the paretic and non-paretic legs during Sit to Stand showed that the STP position, in which a step was used to inhibit weighting of the non-paretic leg, and the GA position, in which the subject's

Table 2. Comparison of peak Fz between paretic and non-paretic legs (Mean ± SD) (%BW)

Position		Non-paretic leg	Paretic leg	p
SYM	SA	71.33 ± 5.18	28.67 ± 8.24	*
	GA	67.27 ± 6.76	32.73 ± 5.52	*
AYM	SA	70.13 ± 6.42	29.87 ± 3.47	*
	GA	64.48 ± 7.84	35.52 ± 2.94	*
STP	SA	65.24 ± 7.54	34.76 ± 6.49	*
	GA	59.82 ± 7.37	40.18 ± 9.44	*

*p<0.05.

SYM: symmetrical; AYM: asymmetrical; STP: non-paretic limb supported on a step and paretic limb at ground level; SA: symmetrical arms; GA: grasped arms.

Table 3. Descriptive statistics of the symmetry ratios of the peak Fz for each position (Mean ± SD)

BMD	Elderly	Stroke	P
SYM	0.56 ± 0.24	0.61 ± 0.04	*
AYM	0.64 ± 0.11	0.69 ± 0.29	*
STP	0.71 ± 0.34	0.79 ± 0.09	*

*p<0.05.

SYM: symmetrical; AYM: asymmetrical; STP: non-paretic limb supported on a step and paretic limb at ground level; SA: symmetrical arms; GA: grasped arms.

Table 4. Results of two-way repeated ANOVA for posture symmetry ratios

Posture	Type III SS	df	Mean square	F	p
Foot	0.74	2	0.31	68.42	*
Arm	0.25	1	0.01	52.64	*
Foot*arm	0.13	2	0.14	1.85	0.17

*p<0.05.

hands were clasped together, had a significantly higher symmetry ratios (p<0.05) (Table 3).

The results of the two-way repeated ANOVA test revealed statistically significant main effects in each arm and leg position. However, there were no significant differences in the effects of these positions on one another. The results of the post-hoc test revealed a significant difference between each leg position, with STP showing a higher symmetry ratio compared to that of AYM (p<0.05) (Table 4).

DISCUSSION

Sit to Stand is one of the most frequently performed skills in everyday life³⁰). The World Health Organization defines it as a critical criterion of functional mobility; it is closely associated with efficient gaits and fall and mobility rates³¹). Asymmetric weight bearing during Sit to Stand in chronic stroke patients is a major cause of fall injuries. Treatment strategies that encourage patients to put more weight on the paretic limb are reported to be effective for recovery³²). Stroke patients themselves reportedly do not perceive the asymmetry during Sit to Stand; therefore, treatment intervention is of paramount importance⁷). Shepherd³³) reported that improving paretic limb function in stroke patients can alleviate chronic underuse of these limbs, and that active and repeated use of the paretic limbs can reverse neurological damage.

The current study examined the effects of posture elements (arm and leg positions) on symmetric weight bearing during Sit to Stand. The peak Fz during Sit to Stand was measured with force plates during two different arm placements (SA, GA) and three different foot positions (SYM, AYM, and STP). During Sit to Stand, STP showed higher weight bearing symmetry ratios than those of AYM or SYM. These findings are similar to those reported by Rocha et al.²²) and Brunt et al.³⁴), where STP was shown to greatly reduce weight-bearing asymmetry compared to that of SYM, likely because STP forces patients to use their paretic leg in order to come to a full standing position, despite the increased length of time to complete the movement. Laufer et al.³⁵) reported that force-shifting the load to the paretic leg by having the subjects place the non-paretic leg on steps of various heights (10 cm, 17 cm, etc.) led to increased load bearing of the paretic leg. Rodriguez and Aruin²⁰)

reported that shifting the body weight to the paretic leg with step of various angles and heights improved position symmetry. They also found that steps with outer angles of 5° and 9 and 12 mm heights resulted in the greatest symmetry improvements. Because the weight-bearing ratio of the paretic leg is closely related to functional movements such as Sit to Stand³⁶⁾, various methods designed to increase the weight-bearing ratio of the paretic side have been adopted in clinical setting³⁷⁾. Rocha et al.²²⁾ suggested that STP is an effective strategy with which to reduce weight-bearing asymmetry during Sit to Stand.

Among the arm placements assessed in the current study, GA was significantly more effective than SA for promoting symmetrical weight bearing during Sit to Stand. Normal biomechanics necessitates bending of the pelvis while rising from the seated position, which requires anterior tilt of the body. Carr et al.³⁸⁾ found that stroke patients tend to exhibit a posterior tilt in the sitting position for various reasons, and that this tilt causes energy inefficiency as the body must over-tilt forward during Sit to Stand, which can place excess load on the knees and ankles. Gjelsvik et al.³⁹⁾ reported that a straight and upright back in the sitting position allows increased shoulder ROM and subsequently longer reach, and that GA reduces posterior tilt of the pelvis more than SA and ensures active stability as it requires less momentum to lift the upper body when Sit to Stand is initiated.

These results suggest that STP posture of the legs and GA posture of the arms should be able to increase the use of the paretic side during Sit to Stand behavior and induce normal STS mechanism through the anterior tilt of the hip in clinical practices, by which loads onto the knee joint and the ankle joint can be reduced, and the trunk righting response can be promoted by making the back fully stretched, so that it seems that STP and GA could be appropriate treatment strategies to reduce asymmetry of weight support between the paretic and the non-paretic sides.

The limitations of the current study include the small sample size, and the fact that all subjects were high functioning. Thus, caution is necessary when generalizing its findings. Additionally, because the Sit to Stand exercise was not broken down into individual phases, biomechanical analysis was not performed. A follow-up study that incorporates a larger sample size and sufficient equipment for biomechanical analysis may suggest diverse and precise analyses.

This study examined the effects of arm and leg placement on weight-bearing symmetry during Sit to Stand in chronic stroke patients. Twenty-two patients who met the study's subject selection criteria participated in the experiment to measure the peak Fz and symmetry ratios of two arm (GA and SA) and three foot positions (SYM, AYM, and STP) during Sit to Stand. The study found that arm and leg positions affected weight-bearing symmetry during Sit to Stand, and that GA and STP combined had the greatest effect in reducing weight-bearing asymmetry in stroke patients performing Sit to Stand.

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