Sagittal lumbar motion during sit-to-stand task and its relation to balance in chronic stroke patients

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Background and purpose
Sit-to-stand (STS) task requires the ability to maintain balance while pivoting the body mass over the feet. Following stroke, the rising ability from the seated position is reduced because of difficulty in generating timing and sufficient force in muscles of the trunk and lower limbs to propel the body mass vertically. The aims of this study were to analyze the sagittal lumbar range of motion (ROM) during STS task, calculate the total time of the task, and investigate their relations to balance in patients with chronic stroke.

Patients and methods
Thirty male patients with chronic stroke (mean age: 51.2±3.75 years) were included in this study. They were divided into two equal groups (group I and group II). Group I had a mild degree of spasticity, whereas group II had a moderate degree in the affected lower limb. Lumbar ROM before and after buttock lift-off (LO) and the total time of STS were recorded using three-dimensional motion analysis system. Balance was assessed using Berg Balance Scale (BBS).

Results
The patients in group I showed a significant increase of lumbar ROM before (P=0.02) and after (P=0.03) buttock LO and also in BBS scores (P=0.0001) as compared with the patients in group II. However, there was a significant reduction in STS duration in favor to group I compared with group II (P=0.01). In addition, there was a statistically significant moderate negative correlation between BBS scores and lumbar ROM before buttock LO in both groups ($P<0.05$) and after LO in group I only (r=–0.69).

Conclusion
Patients suffering from stroke with moderate degree of spasticity show less lumbar ROM at pre-LO and post-LO phases than those with mild spasticity, and took longer time to execute STS task aiming to improve balance and postural stability.

Keywords:
balance, lumbar spine, motion analysis, sit to stand, stroke

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Introduction

Stroke is an acute onset of neurological deficits because of the defect in cerebral circulation with resultant signs and symptoms according to the involved focal areas of the brain. Focal neurological deficits must persist for at least 24 h to be classified as stroke [1]. Stroke ranks as the second leading cause of death and the first cause of morbidity all over the world. Among all the neurological diseases of adult life, stroke clearly ranks first in frequency and importance. At least 50% of the neurological disorders in hospitalized patients are of this type [2].

Transferring from sitting to standing position is one of the most common daily activities. It is a complex task that involves movement of all body segments. It requires sufficient joint mobility, lower-limb strength, and balance to enable the center of mass to be transferred forward and upward from the stable seated position to erect standing on a small base of support, the feet [3]. The ability to effectively rise from a chair is an important prerequisite and postrequisite for upright mobility and, therefore, for the performance of other common daily activities. Thus, these functional activities are fundamental components for the independence of disabled persons [1].

Following stroke, the rising ability from the seated position is reduced. The most common reason concerned with this problem in patients with stroke is mainly related to the difficulty in generating appropriate timing and sufficient force in the lower-limb extension muscles to propel the body mass vertically [4].

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Balance deficits are commonly observed poststroke, resulting in limitations in activities of daily living. Postural balance is necessary for carrying out different daily activities such as standing from a seated position [5]. Patients with stroke are liable to falling more than age-matched people, with many falls occurring during rising from a chair because of impaired balance [6].

In healthy elderly, forward trunk lean before buttock lift-off (LO) during sit-to-stand (STS) task is accomplished by concurrent lumbar and hip flexion. Hip flexion dominates, with a hip/lumbar ratio of 4.7 : 1 and the thoracic spine is flexed. Following buttock LO, the hips and lumbar spine extend (ratio of 5.2 : 1), and the thoracic spine becomes extended [3].

Full flexion of the trunk and hip in the early stages of standing up from sitting is an important part of a complex compensatory mechanism used by patients with stroke owing to muscle weakness and spasticity [7]. This excessive forward trunk flexion during rising from a chair in adult hemiplegics is probably to improve stability at buttock LO and during standing up [8].

Although trunk movement during STS task has been measured and analyzed in patients with stroke [9], the contribution of lumbar spine to STS task and its relation to balance have not been subjected to any detailed analysis in this group of patients. In most studies, spine has been viewed as a rigid body that failed to clarify the appropriate role of lumbar spine during this activity. Therefore, the purposes of this study were to analyze the sagittal lumbar range of motion (ROM) during STS task, calculate the total time of the task, and investigate their relations to balance in patients with chronic stroke.

Patients and methods

Patients

The design of this study was a comparative one. Thirty male patients with stroke were enrolled in this study. They were selected from the outpatient clinic of the Faculty of Physical Therapy, Cairo University, Egypt. The patients were diagnosed as having stroke based on careful clinical assessment by a neurologist and radiological investigations including computed axial tomography or MRI of the brain.

Inclusion criteria were medically stable patients with ages between 40 and 60 years old, duration of illness ranged from 6 months to 1 year, the muscle tone of the affected lower limb ranged from 1 to 3 according to Modified Ashworth Scale (MAS) [10], and preserved ability to stand from sitting position three times independently without assistance. The patients were excluded if they had other previous strokes, neurological disorders affecting the ability to perform STS task, balance disorders due to cerebellar or vestibular dysfunction, or limitation in ROM of the spine and joints of the lower limbs. Furthermore, they were excluded if they had orthopedic disorders and injuries of the lower limbs and spine (i.e. severe osteoarthritis, rheumatoid arthritis, peripheral nerve injuries, fractures or surgeries involving lower limbs, pelvis, or back). Patients with superficial and/or deep sensory loss, deafness, blindness, and cognitive impairment (inability to follow simple verbal commands during testing) were also excluded.

The patients were divided into two equal groups (group I and group II) according to the degree of spasticity in the affected lower limb. Group I included 15 patients with mild degree of spasticity of the affected lower limb (grades 1 and 1+ according to MAS) and group II included the other 15 patients with moderate degree of spasticity of the affected lower limb (grades 2 and 3 according to MAS). This study was approved by the ethics committee of the Faculty of Physical Therapy, Cairo University, and all participants provided informed written consent form.

Procedures

The procedure of this study started with complete history taking, and muscle tone assessment of the affected lower limb according to MAS was performed for each patient. The weight and height were recorded and the BMI was calculated. Assessment of balance was conducted using Berg Balance Scale (BBS) that consists of 14 items graded from 0 (unable) to 4 (independent), with a maximum score of 56. This scale is a reliable test to assess balance with an inter-rater reliability of intraclass correlation coefficient (0.98) and an intrarater reliability of intraclass correlation coefficient (0.97) [11].

Assessment of lumbar spine motion during STS task and recording its total time for each participant were conducted in the Motion Analysis Laboratory, Faculty of Physical Therapy, Cairo University. The ProReflex Qualisys Motion Capture System (Savedalen, Sweden) was used for these purposes. This system consisted of three ProReflex infrared high-speed cameras to perform multicamera measurements and have a capture capability of 120 frames/s. The basic principle of the system is to expose the ball-shaped reflective markers, positioned on the body, to infrared light from camera flashes and to detect the light reflected by the markers, and these markers only are displayed on the computer image. Each participant was instructed to take off his clothes except for the short and to sit with the examined side facing the three cameras. Five light-reflective markers of the same size (9 mm) were used and placed unilaterally over specific bony prominences over the patient's skin. Markers were placed on all patients by the same examiner for placement consistency. Markers were placed on the spinous process of the first thoracic vertebra (T_1), the spinous process of the tenth thoracic vertebra (T_{10}), the spinous process of the first lumbar vertebra (L_1), the posterior superior iliac spine (PSIS), and 3 cm lateral to the anterior superior iliac spine (ASIS) [12].

Each participant was seated on an armrest-less chair with adjustable height while keeping the trunk erect, and his two bare feet positioned at the same level and fully supported on the ground by a strap. The knee angle was measured to be 100° flexed from full extension by the use of universal goniometer [13]. The height of the seat was standardized to the length of the participant's leg from floor to mid-lateral knee joint line, so that the long axis of the thigh was in the horizontal plane.

Each participant was instructed to stand up in a natural way without using the upper extremities by folding the arms in front of his chest and without moving his feet. This procedure was repeated three to five times until the patient became familiar with the procedure, and then the measurements were recorded three times (with 1 min rest in between) and the average was taken.

Each participant was instructed to stand up after hearing the command (stand) and not to sit until he was asked to do so. Data collected from Qualisys Motion Capture System were transformed to personal computer and analyzed by using Qualisys (Q) tools. The 2D data created by the tracker were automatically transferred to the 3D where marker names were identified and exported as Tab Separated Values to the Q tools program for further analysis. Three events were defined to provide reference points during STS task:

(1) The 'start' of STS: it is defined as the instant at which the first horizontal displacement of the T_1 marker was seen [12].
(2) Buttock LO: it is defined as the instant at which the first vertical displacement of the T_1 marker was seen [14].
(3) The end of STS: it is defined as the point of maximal vertical displacement of the T_1 marker [12].

Sagittal lumbar spine angle was calculated between two lines (Fig. 1): line 1, the straight line defined by T_{10}–L_1, and line 2, perpendicular to the line joining PSIS–ASIS of the examined side (representing the plane of the pelvis). Q Tools program was used to determine the angle drawn by line 1 and the line extends between the PSIS and ASIS, which is represented as angle X (the red angle). Then, the sagittal lumbar spine angle (angle Y which is the desired angle, the blue one) was calculated as follows: Y=90–X.

A zero lumbar spine angle was defined when the straight line T_{10}–L_1 was perpendicular to the line joining PSIS–ASIS of the examined side. If Y is positive, the trunk is in flexion direction. On the other hand, if Y is negative, the trunk is in extension direction.

The angle of the lumbar spine during pre-LO and post-LO phases of STS task were measured three times and the average was taken. In addition, the total time of STS task was calculated for each patient.

Statistical analysis

All data were analyzed by the IBM SPSS software, version 23.00 (SPSS Inc., Chicago, Illinois, USA). Descriptive statistics were used in the form of mean and SDs for all variables. Normality test of data using Kolmogorov–Smirnov test was used, and it reflected that the data were normally distributed for all dependent variables. Therefore, this allowed conducting parametric analysis. Unpaired sample t-test was used in this study to determine the differences between the two groups for all variables.

Figure 1

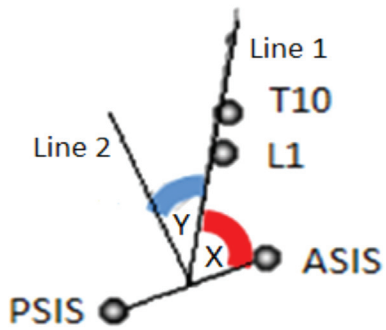

Diagram illustrating the method of calculation of sagittal lumbar spine angle (see text for details). ASIS, anterior superior iliac spine; PSIS, posterior superior iliac spine.

In addition, Pearson's correlation coefficient (*r*) was used to determine the relation between BBS scores and each of the duration of STS task and lumbar ROM during STS task before and after buttock LO in both groups. Correlations were defined as strong (≥0.7), moderate (0.4 to 0.69), and weak (≤0.39) [15]. The α level was set at 0.05.

Results

A total of 47 male patients with stroke were identified as potential participants. Of them, 30 patients were conveniently selected to participate in the study. They were allocated into two groups according to the degree of spasticity.

Demographic and clinical data

As indicated by the independent *t*-test, there were no statistically significant differences ($P>0.05$) between patients in both groups concerning age, body weight, height, BMI, and duration of illness (Table 1).

Lumbar ROM pre-LO and post-buttock LO, STS duration, and BBS scores

The results revealed a statistically significant difference between both groups for lumbar ROM during STS movement before and after buttock LO, total STS time, and BBS score (Table 2). Specifically, the patients with mild degree of spasticity (group I) showed a significant increase of lumbar flexion ROM before buttock LO ($P=0.02$), lumbar extension ROM after buttock LO ($P=0.03$), and BBS scores ($P=0.0001$) compared with the patients with moderate degree of spasticity (group II). On the other hand, there was a significant reduction of STS duration ($P=0.01$) in favor to group I compared with group II.

Correlation between BBS scores and other dependent variables

The correlation between BBS scores and lumbar ROM during STS task before and after buttock LO and the correlation between BBS score and STS duration in both groups are listed in Table 3.

Discussion

The findings of the present study revealed that there was a statistically significant decrease in lumbar spine ROM in group II compared with group I during the two phases of STS task. This might be attributed to the higher degree of spasticity in the back extensors of patients in group II than patients in group I, which is suggested to limit spinal ROM [16].

As regards the correlation between BBS scores and lumbar ROM during STS task, the findings showed a statistically significant negative moderate correlation between BBS scores and lumbar flexion ROM before buttock LO in both groups I and II. This result comes in agreement with the findings of Cheng *et al.* [7], who reported that an important part of a complex compensatory mechanism used by patients with stroke is increased flexion of the trunk and hip in the early stages of STS transfer because of the presence of spasticity and muscle weakness. Increased forward trunk flexion during the standing up movement is probably produced to improve stability at seat-off and during standing up [8]. By bringing the body center of mass over the feet before seat-off, the body could remain relatively stable during buttock LO [17]. This negative correlation between lumbar flexion ROM and BBS scores might be attributed to two main reasons: weakness of ankle dorsiflexors (mainly tibialis

Table 1 Descriptive statistics and unpaired *t*-tests for the mean values of age, body weight, height, BMI, and duration of illness of the patients in both groups

	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)	Duration of illness (months)
Group I	51.26±2.34	66.33±4.18	166.6±1.76	23.95±1.23	9.4±2.06
Group II	51.13±4.86	64.06±3.8	165.66±2.35	23.20±0.83	9.93±1.48
t-Value	0.096	1.551	1.23	1.953	−0.812
P-value	0.925	0.132	0.229	0.061	0.423

Values are represented as mean±SD. Group I: patients with mild degree of spasticity; group II: patients with moderate degree of spasticity. $P<0.05$, significant.

Table 2 Two-group comparisons of lumbar ROM during STS task, STS duration, and BBS scores for patients in both groups

	Lumbar flexion ROM before LO phase	Lumbar extension ROM after LO phase	Total STS duration	BBS scores
Group I	14.48±3.95	36.64±4.05	2.66±0.69	49.4±2.06
Group II	11.55±2.36	33.56±3.65	3.64±1.19	42.2±2.62
Mean difference	2.93	3.08	0.98	7.2
t-Value	2.64	2.19	−2.74	8.35
P-value	0.02*	0.03*	0.01*	0.0001*

Values are represented as mean±SD. Group I: patients with mild degree of spasticity; group II: patients with moderate degree of spasticity. BBS, Berg Balance Scale; LO, lift-off phase of sit-to-stand; ROM, range of motion; STS, sit-to-stand. *$P<0.05$, significant.

Table 3 Correlation between BBS scores and lumbar ROM during sit-to-stand task in both groups

	BBS scores (group I)		BBS scores (group II)	
	r	*P*-value	*r*	*P*-value
Lumbar flexion ROM at pre-LO phase	−0.55	0.03*	−0.68	0.005*
Lumbar extension ROM at post-LO phase	−0.69	0.004*	0.06	0.84
Total time of STS task	−0.87	0.0001*	−0.84	0.0001*

Group I: patients with mild degree of spasticity; group II: patients with moderate degree of spasticity. BBS, Berg Balance Scale; LO, lift-off phase of sit-to-stand; *r*, Pearson's correlation coefficient; ROM, range of motion; STS, sit-to-stand. *$P<0.05$, significant.

anterior) in these patients and their inability to use efficiently the available hip flexion ROM to avoid a high level of effort on the affected hip flexors. Patients increased lumbar flexion ROM to compensate for weakness of tibialis anterior and increase stability [18]. During pre-LO phase, tibialis anterior muscle acts to pull the tibia forward to move the body mass forward and to stabilize the ankle, as well as to maintain the heel on the ground [19,20]. In stroke patients, there is weakness in tibialis anterior. Subsequently, the patient compensates for this weakness by increasing trunk flexion to move the body mass forward. This is in accordance with Cheng *et al.* [7], who reported that most of stroke patients exhibit no or merely low-amplitude activity in their tibialis anterior muscle when they were rising from a chair. Those patients need to make excessive flexion by the trunk to compensate for this weakness. Also, it was reported that tibialis anterior muscle seems to be the most representative muscle for anticipatory postural adjustments during STS task, so it should be activated early with enough force to stabilize the foot before forward movement of the body [21]. Silva *et al.* [22] reported that the activation of the muscles involved in postural control occurs before the main movement, aiming to avoid excessive or unnecessary movements that could result in loss of body stability. Weakness of tibialis anterior or the inability to activate it early when attempting STS task makes it difficult for a patient to stand without significant compensations such as increased forward trunk movement before buttock LO [19]. The other expected reason is the inability of patients with stroke to use efficiently the available hip flexion ROM to avoid a high level of effort on the affected hip flexors. Therefore, they improve their balance and postural stability during pre-LO phase by increasing the lumbar flexion ROM. This opinion comes in agreement with the opinion of Layne and Abraham [23] who suggested that there are numerous biomechanical solutions to postural stability associated with a specific movement. Each individual would use the strategy that is most efficient for him during rising from a chair. Moreover, Neumann [24] reported that if greater trunk ROM is required, the hip joint or lumbar region may be mutually increased to compensate for the other's limited mobility.

During post-LO phase, there was a statistically significant negative moderate correlation between BBS scores and lumbar extension ROM in group I. This might be attributed to the weakness of lumbar extensors. Balance impairment in this group of patients makes them tending to increase lumbar extension to prevent them from falling forward. They tend to increase lumbar spine extension to shift the line of gravity posteriorly to decrease load on back muscles. This opinion was supported by the findings of Karatas *et al.* [25] who found that peak torque values for trunk extensors were lower in the patients with stroke than in the normal individuals.

During post-LO phase, there was a statistically nonsignificant correlation between BBS score and lumbar extension ROM in group II. This might be explained by the individual variability in the degree of posterior pelvic tilt among the patients who participated in this group. This causes change in the ratio of hip to lumbar ROM after buttock LO (which is normally 5.2 : 1). Patients with increased posterior pelvic tilt have exaggerated hip extension, and patients with limited posterior pelvic tilt have less hip extension [26] and, subsequently, lumbar ROM of the patients with stroke changes according to the motion that occurs in the hip.

The findings of the present study revealed that there was a statistically significant increase in mean values of the total STS duration of the patients with moderate degree of spasticity (group II) compared with the patients with mild spasticity (group I). This might be attributed to the greater weakness of knee extensors in group II than that of group I as a result of spasticity. This justification is consistent with the findings of Bohanon *et al.* [27], who concluded that agonist muscle group spasticity is significantly and positively related to agonist muscle group strength deficits. The weakness of knee extension muscles following stroke results from a decrease of the voluntary activation and alteration of the mechanical properties of the muscle and tendon complex [28]. Muscles affected by upper motor neuron lesion have been found to have reduced resting sarcomere length and increased stiffness [29], which could potentially interfere with cross-bridge formation and in turn affect torque production. The higher degree of spasticity in group II than group I might also be suggested as another cause of the significant increase of the total STS duration of group II, because this affects the speed of movement. This justification is supported by the findings of Exner [30] who reported that damage to the central nervous system causes tone abnormalities, which can affect joint ROM and subsequently decrease the speed of movement.The findings revealed a statistically significant negative correlation between BBS scores and STS duration in both groups I and II. These findings are in agreement with the opinion of Lord *et al.* [31], who mentioned that balance deficits can affect the performance and increase the time to do the STS task and they concluded that STS task can be used as an indicator of postural control. In addition, Lee *et al.* [32] found that the time taken to stand from a seated position is moderately correlated with the symmetry in standing, postural sway, and directional control. A shorter duration of time taken to perform STS indicates better symmetry of standing position, less postural sway, and better directional control.

There are some limitations to this study. The small number of patients who participated in the study might limit the generalization of the results. Future studies are recommended to target duration of illness beyond 1 year to enable comparison of the results across different durations of illness. All patients included in this study were capable of performing STS task independently and did not require the use of a handrail or lower-extremity orthosis. Further studies are required to investigate the relationship between balance and lumbar ROM in patients with stroke with more serious disabilities, who have to use a handrail or lower-extremity orthosis. In this study, each patient was instructed to stand from sitting position in his natural way without any restriction of other regions of the spine. Therefore, further studies are advocated to study lumbar ROM while restricting the movement of other areas of the spine. Although the findings indicate the importance of lumbar ROM and balance for the ability of patients with stroke to perform STS task, other factors, such as muscle strength, coordination, and thoracic spine and hip ROM, should be investigated in future studies. In addition, this study did not investigate the relationship between balance and the degree of pelvic inclination in patients with stroke. Therefore, future studies are recommended to determine this relationship.

Conclusion

Patients suffering from stroke with moderate degree of spasticity show decreased lumbar ROM during both pre-LO and post-LO phases of STS task as compared with patients with mild spasticity. Also, they take longer time to execute the task, aiming to improve balance and postural stability. Moreover, there is negative correlation between balance and both of lumbar ROM (at pre-LO phase) and time of STS task.

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Conflicts of interest

There are no conflicts of interest.

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