



Original Article

## Effects of anterior weight-shifting methods on sitting balance in wheelchair-dependent patients with spinal cord injury

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**Abstract.** [Purpose] This study aimed to compare changes in the center of pressure between healthy subjects and patients with spinal cord injury and to provide basic information to these patients for improving their sitting balance. [Subjects and Methods] A total of 12 healthy subjects without histories of neurological or psychiatric disorders and 12 patients with spinal cord injuries were recruited. In all subjects, a change in the center of pressure during the performance of the modified functional reach test was measured using a Force Sensing Array system while the subjects were seated in a wheelchair. In the spinal cord injury group, the change in the center of pressure was highest when subjects reached forward while holding a gym ball. [Results] In the spinal cord injury group, the change in the center of pressure was highest when subjects reached forward while holding a gym ball. A significant correlation between forward reaching of the upper limbs with shoulders at 90° flexion and a change in the center of pressure was found. [Conclusion] Our findings suggest that the combination of functional reaching and the change in the center of pressure assessment is novel enough to be attempted to achieve sitting balance control in patients with spinal cord injury. The findings can provide clinical interventions that contribute to the improvement in the balance ability of wheelchair-dependent individuals.

**Key words:** Spinal cord injury (SCI), Modified functional reach test (MFRT), Center of pressure (COP)

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### INTRODUCTION

The types of disability associated with spinal cord injury (SCI) vary widely, depending on the degree of injury, the segment of the spinal cord in which the injury has occurred, and the damaged nerve fibers<sup>1,2)</sup>. Among them, loss of sensory functions such as tactile, pressure, and warmth sensations due to motor dysfunction and sensory nerve fiber destruction caused by destruction of the motor nerves from the brain to the trunk and limb leads to a balance disorder during walking, standing, and sitting position<sup>3)</sup>. This is an important factor limiting the range of activities of daily living in patients with SCI<sup>4)</sup>. In patients with SCI, the higher the injury level, the greater the loss of muscle strength and sensation<sup>5)</sup>. Even though partial nerve innervations to muscles remain, patients experience balance disturbance, which reduces the ability to maintain postural stability to place the center of gravity in support surface<sup>6)</sup>. Most patients with SCI engage in activities that require prolonged sitting. To have access to society and secured mobility, patients rely on a wheelchair for their entire lifetime, which is the only critical source of mobility. Appropriate sitting and proper posture of wheelchair users are essential for functional ability, increased skin integrity, and independence<sup>7)</sup>. To improve the quality of life and the ability to perform activities of daily living of patients with SCI, in this process, they should assume a dynamic posture rather than a static posture in a wheelchair.

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Balance adjustment training in the sitting position can improve the quality of daily life of patients with SCI, and it can be one of the factors for the development of rehabilitation programs for activation of the paralyzed and other muscles<sup>8</sup>). Therefore, functional assessment of static and dynamic balance ability which maintains a correct posture while sitting on a wheelchair and reduces biased pressure is very important for patients with SCI using a wheelchair.

To date, studies on spinal cord injuries have been conducted using FIM (Functional Independence Measure) to predict the degree of motor recovery and analyze the correlation between neurological injury and functional dysfunction<sup>9-11</sup>), proper seating and posture for wheelchair users<sup>12</sup>), and trunk muscle response while performing anterior shift in patients with SCI<sup>13</sup>). However, studies related to the type of forward weight shift in patients with SCI in a wheelchair are lacking.

Thus, this study aimed to investigate the effect of forward weight shift methods on the dynamic balance ability of patients with SCI in a wheelchair. Comparing dynamic balance assessment between healthy adults and patients with SCI can provide more effective intervention methods in physical therapy and provide basic data for comprehensive physical function improvement.

## SUBJECTS AND METHODS

In this study, 12 patients with SCI who were hospitalized and had received outpatient treatment at K Hospital in Daegu Metropolitan City, South Korea and 12 healthy subjects were recruited. The selection criteria of the experimental group were the followings: (1) diagnosis of complete SCI and propelling a wheelchair, (2) no hearing and visual impairment, (3) no cognition impairment and neuropsychiatric disorders so to understand and follow instructions, (4) no severe ulcers or orthopedic problems in the upper limbs, and (5) cases belonging to grade A or B which is classified by the American Spinal Injury Association (ASIA) from cervical 6 to thoracic 5. No significant difference in age and weight was found on a homogeneity test ( $p < 0.05$ ) (Table 1). The purpose of the study was sufficiently explained to all of the subjects and their agreement to participate in this study was received before the study started.

To measure the pressure distribution of the buttocks and back while sitting on a wheelchair or chair, Force Sensing Array (FSA) 3.1 was used. FSA is widely used clinically to measure pressure distribution on the seat surface between the buttocks and thighs of the subjects. FSA's measurement mat material is very thin, allowing precise pressure measurement and precise analysis of changes in pressure. Additionally, the pressure distribution in both static and dynamic states can be measured using an FSA. Real-time measurement is possible with the computer software connected to the pressure-sensitive mat. The pressure distribution is displayed on the screen as numbers and colored isobars when the subject is sitting on the mat. The functional reach test measures the maximum distance that the subjects can reach forward as far as possible in a relaxed sitting position while maintaining the supporting surface. The MFRT (Modified Functional Reach Test) measures the maximum horizontal moving distance (0.1 cm) of the acromion during the forward weight shift without touching the hands on the wall<sup>14, 15</sup>).

The forward weight shift methods in patients with SCI are as follows: Test 1, maximum weight shift with arms crossed over the chest; Test 2, maximum weight shift with both arms extending forward with a 90° shoulder flexion; and Test 3, maximum weight shift with both arms extending forward with a 90° shoulder flexion and holding a ball.

A measuring tape was placed on the wall, and subjects sat parallel to the wall on which the tape was placed. The acromion is attached to the FSA during sitting on the wheelchair. The subject should be close to the wall so that the measuring tape can be placed on the acromion. The subject's hips, knees, and ankle joints were flexed at 90°. A footrest was provided when needed. The examiner randomly performed each forward weight shift. Before the measurement, the subjects were given a brief explanation about the motion followed by taking a neutral position with supported hands and simultaneously hands off when each motion was performed. The subjects took a five-min rest between each motion. A measurement was repeated if the starting position was misaligned or if the subjects lost balance and fell during the forward shift. While performing the three motions of forward weight shift, the COP movement was measured using the FSA.

Data in this study were analyzed using the Statistical Package for the Social Sciences (SPSS) for Windows, version 12.0. The general characteristics of all subjects were analyzed using the mean and standard deviation. The t-test was used to compare between experimental and control group. To analyze the difference between the horizontal moving distance of the acromion and the maximum COP during three forward weight shifts, one-way ANOVA (Analysis of Variance) was used. The least significant difference (LSD) was used for post hoc tests. Pearson's correlation analysis was used to analyze the correlation between the moving distance of the acromion and the maximum COP. The significant  $\alpha$  value was set at 0.05.

**Table 1.** General characteristics of subjects

	Experimental group (n=12)	Control group (n=12)
Age (years)	40.8 ± 6.45	28.5 ± 4.95
Weight (kg)	69.4 ± 8.27	58.7 ± 7.56
Gender (Male/Female)	12/0	5/7
SCI level (Cervial)	8	-
SCI level (Thoracic)	4	-

Mean ± Standard Deviation.

**Table 2.** The change of average excursion of COP according to functional reaching test and each functional reaching test (Experimental and Control group) (Unit: cm)

	Experimental group	Control group	p
FRT	5.34 ± 5.76	11.34 ± 2.57	**
Test 1	2.97 ± 3.34	10.35 ± 2.48	
Test 2	6.46 ± 6.39	11.90 ± 2.50	
Test 3	6.60 ± 6.81	11.76 ± 2.50	
Test 1–Test 2	-3.48*	-1.55**	
Test 1–Test 3	-3.63*	-1.41**	
Test 2–Test 3	-0.15	0.14	

Test 1: Trunk full flexion with crossing arms at the chest.

Test 2: 90° shoulder flexion with full extended elbow and then trunk full flexion.

Test 3: Trying to make full flexion of the trunk bringing the gym ball with fully extended arm

\*p<0.05, \*\*p<0.01.

**Table 3.** Relationship between the change of average excursion of COP and functional reaching test

	Correlation index	p
Test 1 (FRT-COP)	0.650	
Test 2 (FRT-COP)	0.822	**
Test 3 (FRT-COP)	0.661	

\*\*p<0.01.

## RESULTS

The results of changes of moving the COP in the modified functional reach pattern showed that the experimental group had more significant difference compared to the control group (p<0.05) (Table 2).

A significant difference was found when comparing the mean changes of moving the COP between the three motions in the modified functional reach test (p<0.05). The results of the post hoc test showed that a significant difference was noted among groups between test 1 and test 2 and between test 1 and test 3 (p<0.05). However, no significant difference was observed between test 2 and test 3 (p>0.05) (Table 2).

The correlation of changes of the COP between the horizontal moving distance test of forward weight shift of each subject and changes of moving the COP when performing each motion showed that arm extended forward with 90° shoulder flexion was significantly strong (r=0.82, p<0.05). No significant difference was found in other groups (p>0.05) (Table 3).

## DISCUSSION

This study investigated the horizontal moving distance of the acromion and moving distance of the maximum COP during three forward weight shifts using MFRT in patients with SCI and compared them with healthy subjects. The correlation between the moving distance of the acromion and the maximum COP was analyzed.

Lynch et al.<sup>14)</sup> measured the dynamic balance ability of patients with SCI, which modified Duncan et al.<sup>15)</sup> method in sitting. The reliability of this test was high (0.89–0.94). Kim et al.<sup>16)</sup> found that the reliability and validity of MFRT was more than 0.97 in patients with SCI. This study based on the modified FRT applied the functional motion separately to evaluate the balance. Song et al.<sup>17)</sup> found that forward weight shift was reduced due to the change in anatomical functions after SCI such as musculoskeletal, neurological, and proprioception control factors, which affect the posture and balance. This study also showed that the moving distance values of the COP were 5.34 cm and 11.34 cm in the experimental group and in the control group, respectively. The moving distance was reduced in the experimental group compared to the control group.

The FSA used in this study can measure the movement of the COP in both static and dynamic states<sup>18)</sup> and measure the moving distance of the COP during the dynamic posture and forward weight shift, which showed the degree of shaking by the movement trajectory. The changes in the distance of the COP in three motions were 2.97 cm, 6.46 cm, and 6.60 cm respectively, which was less in comparison to the control group. The motion performance of the subjects may have been affected due to kinematic and physiological changes and the fear of falling experienced after SCI.

The changes of COP during the performance of the three types of forward weight shift showed that bending with arms crossed on the chest had the lowest result while the highest was bending with extended arms and holding a gym ball. The postural stability strategy that stably moves the center of the body in the dynamic posture through expanding the base of support maintains postural stability in forward extended arm motion than in crossed arms on the chest. Additionally, the forward extended arm motion may have relieved anxiety of falling in comparison with crossed arms on the chest.

The changes of the COP between the maximum bending with extended arms at 90° shoulder flexion and the maximum bending with extended arms at 90° shoulder flexion and holding a gym ball were slightly increased in patients with SCI (from 6.46 cm to 6.60 cm) and decreased in healthy adults (from 11.90 cm to 11.76 cm), which showed no significant difference. Holding a ball did not affect the postural stability in the motion strategy for maintaining the balance in the control group, and the small reduction may have been affected by the weight of the ball. Using both hands to hold the ball was a support

for movement in patients with SCI. The movement of the COP had increased due to the increased muscle coordination and recruitment caused by the use of the upper limb. The previous study by Potten et al.<sup>13)</sup> supported our findings that when the erector spinae lost its function, the scapular stabilized and increased the activation during sitting through the coordination of the latissimus dorsi and trapezius.

A significant correlation was found between maximum bending forward and both arms extended forward with 90° shoulder flexion. This high correlation means that the farther the motion is, the more will be the movement of the COP. This moves the center of the body with stability to maintain the balance. However, no significant correlation was found between bending forward with both arms extended forward and holding a gym ball, which is associated with the motor function of the hand in patients with SCI. The higher the damage level is, the more difficult it is to use the hands. The muscle strength of the upper extremities in prolonged holding of an object, endurance, and coordination and control of the muscles may have affected the actual performance. This result agrees with the findings of Catz et al.<sup>19)</sup> that functional level in patients with SCI is related to damage level.

To date, more studies on postural and control of balance and its related dysfunctions after SCI have been conducted. Therefore, more studies exist on exercise programs to improve sitting balance ability and the balance ability of patients with SCI. The muscles in the torso increase the balance of the limbs, making it easier to adapt to changes in force or dynamic movements, to perform daily activities or functional movements easier, and to move freely while performing independent activities or in using assistive devices. Kim et al.<sup>20)</sup> found that decreased upper limb function reduces the torque and stability in the trunk. The results suggest that the increase in muscle coordination due to the use of the upper limb increases the dynamic postural stability. The trunk muscle strength training program using the upper limb may increase the sitting balance, which is beneficial for the clinical approach to treatment of patients with SCI.

The current study has several limitations that should be considered: differences in trunk muscle strength according to the level of SCI of the subjects, the degree of fixation of the upper body by using the trunk muscles, and the psychological factors including the fear of falling in three forward weight shift movements to evaluate the dynamic balance and upper limb movement. Further studies are necessary to assess the balance evaluation and control considering the functional movements of various parts of the upper extremity based on the movement strategy for balance and postural stability. In this study, the ability to perform exercises according to the damage level in patients with SCI varied greatly. To compensate for this, a classification study should be conducted according to the ability of the upper extremities to perform functional movement. Balance assessment and postural control while sitting after SCI are important in performing independent daily activities in a wheelchair and are important goals for rehabilitation and physical therapy interventions. The changes in the dynamic movement and the body center movement using the upper limb according to the degree of damage are significant as these are the basic data for evaluating the dynamic balance of patients with SCI, and strength training programs of the trunk muscles using the upper limb may increase stability while sitting.

### *Conflict of interest*

None.

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