

Effect of different hand positions on trunk and shoulder kinematics and reaction forces in sitting pivot transfer

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Abstract. [Purpose] The purpose of this study was to compare the changes in trunk and shoulder angles, and reaction forces under the two hands elicited by different hand base of support positions during sitting pivot transfer. [Subjects and Methods] Eighteen unimpaired subjects performed independent sitting pivot transfer. Subjects performed sitting pivot transfer between an initial seat to a target seat by only using their hands positioned at the same height as and lower than the seat position. Trunk and shoulder kinematics, and reaction forces on the trailing and leading hands were calculated. Mean peak joint angles and forces were compared between the hand positions using the paired t-test for the lift phase of the transfer. [Results] There were significant increases in the trunk angles of forward and lateral flexion, even though rotation decreased while transferring in the lower hand position. Increased shoulder flexion, anterior/posterior forces and reduced lateral forces were also shown. [Conclusion] Placing the hands of the supporting arms lower than the seat position during sitting pivot transfer was identified as having biomechanical advantages. Therefore, the lower hand position can be recommended as an effective and safe method for sitting pivot transfer by patients with spinal cord injury and can be utilized as a reference data for considering the appropriate height of aids for a wheelchair.

Key words: Hand position, Sitting pivot transfer, Shoulder pain

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INTRODUCTION

Patients with spinal cord injuries (SCI) have motor and sensory disorders, resulting in disabilities in daily activities¹⁾. Although they should receive intensive care and rehabilitation treatment after injury, most patients experience disorders (e.g., impingement syndrome, osteoarthritis, bursitis, paralysis, parasthesia) in their upper extremities, trunk, or lower extremities due to physiological and physical changes. They experience functional disorders in ambulation, particularly with respect to activities of daily living (ADL)^{2, 3)}. Due to these ambulatory disorders, spinal cord injury patients often use wheelchairs and learn to perform basic ADL (e.g. propulsion, lifting, transfer) in relation to the use of a wheelchair.

These patients often suffer upper extremity pain due to performance of ADL almost exclusively by the upper extremities (overall upper extremity pain prevalence rates: 58.5%; shoulder: 71%, elbow: 35%, wrist: 53%, hand:

43%)⁴⁾, and such pain impedes the performance of ADL⁵⁾. Among the basic ADL, transfer is a task that is performed by each patient 15–20 times per day, on average. This is the most burdensome task for the musculoskeletal system, the nervous system, and the cardiovascular system among wheelchair related ADL. In particular, transfer imposes the largest load on the shoulder joint^{6, 7)}.

Sitting pivot transfer (SPT) is the most frequently used transfer method using the upper extremities. Using this method, the hip is moved from the initial seat (Iseat) to the target seat (Tseat) using the trailing hand (TH) and the leading hand (LH) while both lower extremities maintain contact with the floor as an axis⁶⁾. There are largely two main SPT strategies. One is a translational strategy in which the head and the hip move horizontally in the same direction, and the other is a rotational strategy in which the head and the hip move while rotating in different directions using both feet as a pivot²⁾. During SPT movements, the shoulder is in a position of internal rotation and abduction, which will invariably cause shoulder impingement unless other aids are used⁶⁾. Although there are many shoulder pain treatment methods, the shoulder cannot take any rest because of transfer movements, which are essential for patients' ADL. Consequently, shoulder pain leads to various complications⁵⁾.

Recently, some studies have been conducted of methods for minimizing shoulder injuries through dynamic analyses of transfer movements. According to a recent study, SPT is

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the most efficient and imposes the lowest loads on individual joints when the wheelchair moves horizontally without any variation in floor height compared to when there are differences in height between the position of the wheelchair and the floor on which the wheelchair moves⁸⁾.

A previous study using kinematic analysis of SPT movements reported that, in an experiment conducted to measure loads on the shoulder joint in three different positions, anterior trunk positions mobilized large muscles around the shoulder and the mobilization of muscles reduced the risk of rotator cuff impingement²⁾. The maximum flexor momentum at the shoulder joint during SPT movements is known to be approximately 1.45 Nm/kg at the TH and approximately 1.36 Nm/kg at the LH of patients and approximately 1.56 Nm/kg in healthy adults⁹⁾. Joint reaction force is known to be always higher at TH than at LH, and joint loads are known to be higher during transfer to higher seats¹⁰⁾.

In a recent study of human movement, it was reported that the destabilizing force (dF), which tends to make movements, was determined by the height of the center of mass (COM), center of pressure (COP), base of support (BOS), and the reaction force and shear force acting on the floor¹¹⁾. In a study of the dF and stabilizing force (sF) occurring in SPT movements, it was reported that low dF and high sF were shown, and that the low dF and high sF were related to the securing of stability against the risk of falls^{12, 13)}.

Nevertheless, no study to date has been conducted on changes in loads on the lower extremities during actual SPT in relation to decreases in BOS and increases in the height of the COM. Additionally, little is known about the effects of these changes. Studies of transfer methods that will reduce the burden on the upper extremity will contribute to the relief of shoulder pain eventually leading to the prevention of paraplegic patients' shoulder pain. Therefore, the purpose of the present study was to examine the effects of different heights of the hands of the supporting arms on the loads on the shoulder joint during transfer movements in order to seek effective and safe transfer methods.

SUBJECTS AND METHODS

The subjects of the present study were recruited from among students, who voluntarily wanted to participate in the study, attending in Hallym College located in Chuncheon-si. Based on the principles of the Declaration of Helsinki, research ethics, the purpose and contents of the study were sufficiently explained to the subjects before they participated in the experiment, and they were required to submit their written informed consent. The subjects had no history of musculoskeletal system disease of their upper extremity. Among the recruited subjects, only 18 adult males participated in the experiment: excluding those who could not lift their trunk because their upper extremity muscle strength was not sufficient to perform SPT movements and those who could not wear the tight suit for motion analysis were excluded.

The Iseat and Tseat of the device specially designed for SPT were made from 30 × 50 cm² sized 3.2 mm thick steel plates, and the plates for TH and LH were made using 60 × 50 cm² sized steel plates of the same thickness as the seats.

For height adjustment, hand jerks that could endure at least 2,000 kgf were fixed by welding between the steel plates. Thereafter, 1 cm diameter holes were drilled at the four corners of the welded steel plated using a laser. Long steel bolts were inserted through the holes to fix the upper and lower steel plates of the Iseat and Tseat. The TH and LH plates were fixed with bolts in order to minimize vibration or shaking caused by loads during transfer movements. Then, 20 cm high aluminum profiles were fastened to the two fixed steel plates using bolts so that the final height could be adjusted to between 35 cm and 65 cm. All joint areas except for the hand jerks were firmly fastened using bolts.

Each subject performed SPT movements on a special device designed for the experiment. Prior to the experiment, audio-visual education on the rotational strategy among SPT method was conducted along with a verbal explanation. The experiment was conducted following changing the height of the hands. The subjects moved from the Iseat at a height of 50 cm to the Tseat at the same height at an angle of 90°. The subjects adopted a posture with the TH located as close as possible to the hip on the Iseat and the LH located as close as possible to the Tseat. To keep the same hand positions for all subjects, the shape of a hand was printed and attached to the positions of the TH and the LH on the force plates (Fig. 1).

After the verbal order "Start", the subjects moved from the Iseat to the Tseat by lifting their hips solely using the strength of their arms. At this time, the subjects were instructed to limit the activity of their lower extremities maximally. Then, the subjects performed the same movement after reducing the height of the TH and the LH plates by 10 cm. The height of 50 or 40 cm was randomly selected to

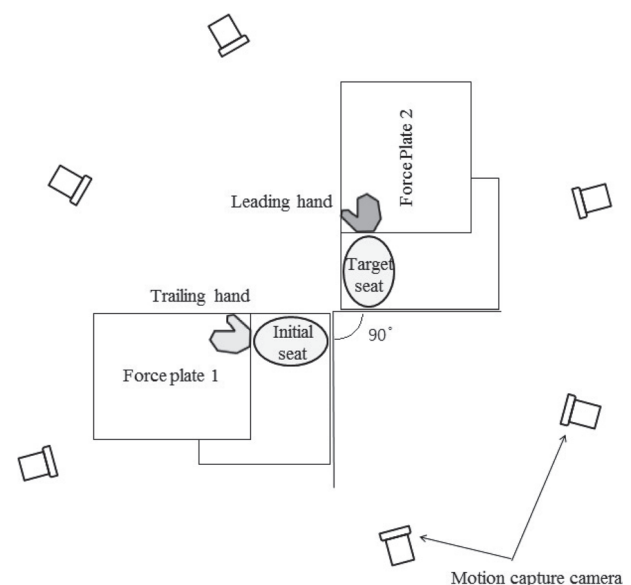


Fig. 1. Two tables that can be adjusted in height and two force plates

Six motion analysis cameras were placed around the device. The trailing hand and the leading hand were placed on the hand shaped marks attached to the force plates and the initial seat and the target seat were placed immediately next to the two hand positions. The angle between the two tables was set to 90°

eliminate order effects. Each movement was measured five times repeatedly at the two heights. The subjects took a sufficient rest of one minute between each movement. During the SPT movements, if a subject complained of pain in any part of the upper extremity, the experiment was immediately stopped.

In the present study, SPT movements were divided into two events: the start and ending events. The time labeled at which loading occurred on the force plate below the LH after the verbal order "Start" was labeled event1, and the time at which the loading became 0 at the TH plate, when the transfer to the Tseat had been completed, was labeled event2.

The angles of the movements of the upper extremity and the trunk were measured using a motion analyzer (Oqus100, Qualisys, Sweden). Before the experiment, the study subjects wore upper and lower body stockings that clung to their body shapes, and 15 mm diameter reflective markers, that could be recognized by infrared cameras, were attached to the C7 and T10 vertebrae, jugular notch, xiphoid process of the sternum, head (left/right forehead and rear head), acromion, upper arms, humeral lateral epicondyles, wrist lateral/medial epicondyles of the wrists, 2nd metacarpal heads, and ASIS and PSIS. The light signals reflected individual markers were recorded using six cameras and QTM (Qualisys, Sweden) at a rate of 100 frames per second. The body joints and segments in the obtained data were labeled, and the kinematics of individual joints and segments were quantitatively analyzed using Visual 3D software (C-Motion, USA). To reduce measurement errors, the markers for motion analysis were all attached by one person.

Force plates (9260AA6, Kistler, Switzerland) were used to measure the external force generated by the upper extremities while SPT movements were being performed. The voltages measured at different loads were amplified through an amplifier (5233A2, Kistler, Switzerland) and transmitted to the computer through an A/D board (USB-2533, Measurement Computing Corporation, USA). Then, the values of the force applied to the force plates by external loads were calculated using QTM motion analysis software program. Kinetic data were sampled at 1,000 Hz to align with the kinematic data. The kinematic data measured between event1 and event2 of each subjects were evenly divided into 101 frames (0 to 100 frames) and normalized to each subject's height and weight values. Each subject's SPT movements were measured five times and the average was used in the analysis.

Statistical analysis was conducted using PASW ver. 18.0 (SPSS, IBM, USA). The paired t-test was used to compare kinetic and kinematic data between the two heights of the

TH and LH. The significance level, α , was chosen as 0.05.

RESULTS

The group means (standard deviation) of age, height, weight of the participants were 21.11 (1.71) years, 1.78 (0.04) meters, 74.28 (9.40) kilograms, respectively.

The trunk movements measured at the different hand heights were as follows. The maximum flexion of the trunk was significantly larger when the hand position was low 75.14 (7.95) $^{\circ}$ than when the hand position was normal 53.12 (13.50) $^{\circ}$ ($p=0.000$). The maximum ranges of lateral flexion when the hand positions were low and normal were 48.04 (9.37) $^{\circ}$ and 42.82 (9.74) $^{\circ}$, respectively, and the difference was significant ($p=0.022$). The maximum ranges of rotation when the hand positions were low and normal were 0.26 (9.72) $^{\circ}$ and 17.89 (11.24) $^{\circ}$, respectively, and the difference was significant ($p=0.000$; Table 1).

The maximum flexion angles of the shoulder joint when the hand positions were low and normal were 51.55 (10.25) $^{\circ}$ and 40.89 (11.35) $^{\circ}$, respectively, at the TH ($p=0.000$) and 32.03 (8.87) $^{\circ}$ and 18.68 (7.29) $^{\circ}$, respectively, at the LH ($p=0.000$). The differences in the angles between the two hand heights were significant at both the TH and at the LH. The maximum abduction angles were not significantly different between the two hand heights at the TH, but showed significant differences at the LH, with values of 15.60 (10.53) $^{\circ}$ and 13.51 (8.04) $^{\circ}$ when the hand positions were low and normal, respectively ($p=0.027$). The maximum rotation angles were not different between the two hand heights at the TH, but they showed significant differences at the LH, with values of 74.79 (14.22) $^{\circ}$ and 64.90 (11.20) $^{\circ}$ when the hand positions were low and normal, respectively ($p=0.000$; Table 2).

The values of anterior/posterior force measured at the force plates below the TH and LH when the hand positions were low and normal were 8.98 (1.96)% (BW) and 7.89 (1.96)% (BW), respectively, at the TH, and the difference

Table 1. Means (\pm SD) of the peak trunk angles of each hand height

Component		Trunk	
		HL	HN
Peak angle (degree)	Flexion	75.1 (8.0) *	53.1 (13.5)
	Lateral flexion (left)	48.0 (9.4)	42.8 (9.7)
	Rotation (left)	0.3 (9.7) *	17.9 (11.2)

HL: low hand height (40 cm), HN: normal hand height (50 cm), * $p<0.05$

Table 2. Means (\pm SD) of the peak shoulder angles of each hand height

Component		Trailing hand		Leading hand	
		HL	HN	HL	HN
Peak angle (degree)	Flexion	51.6 (10.3) *	53.1 (13.5)	32.0 (8.9) *	18.7 (7.3)
	Abduction	16.6 (8.6) *	42.8 (9.7)	15.6 (10.5) *	13.51 (8.0)
	Rotation (internal)	37.5 (19.3) *	17.9 (11.2)	74.8 (14.2) *	64.9 (11.2)

HL: low hand height (40 cm), HN: normal hand height (50 cm), * $p<0.05$

was significant ($p < 0.05$), but there was no significant difference at the LH. The values of lateral/medial force showed significant differences between the two hand heights at the TH with values of 7.96 (2.33)% (BW) and 8.92 (2.92)% (BW), respectively ($p < 0.05$), but did not show any significant difference at the LH. The values of vertical force did not show statistically significant difference between the two hand heights at the TH or the LH (Table 3).

DISCUSSION

The purpose of the present study was to analyze the movements of the shoulder joint and the trunk at different heights of the TH and the LH in SPT movements to provide reference data for effective and safe transfer methods for spinal cord injury, paraplegia, and lower extremity amputation patients. Gagnon et al. reported that during transfer to seats of different heights, trunk flexion of 68–71° appeared at the initial hip lifting, that trunk flexion facilitated SPT movements during which the hip was lifted and moved, and that trunk flexion affected balance and stability in spinal cord injury patients with weakened erector spinae muscle or neurological disorders with upper extremity muscle strength⁸. Tanimoto et al. advised that the degree of trunk flexion increased the time of hip lifting for the entire SPT movement¹⁴. Finley noted that patients who complained of shoulder impingement showed smaller trunk flexion angles, and that smaller angles were associated with the formation of small trunk flexion moments at the beginning of the initial phase of hip lifting after injury⁶. In the present study, when the hand height was in the lower position (40 cm), trunk flexion essentially increased to use the lower hand position as the weight-bearing surface. Positive effects could be expected from this in that trunk flexion generally acts as propulsion during hip lifting at the beginning of transfer movements.

Another movement that indispensably appears along with trunk flexion in SPT movements is rotation. Trunk rotation occurs in the opposite direction to the seat that would move around the TH. According to a study conducted by Forslund et al.¹⁵, trunk rotation of 41° can occur at the maximum in females, and 32° can occur at the maximum in males. The difference was assumed to be attributable to differences in shoulder widths and pelvis sizes between the genders. In the present study, rotation was shown to be smaller by 17.73° on average when the hand height was lower. This is assumed to be associated with the increase in trunk flexion appearing when the hand height is low. In addition, increases in trunk rotation are thought to affect shoulder joint angles and the

strength of the surrounding muscles directly.

In previous SPT movement analysis studies, maximum shoulder joint flexion was 36°, abduction was 50°, and internal rotation was 15–30°^{6,16,17}. It is known that during transfer movements, complicated upper extremity movement combinations reduce the subacromial space and eventually affect the rotator-cuff muscle and soft tissues (e.g. bursae) around the shoulder joint resulting in shoulder impingement. The angles of flexion and abduction at low hand positions in the present study were different from those reported by previous studies. Flexion should increase when the bearing surface is low, and larger flexion and abduction angles should occur to compensate for the bent trunk (Fig. 2).

Since trunk rotation movements occur around the axis of the TH at the beginning, of SPT movements, internal rotation of the TH shoulder is inevitable. In a study conducted by Finley et al., patients with shoulder impingement were identified as utilizing more internal rotation than other patients during SPT movements⁶. Also, a study conducted by Riek et al. reported that internal rotation of 4–9° occurred at the TH of spinal cord injury patients. In the present study, internal rotation at the TH occurred more frequently when the hand was low, and this seems to increase the risk of shoulder impingement¹⁷. However, Gagnon et al.⁸ advised that the maximum angle of internal rotation might vary with hand position when SPT movements began. Therefore, this problem might be resolved by studies seeking the hand position that can minimize internal rotation of the shoulder.

Forslund et al.¹⁵ reported that when SCI patients transferred to a seat that was 7 cm higher, the maximum vertical reaction force at the TH was always higher than that at the LH, and that this seemed to be a natural phenomenon because

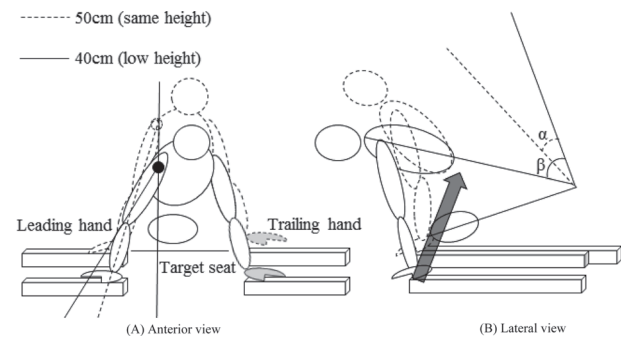


Fig. 2. Changes in shoulder joint and trunk angles according to bearing surface heights
 α : trunk flexion angle at HN, β : trunk flexion angle at HL

Table 3. Means (\pm SD) of the peak forces of each hand height

Component		Trailing hand		Leading hand	
		HL	HN	HL	HN
Peak	Posterior	9.0 (2.0) *	7.9 (1.7)	0.1 (0.5)	0.1 (0.3)
Force	Lateral	8.0 (2.3) *	8.9 (2.9)	1.4 (1.8)	1.3 (0.8)
(%BW)	Vertical	44.7 (6.0)	45.4 (4.9)	43.2 (7.2)	45.2 (6.5)

BW: body weight, * $p < 0.05$

the TH is closer to the body to initiate movements at the beginning of the movement. They reported that the average vertical reaction force at the TH was 32% (BW), and that it was 24.5% (BW) at the LH. In a study conducted by Gagnon et al.¹⁸⁾, the values were 44.5% (BW) at the TH and 39.6% (BW) at the LH, similar to the values of the present study, 43.2% (BW) at the TH and 41.3% (BW) at the LH. Gagnon et al. advised that the maximum vertical reaction force was different between male and female spinal cord injury patients because in the case of males, force was delivered from the TH to the LH while in the case of females, force was exerted on both hands almost simultaneously because males were stronger than females¹⁸⁾. In the present study, since all of the subjects were males, the subjects exerted more force at the TH when they transferred and a relatively smaller vertical reaction force was observed at the LH. When the hand positions were low, the movement accordingly began with the trunk more bent, and this seems to have acted as a dynamic advantage for vertical reaction force in the phase of hip lifting during transfer movements.

With regard to the shearing force (anterior/posterior, medial/lateral) measured at the force plates, the anterior shearing force was found to be higher when the hand position was lower than the seat position, and the lateral shear force was found to be higher when the hand height was the same as the height of the seat. When the hand position is low, greater movement to bend the trunk forward occurs. In reaction to the forward bending of the trunk, relatively more anterior and relatively smaller lateral forces act. This is associated with the destabilizing force that decreases when the hand height decreases due to the COM becoming farther from the BOS as the hand height decreases. Duclos et al.¹¹⁾ advised that if the destabilizing force is large, the movement of the center of pressure (COP) to the outside of the BOS would become more difficult, and that if the COM is high, the destabilizing force would be reduced allowing movements to be made with a smaller force. Given that when the hand is lower, the vertical reaction forces at the TH and the LH as well as the lateral force are smaller, it is our opinion that when the bearing surface for the arm is lower, transfer movements can be made with smaller force, and, in particular, the vertical loads and lateral loads on the shoulder joint can be reduced.

Limitations of the present study include the fact that the experiment was not conducted with spinal cord injury patients with shoulder pain, and that data were not obtained through measurements in actual transfer environments, but were obtained in a laboratory setting. Furthermore, since the experiment was conducted with only healthy male, the results cannot be generalized to both sexes, and even though the subjects were educated not to use their lower extremity, they might not have been able to control their lower extremities as completely as actual patients.

Taken together, our results indicate that as the hand position becomes lower, trunk flexion increases. This would act as a dynamic advantage (propulsion) for the movement to lift the hip, thereby reducing the vertical reaction force and shear force acting on the shoulder joint, thereby reducing the load on the shoulder joint.

Through the present study, the position of the supporting arms during SPT movements lower than the seat position was identified to have biomechanical advantages over the position of the supporting arms at the same height as the seat position. The results of the present study can be applied as guidelines for effective and safe methods for quadriplegia or spinal cord injury patients' SPT, and can be utilized as reference data when considering the appropriate heights of aids for wheelchairs.

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