Original Article

Investigation of effect of leg support elevation timing on the horizontal force acting on the buttocks in a reclining wheelchair

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Abstract. [Purpose] The purpose of this study was to investigate the effect of the timing of leg support elevation on the horizontal force acting on the buttocks in a reclining wheelchair. [Subjects and Methods] The participants were 17 healthy men. Two experimental conditions were tested: the leg-down and leg-up conditions. The back support was reclined at increasing angles, from the initial upright position (IUP), proceeding to the fully reclined position (FRP), and returned to the upright position (RUP). The posterior inclination phase was from IUP to FRP, and the returning inclination phase was from FRP to RUP. [Results] The horizontal force under the leg-up condition was significantly higher than that under the leg-down condition in all positions of back support. [Conclusion] The leg supports should be positioned downward before reclining the back support of a wheelchair.
Key words: Elevate the leg support, Horizontal force, Decubitus ulcer

INTRODUCTION

Wheelchairs with reclining back supports are often used for individuals with leg and trunk disorders, including those with post-stroke hemiplegia and spinal cord injuries. Individuals who have difficulty sitting in the hospital can sometimes be more easily transported sometime in wheelchairs with reclining back support. In a previous study of reclining wheelchairs, individuals with flaccid hemiplegia were often found to often slide forward when returning to a seated position from a reclined position[1]. Many wheelchair users who need reclining back support cannot correct this slouching posture unassisted. This leads to a sacral sitting posture which results in increased shear force on the sacrum, predisposing the individual to a sacral decubitus ulcer[2]. To address these problems, reclining wheelchairs with tilting seats have recently begun to be used in hospitals and nursing homes. Jan et al.[3] suggested that wheelchairs that can tilt and recline can enhance skin perfusion over ischial tuberosities without reducing sacral skin perfusion when moving the person from an upright to a tilted and reclined position. However, wheelchairs with tilting seats remain uncommon. Therefore, it is important to evaluate the reduction in the shear force acting on the buttocks when such a wheelchair's

back support is reclined. In our previous research[4–6], we investigated the functions that reclining wheelchairs should possess to reduce the shear force acting on the buttocks when reclining the back support. The results obtained suggested that reclining wheelchairs should be adjustable with the rotational axis position of the back support closer to the hip joint. Carlson and Payette[7] described other techniques for minimizing friction and shear forces in wheelchair seating through orientation of the seat surface, positioning of the foot supports, and the use of low-friction seat cover materials. When patients are transported in wheelchairs with a reclining back support, their lower legs are elevated by leg supports. Elevated leg support has been described as being important for easy patient transfer and wheelchair stability[8–10]. Elevated leg supports are generally used to augment venous circulation and reduce dependent edema, or to fix the knee in extension because of orthopedic deformity, surgical immobilization, or severe hypertonicity in the extensors[11]. However, the influence of any of these factors on the shear force acting on the buttocks has not yet investigated.

The rationale behind footplate adjustment usually appears to be empirically based and differs from researcher to researcher. Hobson[12] reported that the foot plates should be adjusted to support approximately 10% of the body weight. Gilsdorf et al.[13] found that the lowest ischial interface pressures on any cushion occurred with the legs dangling. The results of these studies suggested that the position of the lower extremities affects the forces acting on the buttocks. Thus, we hypothesized that the forces acting on the buttocks, which result in the formation of decubitus ulcers, are influenced by the elevation of the leg supports. Aissaoui et al.[14] investigated the effects of elevated leg support on

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posture and pressure distribution in healthy subjects sitting in a wheelchair. Their results showed that the elevating the leg support induces an increase in pressure under ischial tuberosities. No studies exist, however, on the relationship between the elevation of leg support and the shear force acting on the buttocks when a wheelchair's back support is reclined. Moreover, the timing of leg support elevation, i.e., whether leg support elevation before or after reclining of the back support is better, has not been investigated. Therefore, the purpose of this study was to investigate the influence of elevating wheelchair leg supports and the timing of the leg support elevation on the shear forces acting on the buttocks in wheelchairs with reclining back support.

SUBJECTS AND METHODS

It was presumed that the size and shape of the pelvis would affect the results of this study. The participants were 17 healthy adult men without leg or trunk disease: mean age, 22.6 ± 6.6 years; mean height, 170.1 ± 4.4 cm; mean body weight, 62.4 ± 8.9 kg. Exclusion criteria were: the participants that had back pain, a history of surgery, rheumatism, or neurologic disorders. Moreover, the participants were excluded if they experienced pain in the wheelchair. This study was conducted with the approval of the Research Ethics Committee of Kawasaki University of Medical Welfare (no. 415), and informed consent was obtained from all the participants prior to their participation.

We used an experimental chair with electric controls for reclining the back support (Hashimoto Artificial Limb Manufacturer, Okayama, Japan). The dimensions of the experimental chair were as follows: back support height, 104 cm; seat depth, 40 cm; backward angle of the seat, 0°; reclining angle of the back support, 10–40°; angular velocity at which the back support reclined, 3°/s. The chair's back support was covered with artificial leather. The rotational axis of the back support, the joint between the seat and back support, were located at the same height as the seat. In addition, the experimental chair had leg supports for elevating the legs. The elevation angle of the leg supports could be adjusted between 10° and 80° backward from the vertical line. The rotational axes of the leg supports, which the joint between the seat and the top edge of the leg support frame, were located at the same height as the seat (Fig. 1).

Measurements were obtained which each participant sat comfortably with bilateral symmetry and rested on the back support and force plate located on the chair seat. Hirose[15] reported that inclinations of the sternum and abdominal line are correlated with inclinations of the thoracic and lumbar spine in both the frontal and sagittal planes. Therefore, the posture of each participant was checked, by visually and manually inspecting the sternum and abdominal line, to ensure that the thoracic and lumbar spine in the frontal plane did not lean laterally. In addition, to maintain constant friction between the clothing of each participant and the seat surface, all participants wore 100% cotton clothing during the experiment. Because the smooth metal surface of the force plate was conducive to the participant sliding forward in the chair, a rubber net was laid over the plate to minimize sliding and the risk of postural collapse. The coefficients of friction
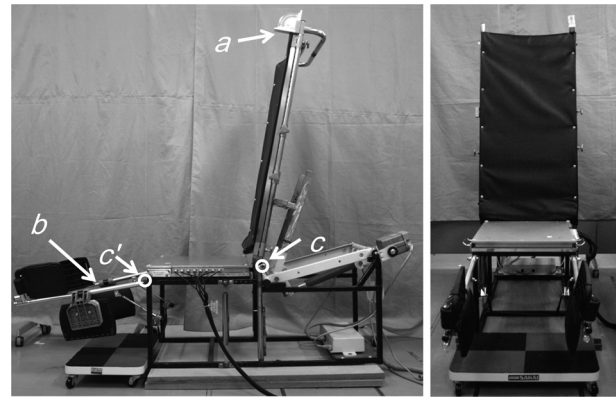

Fig. 1. Experimental chair
The dimensions of the experimental chair were as follows: back support height, 104 cm; seat depth, 40 cm; backward angle of seat, 0°; reclining angle of back support, 10–40°; angular velocity at which the back support reclined, 3°/s. The elevation angle of the leg supports could be adjusted between 10° and 80° backward from the vertical.
a: Level goniometer, *b*: Leg-support, *c*: Rotational axis of back support, *c'*: Rotational axis of leg support

were calculated on the basis of the maximum static friction force, measured using a pull-tension gauge and weight. The measured coefficients of friction between the clothing and the rubber net, between the rubber net and the surface of the force plate, and between the surface of the back support and the clothing were 0.9, 0.8, and 0.4, respectively. The participants were instructed to fold their arms in front of their chests in a relaxed state and to not intentionally change their body position during the experiment. Kemmoku et al.[16] reported that the vertical and horizontal forces acting on the sacrococcygeal and ischial tuberosity areas increase in a seated posture as the angle of pelvic tilt increases. Thus, to ensure consistency in the pelvic tilt angle, each participant's buttocks were positioned so that the back support and dorsal surface were in contact.

Two experimental conditions were used. Under the leg-down condition, the positions of the lower legs were adjusted to be perpendicular to the feet on the floor, and the horizontal thigh angle was then adjusted by stacking wooden boards under the experimental chair. Furthermore, to reduce the resistance of the lower extremities, a roller board was placed under the participants' feet. In contrast, under the leg-up condition, the positions of the lower legs were elevated upward to an 80° incline backward from the vertical line by elevating the leg supports. Aissaoui et al.[14] reported that the angls of lower leg supports can affect the posture of a sitter's hip if the angular modification changes the distance from the seat front to the foot plates. This change results from the fact that the leg support's axis of motion is not aligned with the knee joint axis. This interdependency between leg support angles and the distance between the footplate and the seat requires the linear placement of the lower leg and foot plate to be adjusted in synchrony with the leg support's angular modification. In addition, the soles of the feet did not counteract the horizontal force applied to the buttocks by
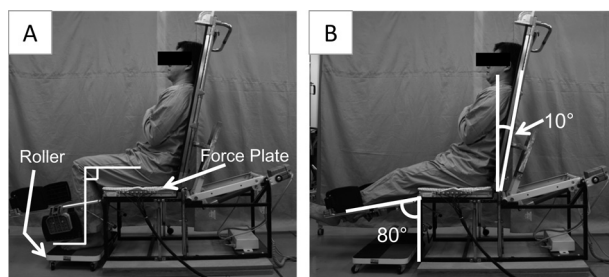
Fig. 2. Measured posture and experimental conditions
A. The leg-down condition, B. The leg-up condition
Measurements were made while each participant sat comfortably with bilateral symmetry and resting on the back support and force plate located on the chair seat.

applying pressure to the foot plates during the experiment. Thus, under the leg-up condition, the foot plates were not used in this study (Fig. 2).

To investigate the cause of the increased shear force acting on the buttocks, we measured the horizontal and vertical forces when the back support was reclined. In addition, we also measured the center of pressure (COP) on the force plate and the trunk sliding distance along the back support to examine how the shear force increased. The NPUAP[17] defines "shear" as "an action or stress resulting from applied forces which causes or tends to cause two contiguous internal parts of the body to deform in the transverse plane." As measuring shear force is difficult, we measured the horizontal and vertical forces to determine the shear force as described by Kemmoku et al[16]. The horizontal and vertical forces acting on the buttocks were measured using a force plate (400 × 400 mm; sampling frequency, 100 Hz; Kyowa Electronic Instruments, Tokyo, Japan) that measured the reaction force in the posterior direction, which is equivalent to the horizontal force in the anterior direction when the back support was inclined. In addition, the anterior-posterior position of the COP on the force plate was measured. The point of origin of the measured COP was the center of the plate. Thus, a positive value indicated that the COP was located farther forward than the center of the plate. Furthermore, we measured the trunk sliding distance along the back support (BS) was using a video camcorder. Videos of the trunk and back support were taken from the left side using a digital video camera (Panasonic, Osaka, Japan) for the duration of the back support movement. Dartfish TeamPro Data 6.0 video analysis software (Dartfish, Fribourg, Switzerland) was used to measure the trunk sliding distance along the back support. The distance was defined as follows:

$$BS = V_a - V_s \qquad (1)$$

where V_a and V_s correspond to the distances between the acromion and the reference base point (B), projected on the back support plane, from a position of back support after reclining (a) and at each start position (s), respectively[18]. A positive value indicates that the trunk was slid farther downward from the start position.

To correct for the influence of each participant's pos-

tural collapse during measurement, measurements were performed 10 seconds after the posture was set. With respect to the angle of back support inclination, Park et al.[19] reported that decubitus ulcers may be prevented or diminished in tetraplegia patients when the back support angle of the wheelchair is more than 120°, which is similar to 30° from the vertical line. Accordingly, the experimental back support was reclined at increasing angles, beginning at 10° from the vertical (the initial upright position, IUP), proceeding to a fully reclined position (FRP) of 40° from the vertical, and then returning to the upright position (RUP). In this study, the reclining cycle of back support was divided into two phases (i.e., the posterior inclination phase and the returning inclination phase). The posterior inclination phase was from IUP to FRP, and the returning inclination phase was from FRP to RUP.

The position of the lower legs was set according to the experimental condition before the back support was reclined. Between each phase, the participants were asked to stand up and relax for one minute to release the residual forces on the back support and the seat. In both inclination phases, the time required to measure the forces in each position of back support was 5 seconds. For each experimental condition, we used the average of the forces acting on the buttocks and the position of the COP after measuring 201 stable samples for each participant. The two conditions were measured in a random order, with three trials for each experimental condition. If the participant could not continue sitting because of intolerance of the position or danger of sliding out of the wheelchair, the experiment was stopped for safety reasons. Between each trial, the participants were asked to reset and relax for one minute.

To correct for the effects of body weight, the measured horizontal and vertical forces acting on the buttocks were normalized by body weight (percent body weight; %BW), on using of the raw data measured by the force plate. Preliminary analysis of the forces acting on the buttocks and the distance sliding along the back support was performed using the Shapiro-Wilk normality test. To investigate the influence of elevating the leg supports, the forces acting on the buttocks, the position of the COP, and the sliding distance were compared between the two experimental conditions in each of the reclining positions in the inclination phase. In addition, to investigate the influence of the reclining the back support, the forces and the position of COP were compared between the two positions of the back support in each inclination phase. The data were analyzed using the paired t-tests. The statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 16.0 J for Windows (SPSS, Chicago, IL, USA), and a significance level of $p < 0.05$.

RESULTS

Tables 1 and 2 show the horizontal and vertical forces acting on the buttocks, Table 3 shows the position of the COP on the force plate, and Table 4 shows the sliding distance along the back support.

Regarding the horizontal force acting on the buttocks, there were significant differences in the horizontal forces

Table 1. Horizontal force acting on the buttocks in the various positions of back support (n=17)

Phase	Position	The leg-down condition	The leg-up condition
The posterior inclination	IUP**	10.2 ± 1.0	15.5 ± 2.8
	FRP**	10.3 ± 1.0	14.9 ± 1.5
Phase	Position	The leg-down condition [a]	The leg-up condition [a]
The returning inclination	FRP**	13.2 ± 0.9	16.4 ± 1.7
	RUP**	17.4 ± 2.0	22.8 ± 3.4

mean ± SD (%BW)
** p < 0.01 (significant differnce between two experimental conditions)
[a] p < 0.01 (significant differnce between the two positions of back support)

Table 2. Vertical force acting on the buttocks in the various positions of back support (n=17)

Phase	Position	The leg-down condition [b]	The leg-up condition [b]
The posterior inclination	IUP**	71.8 ± 2.9	74.8 ± 4.1
	FRP**	60.3 ± 5.0	68.0 ± 5.6
The returning inclination	FRP**	60.4 ± 3.3	67.3 ± 3.0
	RUP**	79.4 ± 4.6	87.5 ± 3.6

mean ± SD (%BW)
** p < 0.01 (significant differnce between the two experimental conditions)
[b] p < 0.01 (significant difference between the two positions of back support)

Table 3. Position of the COP on the force plate in the various positions of back support (n=17)

Phase	Position	The leg-down condition [c]	The leg-up condition [c]
The posterior inclination	IUP**	−87.3 ± 14.3	−46.1 ± 11.8
	FRP**	−114.7 ± 14.5	−69.8 ± 12.4
The returning inclination	FRP**	−111.8 ± 13.7	−67.1 ± 10.5
	RUP**	−82.7 ± 16.6	−49.5 ± 12.3

mean ± SD (mm)
** p < 0.01 (significant differnce between the two experimental conditions)
[c] p < 0.01 (significant differnce between the two positions of back support)
A negative value indicates that the COP was located farther backward than the center of the plate.

Table 4. Trunk sliding distances of the back support in the various inclination phases (n=17)

Phase	The leg-down condition	The leg-up condition
The posterior inclination	78.8 ± 10.4	81.2 ± 12.9
The returning inclination	−66.8 ± 13.2	−68.8 ± 13.1

mean ± SD (mm)
A positive value indicates that the trunk was slid farther downward than the start position.

measured under the two experimental conditions in all the reclining positions of the back support. In addition, there were not significant differences between the two positions of back support in the posterior inclination phase, but there were significant differences for that in the return-to-the-upright phase (Table 1). Regarding the vertical force acting on the buttocks, there were significant differences in the vertical forces between the two leg elevation conditions in all reclining positions of the back support. In addition, there were significant differences between the two leg elevation positions in each inclination phase (Table 2). Regarding the

anterior-posterior position of COP on the force plate, there were significant differences in the anterior-posterior positions of the COP between the two leg elevation conditions in all reclining positions of the back support. In addition, there were significant differences between the two leg elevation positions in each inclination phase (Table 3). Regarding the trunk sliding distance along the back support, the differences in the sliding distances of the back support under the two conditions were not significant (Table 4).

DISCUSSION

This study examined the influence of elevating leg support elevation on the shear force acting on the buttocks during reclining of the back support to aid in the prevention of decubitus ulcers in supposed individuals who use wheelchairs with reclining back supports. In the RUP, under both experimental conditions, the forward horizontal force acting on the buttocks increased significantly in comparison with that in the FRP as the back support reclined. In previous research[4–6], we investigated the mechanism of the increase in the horizontal force acting on buttocks from the FRP to RUP. The results suggested that the increase in horizontal

force was produced by the friction force on the back support and the difference in the position of the rotational axes of the back supports and the trunk-pelvis. With respect to the influence of elevating leg support elevation, in the IUP as the start position of the posterior inclination phase and the RUP as the end position of the returning inclination phase, the horizontal forces acting on the buttocks under the leg-up condition were significantly greater than under the leg-down condition. Kemmoku et al.[16] reported that the horizontal forces acting on the sacrococcygeal and ischial tuberosity areas increased in a seated posture as the angle of pelvic tilt increased. In the present study, the angle of backward pelvic tilt was increased by extending the hamstrings as a result of elevating the leg support. Moreover, Aissaoui et al.[14] reported that the pressure on the back support during sitting on a chair was increased by elevating leg support. In addition, there is a strong relationship between the reaction force on the back support and the horizontal force acting on the buttocks[20]. The pressure, i.e., the reaction force, on the back support is increased by increasing the angle of backward pelvic tilt. With respect to the present study, therefore, it might be suggests that the horizontal force acting on the buttocks under the leg-up condition was also increased significantly in the IUP and RUP.

Incidentally, with the FRP as the start and end positions of each inclination phase, the hamstrings should not be extended by elevating the leg support so that the pelvis is inclined backward by reclining the back support. However, the horizontal and vertical forces acting on the buttocks under the leg-up condition were significantly higher than under the leg-down condition. Gilsdorf et al.[13] reported that the anterior-posterior position of the COP is located forward on the seat, so that the mass of the thighs produces a load on the front of the seat that can be adjusted by adjusting the thigh angle downward from the horizontal plane when sitting on a chair. Under the leg-up condition in the present study, the COP was located significantly more forward on the seat than under the leg-down condition, even although the differences in the sliding distances of the back support of the two conditions were not significant. The lower legs were elevated by the leg supports under the leg-up condition. The angle of the lower legs was 10° less than the horizontal plane at the maximum elevating on angle of the leg supports. The inclination of the leg support and the mass of the lower legs resulted in rotated the thighs forward. Under the leg-up condition, the vertical force on the seat was significantly increased, and the position of the COP was shifted forward as a result of the thighs pressing the seat due to the rotation. These findings suggest that the leg support used in this study did not sufficiently support the mass of the lower legs.

The vector of the lower leg weight was separated into parallel and vertical components for analysis of the leg support inclination. The resistance force in the parallel direction was the static friction force between the leg support surface and the lower legs. The maximum static friction force just before sliding of the lower legs occurs is defined as the product of the friction coefficient and the vertical force on the surface of the leg support. This implies that in regions where the vertical force is relatively high, the static friction can become high as well, suggesting that the static friction value was low, and thus that the vertical force on the leg support was low because the vector of the lower leg mass was separated into two components for the leg-up condition in this study. Therefore, in the FRP, the horizontal force acting on the buttocks under the leg-up condition, which did not sufficiently support the lower legs, was significantly higher than that under the leg-down condition, in which sufficient support was perpendicularly provided to the lower legs through the soles of the feet.

The main limitation of this study was that it included only healthy adult males. In addition, because the measurement times were short, the effect of delayed postural collapse was not evaluated. Also, the COP is easily affected by the body alignment. However, we did not measure body alignment in this study. Furthermore, the form (i.e., the rotational axis position of the leg support), material, and coefficient of friction of the experimental wheelchair's seat differed from those used to measure the horizontal forces. For example, the foot plates were not used in this study so that the soles of the feet did not resist the horizontal force acting on the buttocks by pressing against the foot plates. If the foot plates had been used in this study, it might be presumed that the fluctuation of the horizontal force applied to the buttocks under the leg-up condition was decreased by resistance to the parallel force forward and downward on the leg support. Moreover, we did not consider factors that interact with the friction force, such as urinary incontinence and sweat, which affect many wheelchair users. Therefore, the present results should be extrapolated to actual wheelchair users with great caution.

The results of this study suggest that leg supports should be positioned downward before reclining the back support of a wheelchair to prevent decubitus ulcer formation. We plan to investigate the influences of the seat material and the friction force of the back support on the horizontal force acting on the buttocks while the wheelchair is reclining. These results will aid in the development of reclining wheelchairs and ultimately reduce the occurrence of decubitus ulcers.

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