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Original Article

Investigation of the effect of a 15-degree tilt-in-space on the fluctuation of shear forces exerted on the buttocks when the back support is reclined

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Abstract. [Purpose] This study aimed to investigate the effect of the combination of 15° tilt-in-space and recline angles on the fluctuation of shear forces exerted on the buttocks. [Participants and Methods] The participants were 11 healthy adult males. The parameters of the shear forces were the parallel and perpendicular forces exerted on the buttocks as measured by a force plate. The two conditions tested were T0R100-130 and T15R100-130. The tilt-in-space angles were set to 0° and 15° in the T0R100-130 and T15R100-130 conditions, respectively. The reclining angles were determined to be 100° to 130° in both conditions. [Results] Upon comparing the two conditions, the parallel and the perpendicular forces exerted on the buttocks in the T15R100-130 condition were significantly lower than those in the T0R100-130 condition in all positions of back support. Upon comparing the fluctuation values of the parallel and perpendicular forces, those applied in the T15R100-130 condition were significantly higher than those in the T0R100-130 condition. [Conclusion] These results suggest that the fluctuation of shear forces exerted on the buttocks could be decreased by using a combination of 15° tilt-in-space and reclining functions.

Key words: Tilt-in-space, Shear force, Reclining

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INTRODUCTION

Since the 1980s, it has been internationally recommended that older, bedridden patients be seated to prevent excess pressure or pressure injurys[1)]. Japan adopted this recommendation several decades ago. Today, many assistive devices have been developed that are important for the long-term care of individuals with impaired mobility. In Japan, however, many older persons living in residential care facilities sit in standard wheelchairs for extended periods as it is easier to transport the person around the facility in a wheelchair[2)]. Elderly people who are unable to sit in a standard wheelchair with a low backrest often use a wheelchair with tilt-in-space or reclining functions. The tilt-in-space function allows continuous seat-to-ground angle changes against a constant seat-to-back support angle. The reclining function allows continuous seat-to-back support angle changes against a constant seat-to-ground angle. Older patients who cannot maintain a sitting posture may be able to approximate a sitting posture by leaning their head and trunk on a reclined back support. However, they may remain in the same position for extended periods of time because they cannot change positions by themselves. The adverse consequences of impaired mobility and remaining in a sitting position for a prolonged period have been described since the 1990s and these include joint contractures of the lower extremities and/or pressure injuries on the buttocks[3)].

Pressure injuries are some of the most prevalent and costly adverse effects of impaired mobility, with estimated healthcare

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expenses of up to $3 billion annually[4]. Cellular deformation due to external forces is considered the main cause of pressure injury development[5]. Lahmann et al.[6] reported a strong relationship between friction forces and superficial skin lesions and between pressure forces and deeper pressure injuries. Goossens et al.[7] reported that in areas where the pressure is relatively high, shear stress may also increase. Various cushions are used to effectively decrease the external forces exerted on the buttocks while sitting[8, 9]. Other studies have investigated the pressure exerted on the buttocks and blood perfusion in the skin within the ischial bone region while using both functions of tilt-in-space and reclining[10–13]. They reported that the pressure was decreased and that blood perfusion increased when reclining the back support to a nearly horizontal position by using both functions.

There are very few reports on the fluctuation of the shear force exerted on the buttocks when combining the tilt-in-space and reclining functions. Koda et al.[14] investigated to the effect of the difference in each angle of the tilt-in-space and the reclining on the forces exerted on the buttocks. This previous report considered the forces exerted on the buttocks when the back support is at rest at any angles, and did not consider the fluctuation of the forces exerted on the buttocks during the reclining cycle. Gefen et al.[15] and Breuls et al.[16] suggested that an engineering strain of approximately 50% in tissue is the threshold for pressure injury development. The deformation of the soft tissue is facilitated by force fluctuations. Therefore, it is important to investigate the effect of these combinations on the shear force fluctuation for the prevention of pressure injuries.

The tilt-in-space function is used prior to the reclining function to prevent the buttocks moving forward on the wheelchair surface. Thus, when a combination of the tilt-in-space and the reclining function is used, the body is tilted backward before the backrest is reclined. We hypothesized that as a result of using a combination of tilt-in-space and reclining functions, the fluctuation of the shear force exerted on the buttock will be decreased. The purpose of the present study was to investigate the effect of using a combination of tilt-in-space and reclining on the fluctuation range of the shear force exerted onto the buttocks, and to verify this hypothesis.

PARTICIPANTS AND METHODS

The participants were 11 healthy adult males (mean age, 33.0 ± 9.0 years; height, 171.3 ± 5.7 cm; body weight, 65.9 ± 8.1 kg). Participants were excluded if they experienced pain while sitting on a chair or had back pain or had a history of surgery, rheumatism, or neurologic disorders.

The study was approved by the 2019 Ethics Committee of Kawasaki University of Medical Welfare (No. 19-107), and written consent was obtained from all participants.

It is challenging to measure shear force accurately because the shear forces exerted on the buttocks are related to the parallel force for the seat, and the perpendicular force is related to the static friction forces, which strongly influence the shear force. Thus, the parallel and perpendicular forces exerted on the buttocks as parameters of the shear force were measured using a force plate (K07-1712, Kyowa Electronic Instruments, Tokyo, Japan). The backward reaction force corresponding to the forward parallel force and the perpendicular reaction force were measured using a force plate at a sampling frequency of 100 Hz. In this study, we used an experimental chair with the function of tilt-in-space and electrical controls that reclined the back support (Hashimoto Artificial Limb Manufacturer, Okayama, Japan). The dimensions of the experimental chair were as follows: back support height, 97 cm; seat depth, 40 cm; angular speed at which the rear support reclines: 3°/s. A force plate was placed on the seat of the experimental chair. To reduce the buttock pain experienced during this experiment, a thin of 10 cm and single layer of a low-rebound flexible urethane foam cushion was placed on the force plate. A rubber net was placed between the force plate surface and the cushion so that the cushion did not slide on the force plate. The body slides downward relative to the back support while the back support reclines and slides upward while returning to the original inclination angle. This occurs because there is a difference between the rotational axis position of the back support relative to the hip joint, which is the rotational axis of the upper body. Additionally, the shear forces exerted on the buttocks show marked fluctuation due to the friction force between the back support surface and the body trunk[17]. A proportional relationship exists between the friction force and the parallel force of the surface[18]. Thus, to achieve consistent friction between the participants' clothing, the seat surface, and the back support, all participants wore clothing made of 65% polyester and 35% cotton. The coefficient of static friction between the clothing and the urethane foam cushion surface was 1.0, and the coefficient between the clothing and the surface of the back support was 0.6. In order to investigate the trunk sliding distance along the back support as a secondary outcome, the inclination of the trunk and back support were filmed from the left side using a digital video camera (HC-V520M, Panasonic Corp., Osaka, Japan) (Fig. 1).

Participants' posture was measured using the following procedure. The sternal and abdominal lines of the participants were visually and physically inspected to ensure that the lumbar and thoracic spine were not flexed laterally in the frontal plane. The participants were instructed to sit comfortably and symmetrically on the back support. The pelvis was inclined backward by the distance between the back support and the pelvis. The forward shear force exerted on the buttocks is changed by the inclination angle of the pelvis[19]. Therefore, the buttocks of each participant was placed in contact with the back support and the surface of the back of the trunk to avoid differences in the pelvic tilt angle between experimental conditions. Each participant's pelvic tilt angle was controlled between the two experimental conditions by marking the position of the greater trochanter. The mass of the lower extremities affects the forces exerted on the buttocks[20]. Therefore, the height of the footplates was adjusted so that the upper surface of the thigh was parallel to the seat surface, and the position of the foot was the same under two conditions. Lower extremity extension can counteract the forward sliding of the buttocks. To minimize this effect between conditions, participants were instructed to relax their lower limbs. Moreover, the trunk sliding distance along the back support was calculated by measuring the distance between the acromion and the upper end of the back support in each of the three back support inclination positions. 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 is defined as:

$$BS = V_a - V_i \quad (1)$$

where V_a and V_i correspond to the distances between the acromion and the upper end of the back support, respectively, after the back support was reclined (*a*) and an initial upright position (*i*)[21] (Fig. 2).

Chen et al.[12] reported that the pressure applied to the ischial bone decreased as the angle increased, even by as little as 15°, as a result of measuring the pressure in combination with tilt-in-space and reclining functions. Therefore, to investigate the effect of the presence or absence of tilt-in-space on the shear force exerted on the buttocks, the angles of tilt-in-space were set to 0° and 15°. We tested two experimental conditions. In the T0R100-130 condition, the tilt-in-space angle was 0°, and the back-support was reclined from 100° to 130°. In the T15R100-130 condition, the tilt-in-space angle was 15°, and the back-support was reclined from 100° to 130° (Fig. 3).

Participants were instructed to sit on the experimental chair and data measurement was initiated after 60 s of sitting in the experimental posture, which allowed the foam cushion to adapt to the shape of each participants' buttocks. The reclining angle was set to 100°, which is the starting position of the back support, in all conditions (initial upright position; IUP). Then, the back support was reclined to the fully reclined position (FRP) of 130°. Subsequently, the back support was returned to the upright position (RUP). The back support was held in each position for 5 s (Fig. 4). For each experimental condition, the average values of the parallel and perpendicular forces exerted on the buttocks were used after measuring 201 stable samples for each participant, and the average values of the shear force exerted on the back were used after measuring eight stable

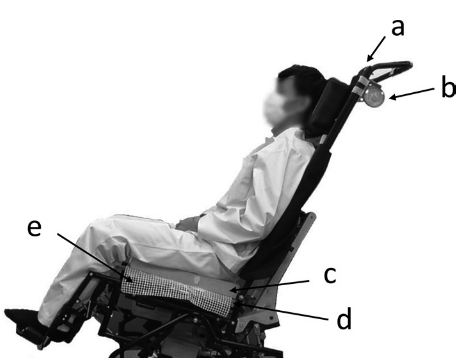

Fig. 1. Materials for measurement of experimental data & measured posture.
a. Experimental chair with the function of tilt-in-space and electrical controls that reclined the back support, b. level goniometer, c. single layer of a low rebound flexible urethane foam cushion, d. force plate, e. rubber net.

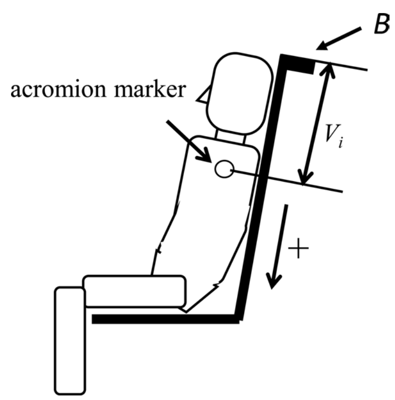

Fig. 2. The definition of sliding distance along the back support[20].
Vi: distance between reference point B and the acromion marker along the back support surface.
B: the basis of point on the back support.
+: the trunk was slid farther downward. -: the trunk was slid farther upward.

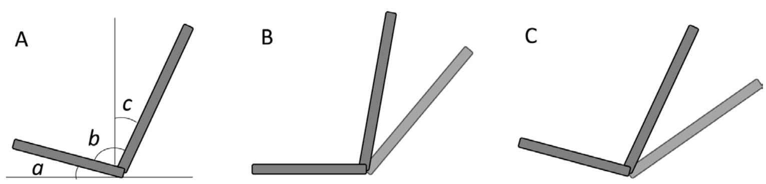

Fig. 3.
A. Angles & experimental conditions.
a. tilt-in-space angle, *b*. reclining angle, *c*. back support sagittal angle.
B. The T0R100-130 condition which the tilt-in-space angle was 0°, and the reclining angle was from 100° to 130°.
C. The T15R100-130 condition which the tilt-in-space angle was 15°, and the reclining angle was from 100° to 130°.

samples for each participant. The two experimental conditions were measured in random order and tested three times for each condition. Between each trial, the participants were required to take a 60 s break by moving to another chair. We normalized the measured forces exerted on the buttocks and back using body weight (percent body weight; %BW) and raw data from the force plate. In addition, to investigate the effect of the combination of 15-degree tilt-in-space and reclining on the fluctuation of the shear force exerted on the buttocks, the fluctuation was calculated by subtracting the minimum value of the parallel and perpendicular forces exerted on the buttocks from the maximum value during reclining of the back support.

A preliminary analysis of the data of the present study was conducted using the Shapiro–Wilk normality test. To detect differences between two conditions, a paired t-test was used in normally distributed data sets, and a Wilcoxon rank sum test was used in data sets that were not normally distributed. Statistical significance was set at $p<0.05$. All statistical analyses were performed using IBM SPSS Statistics ver. 23.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Figure 5 shows the wave representing the fluctuation pattern of the force in a typical measurement. Table 1 shows the measured forces exerted on the buttocks, and Table 2 lists the trunk sliding distance along the back support.

The T0R100-130 condition showed a slight decrease in the wave pattern of the parallel force exerted on the buttocks from the IUP to the FRP. Further, this condition showed an increase from the FRP to the RUP. In the IUP, the mean value under the T15R100-130 condition was nearly zero. The parallel force under the T15R100-130 condition decreased from the IUP to the FRP, reflecting backward parallel force. From the FRP to the RUP, the parallel force was markedly increased and the direction of parallel force was reversed. Both conditions showed a similar wave pattern for the perpendicular force exerted on the buttocks throughout the reclining cycle of the back-support.

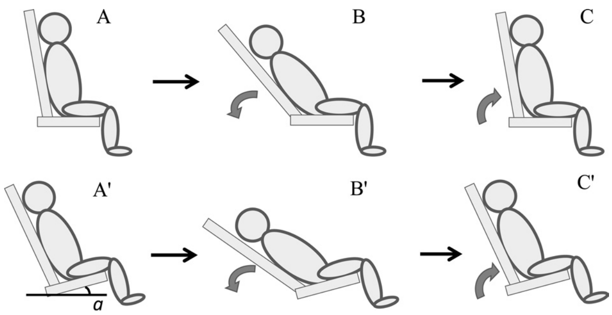

Fig. 4. The position of the back support.
A, A'. initial upright position: IUP, B, B'. fully reclined position: FRP, C, C'. return to upright position: RUP.
a. tilt-in-space angle, 15°.
The times at which the data of this experiment were measured were 5s, 5s, and 5s in the IUP, FRP, and RUP, respectively.

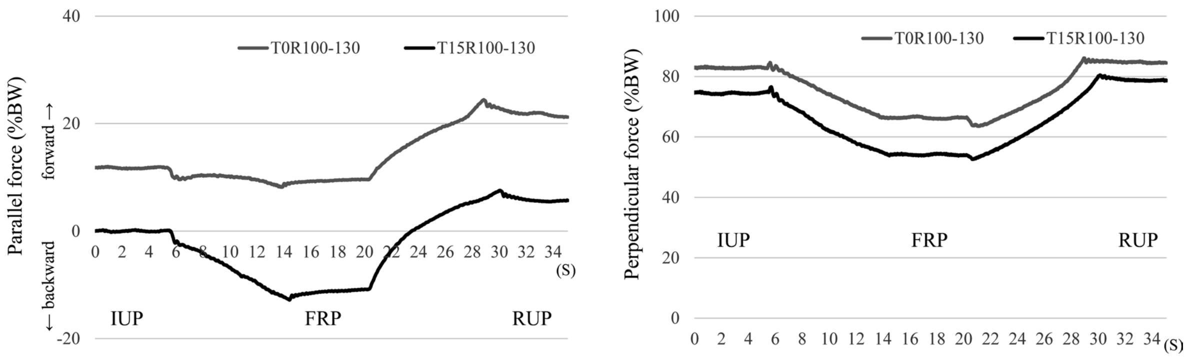

Fig. 5. The wave representing the fluctuation pattern of the force exerted onto buttocks in a typical example.
IUP: initial upright position, FRP: fully reclined position, RUP: return to upright position.
Parallel force: In the IUP, the force to forward showed to decrease under the T15R100-130 condition. In the FRP, the force direction showed changing to backward. In the RUP, the force direction showed changing to forward again, and lower value than the T0R100-130 condition. The fluctuation range showed to be widened under the T15R100-130 condition.
Perpendicular force: The same wave pattern of the force showed under two conditions. In the FRP, the force showed a markedly decreasing under the T15R100-130 condition.

Table 1. The parallel and perpendicular forces exerted on the buttocks

n=11

The parallel force	T0R100-130 condition	T15R100-130 condition
IUP**	9.5 ± 2.2	−0.2 ± 2.4
FRP**	7.4 ± 1.9	−9.6 ± 4.2
RUP**	18.6 ± 3.2	6.3 ± 2.3
Fluctuation range**	10.8 (10.0 to 11.2)	17.1 (12.7 to 18.1)
The perpendicular force	**T0R100-130 condition**	**T15R100-130 condition**
IUP**	82.7 ± 3.4	73.6 ± 3.1
FRP**	65.6 (63.5 to 67.5)	54.3 (52.3 to 56.4)
RUP**	84.6 ± 4.2	77.2 ± 3.2
Fluctuation range**	17.8 ± 4.2	22.7 ± 3.9

Mean ± SD, median (interquartile range) (%BW), +: to forward, −: to backward.
**p<0.01 (paired t-test, Wilcoxson rank test).

Table 2. The trunk sliding distance along the back support

n=11

	T0R100-130 condition	T15R100-130 condition
FRP-IUP**	5.3 ± 0.9	3.3 ± 0.4
RUP-IUP**	1.4 ± 0.5	0.6 ± 0.7

Mean ± SD (cm), +: to downward.
**p<0.01 (paired t-test).
FRP−IUP, RUP−IUP: The difference compared the distance between the acromion and the upper end of the back support in the FRP or the RUP and the distance in the IUP.

The parallel and the perpendicular forces exerted on the buttocks were significantly lower in the T15R100-130 condition versus the T0R100-130 condition in all back support positions (p<0.01). The fluctuation of the parallel and perpendicular forces exerted on the buttocks was significantly higher in the T15R100-130 condition than that in the T0R100-130 condition (p<0.01).

The amount that the trunk slid downward along the back support was compared between the two conditions using the FRP and the RUP, and the shear force applied by the T0R100-130 condition was significantly higher than that by the T15R100-130 condition (p<0.01).

DISCUSSION

It is known that the forces exerted on the buttocks and the back fluctuate greatly when using the reclining function, which reclines only the back support, and this fluctuation of forces results in a collapsed sitting posture, discomfort, and an increased risk of pressure injuries[15, 16]. We investigated whether the fluctuation of the forces exerted on the buttocks was altered by using a combination of the functions of reclining and 15-degree tilt-in-space. The results of this study demonstrate that the fluctuation of the parallel and perpendicular forces exerted on the buttocks were increased by using the tilt-in-space function. Therefore, the hypothesis that using a combination of 15-degree tilt-in-space and reclining functions would decrease the fluctuation of the shear force exerted on the buttock was supported.

The T15R100-130 condition exerted significantly less force on the buttocks than the T0R100-130 condition in all back support positions. There are two potential explanations, the first being gravity. The seat and the back support are tilted at the same time by the tilt-in-space function. Gravity as the vertical force is divided into perpendicular and backward vectors with respect to the seat, because the seat is tilted backward under the T15R100-130 condition. Therefore, the forces exerted on the buttocks in the T15R100-130 condition were significantly lower than those in the T0R100-130 condition.

The second potential explanation is the difference in the amount that the body trunk leaned on the back support. From the IUP to the FRP, the body slides down the back support when the back support is reclined[22]. Then, a static frictional force occurs between the back of the body and the back support to prevent the body from moving when it attempts to slide downward on the surface of the back support. This static frictional force relates proportionately to the shear force exerted on the body. Moreover, the static frictional force changes proportionately to the perpendicular force with respect to the surface[18]. If the tilt-in-space function is used, the upper body reclines backward as the back support does, so that the mass of the upper body resting on the back support increases; specifically, the perpendicular force on the back support increases. The stronger static frictional force inhibits the body sliding downward on the back support surface under the T15R100-130 condition in the FRP. This is because the shear force exerted on the back under the T15R100-130 condition was significantly higher than that under the T0R100-130 condition. Accordingly, we suggest that the stronger shear force exerted on the back and the stronger static frictional force between the back and the back support is decreased by using the tilt-in-space feature, because this decreases the parallel and perpendicular forces exerted on the buttocks in the FRP.

The parallel and the perpendicular forces exerted on the buttocks in the RUP under the T15R100-130 condition showed a large increase from the FRP to the RUP. However, the force exerted under the T15R100-130 condition was significantly lower than that in the T0R100-130 condition. This may be because the parallel force exerted on the buttocks in the FRP is vectored backward, and the forward parallel force increases from there. Furthermore, under the T0R100-130 condition, the body slid down with respect to the back support in the FRP and it did not return to its original position in the RUP. As the back support rises from the FRP to the RUP, the trunk should slide proportionally upward on the back support surface, but it is inhibited by the frictional force between the back of the body and the back support. The trunk does not fully return to the original position when the back support is raised to the RUP, and the parallel force exerted on the buttocks increases sharply due to the pressure of the back support against the body[17)]. For these reasons, it was presumed that the parallel force exerted on the buttocks under the T0R100-130 condition showed an increase in the RUP.

As described above, when the 15-degree tilt-in-space and reclining functions are used together, the parallel force exerted on the buttocks changes significantly from the forward vector to the backward vector, and then to the forward vector again as the direction of the back support inclination changes. An engineering strain of approximately 50% in tissue is the threshold for pressure injury development[15, 16)]. Taken together, these facts suggest that the combined use of tilt-in-space and reclining has a considerable effect on the skin.

One limitation of this study is the short measurement time. In addition, the effect of delayed postural collapse from fatigue could not be evaluated; furthermore, the microclimatic factors that interact with the frictional force could not be determined. Moreover, the coefficient of static friction between the back support of the experimental chair and the participants' backs differs from the coefficient of static friction between the commercially available tilt-reclining wheelchair and the back of the body. The participants in this study were healthy adult men; however, older people are the main users of tilt-reclining wheelchairs and have different health conditions, including spinal kyphosis and dermatological disorders, compared with healthy adult men. Therefore, the results of this study cannot be applied to all wheelchair users.

These results suggest that the fluctuation of the shear force exerted on the buttocks in the FRP and RUP could be decreased by adjusting the back support sagittal angle in combination with 15-degree tilt-in-space and reclining functions. However, the direction of the forces exerted on the buttocks changes when the back support is reclined. Thus, the tilt-in-space and reclining functions should be used with this in mind.

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Conflict of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this paper.

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