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Original Paper

Effect of the Reclining Range of Back Support on Fluctuation of the Shear Force Exerted on the Buttocks When a Tilt-in-space and the Reclining Function Is Used in Combination

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Key words: reclining, tilt-in-space, shear force, pressure injuries

Abstract

This study aimed to investigate the effect of the difference in the reclining range of back support on the fluctuation of the shear force exerted on the buttocks when the tilt-in-space is used in combination with the reclining function. The participants included 13 healthy adult men. The parallel and perpendicular forces exerted on the buttocks were measured as parameters of the shear force using a force plate. The reclining angles were set from 100° to 115° and from 100° to 130° in the two experimental conditions T15R100-115 and T15R100-130, respectively. The tilt angle was set to 15° under both conditions. Comparing the parallel and perpendicular forces exerted on the buttocks, there were no significant differences between the two conditions in the initial upright position. In the fully reclined position, the parallel and perpendicular forces exerted on the buttocks were significantly lower in the T15R100-130 condition than under the T15R100-115 condition. In the return to the upright position, these forces were significantly higher in the T15R100-130 condition than in the T15R100-115 condition. These results suggest that the fluctuation range of the shear force exerted on the buttocks increases as the reclining range becomes wider when using a combination of tilt-in-space and reclining functions.

1. Introduction

Pressure injuries are some of the most prevalent and costly adverse effects of impaired mobility. Brem et al.[1] reported that the cost of treatment of stage IV pressure injuries is in excess of $120,000 per person, far exceeding previous estimates. Thus, pressure injuries are expensive to treat and are associated with increased mortality[2]. The main cause of pressure injury development is cellular deformation, and the main factor causing deformation is external forces[3]. Among the external forces, shear and pressure have

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attracted attention as factors in the development of pressure injuries. There are a lot of reports about countermeasures for pressure which the external forces exerted on the buttocks in the sitting position. By these reports, a wide variety of cushions have been developed and used, and their effects have been verified[4,5]. Furthermore, Jan et al.[6,7] investigated the pressure exerted on the buttocks and the blood perfusion of the skin of the ischial bone region while using both tilt-in-space and reclining functions as the countermeasure for pressure. As a result, the pressure decreased and the blood perfusion increased when the back support was inclined to a backward position by using both functions.

Meanwhile, there are very few reports of countermeasures against shear forces as the external forces exerted on the buttocks. Shear forces fluctuate significantly when inclining the back support using the reclining function[8-10]. In particular, the sharp increase in the shear force when raising the back support from the full inclination posterior position to the return to the upright position causes discomfort in the sitting posture and pressure injuries on the buttocks[11,12]. Sabol and Haley[12] reported that the risk of pressure injuries occurring in the sacral region increases when the buttocks slide forward when sitting on a reclining wheelchair. Huang et al.[13] developed a structure in which the seat of the reclining wheelchair was flexed to a V-shape as the countermeasure against shear force, so as not to slide the buttocks forward when the back support was inclined. This structure prevents forward sliding of the buttocks while inclining the back support backward. In addition, we developed the seat cover assembly for decreasing the shear force exerted on the buttocks while reclining for back support[14]. This seat cover assembly is a collection of parts such as seats and dynamic pulleys that are attached to the back support. There are only a few scattered reports on countermeasures against shear force fluctuations, which are the cause of pressure injuries while reclining the back support, as described above, and they are significantly fewer than reports on countermeasures against pressure. Furthermore, from the previous reports that the shear force exerted on the buttocks increases as the back support reclined[8-12], it is able to be inferred that the larger the reclining range of the buck support, the larger the fluctuation of the shear force exerted on the buttocks during reclining. However, to the best of our knowledge, there is no report that investigates the effect of different back support reclining ranges on the shear force exerted on the buttocks.

Kawasaki et al.[15] and Sonenblum et al.[16] reported that the contact area between the ischial bone region and the sitting seat is limited and the pressure is strongly exerted on the buttocks for a long time, as a person with pressure injuries has a projecting shape in the ischial bone region. Such persons are susceptible to external forces; therefore, these forces should be redistributed to prevent further pressure injuries. Nevertheless, a method of the body weight shifting on the seat as a prevention for pressure injuries while sitting for a long time has not been established[17]. Groah et al.[9] concluded that the risk of pressure injuries is highly individualized, which requires flexible and personalized pressure injury prevention strategies. Although the fact that there is no established method of the body weight shifting on the seat, it is difficult to take complex measures that are adaptable to the individual. The use of both reclining and tilt-in-space functions is recommended because this is an easy method for decreasing the shear force exerted on the buttocks[18]. Based on the above, it would be desirable to use both function of reclining and tilt-in-space to lie the wheelchair user down to a near supine position to rest when using a wheelchair. When the back support is reclined only, it is assumed that the larger the reclining range, the greater the shear force exerted on the buttocks. Therefore, reclining the backrest significantly backward to a near supine position by reclining can only cause an increase in the shear force and increase the risk of pressure injury occurrence. However, there are no reports on the effect of different back support recline ranges on the fluctuation range of the shear force exerted on the buttocks when tilt-in-space and reclining functions are used simultaneously. Force fluctuations can cause soft tissue deformation. Thus, investigating the effect of using a combination of tilt-in-space and reclining functions on the range of shear force fluctuation is very meaningful for the prevention of pressure injuries. The purpose of this study was to investigate the effect of the difference in the reclining range of the back support on the fluctuation of the shear force exerted on the buttocks when a combination of the tilt-in-space and reclining functions was used.

2. Methods

2.1 Participants

The participants were 13 healthy adult males (mean age, 31.1 ± 9.4 years; height, 172.2 ± 5.7 cm; body weight, 65.2 ± 7.6 kg). Participants were excluded if they experienced pain applied to the buttocks while sitting on a chair or had back pain, a history of surgery, rheumatism, or neurologic disorders.

The study was approved by the 2019 ethics committee of Kawasaki University of Medical Welfare (# 19-107), and written consent was obtained from all participants.

2.2 Procedures

2.2.1 Materials

It is difficult to accurately measure shear force. The shear forces exerted on the buttocks are related to the parallel force of 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, which was the main outcome in the present study, were measured using a force plate (K07-1712, Kyowa Electronic Instruments, Tokyo, Japan). The perpendicular reaction force and the backward reaction force corresponding to the forward parallel force were measured using a force plate at a sampling frequency of 100 Hz. By reclining the back support, the body slides downward relative to the back support while the back support is inclined backward and upward while returning to the original inclination angle, as there is a difference between the rotational axis position of the back support and the hip joint position as the rotational axis of the upper body. Additionally, the shear forces exerted on the buttocks show remarkable fluctuations owing to the friction force between the back support surface and body trunk[19]. A proportional relationship exists between the friction force and parallel force of the surface[20]. Thus, in the present study, the shear force exerted on the back as the secondary outcome, which occurred between the back support and back, was measured using a device that measured the total shear force (iShear, Vicair B. V., AX Wormer, Netherland) at a sampling frequency of 4 Hz. In the present study, we used an experimental chair with a tilt-in-space function 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; and 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 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 would not slide on the force plate. The device used for measuring the shear force was placed on the back support of the experimental chair so that the downward force had a positive value. To achieve constant friction between the participants' experimental clothing, seat surface, and back support, all participants wore clothing made of 65% polyester and 35% cotton. The coefficient of static friction between the experimental clothing and the urethane foam cushion surface was 1.0, and the coefficient between the experimental clothing and the surface of the device used for measuring the shear force was 0.6 (Figure 1).

2.2.2 Measurement posture

Hirose[21] reported that the inclination of the thoracic spine correlated with that of the sternal line in both the sagittal and frontal planes. He also described that the inclination of the abdominal line, which lies between the lower sternum point and the center point of the right and left anterior superior iliac spines, correlated with that of the lumbar spine in both planes as well[21]. Thus, the sternal and abdominal lines of the participants were visually and manually inspected to ensure that the lumbar and thoracic spine did not incline laterally in the frontal plane. The participants were instructed to sit comfortably and symmetrically on the back support. The pelvis is inclined backward by the distance between the back support and the pelvis in a comfortable sitting position. The shear force exerted on the buttocks forward is changed by

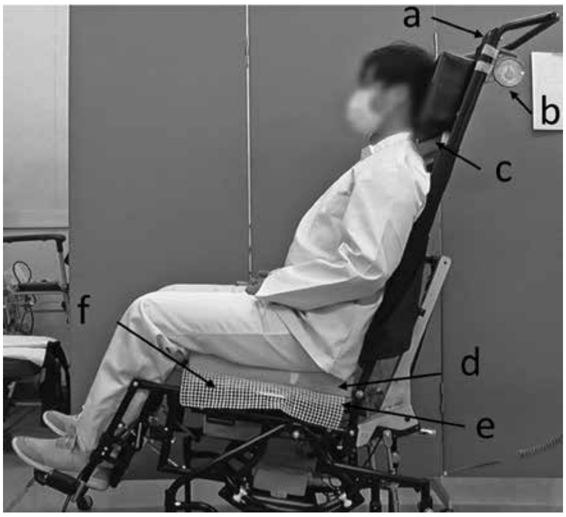

Figure 1 Materials for measurement of experimental data, and measured posture

a: Experimental chair with the function of tilt-in-space and electrical controls that reclined the back support;
b: Level goniometer; c: Device for measuring the total shear force (iShear);
d: Single layer of a low rebound flexible urethane foam cushion; e: Force plate; f: Rubber net

the inclination angle of the pelvis[22,23]. Therefore, the buttocks of each participant were 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 the experimental conditions. Each participant's pelvic tilt angle was unified between the four experimental conditions by marking the position of the greater trochanter as a marker of the pelvic position on the experimental chair. The mass of the lower extremities affects the forces exerted on the buttocks[24]. 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 unified in the footplate under all conditions. Regarding the effect of lower extremity extension that can counteract the forward sliding of the buttocks, participants were instructed to relax their lower limbs to minimize the effect of unifying all conditions.

2.2.3 Experimental conditions

The pressure applied to the ischial bone decreased if the reclining angle range was wide, even at a tilt angle of 15°, as a result of measuring the pressure in combination with tilt-in-space and reclining functions[18]. Thus, the angles of the tilt-in-space were set to 15° under all experimental conditions. In the present study, two experimental conditions were tested: the reclining angle range was set from 100° to 115° and from 100° to 130° for the T15R100-115 condition and the T15R100-130 condition, respectively (Figure 2).

2.2.4 Procedures

Measurement of data from this experiment was initiated after the participants sat for 1 min in the experimental posture so that the low-rebound flexible urethane foam cushion adapted to the shape of each participant's buttocks. Participants were instructed to sit on the experimental chair, which was set to a tilt-in-space angle of 15° in the T15R100-115 and T15R100-130 conditions. The participants' seated postures were adjusted to the measured posture, as mentioned above. The reclining angle was set to 100°, which is the starting position of the back support, under all conditions (initial upright position [IUP]). Then, the back support was inclined to a fully reclined position (FRP) of 115° in the T15R100-115 condition and 130° in the T15R100-130 condition, respectively. Subsequently, the back support was operated to return to the upright position (RUP). The times at which the reclined back support in this experiment was maintained were 5s, 5s, and 5s in the IUP, FRP, and RUP, respectively (Figure 3). 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 samples for each participant. The two experimental conditions were measured randomly by using dice and tested three times for each condition. Between each trial, the participants were required to move to another chair and relax during a one-minute break. We normalized the measured forces exerted on the buttocks and back by body weight (percent body weight [%BW]) based on raw data from the force plate to compensate for the effect of body weight. In addition, to investigate the effect of the difference in the reclining range of the back support on the fluctuation range of the shear force exerted on the buttocks, the fluctuation range was calculated by subtracting the minimum value of the parallel and perpendicular forces exerted on the buttocks from the maximum value while reclining for the back support.

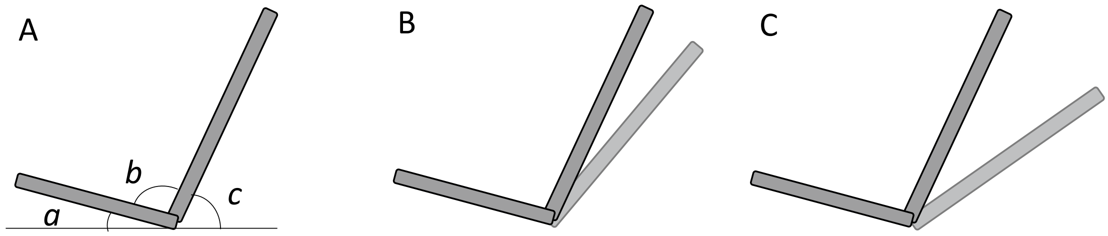

Figure 2　Angles and experimental conditions

A: Angles
a: tilt-in-space angle, *b*: reclining angle, *c*: raising angle
B: The T15R100-115 condition in which the tilt-in-space angle was 15°, and the reclining angle was from 100° to 115°
C: The T15R100-130 condition in which the tilt-in-space angle was 15°, and the reclining angle was from 100° to 130°

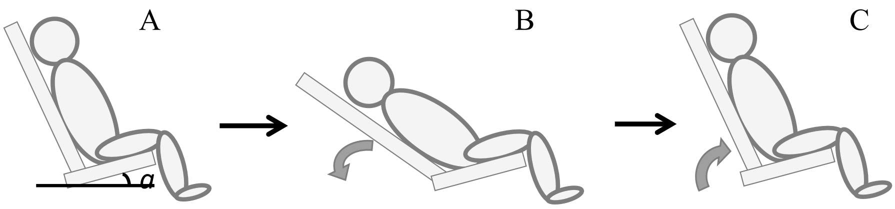

Figure 3　Measuring position of the back-support

A: initial upright position: IUP; B: fully reclined position: FRP;
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.

2.3 Statistical analysis

A preliminary analysis of the data of the present study was conducted using the Shapiro-Wilk normality test. All the outcomes showed a normal distribution. Therefore, to detect differences between the two conditions, a paired t-test was used for all outcomes. Statistical significance was set at $p < 0.05$. The above statistical analyses were performed using IBM SPSS Statistics ver. 23.0 (IBM Corp., Armonk, NY, USA). In addition, the effectual size and power of the test were determined for the values measured using G*power

3.1.9.7 (Faul, Erdfelder, Lang & Buchner).

3. Results

Figure 4 shows the wave representing the fluctuation pattern of force in a typical example. Table 1 shows the measured forces exerted on the buttocks, and Table 2 shows the measured shear force exerted on the back.

Regarding the wave pattern of the parallel force exerted on the buttocks, in the IUP, the mean values under the T15R100-115 and T15R100-130 conditions were nearly zero. The parallel force under both conditions showed a marked decrease and negative value from the IUP to the FRP; that is, the backward parallel force was shown. From the FRP to the RUP, the parallel force showed a marked increase, and the direction of the parallel force changed to forward. Regarding the wave pattern of the perpendicular force exerted on the buttocks, both conditions showed a similar pattern throughout the reclining cycle of the back support (Figure 4).

Regarding the parallel and perpendicular forces exerted on the buttocks comparing the two conditions, there were no significant differences between the two conditions in the IUP. In the FRP, the parallel and perpendicular forces exerted on the buttocks were significantly lower under the T15R100-130 condition

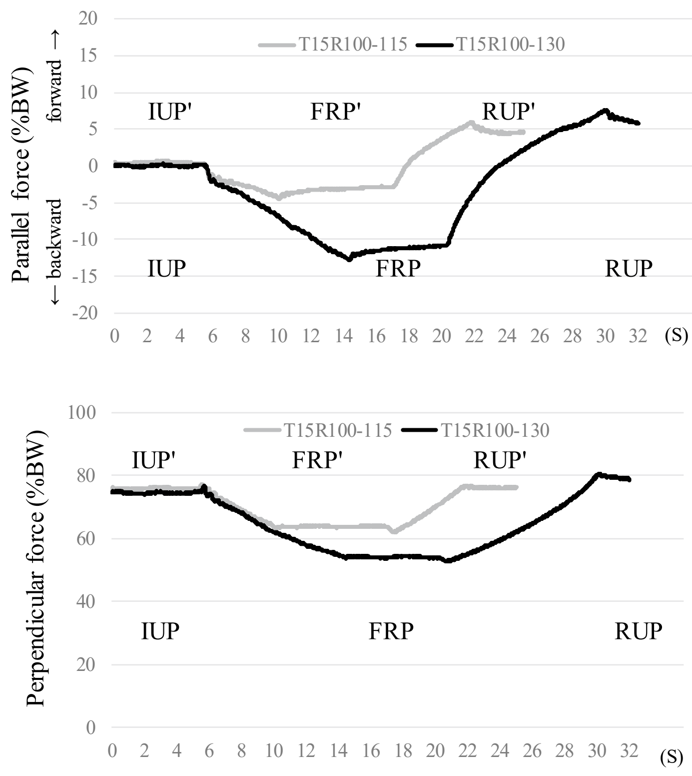

Figure 4 The wave representing the fluctuation pattern of the force exerted on the buttocks in a typical example

IUP: Initial upright position, FRP: Fully reclined position, RUP: Return to the upright position
IUP', FRP' and RUP' are the position of the back-support under the T15R100-115 condition.
IUP, FRP and RUP are the position of the back-support under the T15R100-130 condition.
Parallel force: both conditions showed a marked decrease and negative value from the IUP and the IUP' to the FRP and the FRP'. From the FRP and the FRP' to the RUP and the RUP', the parallel force showed a marked increase, and the direction of parallel force changed to forward.
Perpendicular force: both conditions showed a similar pattern throughout the reclining cycle of the back-support.

than under the T15R100-115 condition ($p < 0.01$). In the RUP, the parallel and perpendicular forces exerted on the buttocks were significantly higher under the T15R100-130 condition than under the T15R100-115 condition ($p < 0.01$). The fluctuation range of the parallel and perpendicular forces exerted on the buttocks was significantly higher under the T15R100-130 condition than under the T15R100-115 condition ($p < 0.01$) (Table 1).

Regarding the shear force exerted on the back, both conditions showed a positive value in the IUP and FRP, that is, downward shear force was shown. The shear force exerted on the back in the RUP under the T15R100-130 condition showed approximately zero value. The individual values varied from -4.6 to 2.6. In the IUP, there were no significant differences between the two conditions. In the FRP, the downward shear force exerted on the back was significantly higher under the T15R100-130 condition than under the T15R100-115 condition ($p < 0.01$). In the RUP, the downward shear force exerted on the back was significantly lower under the T15R100-130 condition than under the T15R100-115 condition ($p < 0.05$) (Table 2).

Table 1 The parallel and perpendicular forces exerted on the buttocks

n=13

The parallel force	T15R100-115 condition	T15R100-130 condition	Effect size dz	Power
IUP	0.1 ± 2.1	-0.3 ± 2.4	0.18	0.09
FRP**	-4.7 ± 3.3	-9.4 ± 4.0	1.27	0.99
RUP**	4.2 ± 2.0	6.1 ± 2.2	0.9	0.85
Fluctuation range**	9.0 ± 2.5	15.5 ± 3.7	1.99	1
The perpendicular force				
IUP	74.3 ± 3.8	73.9 ± 3.0	0.12	0.07
FRP**	62.8 ± 4.7	55.4 ± 5.0	1.52	1
RUP**	74.9 ± 3.6	77.5 ± 3.3	0.75	0.7
Fluctuation range**	12.1 ± 2.5	22.1 ± 3.9	2.92	1

IUP: Initial upright position, FRP: Fully reclined position, RUP: Return to the upright position
mean ± SD (%BW), +: to forward, -: to backward
**: $p < 0.01$ (paired t-test)

Table 2 The shear force exerted on the back

n=13

	T15R100-115 condition	T15R100-130 condition	Effect size dz	Power
IUP	5.1 ± 1.4	5.2 ± 1.5	0.07	0.06
FRP**	11.2 ± 2.6	13.5 ± 2.4	0.92	0.86
RUP*	1.5 ± 1.6	-0.1 ± 2.4	0.76	0.71

IUP: Initial upright position, FRP: Fully reclined position, RUP: Return to the upright position
mean ± SD (%BW), +: to downward, -: to upward
**: $p < 0.01$, *: $p < 0.05$ (paired t-test)

4. Discussion

The main causes of the development of pressure injuries are external forces, such as shear force and pressure. In the present study, we investigated the effect of the difference in the reclining range of the back support on the fluctuation range of the shear force exerted on the buttocks when a combination of the tilt-in-space and the reclining functions was used to prevent pressure injuries while sitting on a wheelchair. Regarding the parallel force exerted on the buttocks in the present study, both conditions were shown to be approximately zero in the IUP. In the FRP, the direction of the parallel force under both conditions was shown to be backward with respect to the seat. The value of the backward force under the T15R100-130 condition was significantly higher than that under the R15R100-115 condition. Then, in the RUP, the direction of the parallel force under both conditions changed to forward, and the value under the T15R100-130 condition was significantly higher than that under the R15R100-115 condition. In the FRP, the perpendicular force exerted on the buttocks was shown to be significantly lower under the T15R100-130 condition, which had a wide range of reclining, than under the T15R100-115 condition, which had a narrow range of reclining. Subsequently, in the RUP, the perpendicular force exerted on the buttocks was significantly higher under the T15R100-130 condition than under the T15R100-115 condition. From these results, we concluded that the fluctuation ranges of the parallel and perpendicular forces were significantly higher under the T15R100-130 condition than under the T15R100-115 condition.

Regarding the forces exerted on the buttocks in the FRP, the T15R100-130 condition with a wide reclining range showed significantly stronger backward parallel force exerted on the buttocks and significantly lower perpendicular force exerted on the buttocks than the T15R100-115 condition with a narrow reclining range. Furthermore, the downward shear force exerted on the back support under the T15R100-130 condition was significantly lower than that under the T15R100-115 condition. Zemp et al.[25] investigated the variations in the ischial interface pressure and ischial blood flow in elderly individuals while sitting when a combination of the tilt-in-space and the reclining functions of the wheelchair was used. Chen et al.[18], in a similar way, investigated the influence of using a combination of the tilt-in-space and the reclining functions on the ischial and the coccygeal interface pressures in individuals with spinal cord injury. They reported that the tilt-in-space alone did not change the ischial interface pressure unless the tilt-in-space angle was large, for example from 35 to 45 degrees, but the combined use of reclining and tilt-in-space significantly decreased the pressure at a tilt-in-space angle of 15 degrees. These results suggest that the reclining function has a stronger effect on the force exerted on the buttocks than the tilt-in-space function. In addition, the body trunk leans down stronger on the back support with respect to the backward inclination of the back support by using the tilt-in-space function[26]. The maximum static friction force is proportional to the force perpendicular to the surface[27]. Thus, the maximum static force between the back of the body and the back support surface might be stronger if the back support is inclined backward by using the tilt-in-space function. The backward inclination angle of the trunk under the T15R100-130 condition is greater than that under the T15R100-115 condition. Therefore, the perpendicular force on the back support under the T15R100-130 condition is stronger than that under the T15R100-115 condition. Accordingly, the static friction force between the back support and the back under the T15R100-130 condition is stronger than that under the T15R100-115 condition, which is inferred from the results of the shear force exerted on the back support in this study. Since the fluctuation on the forces exerted on the buttocks under the T15R100-130 condition is significantly stronger than that under the T15R100-115 condition, this maximum static friction force, which is stronger by tilt-in-space, could have a stronger influence on the forces exerted on the buttocks. In addition, the positional relation between the body and the back support is more different with respect to the back support inclined backward, that is, the body will slide downward on the back support surface. This is because of the different rotation trajectories for the back support and the body trunk because of the difference in position between the rotational axis of the back support and the hip joint as the rotational axis of the body trunk. This difference in the range of the position between the back support and the hip joint would be larger with respect to back support that was more inclined backwards[11]. In the FRP, however, the backward force exerted on the buttocks would be increased and the perpendicular force exerted on the buttocks would be decreased because the static friction force between the body trunk and the back support surface might cause the body trunk to try to stay in its original position on the back support. Then, the static friction force, which is the reaction force against the force exerted when the body slides downward on the back support, becomes a stronger force to pull the buttocks upward and backward if the reclining range is wide. Therefore, under the T15R100-130 condition in the FRP, the backward force exerted on the buttocks showed a significantly higher value, and the perpendicular force showed a significantly lower value.

Regarding the forces exerted on the buttocks in the RUP, the body was pushed forward for a longer time by inclining the back support forward from the FRP to the RUP under the T15R100-130 condition, which has a wider reclining range. This might be the reason why the forward and perpendicular forces exerted on the buttocks under the T15R100-130 condition were significantly higher than those under the T15R100-115 condition. Based on the above, the reasons for the large fluctuations in the shear force exerted on the buttocks under the T15R100-130 condition could be the influence of the static friction force strengthened by the tilt-in-space and the wider reclining range. Regarding the shear force exerted on the back, the downward shear force showed a decreasing trend in both conditions. In addition, under the T15R100-130 condition, there were some subjects who showed negative values, that is, the upward shear force. Under the T15R100-130 condition with a wide reclining range, the back of the body moves upward on the back support surface from the FRP to RUP, but the static friction force between the back support surface and the back becomes stronger due to the wide backward tilt-in-space angle[26]. Therefore, it is thought that the average value was approximately zero under the T15R100-130 condition because there were subjects who showed the upward shear force.

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

The results of the present study suggest that the fluctuation range of the shear force exerted on the buttocks increases as the reclining range becomes wider when using a combination of tilt-in-space and reclining functions. It is often used in combination with both functions of the wheelchair to allow wheelchair users to rest daily. Hence, it would be possible to decrease the fluctuation of forces exerted on the buttocks by using a reclining range of 100 to 115 degrees when using a tilt-in-apace function on 15 degrees, keeping in mind that the fluctuation ranges of the shear force exerted on the buttocks increase depending on the width of the reclining range from the viewpoint of pressure ulcer prevention.

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