

1 Background

2 Decubitus ulcers are lesions that can range from areas with intact skin with non-blanchable redness to
3 full-thickness tissue loss with exposed bone, tendon or muscle. The involvement of deep tissue injury
4 is defined as a severe decubitus ulcer.

5 For Medicare patients with decubitus ulcers, the average cost per ulcer was \$ 43,180 in the fiscal year
6 2007, according to data from the Center for Medicare Services ¹. In addition, estimates by Reddy *et al.*
7 in 2006 put total the United States' expenditures on the treatment of decubitus ulcers as high as \$11
8 billion ². Thus, given their high cost of treatment, decubitus ulcers are an important and widespread
9 problem.

10 Pressure ischemia is the primary aetiology of decubitus ulcers. Recently, some investigators have
11 hypothesized that ischemia alone cannot explain the aetiology of deep tissue injuries in decubitus
12 ulcers, and that other mechanisms, particularly excessive cellular deformation, are likely to be involved
13 ³⁻⁶. Linder-Ganz *et al.* ³ reported that skeletal myocytes of rats can survive 2 h of complete ischemia
14 but die within 15 min of a load causing tissue shear deformation. Stekelenburg and associates ⁴
15 conducted rat studies that isolated the effects of ischemia and shear loading, revealing that 2 h of

1 ischemic conditions caused by a tourniquet resulted in reversible tissue changes whereas 2 h of static
2 loading by an indenter induced irreversible damage. The areas damaged corresponded to a region
3 undergoing high shear strain as determined in separate experiments. Other studies involving static
4 loading using animal and finite element modelling have suggested that shear deformation of tissue
5 initiates short-term tissue damage. After damage initiation, ischemia may accelerate injury due to
6 hypoxia, glucose depletion, and acidification^{5,6}. On the other hand, Lahmann and Kottner⁷ reported
7 that there is a strong relationship between friction forces and superficial skin lesions and between
8 pressure forces and deep tissue injury. In any case, some investigators said that there is a strong
9 relationship between the shear force and decubitus ulcers. In addition, various studies have clarified
10 that complex stress generated within the body is responsible for decubitus ulcers, with not only
11 compressive force but also shear force acting on the skin surface⁸⁻¹². In the 1970s, Guttman⁸
12 attributed a larger role to shear force than pressure in reducing the vascular supply. In addition,
13 Bennett *et al.*⁹ reported that a combination of pressure and shear force effectively promoted blood
14 flow occlusion. Dinsdale¹⁰ studied the effect of various pressures on blood flow and ulceration with
15 and without shear in normal and paraplegic swine. He found that in animals subjected to pressure and

1 shear force, ulceration occurred at lower pressures than in those animals experiencing only pressure.
2 To investigate the relationship between compressive pressure and shear force, Sakuta *et al.* ¹¹
3 measured the changes in blood flow due to such loads, suggesting that 50 mmHg of pressure and 0.9
4 N/cm² of shear force were nearly equivalent in biological soft tissue. Goossens *et al.* ¹² also reported
5 that a shear force of 3.1 kPa significantly influenced the reduction in blood flow in the sacrum of
6 healthy subjects, and indicated the importance of reducing the shear force for preventing decubitus
7 ulcers in terms of blood flow.

8 Wheelchairs with reclining back support are often used by individuals with leg and trunk disorders,
9 such as those with post-apoplectic hemiplegia or spinal cord injuries. Back support plays a major role
10 in maintaining the posture of wheelchair users. The trunk of a wheelchair user's body is rendered
11 more stable by reclining back support. Further, reclining back support is also used to treat postural
12 hypotension in people with spinal cord injuries. However, in facilities providing health care services for
13 the elderly, the occurrence of decubitus ulcers has been recently reported in disabled individuals using
14 wheelchairs with reclining back support for long periods of time ^{13,14}. Many wheelchair users who need
15 reclining back support cannot correct collapsed posture on their own. Wheelchair users have often

1 been observed to shift downwards in their chairs in facilities providing health care services for the
2 elderly. We consider that greater shear force is loaded on to the buttocks of these individuals in the
3 collapsed posture ¹⁵, and that this may lead to the increased incidence of decubitus ulcers.

4 Gilsdorf *et al.* ¹⁶ studied the effect of the reclining angle of the back support on the shear and normal
5 forces applied to the buttocks. They found that a shear force was applied to the buttocks in the
6 posterior direction when the back support was reclined and in the anterior direction when it was
7 returned to the upright position. Furthermore, in a previous study, we have investigated the
8 mechanism of fluctuations in the shear force applied to the buttocks in reclining back support in a
9 wheelchair ¹⁷. Our results suggested that differences between the positions of the axes of rotation for
10 the back support and the trunk–pelvis influence the fluctuations in the shear force applied to the
11 buttocks. However, no studies have evaluated the fluctuations in the shear force applied to the
12 buttocks in a shifting downwards sitting posture during reclining a wheelchair’s back support.

13 As mentioned above, disabled people shifting downwards in their chairs cannot control or correct their
14 posture when using repeated reclines. If the back support is of the repeated reclining type, the
15 distance between the positions of the axes of rotation of the trunk–pelvis and the back support might

1 be greater in proportion when the trunk–pelvis of the individual is shifted further downwards. In the
2 sitting posture in a chair, the rotation axis of the trunk–pelvis is the hip joint. We consider that the
3 difference in the rotation axes leads to greater fluctuations in the shear force applied to the buttocks in
4 reclining back support. No studies have investigated the influence of the distance between the rotation
5 axis of the back support and the hip joint on changes in shear force on the buttocks in a comfortable
6 sitting posture in a wheelchair with reclining back support. The purpose of this study was therefore to
7 investigate the influence of the distance between the position of the rotation axis of the back support
8 and the hip joint on changes in the shear force applied to the buttocks in order to contribute to the
9 prevention of decubitus ulcers in individuals using wheelchairs with reclining back support. Using a
10 simulation, this study also evaluated the effects of disabled individuals shifting downwards in
11 wheelchairs with reclining back support.

12

13

14

15

1 Methods

2 Subjects

3 The subjects were 11 healthy adult men without leg and/or trunk diseases (age: 22.0 ± 5.2 years,
4 height: 171.1 ± 5.9 cm, and body weight: 66.1 ± 6.6 kg). It was conducted with the approval of the
5 Research Ethics Committee at XXXXXXXXXXXXXXXX (# 074), and informed consent was obtained
6 from all subjects.

7

8 Measurements of shear force applied to the buttocks

9 In the present study, the horizontal reaction forces were defined as the shear forces. The shear force
10 applied to the buttocks was measured by using a force plate (Kyowa Electronic Instruments Co., Ltd.,
11 Tokyo, Japan, K07-1712), by measuring the reaction force in the posterior direction as the shear force
12 in the anterior direction. The sampling frequency was 100 Hz. In this study, we used an experimental
13 chair with an electrical function for reclining the back support (Hashimoto Artificial Limb Manufacturer
14 Co., Okayama, Japan). The dimensions of the experimental chair were as follows: height of back
15 support: 97 cm, depth of seat: 40 cm, backward angle of seat: 0° , reclining angle of back support:

1 10°–40°, and angular velocity at which the back support reclined: 3°/s. The experimental chair's back
2 support was covered with artificial leather. The rotation axis of the back support was positioned as the
3 joint between the seat and the back support, which was defined as the most backward point in the
4 seat. The measurement posture was a comfortable sitting posture, leaning on the back support and
5 on the force plate in the experimental chair. In addition, to achieve a constant friction between the
6 clothing and the surface of some seat, all subjects wore identical clothing made of 100% cotton. The
7 surface of force plate is easy to slide because it is made of metal. Thus, in order to prevent sliding and
8 collapsing posture on the force plate, the rubber net was laid on the plate. The coefficient of friction
9 between the clothing and the rubber net was 0.9, between the rubber net and the surface of force
10 plate was 0.8, and between the surface of back support and the clothing was 0.4. To reduce the effect
11 of differences in the position of the lower extremities, the thigh angle was adjusted in the horizontal
12 plane by elevating the feet using wooden boards stacked under the experimental chair¹⁸, and the
13 position of the feet was adjusted so that the lower leg formed a line perpendicular to the feet¹⁹.
14 Furthermore, to reduce the resistance of the lower extremities, a roller board was placed under the
15 feet. In addition, participants were instructed to fold their arms in front of the chest in a relaxed state

1 and not to voluntarily change the body position during the experiment. Head support was not used in
2 order to achieve reproducibility. The greater trochanter which can be palpated from the side was used
3 as an index of the hip joint in experimental conditions. In addition, the position of the greater trochanter
4 while sitting such that the dorsal surface of the pelvis lightly touched the back support was defined as
5 the standard position. This study had three experimental conditions: the position of the hip joint was
6 taken as the 3-cm forward from the standard position, 6-cm forward and 9-cm forward (Figure 1). To
7 consider the influence of the subject's postural collapse during the amount of time needed to make the
8 measurements, the measurements were taken 10 s after the posture was set. The experimental back
9 support was reclined at increasing angles, beginning at a full upright position of 10° from the vertical
10 (initial upright position: IUP), proceeding to a fully reclined position (FRP) of 40° from the vertical, and
11 subsequently returning to an upright position (RUP). The time required to measure shear force in each
12 condition was 5 s in the IUP, 10 s in the FRP, and 5 s in the RUP. For each position, we used the
13 average value after measuring 201 stable samples for each subject.

14

15

[Insert Fig. 1]

1

2 Statistical analyses

3 The measured shear force was normalised by body weight [percent body weight; %BW] in order to
4 consider the effect of body weight. To investigate the changes in the shear force applied to the
5 buttocks by reclining the back support, the shear force in the three experimental conditions was
6 compared among the three reclining phases. In addition, to investigate the influence of the distance
7 between the rotation axis of the back support and the hip joint, the shear force in the three reclining
8 phases was compared among the three experimental conditions. For statistical analysis, one-way
9 analysis of variance (ANOVA) and Bonferroni's multiple comparison test were used with the level of
10 significance identified as $p < 0.05$. The statistical analyses were performed using the Statistical
11 Package for the Social Sciences (SPSS) ver. 16.0J for Windows. In addition, we analysed the
12 fluctuation pattern of the shear force applied to the buttocks.

13

14 Results

15 Table 1 shows the measured shear force applied to the buttocks, and Figure 2 shows the wave

1 representing the fluctuation pattern of the force in a typical example.

2 In the 3-cm forward experimental condition, the average value of the shear force applied to the
3 buttocks was 9.4 ± 2.4 [%BW] in the IUP, 9.3 ± 1.2 [%BW] in the FRP, and 15.0 ± 2.9 [%BW] in the
4 RUP. In the 6-cm forward condition, the value of shear force was 11.2 ± 2.7 [%BW] in the IUP, $10.1 \pm$
5 1.4 [%BW] in the FRP, and 16.7 ± 3.6 [%BW] in the RUP. In the 9-cm forward condition, the value of
6 shear force was 11.2 ± 3.6 [%BW] in the IUP, 10.4 ± 0.8 [%BW] in the FRP, and 19.5 ± 5.3 [%BW] in
7 the RUP. In each experimental condition, significant differences appeared between the RUP and the
8 other positions ($p < 0.01$). Furthermore, on comparing the three experimental conditions, significant
9 differences also appeared between the 9-cm forward condition and the other conditions in the RUP (p
10 < 0.05).

11 The fluctuation patterns of the measured forces are described below. The shear force in the anterior
12 direction applied to the buttocks showed no significant changes from the IUP to the FRP.
13 Subsequently, this force showed a sharp increase and a peak value in the middle phase, at a back
14 support angle of 20° to 30° , while returning to the RUP. The value of this force was higher in the RUP
15 than in the IUP. Thus, the fluctuation pattern was similar in all the subjects and all three conditions.

1 However, in the middle phase, a sharp increase in the shear force was clearly observed, indicating
2 that the longer the distance between the position of the rotation axis of the back support and the hip
3 joint, the greater was the shear force.

4

5

6

[Insert Table 1 and Figure 2]

7

8

9

10

11 Discussion

12 In this study, we used a force plate to examine the influence of the downward shifting movement by an
13 individual in a wheelchair with a repeated reclining back support on the shear force applied to the
14 buttocks in order to better understand the aetiology and prevention of decubitus ulcer formation in
15 such disabled individuals. Our results demonstrated that the shear force in the RUP was significantly

1 higher than that in the other positions in each experimental condition. Further, on comparing the three
2 experimental conditions, the shear force in the 9-cm forward condition was significantly higher than
3 that in the other conditions in the RUP. In a previous study, we have measured the shear and normal
4 forces applied to the buttocks and on back support during reclining back support and investigated the
5 mechanism of the fluctuations in shear force applied to the buttocks in the wheelchair ¹⁷. In addition,
6 the fluctuation patterns of the measured forces applied to the back support showed that the shear
7 force in the downwards direction decreased and the normal force increased in proportion to the extent
8 of the return to the upright position of the back support from the FRP until the middle phase (an angle
9 of approximately 20°–30° from the vertical). Further, in the previous study ¹⁷, the fluctuation patterns in
10 the shear force applied to the buttocks in the anterior direction showed a peak value in the middle
11 phase, similar to that observed for back support, and the value of this force was higher in the RUP
12 than in the IUP. Those results were in agreement with the results of the present study, revealing
13 significantly high values in the RUP and similar fluctuation patterns in the shear force applied to the
14 buttocks. We guess that the timing of this fluctuation in the measured forces suggested that the
15 changes in the forces applied to the back support significantly influenced those applied to the buttocks.

1 In addition, based on observations from the previous study, these facts indicate that the shear force
2 applied to the buttocks increases with an increasing difference between the positions of the axes of
3 rotation of the back support and the trunk–pelvis. The observation that the shear force in the 9-cm
4 forward condition was significantly higher than in the other conditions in the RUP also supported this
5 hypothesis.

6 Normal force is vertical to a surface, while shear force is parallel. In a previous study, we investigated
7 the temporal elements of changes in the sitting pressure distribution that occurred while leaning
8 against a back support to verify the onset mechanism of shear force in a comfortable sitting posture²⁰.

9 If the trunk and pelvis are inclined with the reclining back support while remaining parallel to it, the
10 primary force applied to the back support would be normal force since the head, trunk, pelvis and
11 arms are supported by the surface of the seat. However, in wheelchair users who shift downwards in
12 their chair, the distance between the rotation axis of the back support and the hip joint is increased. In
13 proportion to this increasing distance, the differences between the directions of the force applied to
14 back support and the rotation of trunk-pelvis increased even further, with significantly higher shear
15 force occurring in the back support. The friction force occurring between the back and back support

1 greatly influences this shear force. The influence of the friction force is described below. Shear force
2 can exist only when two surfaces are pressed against each other. This maximum shear force, which
3 occurs just before sliding downwards, is defined by:

4
$$F_{shear, max} = f^*F_N$$

5 where f is the friction coefficient and F_N is the normal force. This implies that in regions where the
6 pressure is relatively high, the shear and friction forces can become high as well ¹⁰. With downward
7 shifting, the backward inclination angle of the body trunk increases, leading to a greater distance
8 between the rotation axes of the back support and the hip joint. Consequently, as the loaded normal
9 force at the back support from the trunk increases, the friction and shear forces between the back and
10 back support increase proportionately. Therefore, it may be hypothesized that greater shear force in
11 the back support influenced the observation that the shear force in the anterior direction applied to the
12 buttocks in the 9-cm forward condition increased to a greater extent than that observed in the other
13 conditions in the RUP.

14 In the present study which was performed upon able-bodied subjects, unconscious postural muscle
15 activity might have played a role in the lack of sliding. Nevertheless, in the 3-cm forward condition, the

1 shear force applied to the buttocks in the RUP increased by more than 5 [%BW] compared with that in
2 the IUP. Furthermore, the shear force applied to the buttocks in the RUP in the 9-cm forward condition
3 increased by about 10 [%BW] as compared with that in the IUP in the 3-cm forward condition. These
4 facts suggest that reclining back support in the presence of collapse of sitting posture with downwards
5 sliding increased the shear force applied to the buttocks, and therefore increased the risk of decubitus
6 ulcers.

7 Hobson ²¹ reported that a back support recline angle of 30° caused a 25% increase in the surface
8 shear force as compared with a recline angle of 10° in subjects with spinal cord injuries. Bennett *et al.*
9 ²² compared the shear and normal forces applied to the buttocks of normal and paraplegic subjects,
10 and reported that the normal force did not differ significantly between the two groups. However, the
11 shear forces applied in the sitting posture in paraplegic subjects were roughly 3 times those in normal
12 subjects, and the rate of pulsatile skin blood flow volumes applied to the buttocks in sitting paraplegic
13 subjects were only one-third of those of comparable normal subjects. Thus, we consider that shear
14 force applied to the buttocks in wheelchair users who cannot modify their posture on their own is
15 higher in wheelchairs with reclining back support. Therefore, in reclining back support, modifying

1 wheelchair users' collapsed postures and releasing the remaining shear force applied to the buttocks
2 as well as the back support itself are important in preventing decubitus ulcers.

3

4 Limitations

5 A limitation of this study was that the subjects included were healthy adult males. In addition, because
6 the measurement times were short, we could not evaluate the effect of delayed postural collapse.
7 Furthermore, the form, material and coefficient of friction of the experimental wheelchair's seat was
8 different from that when using the force plate for measuring the shear force in the present study.
9 Therefore, it would be difficult to directly extrapolate the results of this study to all wheelchair users.

10

11 Conclusion

12 Our results suggest that the shear force applied to the buttocks changed in reclining back support and
13 an increase in the distance between the rotation axis of the back support and the hip joint led to an
14 increase in the remaining shear force after reclining the back support. Therefore, in order to prevent
15 decubitus ulcers, the remaining shear forces applied to the buttocks and back support were released

1 after reclining the back support. In addition, we consider it important that the position of the rotation
2 axis of the back support and the hip joint be adjusted optimally. However, we did not investigate the
3 hypothesis that an increase in the shear force applied to the buttocks because of the difference
4 between the positions of the axes of rotation of the back support and trunk–pelvis. In order to prove
5 the discussion and conclusion, it is necessary to investigate the hypothesis. In the future, we plan to
6 evaluate the influence of the shear force applied to the buttocks changing the position of the rotation
7 axis of the back support experimentally and adapt our results to practical use.

8

9 Acknowledgement

10 This study was supported by a XXXXXXXXXXXXXXXXXXXX.

11

12 Declaration of interest

13 The authors report no conflicts of interest.

14

1 References

2 1. Armstrong DG, Ayello EA, Leask CK, et al. New opportunities to improve pressure ulcer prevention
3 and treatment: implications of the CMS inpatient hospital care Present on Admission (POA) indicators/
4 hospital-acquired conditions (HAC) policy. A consensus paper from the International Expert Wound
5 Care Advisory Panel. *J Wound Ostomy Continence Nurs* 2008; 35: 485-492.

6 2. Reddy M, Gill SS, Rochon PA. Preventing pressureulcers: a systematic review. *JAMA* 2006; 296:
7 974-984.

8 3. Linder-Ganz E, Engelberg A, Scheinowitz M, et al. Pressure-time cell death threshold for albino rat
9 skeletal muscles as related to pressure sore biomechanics. *J Biomech* 2006; 39: 2725-2732.

10 4. Stekelenburg A, Strikers GJ, Parusel H, et al. Role of ischemis and deformation in the onset of
11 compression-induced deep tissue injury: MRI-based studies in a rat model. *J Appl Physiol* 2007; 102:
12 2002-2011.

13 5. Ceelen KK, Stekelenburg A, Loerakker S, et al. Compression-induced damage and internal tissue
14 strains are related. *J Biomech* 2008; 41: 3399-3404.

15 6. Linder-Ganz E, Gefen A. The effect of pressure and shear on capillary closure in the microstructure

- 1 of skeletal muscles. *Ann Biomed Eng* 2007; 35: 2095-2107.
- 2 7. Lahmann NA, Kottner J. Relation between pressure, friction and pressure ulcer categories: a
3 secondary data analysis of hospital patients using CHAID methods. *Int J Nurs Stud* 2011; 48:
4 1487-1494.
- 5 8. Guttman L. The prevention and treatment of pressure sores. In: Kenedi RM, Cowden JM, Scales
6 JT, editors. *Bed sore biomechanics*. Macmillan, London, 1976, pp153-159.
- 7 9. Bennett L, Kavner D, Lee BK, Trainor FA. Shear vs pressure as causative factors in skin blood flow
8 occlusion. *Arch Phys Med Rehabil* 1979; 60: 309-314.
- 9 10. Dinddale SM. Decubitus Ulcers: Role of Pressure and friction in causation. *Arch Phys Med Rehab*
10 1974; 55: 147-152.
- 11 11. Sakuta Y, Takahashi M. The interaction between pressure and shear force as a factor of pressure
12 ulcers by assessing blood flow measurement [in Japanese]. *JSMBE* 2006; 44: 101-106.
- 13 12. Goossens RHM, Snijders CJ, Holscher TG, Heerens WC, Holman AE. Shear stress measured on
14 beds and wheelchairs. *Scand J Rehab Med* 1997; 29: 131-136.
- 15 13. Trefler E, Hobson DA, Taylor SJ, Monahan LC, Shaw CG. Seating and mobility for person with

- 1 physical disabilities. Therapy Skill Builders, Memphis, 1993, pp.3-5.
- 2 14. Kurihara T, Kinose T, Ohtsu K, Okuyama N, Sakai Y. A study of relation between pressure sores
3 and seating positioning ability in wheelchair use by elderly people [in Japanese]. J.T.H.S 2003; 5:
4 258-262.
- 5 15. Kobara K, Shinkoda K, Watanabe S, Eguchi A, Fujita D, Nishimoto T. Investigation of validity of
6 model for estimating shear force applied to buttocks in elderly people with kyphosis while sitting
7 comfortably on a chair. Disabil Rehabil Assist Technol. 2011; 6: 299-304.
- 8 16. Gilsdorf P, Patterson R, Fisher S, Appel N. Sitting forces and wheelchair mechanics. J Rehab Res
9 Dev 1990; 27: 239-246.
- 10 17. Kobara K, Fujita D, Osaka H, Ito T, Yoshimura Y, Ishida H, Watanabe S. Mechanism of fluctuation
11 in shear force applied to buttocks during recline back support on wheelchair. Disabil Rehabil Assist
12 Technol. 2013; 8: in press.
- 13 18. Kobara K, Shinkoda K, Eguchi A, Watanabe S, Fujita D, Nishimoto T. Influence of thigh angle from
14 a level on shear force and normal force occurred under the buttocks of subjects sitting comfortably on
15 a chair [in Japanese]. Nihon Gishi Sogu Gakkaishi 2009; 25: 108-110.

- 1 19. Kobara K, Eguchi A, Watanabe S, Shinkoda K. The influence of distance between the backrest of
2 a chair and the position of the pelvis on maximum pressure of the ischium and estimated shear force.
3 Disabil Rehabil Assist Technol. 2008; 3: 285-291.
- 4 20. Kobara K, Eguchi A, Fujita D, Nishimoto T, Ishiura Y, Watanabe S. Initial mechanism of shear in
5 comfortable sitting on a chair - Examination by the time element of displacement of seat pressure
6 distribution - [in Japanese]. Rigakuryoho Kagaku 2007; 22:185-188.
- 7 21. Hobson DA. Comparative effects of posture on pressure and shear at the body-seat interfase. J
8 Rehab Res Dev 1992; 29: 21-31.
- 9 22. Bennett L, Kavner D, Lee BY, Trainor FS, Lewis JM. Skin stress and bloodflow in sitting paraplegic
10 patients. Arch Phys Med Rehabil 1984; 65: 186-190.

11

12

13

14

15

1 Figure legends

2 figure 1. Measurement posture (IPU in the 3-cm forward condition)

3 a. Level goniometer, b. Experimental chair (height of back support: 97 cm, depth of seat: 40 cm,

4 backward angle of seat: 0°, reclining angle of back support: 10°–40°, and angular velocity at which

5 back support reclines: 3°/s), c. Rotation axis of back support, d. Force plate, e. Roller board,

6 l . Distance between rotation axis of back support and hip joint

7 l_1 . Experimental conditions (i.e. the 3-cm forward, 6-cm and 9-cm) are the distance between dorsal

8 surface of pelvis and back support.

9

10 table 1. Shear forces at various back angles

11 a. compared RUP with the other positions; $p < 0.01$, b. compared the 9cm condition with the other

12 conditions; $p < 0.05$

13 n.s. not significant

14

15

- 1 figure 2. The wave of fluctuation pattern of the shear force applied to buttocks (the typical example)

- 2 a. the 3-cm forward condition, b. the 6-cm forward condition, c. the 9-cm forward condition