

The influence of the distance between the backrest of a chair and the position of the pelvis on the maximum pressure on the ischium and estimated shear force

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Running title: The influence of sitting posture on location of the points of maximum pressure and the shear force

Abstract

Purpose: As an alternative for some people with leg disorders from becoming bedridden, thus the patients have been forced to sit in a wheelchair for a long period of time. The purpose of this study was to investigate the relation between the backrest of a chair and the position of the pelvis on the maximum pressure at the ischium and the estimated shear force encountered while sitting in a chair.

Methods: Ten healthy males aged 22.4 ± 2.3 years without pathologies in the leg and/or trunk participated in this study. The subjects were instructed to sit in a chair and the pressure and shear forces were measured under three sitting conditions: in the standard position, 5cm forward position, and 10cm forward position. The positions of the pelvis on the maximum pressure at the ischium were measured by an instrument to measure pressure distribution and the shear forces were estimated using an experimental model proposed by us.

Results: Comparisons were made among three sitting positions; the range of displacement of the maximum pressure point was not significant. The estimated shear force on the seat was 15.5 ± 12.4 N in the standard position, 34.4 ± 8.5 N in the 5-cm forward position, and 53.2 ± 16.7 N in the 10-cm forward position. There were significant differences among the three values ($p < 0.01$).

Conclusions: Displacing the pelvis forward and leaning against the backrest tends to increase the shear force and raise the risk of decubitus ulcers.

Key words: sitting posture, shear force, experimental model

Introduction

Some people with leg disorders, such as post-apoplectic hemiplegia and certain spinal cord injuries, spend significantly more time in a chair compared to healthy individuals. In addition, many of them sit in a wheelchair for long periods of time to avoid being bedridden¹. These people tend to sit in the same position for extended periods of time and alleviate uncomfortable compression near the ischial tuberosity by leaning against the backrest to increase the supporting area. The friction between the seating surface of the chair and the skin in the gluteal region prevents a significant positional shift of the pelvic position, but the generated shear force causes muscle and soft tissue deformations near the ischial and sacral bones². Gilsdorf *et al.*³ and Goossens *et al.*⁴ reported that the residual shear force generated when reclining in a wheelchair must be relieved to prevent decubitus ulcers. The risk of a decubitus ulcer in the sacral and caudal regions due to sitting for long periods is high for some institutionalised residents. Hobson⁵ studied seated posture and body orientation on the pressure-distribution and surface shear of 12 subjects with spinal cord injuries and 10 nondisabled subjects in a wheelchair sitting posture. He suggested researchers and clinicians should pay more attention to postures, stress-distribution and shear force of people sitting in a wheelchair. One study documented the effectiveness of seating guidance for the prevention of decubitus ulcers⁶. Providing seating posture guidance for the prevention of decubitus ulcers is becoming recognized as a role of physical therapists. Although analysing sitting postures is important for formulating effective seating guidance, the number of studies regarding sitting postures and shear force remains low²⁻⁵.

In a previous study, the authors verified validity for estimating the shear force for a person sitting in a comfortable position while leaning against a backrest using an experimental model we proposed. The model provided an estimated shear force applied to the gluteal region in a sitting position, and the shear force was measured using a force plate at the same time⁷. No significant difference ($p=0.797$) was found between values gained by those two methods; instead, a strong positive correlation existed ($r=0.897$, $p<0.0001$). As a result, shear force in a comfortable sitting position could be relatively easily estimated without a special device in clinical settings.

The purpose of this study was to investigate the influence of sitting posture and distance between the backrest of a chair and pelvis position on the pressure distribution at the ischium and the estimated shear force in comfortable sitting on a chair, using an instrument to measure pressure distribution and our experimental model to determine the shear forces.

Methods

Subjects

The subjects were 10 healthy adult males without pathologies in the leg and/or trunk (mean age: 22.4 ± 2.3 years; mean height: 171.6 ± 4.1 cm; mean body weight: 64.7 ± 7.6 kg). To estimate the shear force in a comfortable sitting position, the

seating height (92.7 ± 2.0 cm), total head height (from head vertex to gnathion: 21.0 ± 0.9 cm), and neck length (from lower edge of occipital protuberance to the seventh cervical spinous process: 10.7 ± 1.8 cm) were measured. The study objective, significance, methods, and privacy protection policy were outlined to the men in writing, and each subject gave written informed consent.

Measurements of pressure distribution

The points of maximum pressure applied to the gluteal region while sitting in a chair were identified using an instrument that measured the pressure distribution (NITTA Corp. BIG MAT). A preliminary experiment prior to this study showed the repeatability of values using this pressure device was 97.6%. The sampling frequency was 1 Hz, and one stable frame of the data was used to calculate the pressure distribution during each three-second measurement. While in a sitting posture on the chair, the greater trochanter was positioned in the anteroposterior mid position of the trunk and pelvis so that the back lightly touched the backrest (i.e. standard position). To maintain the friction level between the chair seat and clothing constant, all of the subjects wore clothing made from the same material and were instructed to place the arms on the thighs in a relaxed state. The experimental chair was a standard chair (seat height: 40 cm, depth of the seat: 40 cm, backward angle of the seat: 5 degrees, height of the backrest: 35 cm, reclining angle of the backrest: 10 degrees). The film sensor sheet, consisted of 2112 cells with each cell being 10 mm \times 10 mm in size, was placed on the surface of the seat. Here, the location where the maximum pressure was applied was defined as a cell that showed the maximum value. In order to determine relative locations, the relationship between the body and the pressure mat was normalised on the distance from the position of the gluteal region at the standard position. The location of the points of maximum pressure at the basic sitting posture (no leaning on the backrest) and at a comfortable sitting posture (leaning on the backrest) were measured in the standard position, 5-cm forward position and 10-cm forward position compared to the standard position (Figure 1).

To investigate the influence of leaning against the backrest, the locations of the points of maximum pressure in three positions were compared between in a basic sitting posture and in a comfortable sitting posture. Furthermore, the influence of distance between the backrest of a chair and the pelvis position was investigated comparing the distance range of displacing the locations of the maximum pressure between the standard position and other two positions in the comfortable sitting.

Anthropometrics data for estimation of shear force

Estimation of the shear force was done using our experimental model⁷. In preliminary experiments prior to this study, we measured the ground reaction force (GRF) to the sole of feet using a force plate. As a result, the vertical GRF was $18.6 \pm 2.2\%$ body weight (BW), and the horizontal GRF to backward was $2.2 \pm 0.6\%$ (BW). This showed that the GRFs applied to the soles

of the feet depended on the knee flexion angles and flexing the knee at a 90-degree while sitting comfortably could decrease the horizontal RRF to negligible values. Also, in this pressure distribution measurement, the load to the buttocks was 63.7 ± 5.2 of the whole seat load in a standard position, $72.1 \pm 3.5\%$ in 5cm forward and $78.8 \pm 9.0\%$ in 10cm forward, and this meant most of the load was applied to the buttocks. Therefore, our experimental model in this study adopted the method of considering stresses were applied just to the buttocks. In addition, the arms were placed on the thighs in a relaxed state close the trunk to minimize the effects of the weight of the arms.

In the present study, the upper body was divided in the sagittal plane into head, neck, and trunk (including the pelvis) segments, as shown in Figure 2, and the weight and centre of mass (COM) of each segment were calculated based on body measurements and anatomical data^{8,9}. The backward curvature of the spinal column caused by leaning back against the backrest resulted in mild flexure of the trunk. Therefore, the COM of the trunk was set along the body side (centre of front and back diameter) taking into account the mild flexion. The COM of the head and neck segments were set after repositioning from the posterior inclination, and the COM of the three segments was determined according to the method of Kubo *et al.*¹⁰ (Figure 3). In the comfortable sitting posture for the three positions, the following were measured using the goniometer and the anthropometer: the angle formed by the horizontal plane and the line connecting the resultant COM and the ischial tuberosities (α), the distance between the resultant COM and the intersection between the contact point on the backrest and the line perpendicular to the line connecting the resultant COM and the ischial tuberosities (a), and the distance between the resultant COM position and ischial tuberosities (b). Furthermore, the angle between the horizontal plane and the line between the ischial tuberosities and contact point between the back and backrest (β) was measured. The position of the ischial tuberosities were defined as contact point between the horizontal plane and Roser-Nélaton line which links the anterior superior iliac spine and the greater trochanter to the ischial tuberosities. Estimated values were calculated by plugging these values into the experimental model described below.

To investigate the influence of distance the between backrest of a chair and position of the pelvis, the estimated shear force value when in comfortable sitting posture was compared among the three positions.

Statistical Analyses

Each location of the points of maximum pressure were compared between the basic sitting posture and the other three positions while in a comfortable sitting posture. A Wilcoxon signed rank test was used with a level of significance of $p < 0.05$. The estimated value of shear force in each comfortable sitting posture were compared among three positions, using an ONEWAY with the level of significance at $p < 0.05$. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) ver. 14.0J for Windows.

Results

The location of the points of maximum pressure

Distance range for displacing the points of maximum pressure was 3.0 ± 1.2 cm in the standard, 3.0 ± 1.7 cm in the 5-cm forward, and 1.6 ± 3.5 cm in the 10-cm forward position; these differences were not significant. The locations of the points of maximum pressure in the three positions were compared between in the basic and the comfortable sitting posture. The locations of the points of maximum pressure in the comfortable sitting posture significantly displaced forward both in the standard ($p=0.005$) and 5-cm forward position ($p=0.008$), and it tended to displace forward in the 10-cm forward position ($p=0.285$).

The estimated value of shear force

The estimated shear force was 15.5 ± 12.4 N in the standard, 34.4 ± 8.5 N in the 5-cm forward, and 53.2 ± 16.7 N in the 10-cm forward position. There were significant differences among the three positions ($p<0.01$).

Discussion

It has been said that maintaining the pressure load on the body for a sufficient period of time can cause decubitus ulcers^{11, 12}. Similarly, research as those by Souther and colleagues¹³, and Houle¹⁴ who investigated methods of preventing decubitus ulcers in studies of wheelchair cushions and other seat devices, have employed normal pressure concepts exclusively. Although the risk of decubitus ulcer was once considered to be determined by "compression \times time," it is now considered to be regulated by "stress (compressive stress, shear stress, and tensile stress) \times time \times frequency"¹⁵. In addition, results of recent studies on decubitus ulcers have verified that complex stress is generated inside the body. Not only compressive force, but also shear force acts on the skin surface (surface shear force)¹⁵. For these reasons, shear force have to be considered when trying to prevent decubitus as well as the magnitude and duration of pressure.

When a person is sitting comfortably, some shear force is generated between the seating surface and gluteal region. Bennett *et al.*¹⁶ reported the combination of pressure plus shear was particularly effective in promoting blood flow occlusion. To investigate the relation between compressive pressure and shear force, Sakuta *et al.*¹⁷ measured the changes in blood flow due to these loads. Their results suggested that 50 mmHg of pressure and 0.9 N/cm^2 of shear force were nearly equivalent in biological soft tissue, and indicated the importance of reducing shear force for the prevention of decubitus ulcers from the viewpoint of blood flow. Also, Nojima *et al.*¹⁸ investigated *in vivo* stress by adding pressure and shear force using a biological gluteal model and a cushion model and reported that, when compared to pressure alone, shear force and pressure increased

local shearing distortion in the body. Furthermore, Gilsdorf³ reported that, “avoidance of shear force is important.” Therefore, in the present study, the influence of sitting posture on the location of the maximum pressure and estimated shear force while sitting in a chair was investigated using our experimental model.

The trunk and pelvis incline by leaning against the backrest of a chair. The COM line deviates from the sitting pressure centre (action point), and a large posterior-direction rotational moment is generated in the trunk region¹⁹. Subsequently, the posterior inclination of the trunk and pelvis increases, posterior-direction rotational moment increases and is converted into forward shear force by the reaction force of the backrest²⁰. Therefore, the results of this study indicate that the location of the maximum pressure points in a comfortable sitting posture was displaced forward. In addition, increasing the distance between the backrest of a chair and the position of the pelvis increased the angle of posterior inclination of the trunk and pelvis, and increasing that angle increased the estimated shear force. However, upon increasing the distance between the backrest of the chair and the position of the pelvis, no significant difference in the locations of the points of maximum pressure below the ischial tuberosities was found among the three positions. The locations of the points of maximum pressure usually lay below the ischial tuberosities²¹. Therefore, relieving the points of maximum pressure contributes toward displacing ischial tuberosities. The frictional force between skins of the buttocks and the seating surface prevents the buttocks from a marked positional shift, but the ischial bones are slid forward until the deformations of soft tissue such as muscles or the fat interfair², thus, no difference in location was detected. The increased shear force and soft tissue deformations are assumed to cause more blood flow occlusion²². Furthermore, in the sacral position, pressure usually divided by two by the left and right ischial tuberosities concentrates on one side, resulting in very strong pressure. Thus, a comfortable sacral position increases the risk of a decubitus ulcer due to pressure and mechanical factors contributing to the onset of shear force; this supports the higher risk for decubitus ulcer in the sacral and caudal regions in clinical settings⁶.

Conclusion

This study investigated the influence of the distance between a chair backrest and the pelvis position on the points of maximum pressure at the ischium and the resultant shear force, which is estimated using a verified model. Results show that when leaning against the backrest, the location of the points of maximum pressure displaced forward and the estimated shear force increased. These results suggest that displacing the pelvis forward and leaning against the backrest will increase the shear force and raise the risk of decubitus ulcers. Limitations of this study were that only a chair was used for those subjects who had different morphologies. In addition, the surface of the chair seat was different from those of ordinary wheelchairs. The authors are considering investigation of the effects various sizes of chairs and wheelchairs, and the effects of various kind of cushion in the future study.

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Appendix

In a previous study, we investigated the temporal elements of the changes in sitting pressure distribution while leaning against a backrest to verify the onset mechanism of shear force in a comfortable sitting posture²⁰. Results showed that in the central position of sitting, the pressure gradually displaced in a posterior direction as the trunk leaned backward, which was reversed to the anterior direction as the back leaned against the backrest. This suggests that leaning back against a backrest is essential for the generation of shear force in a comfortable sitting posture. Therefore, in the present study, the experimental model with a backrest was prepared.

First, the acting force to the upper body caused by the posterior inclination of the trunk and pelvis was calculated. As shown in Figure 4A, by defining the angle between the horizontal plane and the line connecting the ischial tuberosities and resultant COM as α , the vector orthogonal to the line between the ischial tuberosities and the resultant COM, X , for upper body weight, W , can be expressed as:

$$X = W \times \cos \alpha \quad (1)$$

Second, " a " is defined as the distance between the resultant COM and the intersecting point between the vertical line from the point of contact at the backrest and line connecting the ischial tuberosities and resultant COM; " b " is defined as the distance between the ischial tuberosities and resultant COM. According to the leverage principle, leaning against the backrest generates a force, Xa , at the contact point between the back and backrest, as expressed by Formula (2). According to the action-reaction law, the reaction force, Xa' , which is the same as Xa , is generated from the contact point with the backrest (Figure 4B-i).

$$Xa = b / (a + b) X = Xa' \quad (2)$$

As shown in Figure 4B-i, when dividing reaction force from the contact point with the backrest, Xa' , into vertical and anterior components, the force in the anterior direction, X'' , can be expressed as

$$X'' = Xa' \times \sin \alpha \quad (3)$$

In figure 4B-ii, the angle between the floor and the line connecting the ischial tuberosities and contact point between the back and backrest is defined as β . When dividing the force in the anterior direction, X'' , into the parallel direction of the line connecting the ischial tuberosities and the contact point with the backrest and the line perpendicular to the parallel line, the

force in the parallel direction, X''' , can be expressed as:

$$X''' = X'' \times \cos\beta \quad (4)$$

The force from the backrest, X''' , becomes the force in the lower anterior direction applied to the ischial tuberosities *via* the trunk. As shown in Figure 4B-iii, when dividing this force into the vertical and anteroposterior directions, the force in the anterior direction, XX , can be expressed as:

$$XX = X''' \times \cos\beta \quad (5)$$

The value calculated by this formula, XX is the estimated shear force value⁷.

Figure legends

Figure 1. Sitting posture

A. Chair. Seat and backrest had little cushion (sponge thickness, 5 mm) and were covered with artificial leather. Height of weigh-bearing surface, 40 cm; depth of weight-bearing surface, 40 cm; backward angle of seat: 5°; height of backrest, 35 cm; reclining angle of backrest, 10°.

B. Basic sitting posture, without leaning on the backrest (10-cm forward position).

C. Comfortable sitting posture, leaning on the backrest (10-cm forward position).

Figure 2. COM and resultant position for each body segment

g_1 , COM of head; g_2 , COM of neck; g_3 , COM trunk; G , synthetic COM of each segment.

The upper body was divided into three sagittal segments: head, neck and trunk (including the pelvis). The weight and COM of each segment were calculated based on body measurements and anatomical data (Nakamura et al., 2005. Winter, 2004).

Formulas for the weight and mass centre of each body segment:

W_n , weight of each body segment (kg); W , body weight (kg).

$W_n = W \times \text{mass ratio in relation to body weight (\%)}$.

G_n , COM from the upper edge of each body segment (cm).

L , length of each body segment (cm).

$g_n = L \times \text{COM position ratio from the upper edge (\%)}$.

Figure 3. Resultant COM

S_1 , COM of Part A with a mass (m_1); S_2 , COM of part B with a mass (m_2); S_0 , COM of parts A and B, satisfying $S_1S_0: S_0S_2 = m_2: m_1$ along lines S_1 and S_2 .

(From figure 2 in Kubo, 2006.)

Figure 4. Rigid link model of the upper body

A. Acting force of the upper body accompanying the posterior inclination of the trunk and pelvis.

a , distance between the resultant COM position and the intersecting point between the contact point on the backrest and the line perpendicular to the line connecting the resultant COM and the ischial tuberosities (standard: 2.5 ± 1.7 cm, 5-cm forward: 6.1 ± 2.0 cm, 10-cm forward: 9.1 ± 1.9 cm).

b , distance between the resultant COM position and ischial tuberosities (standard: 34.5 ± 2.4 cm, 5-cm forward: 32.6 ± 3.2 cm,

10-cm forward: 30.8 ± 2.5 cm).

α , angle formed by the horizontal plane and the line connecting the resultant COM and the ischial tuberosities (standard: $77.2 \pm 3.4^\circ$, 5-cm forward: $66.3 \pm 4.3^\circ$, 10-cm forward: $59.0 \pm 6.1^\circ$)

W , body weight of the upper body above the pelvis; X , vector orthogonal to the line connecting the resultant COM and the ischial tuberosities.

B. Shear force estimated based on the reaction force from the contact point with the backrest

β , angle between the horizontal plane and the line between the ischial tuberosities and the contact point between the back and backrest (standard: $67.0 \pm 3.9^\circ$, 5-cm forward: $55.0 \pm 3.2^\circ$, 10-cm forward: $47.8 \pm 4.1^\circ$)

X , force of the upper body applied to the backrest; Xa' , reaction from the contact point with the backrest;

X'' , anterior component of Xa' ; X''' , parallel component of the line connecting the ischial bone and the contact point with the backrest for X'' ; XX , estimated shear force.