Investigation of validity of model for estimating shear force applied to buttocks in elderly people with

kyphosis while sitting comfortably on a chair

Running title: Investigation of model for estimating shear force

Introduction

The results of studies on decubitus ulcers have clarified that complex stress is generated inside the body. Not only compressive force but also shear force acts on the skin surface [1-3]. More than 20 years ago, Bennett *et al.*[1] reported that the combination of pressure plus shear force effectively promoted blood flow occlusion. To investigate the relation between compressive pressure and shear force, Sakuta *et al.* [2] 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.* [3] investigated *in vivo* stress by applying pressure and shear force to a biological gluteal model and a cushion model and reported that, when compared to pressure alone, shear force and pressure increased the local shearing distortion in the body. These examples of research show the focus on decubitus ulcer prevention in the study of shear force.

The authors of the current paper studied the influence of the height of a back-support and the angle of the thigh, head and neck on the shear force applied to the buttocks of young subjects. These studies suggested that the distance between the body and the chair influenced the shear force [4-6]. Based on these results, we devised a model for estimating the shear force applied to the buttocks of people sitting comfortably on a chair and reported that the validity of this model is

high in young people [7]. Furthermore, using this model, we reported the influence of a leaning body trunk and the

deflection of the seat [8, 9]. However, we did not study the shear force on elderly people.

Many elderly people have kyphosis. Nakahara [10] reported that using a chair or wheelchair that was not fitted to his

or her body size deteriorates the quality of life (QOL) in elderly people. It can also be surmised that decubitus ulcers

lead to deterioration of the QOL. However, no studies exist on the relation of kyphosis and shear force. The purpose of

this study was to investigate the validity of the model for estimating shear force applied to the buttocks of elderly people

with kyphosis and to contribute to the prevention of decubitus ulcers.

Methods

Study design

This study design was experimental study. This study was conducted with the approval of the Research Ethics

Committee at Kawasaki University of Medical Welfare (# 107) and informed consent was obtained from all subjects.

Subjects

The subjects were 10 elderly people with kyphosis who were able to sit on a chair without help. The subjects (two males and eight females, age: 85.2 SD 4.3 years; height: 150.7 SD 10.6 cm; and body weight: 47.7 SD 10.1 kg) resided in a facility providing health care services for the elderly. To assess the degree of kyphosis of each subject, we performed measurement of the index of kyphosis in a sitting posture by using a method based on that of Milne *et al*. [11]. Teragaki *et al*. [12] reported the reliability and validity of this index. The average index of kyphosis of the ten subjects was 21.2 SD 3.5; the index of five subjects was in the middle range (16.2 – 20.7) and the index of the other five was in the severe range (21.2 – 28.1).

Measurements of shear force applied to buttocks

When measuring the amount of force applied to the buttocks, a force plate (Kyowa Electronic Instruments Co., Ltd., Japan, K07-1712) was used to measure the reaction force in the posterior direction as the shear force in the anterior direction. The sampling frequency was 100 Hz. The measurement posture was a comfortable sitting posture on the force plate on the experimental chair. The subject sat in the chair and leaned against the back-support. The dimensions of the experimental chair were as follows: height of back-support: 42 cm, depth of the seat: 40 cm, reclining angle of the back-support: 10 degrees, and backward angle of the seat: 0 degrees (figure 1).   "figure 1"

While in a sitting posture on the chair, the buttocks were positioned so that the subjects were comfortable. They were

comfortable because they could lean back against the back- support according to the degree of kyphosis. To reduce the

influence of the difference in position of the lower extremities, the thigh angle was adjusted in the horizontal plane by

elevating the feet [5]. Furthermore, the position of the feet was adjusted so that the lower leg formed a line

perpendicular to the feet [8]. In addition, the arms were placed on the thighs in a relaxed state close to the trunk to

minimize the effect of the weight of the arms. The head and neck were set after repositioning the posterior inclination

[6]. To consider the influence of the collapsed posture of a subject by the passage of time needed to make the

measurements, the measurements were taken ten seconds after setting the posture. Each measurement time was three

seconds, and we used the average values of 301 measured samples for each subject.

Anthropometrics data for estimation of shear force

When a person sitting on a chair has a comfortable posture, most of the loads from the seat are applied to the buttocks

instead of the thighs due to the posture of leaning the body trunk against the back-support. This model did not consider

the mass of the lower extremities. Also, the arms were placed on the thighs in a relaxed state close to the body trunk to

minimize the effect of the weight of the arms. In the present study, as shown in figure 2, the upper body was divided in   "figure 2"

the sagittal plane into head, neck and trunk (including the pelvis) segments, and the weight and center of mass (COM)

of each segment were calculated based on body measurements and anatomical data [13, 14]. The backward curvature of

the spinal column caused by leaning back against the back-support resulted in mild flexure of the body trunk. The COM

of the trunk was set along the body by taking into account the mild flexion. Also, the COM of the head and neck

segments were set after repositioning the posterior inclination, and the COM of the three segments was determined

according to the method of Kubo *et al.* [15] (figure 3). The following were measured: the angle formed by the floor and

"figure 3"

the line connecting the RCOM (resultant COM: RCOM) and the ischial bone (α), the distance between the RCOM and

the intersecting point between the contact point on the back-support and the line perpendicular to the line connecting the

RCOM and ischial bone (ℓ_1), and the distance between the RCOM and ischial bone (ℓ_2). Furthermore, the angle

between the floor and the line between the ischial bone and the contact point between the back and back-support (β)

was measured. The position of the ischial tuberosities was defined as the contact point between the horizontal plane and

the Roser-Nelaton line, which links the anterior superior iliac spine and the greater trochanter to the ischial tuberosities.

These anthropometric data were measured using a level-goniometer and an anthropometer. The estimated values were

calculated by substituting these values into the model [7] for estimating the shear force, described below.

Model for estimating shear force applied to buttocks

In a previous study, we investigated the temporal elements of the changes in sitting pressure distribution while

leaning against a back-support to verify the onset mechanism of shear force in a comfortable sitting posture [16]. The

results showed that in the upright position of sitting, the pressure was gradually displaced in the posterior direction as

the trunk leaned backward, and this was reversed in the anterior direction as the back leaned against the back-support.

This suggests that leaning the back against a back-support is essential for the generation of shear force in a comfortable

sitting posture. Therefore, in the present study, an experimental model with a back-support was prepared.

First, the acting force on 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

"figure 4"

and the RCOM as α, the vector orthogonal to the line between the ischial tuberosities and the RCOM, X, for upper

body weight, W, can be expressed as:

$$X = W * cos\ \alpha \qquad\qquad (1)$$

Second, α is defined as the distance between the RCOM and the intersecting point between the vertical line from the

point of contact at the back-support and the line connecting the ischial tuberosities and the RCOM; β is defined as the

distance between the ischial tuberosities and the RCOM. According to the leverage principle, leaning against the

back-support generates a force, Xa, at the contact point between the back and back-support, as expressed by Equation

(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 back-support (figure 4B-i).

$$Xa = \ell_2 / (\ell_1 + \ell_2) * X = Xa' \qquad (2)$$

As shown in figure 4B-i, when dividing the reaction force from the contact point with the back-support, Xa', into

vertical and anterior components, the force in the anterior direction, X'', can be expressed as:

$$X'' = Xa' * \sin \alpha \qquad (3)$$

In figure 4B-ii, the angle between the floor and the line connecting the ischial tuberosities and the contact point

between the back and back-support 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 back-support and the line

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

$$X''' = X'' * cos\,\beta \qquad\qquad (4)$$

The force from the back-support, 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 vertical and anteroposterior directions,

the force in the anterior direction, XX, can be expressed as:

$$XX = X''' * cos\,\beta \qquad\qquad (5)$$

The value, XX, calculated by Equation (5) is the estimated shear force value [7].

Statistical Analyses

The measured and estimated shear forces were normalized by the body weight [percent body weight; %BW] to

consider the influence of the body weight. To investigate the validity of the model for estimating shear force, we

compared the estimated shear force with the measured shear force. For statistical analysis, a paired t-test and Pearson

product-moment correlation coefficient were used with the level of significance determined as $p < .01$. The statistical

analyses were performed using the Statistical Package for the Social Sciences (SPSS) ver. 15.0J for Windows.

Results

Figure 5 shows the regression line between the two values. The average value of the measured shear force was 8.4

SD 1.4 [%BW], and the average value of the estimated shear force was 5.8 SD 1.0 [%BW]. Although there was a

significant difference between these two values ($p<0.01$), there was a strong positive correlation between them ($r=0.786$,

$p<0.01$). The regression line between the two values was

$$y = 1.097x + 1.96, \text{ where } x = \text{estimated}, y = \text{measured}.$$

Discussion

In the present study, an experimental model was prepared to estimate the shear force in elderly people with kyphosis as they are sitting comfortably on a chair, and the validity of the model was verified by comparing the estimated values and the measured values using a force plate. The results of the present study show that the measured shear force was significantly higher than the estimated force, and there was a strong positive correlation between them. Also, we obtained the regression line from the two values. These results were different from the results of our prior study, in which the validity of the model was verified in young people [7]. There were two differences between the methods of the present study and the prior study. One difference was the shape of the back-support. In the prior study, a metal parallel bar was used as the back-support, and the body trunk was supported by a contact point between the back and the parallel bar. In the present study, a wheel-chair back-support was used, and the body trunk was again supported by a contact surface. However, in the present study, there should be reduced influence due to the difference of the shape of the back-support because the locations of the points of maximum pressure on the back-support were evaluated in detail and we set the estimating model at an optimal position of the back contact point. The other difference was the influence of the lower extremities. We tried to reduce the influence in the prior study, but did not try to do that in the present study. Therefore, in the present study, excluding the influence of friction and/or the mass of the lower extremities should cause

the significant difference between the measured and estimated values.

We reported the possibility that the influence of the lower extremities on shear force to the buttocks was reduced by adjusting the thigh angle and position of the feet [5]. However, it was reported that the different positions of the lower extremities was an influence. If only the position of the lower extremities was adjusted, the influence of all other factors, such as the thigh mass, on the shear force would nevertheless be considered. As mentioned earlier in the "Introduction" section, the risk for the onset of decubitus ulcers is high. Not only compressive force but also shear force acts on the skin surface. Consequently, it is important that our model estimates the shear force considering the influence of the lower extremities for more assured prevention of the onset of decubitus ulcers while sitting on a chair. So, the estimated shear force should be close to the measured shear force and thus may be approximated by substituting the calculated values for the linear regression, $y = 1.097x + 1.96$, where $x =$ estimated, $y =$ measured.

Furthermore, a strong positive correlation between them suggested that the model could be adapted to elderly people with kyphosis: that is, the strategy of the seating approach [7] could include the raising of the back-support height and the body trunk for reducing the shear force applied to buttocks.

Conclusion

The present estimating model makes it possible to estimate the shear force for a person sitting in a comfortable position by using a relatively simple formula. This study result also shows that the model can possibly be adapted to elderly people with kyphosis. But, few elderly people with kyphosis have previously been used as subjects. In the future, we plan to increase the validity of the calculated linear regression in this present study by increasing the number of elderly subjects.

Declaration of interest

References

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Figure legends

figure 1. Measurement posture

a. Force plate

b. The experimental chair (height of back-support: 42 cm, depth of the seat: 40 cm, reclining angle of the

   back-support: 10 degrees and backward angle of the seat: 0 degrees)

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.

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

$W_n = W \times$ 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).

$g_n = L \times$ 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.

figure 4. Rigid link model of the upper body

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

ℓ_1, distance between the resultant COM position and the intersecting point between the contact point on the

back-support and the line perpendicular to the line connecting the resultant COM and the ischial tuberosities (5.9 ± 2.7

cm).

ℓ_2, distance between the resultant COM position and ischial tuberosities (31.6 ± 3.7 cm).

α, angle formed by the horizontal plane and the line connecting the resultant COM and the ischial tuberosities ($68.8 \pm$

$3.1°$)

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 back-support

β, angle between the horizontal plane and the line between the ischial tuberosities and the contact point between the

back and back-support ($52.7 \pm 1.3°$)

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

X'', anterior component of Xa'; X''', parallel component of the line connecting the ischial bone and the contact point with

the back-support for X''; XX, estimated shear force.

figure 5. Correlation between the measured and estimated values