Original article

Fact-finding survey of pressure and shear force at the heel using a three-axis tactile sensor

ABSTRACT

Aims We investigated changes in pressure and shear force at the heel caused by elevating the head of the bed and after offloading pressure from the heel.

Methods Data on heel pressure and shear force were collected from 26 healthy individuals aged >30 years using a three-axis tactile sensor at each angle formed as the participants' upper bodies were raised from a supine position. Data after pressure release of either the left or right foot were collected and compared.

Results The participants' mean age was 45.1 (±11.1) years. Pressure and anteroposterior shear force on the heel increased with elevation. These increases were especially prominent when the angle of elevation was 30˚. In the subsequent 45˚ and 60˚ tilts, body pressure and shear force increased slightly but not significantly. Pressure and shear force were released by elevating the lower extremity each time the head of the bed was elevated. However, further elevations resulted in increased pressure and shear force, particularly lateral shear force. Pressure and shear force did not change significantly when the lower limbs were elevated.

Conclusion The recommended elevation of the bed head to no more than 30˚ yielded major changes. Elevating the leg relieved the heel of continuous pressure and shear force while increasing pressure and lateral shear force. Although leg elevation is an aspect of daily nursing care, it is important to investigate such nursing interventions using objective data.

Keywords heel pressure injury, decompression, shear force, elevating the head of the bed

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INTRODUCTION

In addition to the relationship between pressure intensity and time, it is clear that frictional and shear forces occur as external forces to the living body. Shear forces obstruct blood flow in the tissue, resulting in tissue ischemia[1]. In Japan, pressure injuries tend to develop frequently in bedridden older adults with bony prominences. They are especially susceptible to friction and shear forces due to dryness and reduced elasticity of the skin[2,3]. Therefore, regular repositioning is recommended for reducing pressure and shear force on the skin[4].

Preventing pressure injuries requires not only systemic reduction of body pressure but also local depressurisation and reduction of shear force. When the head of a patient's bed is elevated, the sacrum and coccyx are subjected to severe pressure and shear force, with particular changes in pressure and shear force reported in the sacral region[5]. In clinical practice, these problems are addressed via depressurisation, which includes pressure redistribution devices and providing daily nursing care. Two such forms of nursing care for depressurisation when a patient's bed is elevated or lowered are *senuki* (literally 'back omission') and *ashinuki* (literally 'leg omission'). *Senuki* involves the caregiver lifting the patient's upper body and inserting their hand between the bed and the patient's back to separate the body from the bed when it is elevated, thereby eliminating the friction and shear force between the patient's skin and their bedclothes. *Ashinuki*

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involves the caregiver elevating the patient's legs to eliminate the shear force that would otherwise occur from the hip to the posterior surface of the thigh and heel when the bed is elevated or lowered[6].

When a bed is elevated, factors such as the concentration of pressure in the buttocks and the sliding down of the body create shear force. Therefore, when elevating a patient's bed, nurses provide various forms of care such as elevating the legs first, positioning the patient in multiple methods, such as inserting a cushion under their knees to prevent slippage, and elevating the patient's upper body[7–9]. However, these nursing interventions were reported in studies that examined the sacrum; few studies have examined changes in pressure or shear force on the heel[10,11].

In the supine position, the heel is subjected to continuous pressure, making it vulnerable to tissue injury and pressure injuries. Pressure injuries in the heel are reported to account for one-fourth of all pressure injuries in American hospitals and nursing homes[12–15]. The effects of bed elevation and other factors make the heel susceptible to friction[16]. To reduce this friction, preventive dressings are applied[17].

The present study examined the pressure and shear force on the heel using a three-axis tactile sensor. Additionally, the aim was to confirm changes in the pressure and shear force on the heel after elevating the heads of patients' beds, followed by elevating the patients' lower limbs.

RESEARCH METHODS

Study design

A quasi-experimental study.

Selection of the participants and period of study

Healthy volunteers aged >30 years were recruited from the researchers' universities and hospitals. The participants' number of clinical experiences did not matter in this study design. Posters for research cooperation were displayed on a bulletin board at the facilities to call for participation. The primary author made verbal and e-mail announcements for the same, and used documents to explain the research specifications to individuals who wished to participate. Individuals signed a consent form to confirm participation.

Inclusion criteria required that participants had no wounds on their heels. Temporary redness was considered reactive hyperaemia and such participants were included.

Sample size

When G*Power[18] was used to analyse the sample size with an effect size of 0.8, α of 0.05, and a statistical power of 0.8, the sample size was calculated to be n=15. Due to the possibility of an insufficient measurement effect in some participants, we set the sample size as 20. The target number of 20 participants was set to 15 to account for dropouts during data collection. However, no participant met the exclusion criteria and all were included.

Data collection

Data were collected between October 2018 and March 2019.

Measurement environment

Commonly used bedding was selected for the measurements. However, for the convenience of reproducibility, no pillows were used. Other equipment included:

- Electric bed: Paramount bed KA-5000 (4-split type) (Paramount Bed Corporation, Tokyo, Japan).
- Base mattress: Everfit KE-521Q (Paramount Bed Corporation, Tokyo, Japan); 10cm thick static mattress.
- Bed sheet: plain woven cotton sheet. The sheets were tucked in when the beds were made.
- Measuring device: Three-axis tactile sensor (ShokacChip™T08, Touchence Inc., Tokyo, Japan) 9mm × 9mm × 5mm. The x-, y- and z-axes of the three-axis sensor were set according to pressure, anteroposterior shear force, and lateral shear force, respectively (Figures 1a & b).

Measurement procedure

Two experiments were conducted. Experiment 1 measured the pressure and shear force on the heel. Experiment 2 measured

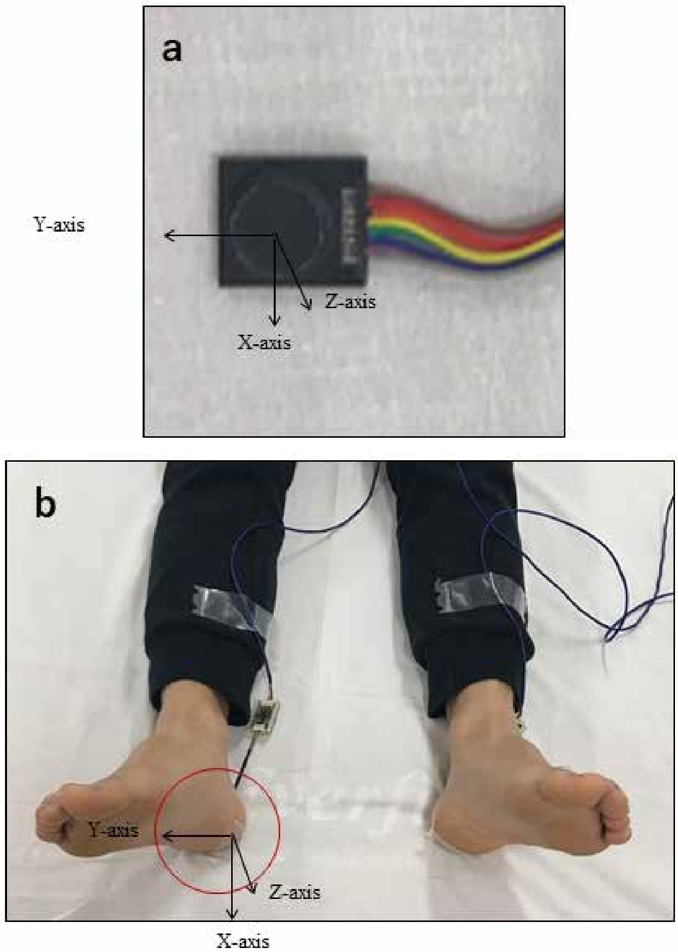

Figure 1. A tri-axial tactile sensor was attached to the skin contact area between the heel and the bed and was covered with a dressing. Three directions were measured – anteroposterior shear force (x-axis), lateral shear force (y-axis), and pressure (z-axis)

the changes in heel pressure and shear force with and without lower limb elevation.

Experiment 1: Changes in heel pressure and shear force upon elevating the head of the bed

The participants slightly opened their lower limbs in a relaxed state and lay in a supine position with their anterior superior iliac spine aligned to the bending point of the bed. The three-axis sensor was applied to the central point of where the left or right heel touched the bed; the film dressing was applied from above (Figures 1a & b). The left or right heel was selected randomly, and the following series of data were collected:

1. After confirming that the participant's body was still, data for the heel were collected over a 20-second period with the bed in a supine position.
2. After 20 seconds, the participant's upper body was elevated from the bending point of the bed to a 30˚ angle measured with a goniometer (Figure 2).
3. After the participant's upper body was elevated, data for the heel were collected while the patient lay still for 20 seconds.
4. The participant's upper body was then elevated to 45˚ and data were collected in the same manner.
5. After the data collection for the 60˚ elevation, the bed was lowered to a supine position and data were measured for 20 seconds, concluding the experiment.

Experiment 2: Changes in heel pressure and shear force with and without lower limb elevation

As in Experiment 1, the left or right lower limb was selected randomly, and the data collection steps 1–3 in Experiment 1 were repeated. In Experiment 2, the following interventions were carried out from that state.

4. After 20 seconds, either the participant's left or right knee and ankle were held, lifted up from the hip, and kept still in that position for 5 seconds (Figure 3).
5. After the lower limb was lowered, it was immediately elevated to a 45˚ angle and data were collected for the heel while the participant remained still for 20 seconds.
6. Similar to Step 5 in Experiment 1, after the lower limb was lowered and the head of the bed was elevated to 60˚, the same measurement was performed.
7. Finally, the head of the bed was lowered to a supine position, data were collected for 20 seconds, and the experiment was concluded.

The researcher, a certified expert nurse in wound, ostomy, and continence, conducted Experiments 1 and 2 in this study.

Data analysis

Data were analysed by estimating the average of the observation points at 18 seconds without considering the seconds before and after; the influence of the anteroposterior movement data of the 20 seconds measured for each angle of elevation was also taken into account. Calculations were made by averaging the observation points without the seconds before and after. At the start of the measurement, the initial data value was calibrated to zero and measured twice. The data obtained from the sensors were analysed along the x-axis (anteroposterior shear force), y-axis (lateral shear force), and z-axis (pressure). The pressure and shear force, with and without offloading pressure from the heel at each angle, were analysed using dedicated data software and two-way ANOVA was performed. All statistical analyses were performed using SPSS 23.0 for Windows (IBM Corp. Armonk, N.Y., USA), and the significance level was set at 5%.

Ethical considerations

The study was approved by the Ethical Review Committee of the Jikei University School of Medicine, Tokyo (9212). The participants were informed of the study orally and in writing, including instructions for the study. The participants' health status was always observed during the data measurement. They were informed that the procedure would be stopped if they experienced distress. After data collection, we looked for any adverse conditions, such as skin indentation caused by the sensor being applied to the subject's heel or epidermal peeling caused by the application of the dressing material.

RESULTS

Subject attributes

The study was conducted with 26 participants (11 men and 15 women) with a mean age of 45.1 (±11.1) years and mean BMI of 22.2 (±3.2). No participant met the exclusion criteria, and no adverse events occurred.

Figure 2. Lying in bed (at the time of elevating the head of the bed)

Figure 3. Lifting the lower limbs

Experiment 1: Changes in heel pressure and shear force upon elevating the head of the bed

The change in pressure at the heel tended to increase and maintain its value as the head of the bed was raised (Figure 4a). In particular, the pressure increased significantly when the head of the bed was raised from the supine position to 30˚. Subsequently, the pressure values were maintained for the elevation angles of 45˚ and 60˚; no significant increase was observed. However, a significant difference was observed when the angle was changed from 60˚ to the supine position. The pressure initially dropped, but did not return to the starting pressure, which further decreased.

The shear force in the front–back direction tended to increase with the elevation angle. Similar to the pressure values found, the value increased significantly at the 30˚ angle of elevation, and a significant difference was observed. After 45˚, the anteroposterior shear force was maintained but did not increase significantly when the angle was raised from the supine position to 60˚. However, when the angle was changed from 60˚ to the supine position, shear force in the opposite direction was added and a significant difference was observed (Figure 4b).

Although the lateral shear force increased as the head of the bed was elevated, it did not change as greatly as the anteroposterior shear force. A significant difference was observed when the bed was lowered from a 60˚ angle to a supine position. However, the large changes that occurred in the anteroposterior shear force did not occur in the case of lateral shear force (Figure 4c).

Experiment 2: Changes in heel pressure and shear force with and without lower limb elevation

Examinations of the changes in pressure with and without elevation of the lower limbs showed no significant differences in pressure, anteroposterior shear force, or lateral shear force (Figure 5). However, as with the measurements taken with simple elevation of the head of the bed, even when pressure and shear force were offloaded, elevating the head of the bed led to the reapplication of external force. Moreover, while the anteroposterior shear force was large when only the head of the bed was elevated, the lateral shear force increased upon lower limb elevation. An example of elevating the head of the bed is presented here to explain these changes.

When the head of the bed was elevated to 30˚, elevation of the lower limbs temporarily offloaded the pressure on the heel. While further bed elevation once again increased pressure on the heel, lower limb elevation tended to inhibit subsequent increases in pressure (Figure 6a).

When the lower limbs were not elevated, the anteroposterior shear force increased slightly when the bed head was elevated to 30˚. On the other hand, when the lower limbs were elevated, no significant change occurred (Figure 6b).

Similarly, the lateral shear force increased without elevation of the lower limb when the head of the bed was elevated to 30˚. On further elevation of the head of the bed, the lateral shear force increased in the absence of lower limb elevation. The greatest change occurred when the bed returned to the supine position. When the lower limb was elevated, the lateral shear force was temporarily offloaded. However, elevating the head of the bed again created lateral shear force. Although the difference in lateral shear force when the bed returned to the supine position was smaller than the difference observed without elevation of the lower limb, the results demonstrated the occurrence of lateral shear force associated with temporary offloading of force (Figure 6c).

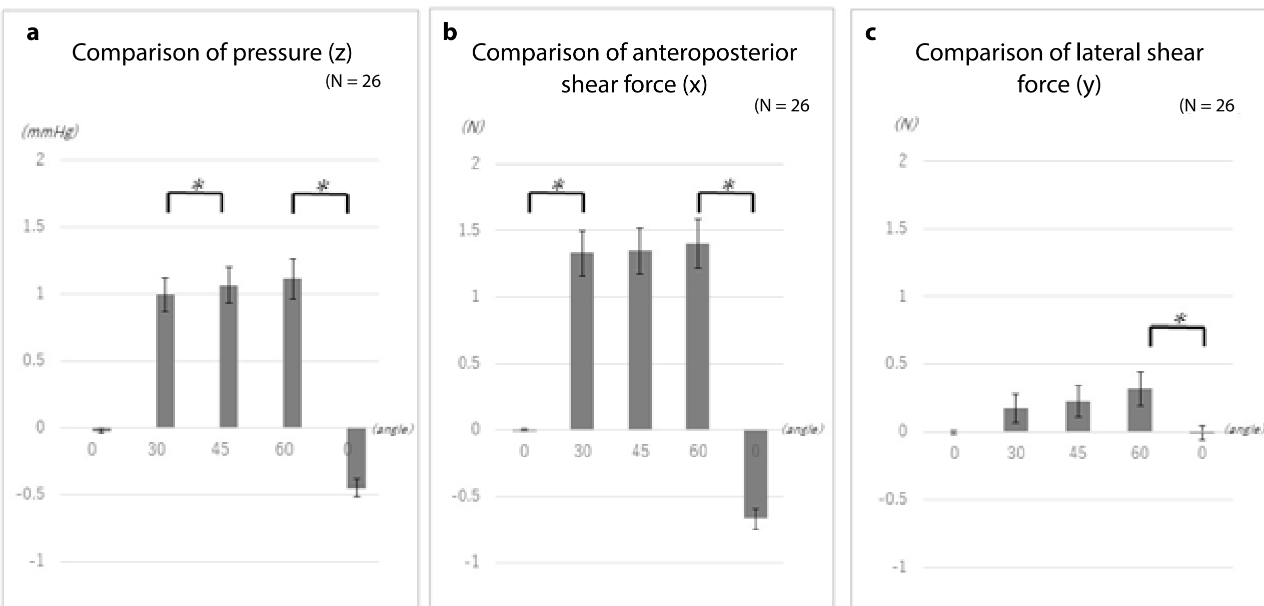

Figure 4. Changes in heel pressure and shear force while elevating the head of the bed (*p<0.05)

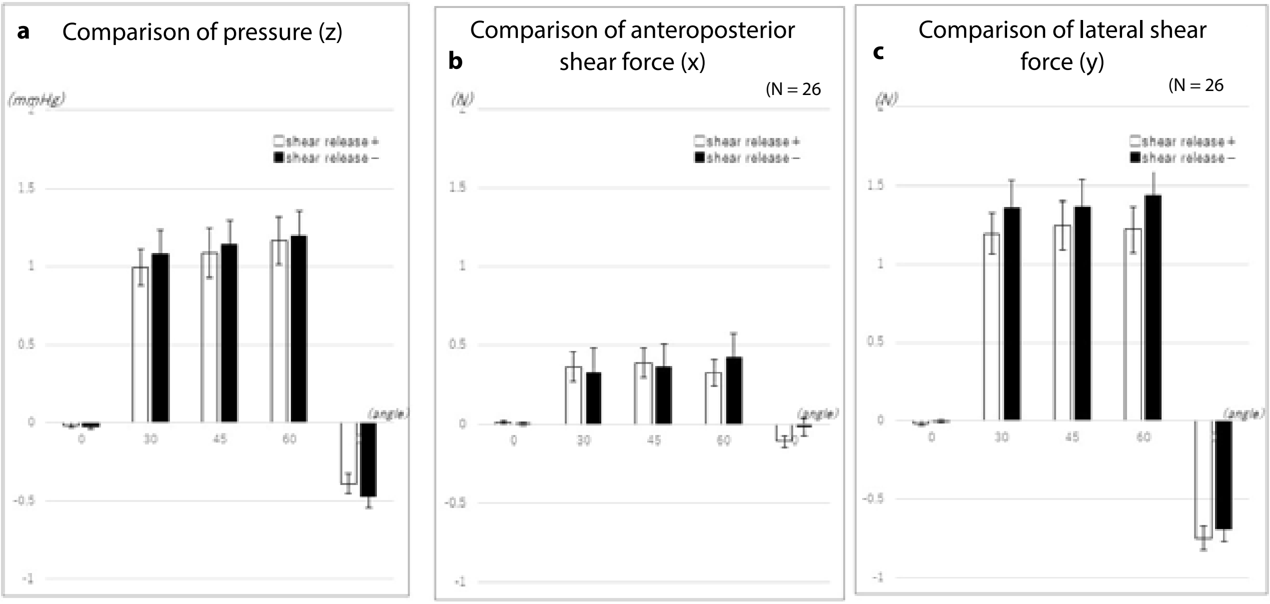

Figure 5. Changes in heel pressure and shear force with and without lower limb elevation

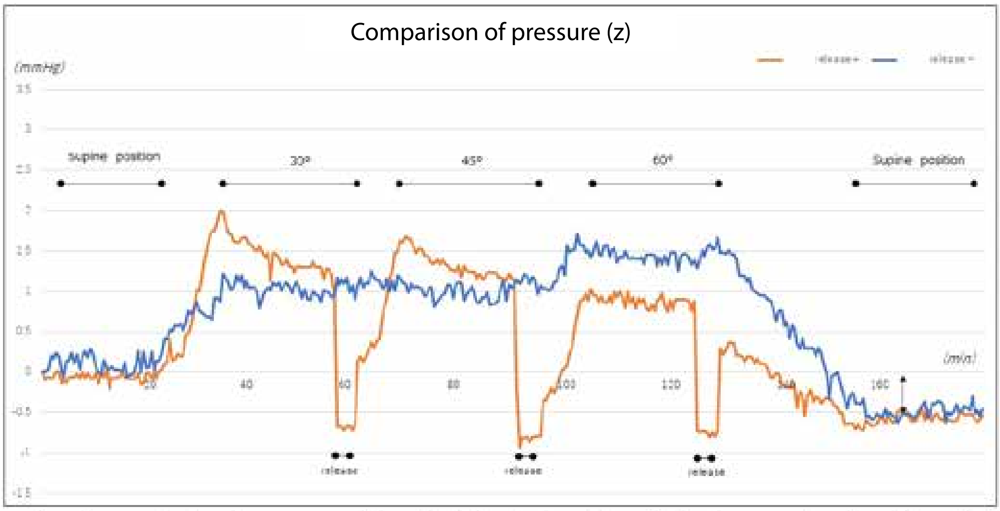

Figure 6a. Changes in heel pressure with and without elevation of the lower extremity (example)

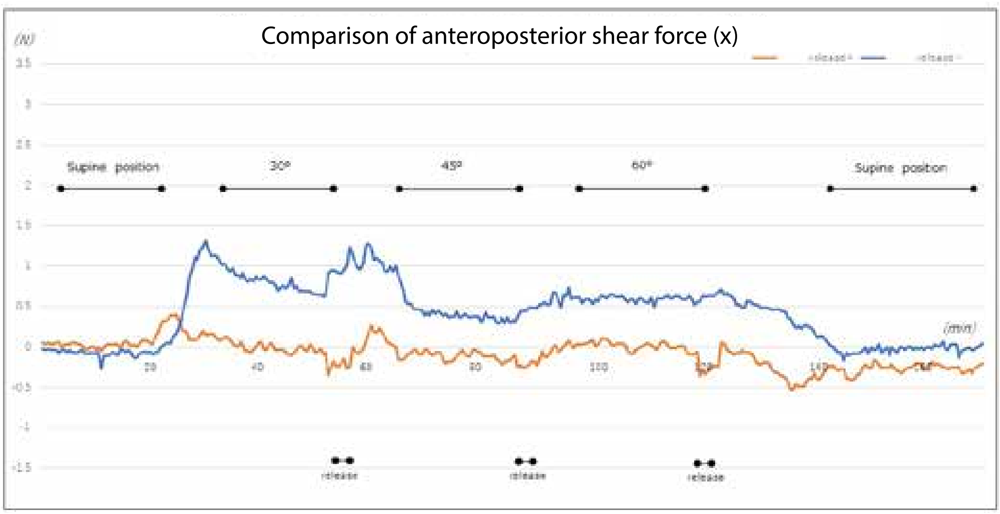

Figure 6b. Changes in anteroposterior shear force at the heel with and without elevation of the lower limb (example)

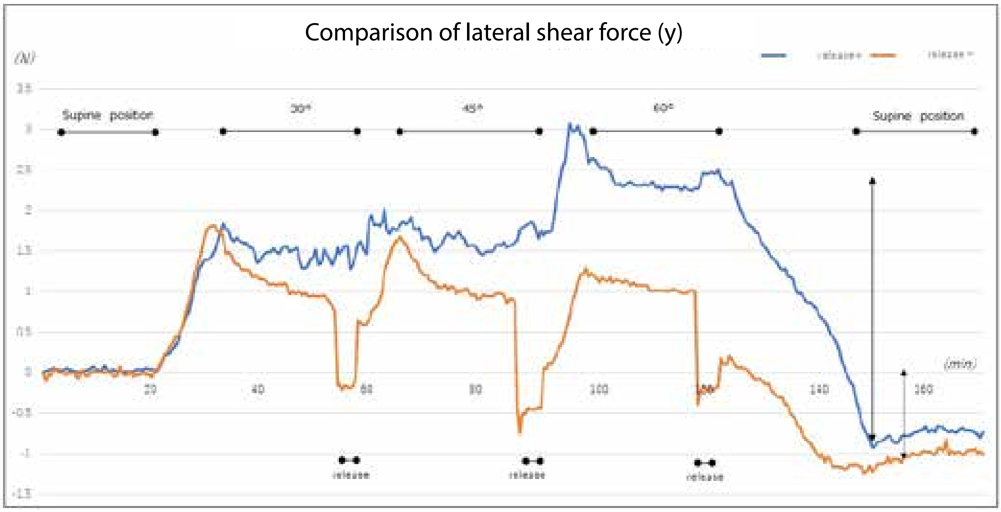

Figure 6c. Changes in lateral shear force at the heel with and without elevation of the lower limb (example)

DISCUSSION

The experimental results revealed that the pressure and shear force at the heel increased with elevating the head of the bed. In particular, the rate of change in the values was large at the 30˚ angle of elevation. As previously reported, this is attributed to the effect of the centre of gravity shifting and upper body sliding down due to head elevation[17–19]. From the viewpoint of preventing pressure injury in the buttocks, it is desirable that the angle of elevating the head of the bed be 30˚ or less[20]. Although the 30˚ rule"(30˚ lateral supine, elevating the head of the bed by 30˚) has been widely used in positioning to prevent pressure injury, it has also been reported to delay healing in patients with pressure injury in the buttocks[21]. Therefore, the 4th edition of the Guidelines for the Prevention and Management of Pressure Ulcers states that positioning other than the 30˚ side-lying and 30˚ supine positions may be performed[22].

The heel is a common site of pressure injuries. Even if a visual assessment identifies no problems, tissue injury occurs, leading to deep tissue injury (DTI) due to changes inside the tissue. When pressure injuries are detected by a physician, the skin is often discoloured and injured, with DTI having already occurred[16]. As the heel is known to have a lower concentration of melanocytes, tissue response to stress and tissue injury are difficult to detect based on changes in skin colour[23]. In addition, while the epidermis may be thick in the lateral aspect of the sole of the heel, the skin of the posterior heel is relatively thin. In older adults and patients with fragile skin, capillary density is low and mass is reduced throughout the soft tissue in the posterior heel, adversely affecting the linkage between the epidermis and skin junctions[24], conceivably increasing the risk of pressure injuries. Similar results were observed among the present study's participants, despite having a mean BMI of 22.2 (±3.2) and standard body type. The participants' BMI led to changes in mass throughout the soft tissue in the posterior heel. Conceivably, BMI and heel bone geometry also affected the linkage between the epidermis and skin junctions, suggesting an effect on pressure and shear force as well.

The present experiments demonstrated that powerful pressure and shear force occur when the head of a hospital bed is elevated to the recommended angle of 30˚. In the initial measurement, the head of the bed was elevated with the participant's superior anterior iliac spine aligned with the bending point of the bed to prevent the body from sliding down. However, because the knees are not elevated and the heels are not supported, continuous strain on soft tissue leads to tissue injury[25] and multiple thrombosis[26], often causing DTI. In fact, this strain was shown to act as the anteroposterior and lateral shear forces due to elevation of the head of the hospital bed, elevation of the lower limbs, and other acts of nursing care. Although the lower limbs are elevated as a form of preventive care, we learned that this elevation does not entirely eliminate external force. This finding suggests the need for further preventive measures based on objective data.

The application of polyurethane foam/soft silicon foam to the heel has been reported to reduce friction and shear force on the heel, resulting in prevention of pressure injuries[27,28]. The skin of elder adults is dry, resulting in friction even when they sleep on bedsheets. The application of moisturiser, particularly the use of ceramide-containing formulations, to moisturise dry skin daily is reported to be an effective nursing intervention[29]; therefore, this intervention is also important to incorporate. European Pressure Ulcer Advisory Panel guidelines also recommend the use of sheets made of silk or other similar material instead of cotton or cotton blends to reduce friction and shear force[30].

Considering the advancements in body pressure redistribution devices, repositioning at conventional 2-hour intervals is reported to not differ from repositioning at 3- or 4-hour intervals[31]. When a patient's body is repositioned (or their posture is maintained), it is supported with cushions and pillows. Although this study used four-section hospital beds, data in the present experiments were collected for the heel with only participants' upper bodies being elevated and without elevation of the lower limb. However, with a bed that permits elevation of the lower limbs, conventional positioning requires elevation of the lower extremity side of the bed to prevent posture collapse and reduce pressure on the buttocks associated with the sliding down of the upper body; elimination of external force through means such as lower limb elevation may thus be required. Patients' bodies are repositioned to regularly change their recumbent position and shift the external force that would otherwise continue to act on the same site.

However, while voluntary movement is also important, it is sometimes difficult for patients who have trouble moving on their own. In Japan, studies are being conducted on 'small changes', a body pressure dispersal method involving the use of a small pillow. 'Small changes' refers to a method in which a small pillow is moved at regular intervals to the shoulder, hip or lower extremity on one side of the body to change the site on which pressure acts and thus redistribute pressure. This method has been reported to reduce the incidence of pressure injuries[32,33]. Furthermore, an air mattress equipped with such a small change system has been developed, with a study having reported on its efficacy in preventing pressure injuries[34].

Along with the measures described above to prevent pressure injuries in the heel, ultrasonography is also being used to detect pressure injuries at an early stage without relying on visual assessment[35]. Acquiring more basic data, such as that obtained in the present experiment, may be necessary.

More comments are needed on what is currently known about nursing interventions such as repositioning, frequency of repositioning to reduce pressure, shear force and friction, and the use of a knee-break or knee elevation capability of beds or simple devices such as pillows, etc to alleviate heel pressure shear and friction.

Limitations of the study and future challenges

In this study, the target age group was relatively young. Their skin structure in the heel region differs from that of older adults, who are more prone to pressure injury, and there are limitations when comparing with patients who are more prone to pressure injury. The mattress used was a urethane mattress, which is used to prevent pressure injury; hence, the effects of using other materials, such as an air mattress, need to be examined in the future.

Based on these results, we intend to consider more clinically-relevant positioning and pressure redistribution methods in the future. Additionally, we would like to check the changes occurring in not only the heel region but also the sacral region and other bone protrusion sites and collect data to provide evidence for nursing practice.

CONCLUSIONS

When elevation was performed, the pressure and shear force on the heel increased significantly at 30˚. The elevation of the lower limbs led to an offloading of continuous pressure and shear force on the heel, although the differences were not significant. However, we noted the pressure and shear force that occurred while elevating the head of the bed and determined that elevation of the lower limbs, a typical act of nursing care, does not prevent the application of shear force. Further examination with more objective data will be conducted to examine preventive nursing interventions.

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CONFLICT OF INTEREST

There are no conflicts of interest to declare.

ETHICS STATEMENT

The study was approved by the Ethical Review Committee of the Jikei University School of Medicine, Tokyo (9212).

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