Relationship between mattress internal air pressure and interface pressure distribution in the lateral position

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Abstract
Previous research shows that maximum interface pressure increases when the patient is lying in the lateral position. However, it was unclear whether it was better to increase or decrease the internal air pressure to reduce the maximum interface pressure in the lateral position; thus, this study investigated this issue. In this study, we investigated the change in pressure redistribution because of the difference in internal air pressure between the supine and lateral positions on an active air mattress for pressure ulcer prevention management. Each participant's five internal air pressure values served as the independent variables. The interface pressure on the active air mattress was measured for 20 minutes. The sacral left iliac crest and left greater trochanteric interface pressures were measured using a portable pressure-measuring device. When seven of the 10 participants switched from the supine position to the left lateral position, there was a decrease in the maximum interface pressure as the internal air pressure increased. The maximum interface pressure in the greater trochanter in the lateral position was twice that in the sacral region in the supine position. These results show that increasing the internal air pressure in the lateral position might help reduce the maximum interface pressure.

KEYWORDS
active air mattress, interface pressure distribution, lateral position, mattress internal air pressure, pressure ulcer prevention

Key Messages
• this study evaluated the relationship between mattress internal air pressure and interface pressure redistribution in the lateral position to prevent pressure ulcers
• the interface pressure was measured using a portable device with 10 healthy participants
• when changing from the supine to lateral position, the maximum interface pressure may be suppressed by increasing the mattress internal air pressure
1 | INTRODUCTION

In principle, there are two methods to prevent the development of pressure ulcers: reduction in the magnitude of the external force; and reduction in the duration of the external force. A support surface is a device particularly designed for pressure redistribution to control the external force on tissues, bed environment adjustment, and other functions. An active air mattress is classified as a support surface. Active air mattresses can provide pressure redistribution through “immersion,” “envelopment,” and “change in the contact area over time.” The function of “change in the contact area over time” for pressure redistribution is significantly affected by the mattress internal air pressure, which is the pressure in the pump when the air cell repeatedly expands and contracts to inject air into itself. Therefore, an appropriate mattress internal air pressure must be set, and various standard values have been established for active air mattress products. The proper mattress internal air pressure is operationally defined as the pump pressure required to maintain the maximum interface pressure at the lowest value and the interface pressure distribution in an optimal state.

Sanada et al. used a cell-type pressure-switching mattress to conduct a quasi-experimental study on the relationship between the mattress internal air pressure and maximum interface pressure in the supine and lateral positions in healthy individuals. Sasaki et al. also evaluated the relationship between a prototype air mattress’s internal pressure and interface pressure. Based on the measurement of the sacral interface pressure, they reported that the interface pressure is high when the internal air pressure is either high or low, with the interface pressure vs the internal air pressure plot forming a U curve. Another study showed that when the head is raised to 45°, the internal air pressure changes according to the posture. As the upper body’s weight was centred on the buttocks when the head was elevated, the internal air pressure increased to control the interface pressure. However, the lateral position has a smaller contact area and higher maximum interface pressure than the supine position. The study results by Matsuo et al. showed that the maximal interface pressure in the lateral position was approximately twice that in the supine position. Currently, no additional operation is performed to control the interface pressure in clinical settings; this is a clinical problem owing to the increased risk of pressure ulcer development when lying in the lateral position, despite the same internal air pressure as that in the supine position.

This study aims to clarify the interface pressure change during the internal air pressure change in the active air mattress and the effect in reducing the high interface pressure in the lateral position to prevent pressure ulcers. For this purpose, the interface pressures on the sacrum in the supine position and on the iliac crest and left greater trochanter in the lateral position have been measured on an air mattress for 10 healthy adults at different high internal air pressure. In addition, interface pressure change during the active air mattress motion and the relation of the interface pressure with body weight and mattress internal air pressure has been investigated.

2 | METHODS

This study was quasi-experimental, and the participants were healthy men.

2.1 | Active air mattress

The air mattress used in this study was an Air Master Tri-cell E (Cape Co., Ltd., Yokosuka, Japan) (Figure 1), an independent two-layer air mattress measuring 84 × 191 × 10 cm (24 air cells in 8 cm width repeat inflation for 10 minutes and deflation for 5 minutes per cycle, with one unit for three cells). Two of the three cells always inflate and support the body. The high internal air pressure for cell inflation is assigned as the value of body weight from 20 to 90 kg in 5 kg increments. Covers or seats were not used to eliminate the hammock phenomenon. Instead, a healthy person lay directly on the bare cells of the mattress.

The internal air pressure was measured by connecting a pressure sensor to one of the tubes from the pressure controller, and the result is shown in Table 1. Although the body weight setting is from 20 to 90 kg in 5 kg increments, mattress internal air pressure does not change linearly with the set body weight. Therefore, we call the internal air pressure at inflation and deflation as high and low internal air pressure, respectively.

2.2 | Interface pressure sensor

A portable pressure-measuring device (Palm Q; Cape Co., Ltd., Yokosuka, Japan) (Figure 2) was used to measure the sacral interface pressure in the supine position, left iliac crest interface, and left trochanteric interface pressure in the left lateral position. This device comprises five sensors in 3 cm diameter on a square pad. Sensor 1 is located in the centre, and the other four sensors are located around the centre sensor. Distance between the outsides of the outer sensors was 10 cm. This sensor can measure a range of pressures from 0 to 200 mm Hg.
2.3 Measurement position

The normal supine position was a 10 cm abduction between the legs and hands folded on the abdomen. Figure 3A shows a schematic of the supine position with the eversion pillow placed on the upper leg and fixed. In the supine position, the portable pressure sensor was fixed such that the lines connecting the right and left iliac crests, sacrum, and spinal column were orthogonal to each other (sensor 1: sacral area, sensor 5: 3 o’clock direction). The measurement position in the left lateral position was defined as shown in Figure 4. Reproducibility was ensured by marking the position at which the sacral and greater trochanteric regions (sensor 1) were placed on the centre of the horizontal surface of the cell.

3 MEASUREMENT PROCEDURE

3.1 Measurement protocol

The characteristics of the participants are shown in Table 2. A researcher explained the procedure to the participants 1 day before the procedure was performed. The participants confirmed their sex and age, and based on their measured weights and height, their body mass index (BMI) was calculated. Information regarding the presence or absence of disease was obtained in advance. The air mattress was kept inflated, and the laboratory temperature was maintained at 25°C. The internal air pressure of the mattress was set according to the participant’s body weight for 20 minutes or more before the measurement. Subsequently, the participants’ blood pressure and pulse were measured for safety purposes. The researcher placed the participant in the left lateral position, touched the sacrum, and fixed the pressure sensor after the fixed position was confirmed. The sensor was attached to the clothes based on ethical considerations. Subsequently, a 10 cm distance was measured between the participant’s legs, and they were encouraged to maintain the distance. Thereafter, the eversion pillow was fixed between the participant’s left and right thighs. The participant was urged to rest for 5 minutes in the supine position; these 5 minutes are important for bringing the participant’s posture to a calm and restful state. After 4 minutes of rest, the researcher recorded the time, temperature, and humidity values. The sacral pressure was recorded every 1 minute for 20 minutes. At the end of the measurement in the supine position, the pressure sensor was removed. After a 10 minutes break, the researcher asked the participant to assume the left lateral position, touched the left trochanteric region and left iliac crest,

| Body weight setting (kg) | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 |
|-------------------------|----|----|----|----|----|----|----|----|----|----|----|----|
| High internal air pressure (mm Hg) | 16 | 18 | 18 | 18 | 18 | 18 | 22 | 23 | 23 | 24 | 24 | 25 |
| Low internal air pressure (mm Hg) | 4  | 4  | 5  | 4  | 5  | 5  | 6  | 6  | 6  | 6  | 6  | 6  |
and fixed the pressure sensor after confirming the fixed position. Using a goniometer, the researcher fixed the left lateral position at 90°, the angles of the left and right knee joints, and the hip joint at 120°, and then asked the participant to rest for 5 minutes in the left lateral position; these 5 minutes are important for bringing the participant’s posture to a calm and restful state. The time, temperature, and humidity measurements were recorded after 4 minutes of rest. Furthermore, the researcher measured the left iliac crest pressure and greater trochanteric pressure every 1 minute for 20 minutes. The participants’ blood pressure and pulse were also measured for safety purposes. Finally, the pressure sensor was removed.

High internal air pressures were assigned according to the body weight W, W ± 5 kg, and W ± 10 kg. According to the relation between the set body weight and internal high pressure in Table 1, the assigned high internal air pressures for each participant’s body weight are shown in Figure 6.

### 3.2 Pressure redistribution measurements

The tissue viability society specified the pressure redistribution index in its consensus document. The interface pressure distribution’s main evaluation attributes include the maximum interface pressure, minimum interface pressure, rate of interface pressure change, pressure redistribution index, and range. These five attributes were evaluated to compare the values at the sacral region, left iliac crest, and left greater trochanter. The definition of maximum interface pressure is “The highest pressure recorded at the interface over the cycle time.”

### 3.3 Ethical considerations

This study was approved by the Kanazawa University Medical Ethics Committee (approval number 66).
The study lasted approximately 1 month (18 November 2019 to 19 December 2019). Individuals were recruited after the relevant people at the Kanazawa University were informed. The participants provided informed consent. Brochures were prepared and distributed to the participants. Dignity was assured by informing the participants that they could choose the sex of the researcher, thereby eliminating any distress regarding sex differences. If pain occurred during the survey, the participant was informed that the survey would be stopped immediately. The survey was conducted once per day for 1 hour and required a total of 5 hours of restraint over 5 days. All participants were healthy people older than 18 years; therefore, no chaperones were needed for the study. Participants were informed that they could withdraw from the survey at any time. Ultimately, no participants withdrew from the survey.

4 | RESULTS

4.1 | Measured sample on the interface pressures

Typical interface pressure diagrams measured on the adult with 75 kg body weight at 23 mm Hg high internal pressure are shown in Figure 5.

Figure 5A shows the results of interface pressure in the sacral region in the supine position measured for 20 minutes with the five sensors. Sensor 2 recorded a maximum interface pressure of 19.4 mm Hg in 15 minutes in the total measurement time of the five sensors.
Figure 5B shows the results of interface pressure at the greater trochanter in the lateral position measured for 20 minutes with the five sensors. Sensor 1 recorded a maximum interface pressure of 47.5 mm Hg in 18 minutes in the total measurement time of the five sensors.

Figure 5C shows the results of the interface pressure at the iliac crest in the lateral position measured for 20 minutes with five sensors. Sensor 4 recorded a maximum interface pressure of 29.6 mm Hg at 6 or 7 minutes in the total measurement time of the five sensors.

4.2 Change in the maximum interface pressure by the change of the body weight with mattress internal air pressure

Changes in the maximum interface pressures of the sacrum, greater trochanter, and iliac crest at mattress internal air pressure are shown in Figure 6. Furthermore, Figure 6 also shows the relationship between each participant’s body weight setting and high internal air pressure.

The lowest maximum interface pressure in the sacral region of identification (ID) 1 was 13.9 mm Hg at a body weight setting of 60 kg (body weight −10 kg) and a high internal air pressure of 18 mm Hg. The lowest maximum interface pressure at the greater trochanter was 27.2 mm Hg at a body weight setting of 65 kg (body weight −5 kg) and a high internal air pressure of 22 mm Hg. The lowest maximum interface pressure at the iliac crest was 20.3 mm Hg at a body weight setting of 60 kg (body weight −10 kg) and a high internal air pressure of 18 mm Hg.

The lowest maximum interface pressure in the sacral region of ID 2 was 13.8 mmHg at a body weight setting of 55 kg (body weight −10 kg) and a high internal air pressure of 18 mmHg. The lowest maximum interface pressure at the greater trochanter was 23.5 mmHg at a body weight setting of 75 kg (body weight +10 kg) and a high internal air pressure of 23 mmHg. The lowest maximum interface pressure at the iliac crest was 19.4 mmHg at a body weight setting of 70 kg (body weight +5 kg) and a high internal air pressure of 23 mmHg.

The lowest maximum interface pressure in the sacral region of ID 3 was 12.6 mm Hg at a body weight setting of 55 kg (body weight) and a high internal air pressure of 18 mm Hg. The lowest maximum interface pressure at the greater trochanter was 14.2 mm Hg at a body weight setting of 45 kg (body weight −10 kg) and a high internal air pressure of 18 mm Hg. The lowest maximum interface pressure at the iliac crest was 23.9 mm Hg with a body weight setting of 45 kg and 65 kg (each body weight ±10 kg) and high internal air pressures of 18 mm Hg and 22 mm Hg, respectively.

The lowest maximum interface pressure in the sacral region of ID 4 was 15.0 mm Hg at a body weight setting of 45 kg (body weight −5 kg) and a high internal air pressure of 18 mm Hg. The lowest maximum interface pressure at the greater trochanter was 33.3 mm Hg at a body weight setting of 45 kg (body weight −5 kg) and a high internal air pressure of 18 mm Hg. The lowest maximum interface pressure at the iliac crest was 17.4 mm Hg with a body weight setting of 55 kg (body weight +5 kg) and a high internal air pressure of 18 mm Hg.

The lowest maximum interface pressure in the sacral region of ID 5 was 11.4 mm Hg at a body weight setting of 35 kg (body weight −10 kg) and a high internal air pressure of 16 mm Hg. The lowest maximum interface pressure at the greater trochanter was 16.6 mm Hg at a body weight setting of 35 kg (body weight −10 kg) and a high internal air pressure of 16 mm Hg. The lowest maximum interface pressure at the iliac crest was 19.1 mm Hg with a body weight setting of 40 kg (body weight −5 kg) and a high internal air pressure of 18 mm Hg.

The lowest maximum interface pressure in the sacral region of ID 6 was 13.4 mm Hg at a body weight setting of 85 kg (body weight +5 kg) and a high internal air pressure of 24 mm Hg. The lowest maximum interface pressure at the greater trochanter was 28 mm Hg at a body weight setting of 85 kg (body weight +5 kg) and a high internal air pressure of 24 mm Hg. The lowest maximum interface pressure at the iliac crest was 21.1 mm Hg at a body weight setting of 80 kg (body weight) and a high internal air pressure of 24 mm Hg.

The lowest maximum interface pressure in the sacral region of ID 7 was 13.8 mm Hg at a body weight setting of 50 kg (body weight −10 kg) and a high internal air pressure of 18 mm Hg. The lowest maximum interface pressure at the greater trochanter was 15.8 mm Hg at a body weight setting of 55 kg (body weight −5 kg) and a high internal air pressure of 18 mm Hg. The lowest maximum interface pressure at the iliac crest was 14.6 mm Hg at a body weight setting of 60 kg (body weight) and a high internal air pressure of 18 mm Hg.

The lowest maximum interface pressure in the sacral region of ID 8 was 10.6 mm Hg at a body weight setting of 50 kg (body weight −10 kg) and a high internal air pressure of 18 mm Hg. The lowest maximum interface pressure at the greater trochanter was 12.9 mm Hg at a body weight setting of 55 kg (body weight −5 kg) and a high internal air pressure of 18 mm Hg. The lowest maximum interface pressure at the iliac crest was 12.9 mm Hg at a body weight setting of 55 kg (body weight −5 kg) and a high internal air pressure of 18 mm Hg.

The lowest maximum interface pressure in the sacral region of ID 9 was 13.0 mm Hg at a body weight setting of 60 kg (body weight) and a high internal air pressure of
FIGURE 6 Change of the maximum interface pressure with body weight at internal air pressure. The changes in the maximum interface pressure with body weight at various internal air pressures are shown.
18 mm Hg. The lowest maximum interface pressure at the greater trochanter was 26.8 mm Hg at a body weight setting of 65 kg (body weight +5 kg) and a high internal air pressure of 22 mm Hg. The lowest maximum interface pressure at the iliac crest was 12.9 mm Hg with a body weight setting of 55 kg (body weight −5 kg) and a high internal air pressure of 18 mm Hg.

The lowest maximum interface pressure in the sacral region of ID 10 was 10.9 mm Hg at a body weight setting of 60 kg (body weight −10 kg) and a high internal air pressure of 18 mm Hg. The lowest maximum interface pressure at the greater trochanter was 23.9 mm Hg at a body weight setting of 80 kg (body weight +10 kg) and a high internal air pressure of 24 mm Hg. The lowest maximum interface pressure at the iliac crest was 17.9 mm Hg at a body weight setting of 75 kg (body weight +5 kg) and a high internal air pressure of 23 mm Hg.

5 | DISCUSSION

This study investigated whether mattress internal air pressure should be increased or decreased to reduce interface pressure in the lateral position.

As shown in Figure 6, the maximum interface pressure is higher at the greater trochanter than at the iliac crest in the lateral position. Therefore, it is reasonable to consider interface pressure management in the lateral position at the greater trochanteric region. The ratio of maximum interface pressure between the sacral and greater trochanteric regions is approximately twice as high, which agrees with the results of Matsuo et al. Therefore, results for maximum interface pressure in the sacral region suggested that the body weight setting of −10 kg was better than other settings in this study. The results of maximum interface pressure in the greater trochanter region suggested that a higher weight setting than the supine sacral weight setting was more effective in reducing maximum interface pressure in 7 of 10 participants. These results for maximum interface pressure in the supine position suggest that the contact area between the body and the air cell increases in the supine position; therefore, the interface pressure decreases in the supine position, which lowers the body weight setting. Similarly, the air cell redistributes pressure to envelop the body by reducing the internal air pressure. On the other hand, the results for the maximum interface pressure in the lateral position indicate that the contact area between the body and the air cell decreases in the lateral position; therefore, the interface pressure in the lateral position increases, which suggests that the air cell supports the body by increasing the setting body weight and by increasing the internal air pressure.

6 | CONCLUSIONS

Previous research shows that maximum interface pressure increases when the patient is lying in the lateral position. However, it was unclear whether it was better to increase or decrease the internal air pressure to reduce the maximum interface pressure in the lateral position, therefore this study investigated this issue. Figure 6 shows that increasing the internal air pressure in the lateral position is best to reduce the maximum interface pressure.

The air mattress used in this study, which is an independent two-layer air mattress, was found to reduce the maximum interface pressure in the lateral position by increasing the internal air pressure compared with the supine position.

ACKNOWLEDGEMENTS

The data in this study were appropriately obtained with the cooperation of the participants. We would like to thank the participants. This study was not funded by a company.
CONFLICT OF INTEREST
The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT
Data available on request due to privacy/ethical restrictions.

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How to cite this article: Kawabata T, Sugama J. Relationship between mattress internal air pressure and interface pressure distribution in the lateral position. Int Wound J. 2022;19(8):2115-2123. doi:10.1111/iwj.13817