**Brief Report**

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# Stability of ischial pressure with 3D thermoplastic elastomer cushion and the characteristics of four types of cushions in pressure redistribution

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**SUMMARY** Wheelchair cushions are recommended to be used with wheelchair and can protect the buttocks from pain and injury by relieving interface pressure for wheelchair users. However, further investigations are required for proper use in response to the development of new types of wheelchair cushions. The objective of this study was to evaluate physical characteristics of wheelchair cushions by comparing pressure redistributing effects of four types of cushions. The participants were 16 healthy adults who consented to participate in this study. A pressure mapping system (CONFORMat, Nitta Corp.) was used for the measurements. Pressure at ischium was measured immediately after the stabilization of the sitting posture and 10 minutes after. The pressure at ischium significantly decreased with any wheelchair cushions ($P < 0.01$). A significant negative correlation between body mass index and pressure at ischium was observed without a wheelchair cushion ($r = - 0.70$), however, the correlation disappeared upon use of a wheelchair cushion. The pressure at ischium increased over time with cushions of urethane, air, and urethane-air hybrid while that with the 3D thermoplastic elastomer cushion did not, and the change in the pressure was statistically less than that in other cushions ($P < 0.01$). Use of wheelchair cushions was effective in redistribution of the pressure at ischium, and the overtime change in the pressure depends on the type of used cushions.

***Keywords*** Wheelchair cushion, ischium pressure, pressure redistribution

## 1. Introduction

Use of wheelchair cushions is recommended to improve activities of daily living and quality of life for wheelchair users (*1,2*) and wheelchair cushions are expected to protect patients from pain and injury by relieving interface pressure on the buttock (*3*), as well as control postural retention (*4*). Stage I pressure ulcers with intact sensation can present as intact skin and pain (*5*). They can require long-term treatment and care, resulting in significant medical and economic costs if these injuries are not prevented or treated early (*6-8*). Therefore, appropriate management of buttock pressure is important for wheelchair users.

When sitting on the seat of a wheelchair, buttock pressure is concentrated on sites of bone, mainly ischia, increasing pain and a risk of injury (*9*). To mitigate the high pressure, it is recommended that wheelchair users intermittently relieve pressure by decompressing every 15 to 30 minutes (*10*). However, this is challenging for some wheelchair users such as elderly patients and those with shoulder pain. In addition, since wheelchair users spend long periods in their wheelchairs (*9*), it is necessary to supply environments to distribute buttock pressure.

This study focused on wheelchair cushions as a method to manage the buttock pressure. Brienza *et al.* reported using air, viscous fluid/foam, or gel/foam

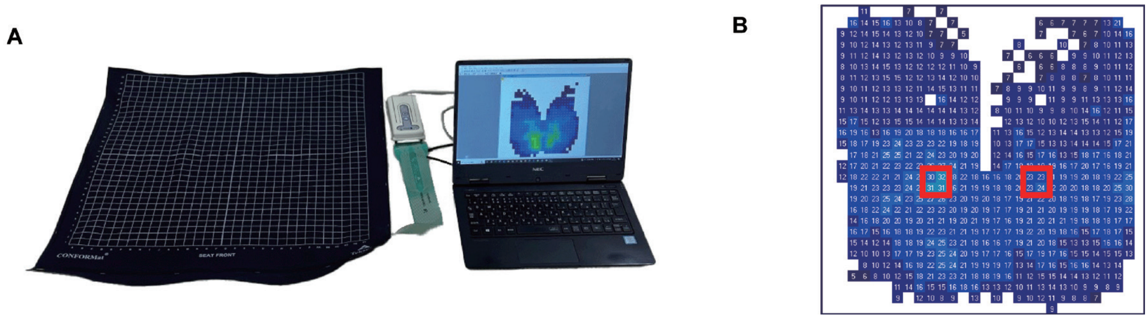

**Figure 1. Calculation of peak pressure index (PPI). (A)** PPI was measured using CONFORMat (Nitta Corp.). **(B)** Mean value of the four sensors €sl161€slmult0 around the maximum pressure (PPI) in the ischium region was calculated.

cushions was more effective than using standard foam cushions in preventing pressure injuries (*11*). European Pressure Ulcer Advisory Panel, National Pressure Injury Advisory Panel, and Pan Pacific Pressure Injury Alliance recommend the use of wheelchair cush-ions for the prevention of pressure ulcers in long-term wheelchair users (evidence level B1) in the Prevention and treatment of pressure ulcers/injuries: Quick reference guide 2019 (*12*). Although it is also recommended to consult experts when choosing wheelchair cushions, there is a lack of established foundational information on selecting the appropriate cushions for specific users (*12*). To establish foundational information regarding the characteristics of cushions, it is necessary to compare healthy young individuals. However, according to a report by Arias *et al.* (*13*), healthy adults experience no pain or discomfort when using alternating cushions. We believe that it is crucial to conduct a pilot study with healthy young adults to acquire objective data on the properties of different cushions. This approach would lay the groundwork for subsequent research focused on high-risk populations, including elderly with diminished cognitive functions and patients with Spinal Cord Injuries (SCI). Therefore, this study aimed to evaluate the fundamental and engineering characteristics of wheelchair cushions by comparing the pressure redistributing effect of different types of cushions in healthy young adults.

## 2. Materials and Methods

The research design was a five-group crossover test comparing ischial pressure in a seated position, either with or without four different types of wheelchair cushions. This study was conducted in a laboratory with controlled temperature and humidity at Naragakuen University. Measurements were taken over two months, from September to October 2021.

### 2.1. Participants

The inclusion criteria were healthy adults in their twenties attending a university in Japan. The exclusion criteria were individuals with orthopedic diseases, those experiencing regular pain, and those with a body mass index (BMI) over 30. Ultimately, the subjects were 16 healthy adults (6 males and 10 females; mean ± standard deviation (SD) age, 20.2 ± 0.6 years; height, 164.3 ± 8.9 cm; weight, 55.3 ± 5.6 kg; BMI, 20.5 ± 1.7) who agreed to participate in this study. This sample number was equivalent to previous studies (*14-16*).

### 2.2. Measurement

A CONFORMat (Nitta Corp.) was used to measure the body pressure (Figure 1). The CONFORMat is a sensor mat that has been tested for reliability and validity (*17-19*). The specifications of the sensor sheet were as follows: sensor sheet depth 471 mm × width 471 mm, 1024 sensors (32 rows × 32 columns), sensor thickness 1.8 mm, and resolution 14.7 mm. The wheelchair used was a standard type (MATSUNAGA MANUFACTORY Co., Ltd.).

Four types of cushions were tested: a urethane foam material (MODERATE CUSHION; LAC Healthcare Ltd.: Special urethane material, 40 × 40 × 6 cm: cushion U), a 3D thermoplastic elastomer material (GELTRON; PACIFIC WAVE Co., Ltd.: 3D thermoplastic elastomer material, 38 × 38 × 3.5 cm: cushion T), an air material (ROHO; Permobil Co., Ltd.: A single-valve, low-profile air material, 40.5 × 43 × 5.5 cm: cushion A), and a hybrid of urethane foam and air material (CUBURENA; CAPE Co., Ltd.: Air and special urethane material, 40 × 40 × 10 cm: cushion H).

The height, weight, seated buttock width, seated bottom length, seated leg length, seated olecranon height, and seated axillary height of the participants were measured. These measurements were taken to adjust features of the wheelchair, such as foot supports and back supports, to minimize the impact of individual body shape variations on seating pressure. After adjusting the wheelchair to each participant's body shape, buttock and ischial pressure was measured in the wheelchair without a cushion. Subsequently, each participant's buttock and ischial pressure was measured while using the four different types of cushions, specifically cushions U, T, A, and H, in a random order. The order of cushion use for each participant was determined by the envelope method (*20*), a standard procedure for randomization in research studies. The ischial pressure was measured in the area on the monitor at a predetermined location. Regarding the measuring position, the pelvis was positioned as far back as possible behind the seat, the seat surface was positioned horizontally, and the position of the foot supports was adjusted so that the thighs became horizontal. The soles of the feet were placed on the foot supports, and both upper limbs were placed on the thighs, not on the arm supports. It is recommended to change positions and reduce pressure every 15 to 30 minutes to reduce the risk of ulcer formation (*10*). In this study, although the subjects were young and healthy, the seating time was set to 15 minutes, considered safe to avoid any risk of pressure ulcer development. The first 5 minutes after seating were allotted for the stabilization of buttock pressure. Then, buttock pressure was monitored in real-time for the next 10 minutes. The ischial pressure was recorded during the first and last minute of this monitoring period. An interval of 5 minutes was maintained between measurements for each condition. For the pressure at ischium, the mean value of four sensors around the maximum pressure area (PPI: peak pressure index) was calculated for each condition.

2.3. Statistical analysis

Comparisons of pressure at the ischium for each condition were performed using ANOVA with Greenhouse-Geisser ε-correction (*21*). When ANOVA detected significant differences, a multiple comparison test was performed using the paired-samples *t*-test with correction by Shafer's method (*21*). Additionally, 95% confidence intervals (CIs) and effect sizes were calculated. Effect sizes were calculated using two different measures. The eta squared ($\eta^2$) was used to measure the proportion of variance accounted for by the group differences, calculated as $\eta^2$ = Sum of Squares Between Groups/Total Sum of Squares. Additionally, Cohen's d was used to measure the standardized mean difference between the two groups, calculated as d = (mean of Group A - mean of Group B) / $\sqrt{((SD^2}$ of Group A + $SD^2$ of Group B) / 2). To examine the relationship between body mass and pressure at ischium, the correlation between pressure at ischium and BMI in each group was analyzed using the Pearson product-moment correlation coefficient. To investigate changes in pressure at ischium over time, multiple comparisons were performed on the amount of change in the pressure at ischium at the beginning of the measurement and at the end of the measurement. All analyses were conducted using R (ver.4.0.3, R Foundation) for Windows software, and statistical significance was set at $P < 0.05$.

2.4. Ethics

This study was conducted following the Declaration of Helsinki. The purpose and significance of the study were fully explained to all subjects, and measurements were performed after obtaining their signatures on a consent form. Written informed consent was obtained from all subjects before the study. This study was approved by APPROVAL NUMBER/ID 3-R003.

## 3. Results and Discussion

The values of ischial pressure 10 minutes after the start of monitoring were 75.7 ± 30.9 mmHg in no-cushion condition, 27.3 ± 5.6 mmHg with cushion U, 36.8 ± 7.6 mmHg with cushion T, 34.4 ± 6.3 mmHg with cushion A, and 26.0 ± 4.2 mmHg with cushion H. ANOVA showed significant differences among the five groups, and the multiple comparison test showed that the pressure at ischium with cushions U, T, A, and H were significantly lower than that in no-cushion condition ($P < 0.01$, effect size: $\eta^2 = 0.61$). In addition, the pressure at ischium was significantly higher with cushions T and A than with cushion U (effect size, T *vs.* U: d = 1.42, A *vs.* U: d = 1.2), and with cushions T and A than with cush-ion H (effect size, T *vs.* H: d = 1.76, A *vs.* H: d = 1.58) (Table 1). A significant negative correlation between BMI and pressure at ischium was found in no-cushion conditions ($r = -0.70$). However, no significant correlation was observed with cushions U, T, A, and H (U: $r = -0.25$, T: $r = -0.45$, A: $r = -0.30$, H: $r = -0.07$)

**Table 1. Pressure redistributing effect of different cushions**

| Cushions | Pressure at ischium (mmHg) | *P* value | effect size: *d* |
|---|---|---|---|
| N *vs.* U | 75.7±30.9 (59.2-92.2) *vs.* 27.3±5.6 (24.3-30.3) | < 0.01 | 2.18 |
| *vs.* T | *vs.* 36.8±7.6 (32.8-40.9) | < 0.01 | 1.73 |
| *vs.* A | *vs.* 34.4±6.3 (31.0-37.8) | < 0.01 | 1.85 |
| *vs.* H | *vs.* 26.0±4.2 (23.8-28.2) | < 0.01 | 2.25 |
| U *vs.* T | 27.3±5.6 (24.3-30.3) *vs.* 36.8±7.6 (32.8-40.9) | < 0.01 | 1.42 |
| *vs.* A | *vs.* 34.4±6.3 (31.0-37.8) | < 0.01 | 1.2 |
| *vs.* H | *vs.* 26.0±4.2 (23.8-28.2) | N.S. | 0.26 |
| T *vs.* A | 36.8±7.6 (32.8-40.9) *vs.* 34.4±6.3 (31.0-37.8) | N.S. | 0.35 |
| *vs.* H | *vs.* 26.0±4.2 (23.8-28.2) | < 0.01 | 1.76 |
| A *vs.* H | 34.4±6.3 (31.0-37.8) *vs.* 26.0±4.2 (23.8-28.2) | < 0.01 | 1.58 |

The values are expressed as mean ± standard deviation (95% confidence interval). Abbreviations: N: no-cushion condition; U: urethane foam material; T: 3D thermoplastic elastomer material; A: air material; H: hybrid type; N.S.: Non-significant.

**Table 2. Correlation of BMI and pressure at ischium with each cushion**

| Cushions | Correlation (BMI and pressure at ischium) | *P* value |
|---|---|---|
| N | –0.72 | 0.001 |
| U | –0.25 | 0.34 |
| T | –0.45 | 0.08 |
| A | –0.3 | 0.26 |
| H | –0.07 | 0.19 |

BMI: body mass index; N: no-cushion condition; U: urethane foam material; T: 3D thermoplastic elastomer material; A: air material; H: hybrid type.

(Table 2). These results indicated that all four types of wheelchair cushions were effective in redistributing pressure at ischium. In the no-cushion group, there was a significant negative correlation between pressure at ischium and BMI, but interestingly, this correlation was not observed with any type of wheelchair cushions. Izaka *et al*. reported that the use of a wheelchair cushion increased the pressure-detected area and distributed regional pressure compared to no use of a wheelchair cushion (*22*). Thus, in this study, the use of wheelchair cushions could lessen the high pressure at ischium due to bony prominences, leading to the disappearance of BMI-dependence in interface pressure by the application of wheelchair cushions. It has been reported that increased regional pressure on soft tissues causes pressure injuries (*23*), and the world guideline also recommends the use of wheelchair cushions for the prevention of pressure injuries (*12*); therefore, the application of wheelchair cushions used in the present study is encouraged for wheelchair users.

On the other hand, The change in the pressure at ischium over time (10 minutes) was 1.07 ± 0.08 in cush-ion U, 1.00 ± 0.05 in cushion T, 1.08 ± 0.09 in cushion A, and 1.08 ± 0.09 in cushion H, significantly larger with cushions A and H than with cushion T ($P < 0.05$, effect size: d = 1.1), and tended to be greater with cushion U than in cushion T ($P = 0.07$, effect size: d = 1.05) (Figure 2). A noteworthy point in this study is that the pressure at ischium with cushions U, A, and H tended to increase over time, but there was no change in pressure over time with cushion T. This result implies that the use of 3D thermoplastic elastomer cushions makes seating pressure less changeable over time. The 3D thermoplastic elastomer material is structured to change its shape per the amount of pressure, thus increasing the contacting area (*24*). Therefore, the 3D thermoplastic elastomer cushion provides high pressure absorption as the material deforms to fit the buttocks and thighs (*24-27*). In addition, 3D thermoplastic elastomer is a durable material (*24,27*). Hence, it is supposed that the pressure on the ischium did not increase even 10 minutes after the start of measurement because the cushion fitted to the shape of the body and did not cause any slides or postural changes due to its durability. Given the above,

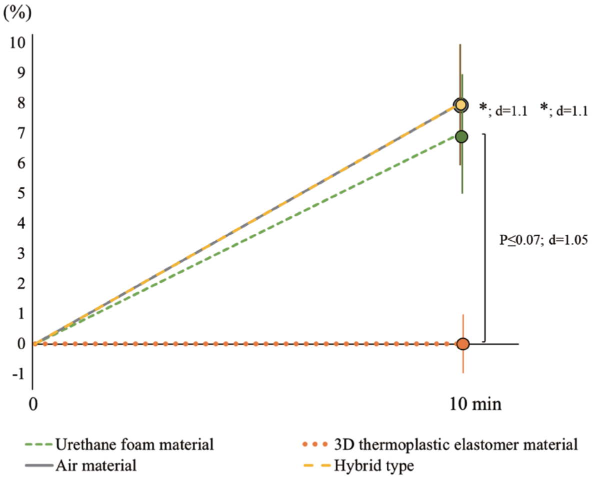


**Figure 2. Change rate of pressure over time with cushions (10 minutes).** Pressure at ischium with each cushion was measured using CONFORMat (Nitta Corp.). Mean ± standard error. *:$P < 0.05$ (3D thermoplastic elastomer material *vs*. air material, hybrid type), d: effect size.

3D thermoplastic elastomer cushions can be effective in the prevention of pressure injuries for wheelchair users with high pressure at ischium by postural changes in prolonged seating. Meanwhile, with the cushion T, the pressure at ischium was slightly higher than that in other cushions from the beginning, suggesting that 3D thermoplastic elastomer cushions might not be suitable for patients with high-risk factors of pressure ulcers such as pathological bony prominences. Further studies are needed to clarify this point.

This study also compared the pressure redistributing effects among the four types of wheelchair cushions and found that hybrid and urethane cushions had significantly greater effects than 3D thermoplastic elastomer and air ones. This supports the need for appropriate cushioning during prolonged seating. A hybrid wheelchair cushion, which showed a greater pressure-redistributing effect, is designed to combine the durability and stability of the urethane foam cushion with the effect of evenly distributing weight on the seating surface of the air cushion. Shin *et al.* reported that adding a base pelvic pad to a wheelchair cushion significantly reduced mean and peak pressures and increased the contact area of the buttocks and thighs compared to a wheelchair cushion alone (*28*). Based on this, it is assumed that the hybrid wheelchair cushion used in this study exhibited better pressure re-distributing effect because it combined the advantages of urethane and air in addition to a pad as the base of the cushion. As for the air and urethane cushions, Koo *et al.* and Cohen *et al.* reported that the air cushion showed lower mean and maximum pressure at ischium than the urethane cushion, indicating different results from the present study (*29,30*). The participants in these studies were SCI patients with sensory impairments in the buttock region, which is distinct from the subjects of our study. Therefore, the discrepancy in the results of the pressure redistributing effect would be different due to the difference of the subjects for the study. Given the rising number of elderly people at a high risk of pressure injuries due to reduced cognitive function and SCI patients with sensory deficits in the buttocks, the need for an appropriate selection of wheelchair cushions based on the user's needs is expected to increase.

Our results suggest that each wheelchair cushion has its characteristics and that it is necessary to appropriately select a wheelchair cushion suitable for each patient. However, there are several limitations in this study. First, since this study was conducted with adults without pathological bony prominences, the effect on patients at high risk for pressure injuries might be different. Consequently, it is not possible to generalize the findings of this study to individuals with different physical and health profiles. Future research needs to be conducted with populations at high risk for pressure injuries such as patients with SCI and cognitively impaired elderly. Second, although the effect sizes in this study were large enough, the sample size may have been small due to the lack of pre-calculation of the required sample size. Future research with a pre-calculated sample size will hopefully confirm these results more robustly.

In summary, the use of wheelchair cushions was effective in the redistribution of the pressure at the ischium. Each type of wheelchair cushion has different effects and characteristics. Additionally, the 3D thermoplastic elastomer cushion was effective in reducing the increase in pressure over time.

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