

Original Article

# Effect of a Dynamic Air Cushion on the Development of Leg Edema during Wheelchair Sitting

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**Abstract.** [Purpose] To clarify how a novel dynamic cushion affects the leg edema evoked by wheelchair sitting, we measured the changes in leg volume induced during wheelchair sitting with the dynamic air cushion or a static cushion. [Subjects and Methods] Nine healthy male subjects participated in this study. Leg edema during wheelchair sitting was evaluated with strain gauge plethysmography (the gauge was placed around the middle portion of the lower thigh). Following a period of rest, each subject was asked to sit on a wheelchair containing the dynamic cushion for 15 min. Then, the protocol was repeated with a static cushion. The angles of the knee and ankle joints were set to 90 degrees, and no footrests were used. [Results] The change in leg volume observed during sitting on the dynamic cushion ( $0.00 \pm 0.03$  mL/100 mL) was smaller than that observed during sitting on the static cushion ( $0.02 \pm 0.02$  mL/100 mL). [Conclusion] These results suggested that the dynamic cushion relieved leg edema during wheelchair sitting.

**Key words:** Wheelchair cushion, Leg volume, Healthy human

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## INTRODUCTION

Wheelchairs are used to transfer physically handicapped patients who are incapable of walking. On the other hand, permanent wheelchair sitting is almost inevitable in patients with severe disorders of the central nervous system such as spinal cord injuries. In these patients, sitting-evoked pressure ulcers are a major concern<sup>1)</sup>, as they can require hospital treatment and a prolonged period of bed rest. Sitting-evoked pressure ulcers typically appear in the soft tissues enveloping the buttock areas (i.e., the sacrum and ischium)<sup>2, 3)</sup>. One strategy for reducing the risk of pressure ulcers in permanent wheelchair users is to provide a pressure relieving wheelchair cushion.

Wheelchair cushions reduce the pressure placed upon the regions inferior to these bony prominences by redistributing the forces over a larger area. Numerous types of wheelchair cushion are available commercially, and nearly all of them claim to prevent the development of pressure ulcers. These cushions can be grouped into three major categories based on the materials they are made out of, i.e., air, gel, or polyurethane foam. Moreover, dynamic wheelchair cushions have been developed as alternative means

of pressure relief<sup>4–7)</sup>. These cushions, which intermittently or continuously change the physical characteristics of the seating surface in order to redistribute the pressure placed on the buttocks, might be able to provide automatic pressure relief. Recently, we reported that the dynamic cushion was more effective at relieving pressure on the seating surface than a polyurethane foam cushion<sup>7)</sup>. This pressure-relieving effect might influence the hemodynamic changes induced in the lower limbs during wheelchair sitting. Moreover, the dynamic cushion might be effective in reducing leg edema associated with increased hydrostatic pressure in the capillaries during sitting. Therefore, this study aimed to clarify whether the use of the abovementioned dynamic cushion affects the change in leg volume during wheelchair sitting.

## SUBJECTS AND METHODS

### Subjects

Nine male subjects participated in this study (mean  $\pm$  standard deviation of the mean, SD; age,  $36.8 \pm 16.1$  yr; height,  $169.2 \pm 4.0$  cm; and weight,  $64.1 \pm 10.7$  kg). All of the subjects were healthy, and none of them were taking any medication. The subjects were informed about the experimental procedures in advance, and their written consent was obtained. This study was performed in accordance with the Declaration of Helsinki and approved by the institutional ethics committee of Nagasaki University.

### Methods

In this study, two types of cushion, a dynamic air cush-

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ion and a static cushion (constructed from polyurethane foam), were used. The dynamic cushion (NK-TC36, Taica Corporation, Tokyo, Japan; length×width, 40×40 cm; thickness, 7 cm) was composed of a battery-powered pump and a dual-air system composed of two air cells (chambers A and B; 6 cm × 6 cm) (Fig. 1A). These air chambers were alternately inflated and deflated over a 1-minute cycle, with a short period of overlapping deflation. The internal pressure of each air cell was controlled within a range from 2 to 8 kPa by a pressure sensor (Fig. 1B), and the air cells were surrounded by a thin layer of polyurethane foam (thickness, 1 cm). The static cushion, which was made of polyurethane foam, was the same size (length×width, 40×40 cm; thickness, 7 cm) as the dynamic cushion.

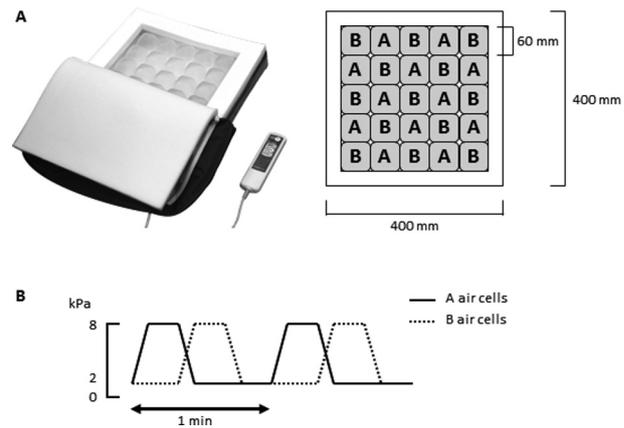
Leg edema was evaluated using strain gauge plethysmography (EC-6, D.E. Hokanson Inc., Bellevue, WA, USA), with the subjects sitting in a wheelchair. The strain gauge was placed around the middle portion of the lower thigh (Fig. 2A). The data obtained from the plethysmograph and the marking signals used to indicate the beginning and end of the study period were simultaneously stored on a computer using an analogue-digital converter (UAS-108S, Unique Medical, Tokyo, Japan) at a sampling frequency of 500 Hz and analyzed using computer software (Unique Acquisition 2.11, Unique Medical, Tokyo, Japan).

All experiments were performed at an ambient temperature of 22–24°C. After the preparations for the experiments had been completed, the subjects were told to lie down on a bed for more than 10 min to allow their cardiovascular variables to stabilize. The experiments consisted of two procedures. Following the resting period, each subject was asked to sit on a wheelchair containing the dynamic cushion for 15 min. Then, the protocol was repeated using the static cushion. The angles of the knee and ankle joints were set to 90 degrees, and no footrests were used. The period between the two protocols were at least 15 min, during which the subjects were instructed to lie on the bed. To control for the order effect of the evaluation sequence, the two cushions were presented in a counterbalanced, random manner.

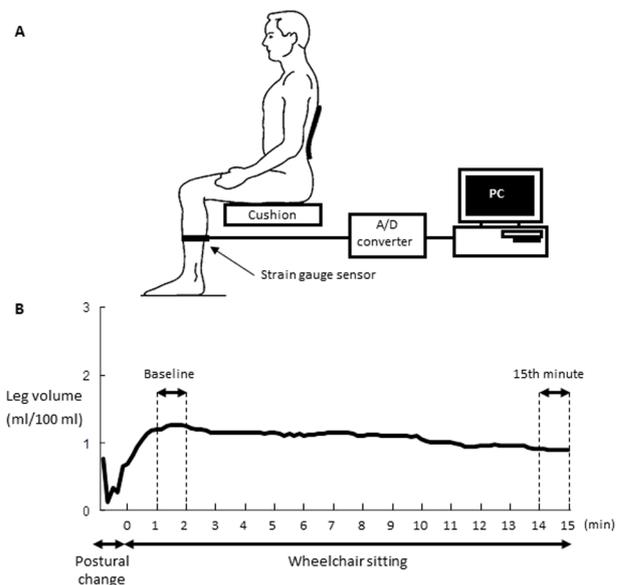
The data obtained from the plethysmograph and the marking signals were displayed on a computer screen. The start and end of the wheelchair sitting period were indicated visually by the marking signals. The changes in leg volume during the prolonged phase (1–15 min) were analyzed. The mean leg volume value obtained for the second minute after the onset of wheelchair sitting was defined as the baseline level, and was compared with the mean leg volume value for the 15th minute of sitting (Fig. 2B). Then, the change in leg volume (ml/100 mL/min) was calculated. The results were compared between the two procedures (the dynamic and static cushion procedures) using the paired t-test. P-values of < 0.05 were considered statistically significant. The data are expressed as mean ± SD values.

**RESULTS**

A comparison of the changes in leg volume between the dynamic and static cushions is shown in Table 1. Leg volume increased during sitting on the static cushion, whereas it remained unchanged during sitting on the dynamic cushion.



**Fig. 1.** The dynamic air cushion



**Fig. 2.** Measurement of leg volume

**Table 1.** Comparison of the change in leg volume between the dynamic and static cushion procedures

	Static cushion	Dynamic cushion
Change in leg Volume (ml/100 ml)	0.02 ± 0.02	0.00 ± 0.03 *

Mean ± SD. \* p < 0.05

ion. There was a significant difference between the changes in leg volume observed during the static and dynamic cushion procedures (p = 0.048).

**DISCUSSION**

The purpose of this study was to clarify whether the effect of wheelchair sitting on leg edema differed depending on whether a dynamic air cushion or static cushion was used. The major finding of the present study was that the increase in leg volume caused by wheelchair sitting was at-

tenuated by using the dynamic air cushion, but not the static cushion. These results suggest that the dynamic air cushion relieved the leg edema induced by wheelchair sitting.

Edema of the limbs usually develops due to an increase in hydrostatic pressure after long periods of sitting or standing. A previous study reported that the calf volume response to the acute phase of head-up tilting (0–1 min) mainly reflects the filling of the veins due to an increase in hydrostatic pressure and that the prolonged phase of head-up tilting (>1 min) mainly reflects the degree of fluid filtration through capillary walls<sup>8, 9</sup>. In this study, the changes in leg volume were measured from 1 min after the onset of wheelchair sitting. Thus, the present results might reflect the changes in fluid filtration through capillary walls during the prolonged phase of wheelchair sitting. On the other hand, it was difficult to analyze the change in leg volume just after the position change, because the plethysmographic recordings were highly influenced by movement artifacts. Thus, the effect on the filling of the veins due to an increase in hydrostatic pressure is unclear but warrants examination.

The increase in leg volume during wheelchair sitting was reduced by using the dynamic air cushion, but not the static cushion. The dynamic cushion used in this study contains air cells that are repeatedly and alternately inflated and deflated by a dual-air system. This action might evoke venous pumping in the buttock regions, which would force blood out of the superficial veins of the lower extremities. It is considered that massaging improves circulatory and tissue fluid levels<sup>10, 11</sup>. When a superficial valve-bearing vein or blind-ended lymph channel is compressed, fluid can only drain towards the heart<sup>11, 12</sup>; thus, massaging promotes venous return, which in turn reduces swelling very effectively, and hence, is widely used for clinical care. The dynamic cushion used in the present study might have a similar effect to massaging.

Another possibility is that the alternating inflation and deflation of the cushion causes imperceptible leg movements, which in turn induce leg muscle pumping. Several studies have reported that muscle exercises have a preventive effect on leg edema<sup>13–15</sup>. This effect is considered to be caused by factors such as decreased venous pressure<sup>16</sup>, increased lymph flow<sup>17</sup>, and the augmentation of muscle tissue pressure<sup>18</sup> during exercise. The passive body movements evoked by sitting on the dynamic cushion might also have a preventive effect on the development of edema.

One limitation of our study is that we only examined male subjects. A previous study has reported that females display a lower tolerance to orthostatic challenge than males<sup>19</sup>. This gender effect may also influence the hemodynamic changes induced in the lower limbs during wheelchair sitting. Moreover, it is possible that the leg edema induced by wheelchair sitting is more pronounced in tall individuals than in short individuals because of the larger hydrostatic pressure changes<sup>20</sup>. But this study was too small to detect the influence of body height. Further studies are necessary to clarify these points.

In conclusion, the increase in leg volume observed during wheelchair sitting was attenuated by using the dynamic cushion, but not the static cushion. The present results suggest that the dynamic cushion could be used to prevent leg

edema during wheelchair sitting.

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