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ORIGINAL ARTICLE

Effect of Footrest Angle on Decrement of Leg Swelling while Sitting

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Abstract: Sitting in the comfort of chairs is an important factor of daily life, but leg swelling results in languor of lower legs and decreases sitting comfort. Many studies have examined the mechanism of increased leg swelling; however, few have investigated the mechanism of decrease leg swelling. We studied the effect of the footrest angle on decreases in leg swelling by measuring leg swelling with bioelectrical impedance method (BI method) and blood flow with near-infrared spectroscopy (NIRS). We performed the sitting experiment with six volunteers. It comprised three parts; (1) lying supine for 20 minutes to alleviate leg swelling, (2) sitting on a high stool for 30 minutes to increase leg swelling, (3) sitting on a trial chair with a footrest for 30 minutes to decrease leg swelling in order to research the differences among three footrest angles (0°, 15°, and 30°). By the results of the BI method, leg swelling increased by sitting on the high stool and decreased by sitting on the trial chair with a 30° footrest. By the results of NIRS, the quantity of deoxygenated hemoglobin (deOXY-Hb) increased by sitting on the high stool and the quantity of oxygenated hemoglobin (OXY-Hb) increased by sitting on the trial chair. In comparison of leg swelling and blood flow, it is considered that increases in deOXY-Hb influences gains in leg swelling, and increases in OXY-Hb influences reductions in leg swelling.
Keywords: *Leg swelling, Bioelectrical impedance method, Near-infrared spectroscopy*

1. INTRODUCTION

We have many occasions to sit on chairs in daily life. Sitting in the comfort of chairs is an important factor of daily life in terms of its relaxation effect, which reduces fatigue. This reduction in fatigue is a desired characteristic of vehicle seats and home-use chairs.

Leg swelling, which frequently occurs during sitting, results in languor of the lower legs and decreases sitting comfort. According to Kawakami [1], 90% of females and 15% of males are bothered by leg swelling while sitting. Therefore, leg swelling is a problem of daily life that must be addressed. Leg swelling is generated by an increase in leg volume secondary to an increase in extracellular interstitial fluid [2]. Leg swelling while sitting has several causes, including blood stagnation due to pressure on the thigh and diminution of the pumping effect of the gastrocnemius [3, 4].

Many studies have examined the mechanism of increased leg swelling [1, 2, 5]; however, few have investigated the mechanism of decreased leg swelling. Thus, the overall mechanism of leg swelling remains unclear. In addition, the gravity effect secondary to lifting of the legs and the pumping effect secondary to the activity of the gastrocnemius effectively decrease leg swelling; however, it is difficult to perform such exercises in a limited space while sitting still. Therefore, we focused on footrests, particularly the footrest angle, because the presence of a footrest or alteration of its angle is an alternative method by which to decrease leg swelling. We studied the effect of the footrest angle on decreases in leg swelling using both a bioelectrical impedance method (BI method) and near-infrared spectroscopy (NIRS).

The purpose of this study was to investigate the effect of the footrest angle on decreases in leg swelling by measuring leg swelling and blood flow. Moreover, we examined the relationship between leg swelling and blood flow when leg swelling increased or decreased.

2. METHODS

2.1 Outline of experiment

The sitting experiment performed in this study comprised three parts. First, the participants lay supine for 20 minutes to alleviate or decrease leg swelling before the experiment. Next, the participants sat on a high stool for 30 minutes to increase leg swelling. Finally, the participants sat on a trial chair with a footrest for 30 minutes to decrease leg swelling (Figure 1).

This procedure was conducted once a day and was repeated three times (3 days) to research the differences among three footrest angles. The order of the footrest angles was randomized for each participant. Experiments were carried out in an experimental room that was adjusted to 22°C and 50% relative humidity. We utilized

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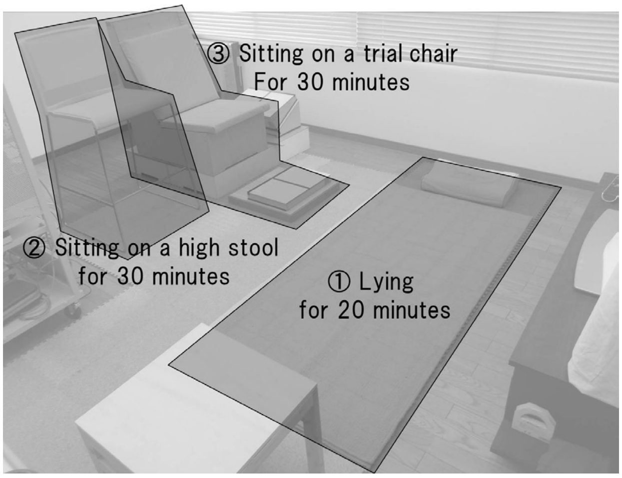


Figure 1: Experiment scenery

two measurements: leg swelling by the BI method and leg blood flow by NIRS.

2.2 Chairs and sitting posture

When the participants sat on the high stool (height, 690 mm; seat, 410 mm [depth] × 470 mm [width]) for 30 minutes, they were instructed to sit back, touch the backrest, and let their legs hang down.

We manufactured a trial chair made of wood frames and cloth-covered urethane cushions, which was assumed to be a relaxation chair. Figure 2 shows the detailed dimensions of the trial chair. The trial chair had three types of footrests, and the top board angle differed among them (0°, 15°, and 30°). The height of the front side edge (50 mm) and dimensions of the top board (300 mm [depth] × 450 mm [width]) were identical among all three footrests.

When the participants sat on the trial chair, the sitting posture from the side view was established as follows; (1) the scapula touched the back of the cushion, (2) the ischium was placed 210 mm from the distal aspect of the seat cushion, and (3) the heel was in contact with the proximal aspect of the top board of the footrest.

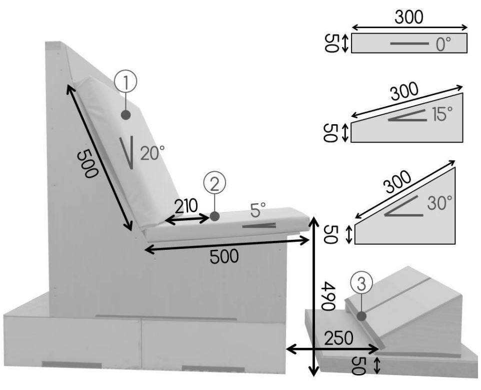


Figure 2: Detailed dimensions of the manufactured trial chair [mm]

2.3 Measurement of leg swelling by BI method

The BI method is a technique that estimates water volume within the human body by measuring changes in impedance (or resistance) while a multifrequency electrical current flows. Several previous studies have measured leg swelling using the BI method [1,6-8]. According to Seo [6], the shape of the lower leg is assumed to be a cylinder (radius of the base = r), and swelling occurs equally at any position in the leg. The value r then changes according to the level of swelling. The resistance or impedance is expressed by the following equations:

$$R = \rho l \pi r^2 \tag{1}$$

$$\therefore\ V = \pi r^2 l = \rho l^2 / R = C \times 1 / R \tag{2}$$

R : resistance (impedance)
ρ : resistance rate (constant)
l : length of the leg (constant)
πr^2: sectional area of leg
V : volume
C : constant numbers

Therefore, the change in water volume leading to leg swelling is inversely proportional to change in resistance or impedance. In addition, a high-frequency electrical current flows inside cells, and a low-frequency electrical current flows through extracellular interstitial fluid. It is hypothesized that the water volume in the extracellular region increases because of the increase in leg swelling and because a low-frequency current flows easily; thus, impedance decreases. In this study, we defined R0 as resistance at zero frequency, and determined BI to be the index of leg swelling by calculating the reciprocal of R0. If BI increases, leg swelling increases:

$$BI = 1 / R_0 \tag{3}$$

R_0 was measured using MLT-50 and MLT-30 (Sekisui Medical Co., Ltd., Tokyo). These two devices have the same specifications. Four electrodes (Eslode ER-240P: Sekisui Medical Co., Ltd., Tokyo) were placed on the shin regions of both legs according to the anatomical features (Figure 2). BI was obtained every 5 minutes while sitting on the high stool and trial chair.

We calculated the ratio of the change in BI (BI%) every 5 minutes while sitting according to the following equation:

$$BI\% = BI_i / BI_0 \times 100 \tag{4}$$

BI_i : measured BI at every 5 min ($i = 1, 2, \cdots, 6$)
BI_0 : measured BI just after sitting

2.4 Measurement of blood flow by NIRS

NIRS is a technique that measures the quantity of oxygenated hemoglobin (OXY-Hb) and deoxygenated hemoglobin (deOXY-Hb) based on their different light absorption characteristics when irradiating near-infrared light with various frequencies. According to Hosoi [9] and Oyama [10], deOXY-Hb is assumed to be associated with outflow of venous blood for internal respiration in a body organ such as the lower leg. In addition, we interpreted OXY-Hb is assumed to be associated with inflow of arterial blood. In this study, we measured blood flow (OXY-Hb and deOXY-Hb) at a depth of 13 to 30 mm from the surface of the skin using BOM-L1TRW (OMEGAWAVE, Inc., Tokyo). Sensor probes were attached to the points of maximum lower leg depth [11] for each leg (Figure 3). The sampling rate was 10 Hz while sitting on both the high stool and the trial chair.

We analyzed three indices at an average interval of 1 minute: OXY-Hb, deOXY-Hb, and Total Hb (OXY-Hb + deOXY-Hb) for noise processing. To exclude individual differences, we calculated the rate of change in each index (OXH%, deOXY%, and Total%) by dividing the average value by the initial value; that is, we performed standardization. Moreover, to study the relationship between blood flow and BI, we also calculated three indices at an average interval of 5 minutes to compare them with the BI every 5 minutes.

2.5 Participants

We recruited six volunteers as participants (three males and three females). Personal data are shown in Table 1. We measured the leg swelling and blood flow of each leg for all 6 participants and obtained 12 data parameters.

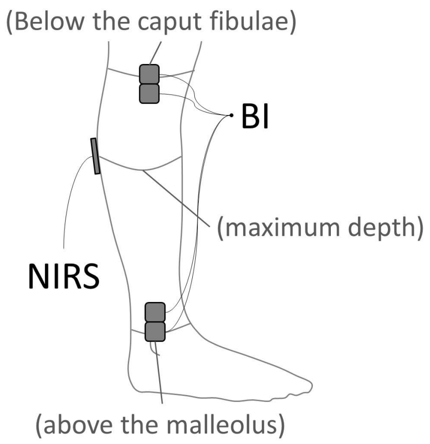


Figure 3: Positions of electrodes for BI and sensor probes for NIRS

Table 1: Participants' personal data

(M = male, F = female)

	P1 (M)	P2 (F)	P3 (M)	P4 (F)	P5 (M)	P6 (F)	**Ave. ± S.D.**
Age	37	38	29	32	41	31	**34.7 ± 4.3**
BMI	24	22	19	18	25	17	**20.9 ± 3.0**
Height [cm]	179	157	170	156	166	162	**165 ± 7.9**
Weight [kg]	76.8	53	56	43	70	45	**57.3 ± 12.4**

3. RESULTS AND DISCUSSION

3.1 Leg swelling by BI method

Figure 4 shows BI% as obtained by the BI method while sitting on the high stool for 30 minutes. These data were averaged among all of the data (n = 36 = 6 participants × 3 days × 2 legs).

These results show that BI% increased with time while sitting on the high stool and increased by an average of about 10% with 30 minutes of sitting. BI% of male subjects was significantly larger than that of female subjects from 5 to 30 minutes (t-test, $p < 0.05$). Although it was anticipated that leg swelling would be saturated, our results did not show this tendency for 30 minutes of sitting. However, because the curve gradient slightly changed at about 15 minutes, there is a possibility that the swelling increased gradually. In addition, because BI% increased with time for all subjects, it is considered that sitting on a high stool generated leg swelling. This is because the backside of the thigh was under pressure due to the legs hanging down while sitting on the high stool. The leg swelling increased in steady increments because the backrest restrained the body motion and there were thus few variations among subjects.

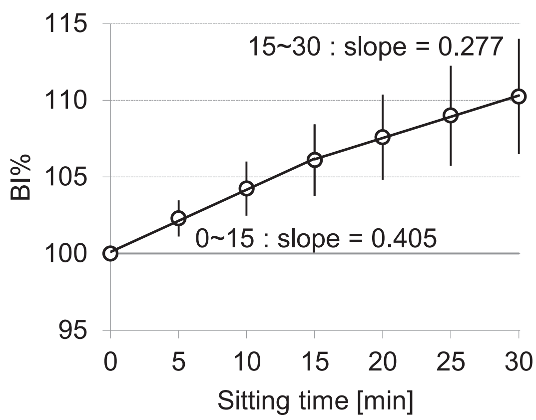


Figure 4: Results of BI% while sitting on the high stool (average ± SD)

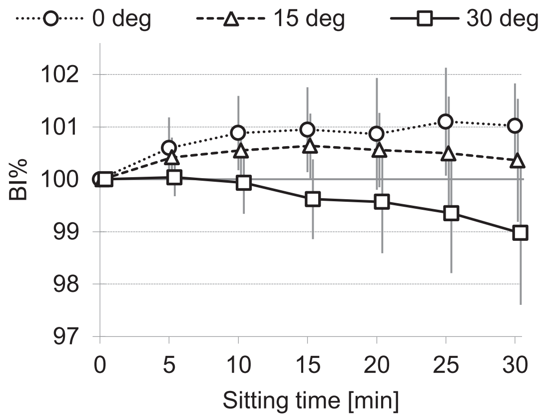


Figure 5: Results of BI% while sitting on the trial chair at each footrest angle (average ± SD)

Figure 5 shows BI% while sitting on the trial chair using the three footrest angles for 30 minutes. The obtained data were averaged among all subjects (n = 12).

The results show the difference in BI%; that is, the differences in leg swelling among the footrest angles. BI% moderately increased at 0º, remained flat at 15°, and slightly decreased at 30°. We performed two-way ANOVA with the time course and footrest angle from 5 to 30 minutes, and only the footrest angle had a main effect ($p<0.01$). Therefore, it is considered that differences in the footrest angle affected the occurrence of leg swelling. Moreover, a footrest angle of 30° was the best condition under which to reduce leg swelling in this study. However, the rate of decrease was about 1%, and the reduction effect was smaller than the gain effect (10% increment) while sitting on a high stool.

3.2 Blood flow

Figure 6 shows the rate of change in the hemoglobin levels (OXY%, deOXY%, and Total%) while sitting on the high stool. These data were averaged among all subjects, excluding one whose data widely varied over time (n = 35).

During 30 minutes of sitting on the high stool, OXY-Hb decreased and deOXY-Hb increased (Figure 5). In particular, because of the change in posture, deOXY-Hb dramatically changed until the 5-minute time point was reached, and total-Hb drastically increased until 5 minutes secondary to the influence of deOXY-Hb. Because the participants lay supine before sitting on the high stool and raising the body, the blood flowed into the lower extremities secondary to the gravity effect, and the total blood flow in the lower leg thus increased. Under the interpretation of deOXY-Hb as outflow of venous blood [9, 10] in internal respiration, the outflow of deOXY-Hb was impeded.

Figure 7 shows the results of blood flow at a footrest angle of 30° while sitting on the trial chair. These data were averaged among all subjects (n = 12).

We found that OXY-Hb increased, deOXY-Hb decreased, and Total Hb slightly increased while sitting on the trial chair. This is because the pressure on the backside of the thigh while sitting on the trial chair was smaller than that while sitting on the high stool. The blood circulation was restored because of the increases in OXY-Hb and deOXY-Hb secondary to sitting on the high stool flew out because of decrease of deOXY-Hb. However, there were no significant differences among the three footrest angles because these results showed a wide variation.

3.3 Comparison between leg swelling and blood flow

To investigate the relationship between leg swelling and blood flow, and especially to examine the difference between increased and decreased leg swelling, we assigned all 36 subjects with an increase in BI% while sitting on the high stool to the increased swelling group

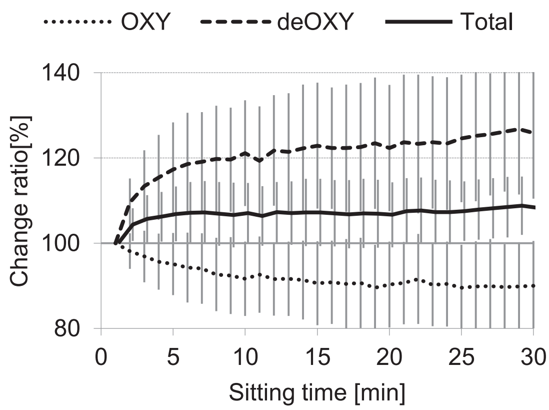


Figure 6: Blood flow while sitting on the high stool (average ± SD)

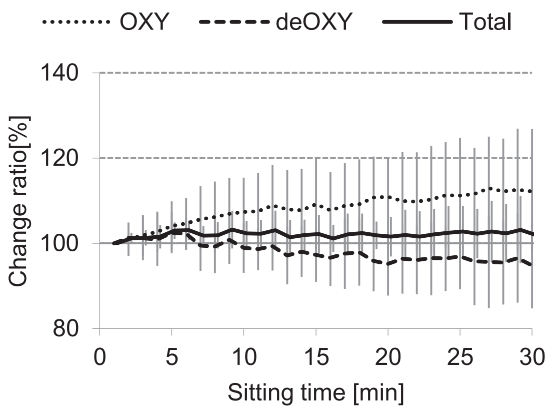
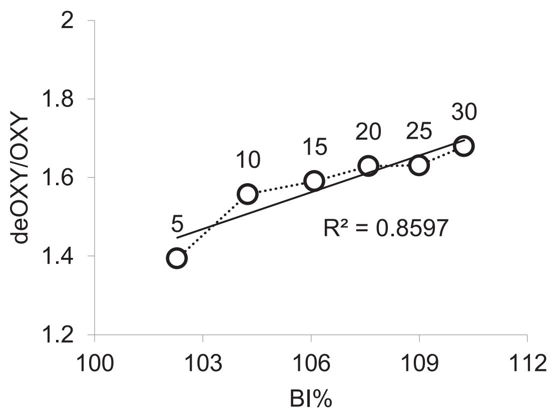


Figure 7: Blood flow while sitting on the trial chair with a footrest of 30° (average ± SD)

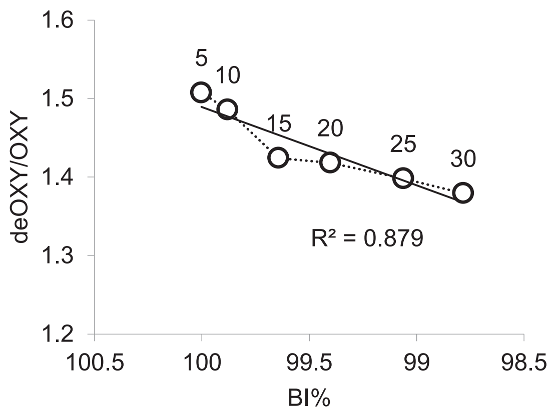
(Group A), 14 subjects with a decrease in BI% while sitting on the trial chair as the decreased swelling group (Group B), and the remaining 22 subjects with no change in BI% while sitting on the trial chair as the unchanged swelling group (Group C).

We calculated the correlation coefficient between BI% (leg swelling) and the ratio of deOXY-Hb/OXY-Hb (blood flow) for each subject in Groups A and B using all measurement values at an average interval of 5 minutes from 5 to 30 minutes. In Figure 8, the horizontal axis indicates BI%, the vertical axis indicates deOXY-Hb/OXY-Hb, and the plotted data were averaged. The circle marks in Figure 8 represent the measurement values every 5 minutes while sitting.

Both Groups A and B showed a strong correlation. In Group A, the data for 31 of 36 subjects had a positive correlation, and the data for 27 of them showed a strong correlation ($r > 0.6$). BI% increased according to the increase in deOXY-Hb because deOXY-Hb increased while sitting on the high stool based on the blood flow as shown in Figure 6. If deOXY-Hb is interpreted as outflow of internal respiration, it is considered that outflow of deOXY-Hb was restrained by sitting on the high stool, and leg swelling consequently occurred.



(a) Results of Group A as increase of swelling



(b) Results of Group B as decrease of swelling

Figure 8: Blood flow while sitting on the high stool (average ± SD)

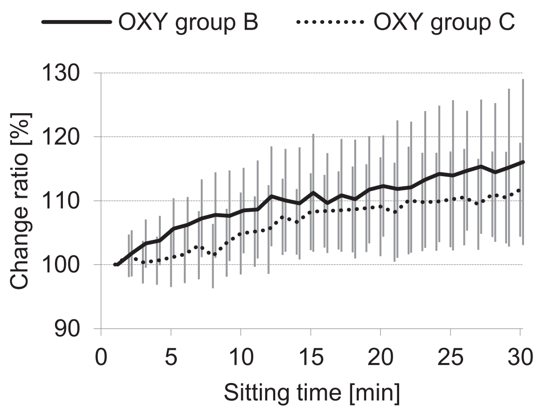


Figure 9: Comparison of OXY-Hb blood flow between Groups B and C (average ± SD)

In Group B, the data for 12 of 14 subjects had a positive correlation, and the data for 9 of them showed a strong correlation ($r > 0.6$). Figure 9 shows the OXY-Hb blood flow at an average interval of 1 minute for Groups B and C. The results show their averages.

The OXY-Hb blood flow showed a significant difference from 3 to 8 minutes (t-test, $p < 0.05$). This indicates that BI% decreased according to increase in OXY-Hb, and leg swelling consequently decreased. It is presumed that inflow of blood was recovered due to the decline in pressure at the back of the thigh by sitting on the trial chair, and OXY-Hb flow was stimulated because of adequate leg muscle activity with use of the footrest.

Therefore, it is considered that deOXY-Hb for outflow affects the occurrence of leg swelling and that increase of OXY-Hb for inflow influences the reduction of leg swelling.

There are some limitations in this study. It is necessary to investigate the reason why the leg swelling decreased with a 30° footrest, and there are two possibilities. First, the dorsal extension of the ankle joint at a 30° footrest enables the muscle activity of the gastrocnemius to increase, and it is assumed that a muscular pumping effect is generated because of this activity. Second, the pressure on the backside of the thigh diminishes because the footrest allows for changes in not only the ankle joint angle, but also body posture parameters such as the knee angle and lumbar angle. In the future, it will be important to measure or the electromyography of the gastrocnemius the pressure distribution on the thigh to investigate these two hypotheses.

4. CONCLUSIONS

This study demonstrated the fact that leg swelling decreases only by using a footrest, and there was a relationship between the blood flow of the lower leg and fluctuations in leg swelling. If it is clarified that swelling can only be reduced by using a footrest, the sitting comfort of chairs, such as home-use relaxation chairs or vehicle seats, can be improved by adding a footrest.

In this study, we measured leg swelling by the BI method and blood flow by NIRS while sitting on a high stool or trial chair with a footrest. Within the scope of this study, it can be concluded that:

(1) BI% increased by about 10% by sitting on the high stool, and BI% decreased by about 1% by sitting on the trial chair with a 30° footrest.

(2) deOXY-Hb increased by sitting on the high stool, and OXY-Hb increased by sitting on the trial chair.

(3) Comparison of swelling and blood flow revealed strong correlations between BI% and deOXY-Hb/OXY-Hb in both the increased swelling and decreased swelling groups.

(4) Increases in deOXY-Hb influences gains in leg swelling, and increases in OXY-Hb influences reductions in leg swelling.

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