RELATIONSHIP BETWEEN CLOTHING PRESSURE AND SKIN TEMPERATURE: SUPPORT KNEE-HIGH SOCKS

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ABSTRACT

An online questionnaire among 1425 female Japanese consumers revealed that knee-high socks were the most desirable product for swelling body parts. We measured clothing pressure using a hydrostatic-pressure balanced method, while subjects wore support knee-high socks (SKSs) in a standing position. Before-after skin temperature of the dorsal lower legs and feet were measured using a thermo-tracer while subjects wore SKSs for 4 hours. The distribution of clothing pressure in a vertical position, with low clothing pressure on the inside part of the leg and high clothing pressure on the arch of the foot, promoted blood circulation.

Key Words: Support knee-high socks, clothing pressure, skin temperature, wearing comfort, thermo-tracer

1. INTRODUCTION

Recently, compression wear for the lower half of the body has been proposed to improve swelling and leg shape, but the effects on human health remain controversial [1]. The relationship between swelling in the lower half of the body and current purchasing trends of "support knee-high socks (SKS)" were examined using an online questionnaire among 1425 female Japanese consumers between 10 to 60 years old [2]. Of the participants, 70.7% were office workers, full-time house-wives, and part-time workers between 20 to 40 years old. Greater awareness of swelling was found to be closely related to free time (i.e., participants who spent more time at home noticed the swelling more). 79.3% of participants who had awareness of their own swelling were aware of swelling in the lower half of the body, including the calf, ankle and instep. Of these, 44.8% bought SKS, hoping that swelling would be relieved. However, 34.4% of participants did not buy SKS, and felt they were ineffective against swelling, for various reasons. Reducing swelling can reduce physical stress on the body. Basic guidelines for the development of comfort SKS can utilize questionnaire data (warm-cold sensation, feeling of stuffiness, pressure sensation, texture) but also physiological data (observation of subcutaneous tissue using ultrasonic diagnostic equipment, skin temperature using a thermo-tracer, clothing pressure using a hydrostatic pressure-balanced method, volume change of lower leg using water displacement method). We tested three types of SKS (two commercially-produced SKSs and our own custom SKS) and examined the distribution of clothing pressure and skin temperature. In the present study, the effects of SKS on skin temperature of the tips of the toes was examined, potentially providing a guideline for future product design.

2. EXPERIMENTAL METHODS

This research study was guided by international ethical standards, and was approved by our institutional ethics committee (Approval No. 173). The experiments were conducted in accord with approved guidelines. We obtained informed consent from all subjects.

2.1 Experimental samples

Three sample SKSs (two commercially-produced SKSs: samples A/B; and our own custom SKS: sample C) were examined in the present study, as shown in Figure 1 (see image “a”, on the left of the figure). All sample SKSs were made of nylon, cotton, polyurethane and other materials, and the thickness and knitting density were measured using a dial thickness gage (Tokyo Seimitsu Kogyo Co., Tokyo, Japan). The basic knitting structure of all SKSs involved single-rib stitches, however samples A and B also included a complex knitted fabric. The strain was measured in six directions using the AUTOGRAPH device (AGS-H 50N Shimadzu Tech, Kyoto, Japan) at a speed of 300 mm/min, chuck of 10 mm, and maximum load of 3.5 kg (Temperature: 20 °C, 65% relative humidity).

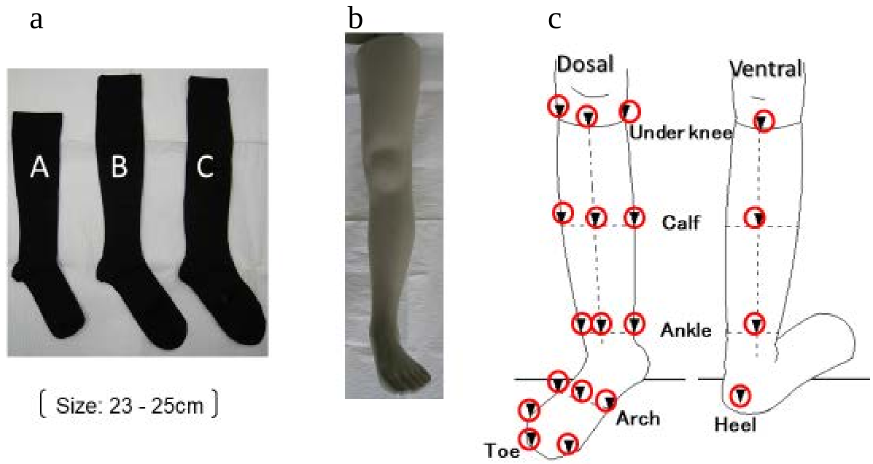

Figure 1. Experimental samples, leg model, and measuring points for clothing pressure

2.2 Measurement of the distribution of clothing pressure

Experimental samples were worn by a Japanese female leg model (Figure 1-b), and the clothing pressure of the lower leg and foot were measured using a hydrostatic pressure-balanced method [3] in the right lower leg at 19 points of intersection between four vertical lines (anterior/posterior midlines, inside/outside lines) and horizontal lines (under knee girth, maximum/minimum girths, arch/tow girths) and heel (Figure 1-c). The physical characteristics of subjects and the female Japanese leg model in her 20’s are shown in Table 1. Subjects in the present study were fitted to the characteristics of the average Japanese 20–30-year-old female, and using the leg model (MSX-20, Nanasai Co., LTD., Japan). All subjects were non-smokers, with no history of systemic disease. Subjects woke at 06:00 after 7 h of sleep and consumed a prescribed diet until 07:30. The same breakfast was used on all four experimental days, which took place in the latter half of subjects’ luteal phase of the menstrual cycle. Subjects then entered a climate-controlled room (environmental temperature, 24.5 ± 0.3 °C; relative humidity, 50.3 ± 2.5%; luminance, 827 ± 27 lx; air current, 8.0 ± 0.1 cm/s) 2 hours before the experiments. Subjects were seated at rest for 1 hour while wearing a short-sleeved 100% cotton t-shirt and 100% polyester running pants, then put on a 100% cotton long-sleeved jersey and pants. After measuring the skin temperature at the tips of the toes, subjects spent 4 hours sitting down while wearing SKS.

Table 1. Physical constitution of subjects, Japanese female average of 20’, and using leg model

Item	Age	Hight	Weight	Girth (cm)				BMI
(unit)	(year)	(m)	(kg)	Under knee	Calf	Ankle	Arch	($kg \cdot m^{-2}$)
Subjects average	20.4	1.58	52.9 ± 0.3	31.8 ± 0.2	33.8 ±0.3	20.0 ±0.3	22.2 ±0.2	21.2
Japanese female average of 20’		1.59	50.8 ± 5.9		34.4 ±2.0	20.6 ±1.1	22.7 ±1.1	20.1
Leg model	20	—	—	32.3	34.9	20.4	22.9	—

2.3 Skin temperature at the tips of the toes

The before-after skin temperature of dorsal lower legs and feet were measured using a thermo-tracer (TH3102MRS, NEC San-ei), before and after subjects wore SKSs for 4 hours. The average temperature of 10 toes on both feet were calculated from the thermo-grams [4]. The thermo-grams were obtained before and after 4 hours of sitting. The tips of the toes were set in the same positon in the thermo-gram using using an “outline function”. Because the skin temperature of the tips of the toes was higher than the temperature of the area as a whole (24.5 °C), it was clearly distinguished from the background using this function. Thus, subjects were able to put both legs along the outline, when the tips of their toes were photographed after 4 hours. The pixels of 10 toes consisting of approximately 20,000 points was obtained from an objective thermo-gram. One section of the thermo-gram provided approximately 53,000 points of temperature information. The pixels of ten toes consisting of approximately 20,000 points were extracted from an objective thermo-gram, from which a histogram of the number of pixels with a temperature rank of 0.1 °C was produced. The temperature information that multiplied the number of pixels by each temperature rank was calculated. All of the temperature information was added, and the accumulated temperature information was calculated. Next, the accumulated temperature information was divided by the total pixels, and mean skin temperature was obtained.

2.4 Statistics

Clothing pressure and skin temperature in three samples were analyzed to reveal significant differences using paired t-tests, because of high individual variation. Skin temperature was obtained using the following equation (1), as the increasing rate of relative temperature based on skin temperature before wearing SKS. The correlation coefficients were calculated between clothing pressure at 19 points and the average skin temperature of the feet.

Increasing rate of skin temperature =

$$\text{After wearing SKS for 4 hours} / \text{Before wearing SKS} \times 100 \qquad (1)$$

3. RESULTS AND DISCUSSION

3.1 Experimental samples

The relative strain of the three samples is shown in Figure 2, and the right figure shows the six directions. In all samples, strain in the wale direction was smaller than that of the course

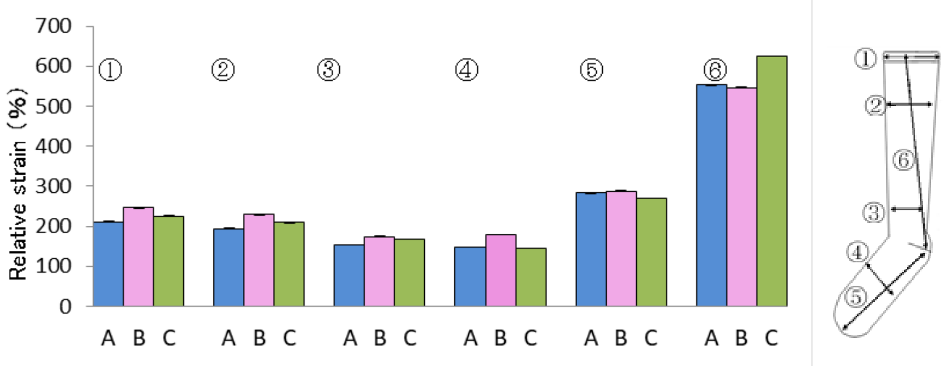

Figure 2. Relative strain of three samples in six directions

direction. The samples were substantially elongated in the wale direction, but exhibited little elongation in the course direction.

3.2 Measurement of the distribution of clothing pressure

Clothing pressure for a Japanese female leg model in her 20's wearing SKSs is shown in Figure 3. The red areas are shown the average of clothing pressure: sample A (mean ± SD: 34.2 ± 12.3 hPa) was higher than B (27.1 ± 6.8 hPa) / C (18.5 ± 7.2 hPa) and sample B was higher than C significantly. On the contrary, the clothing pressure of subjects wearing each SKS is shown in Figure 4. The clothing pressure of each part of the samples had the same order: A (18.5 ± 8.3 hPa) > B (16.1 ± 6.6 hPa) > C (15.6 ± 7.6 hPa). However, the pressure values for the leg model were higher than the subjects' clothing pressure values.

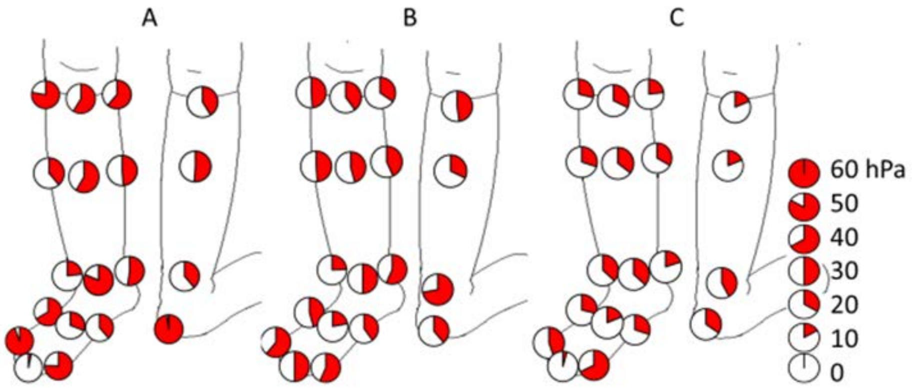

Figure 3. Clothing pressure on leg model of Japanese female

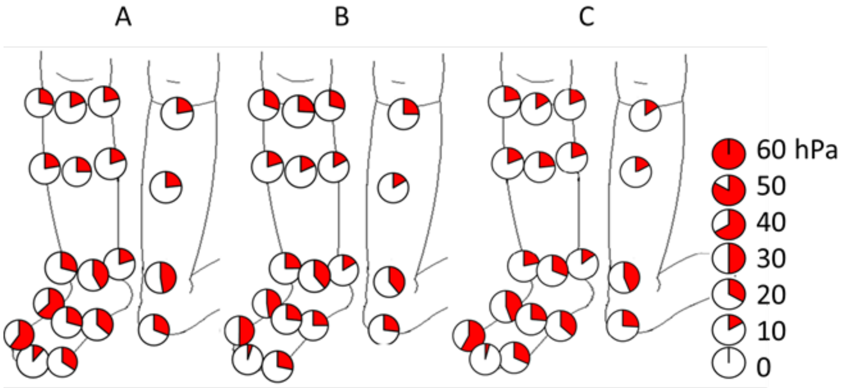

Figure 4. Clothing pressure of subjects wearing each sample

3.3 Skin temperature at the tips of the toes

Four coupled thermo-grams of the same subject are shown in Figure 5 as a typical example of before/after wearing SKS for 4 hours in a sitting position. The left/right image of a thermo-gram pair are shown before/after wearing SKS in the morning/afternoon. In the control condition, the skin temperature appeared to be lower after wearing SKS than before. In contrast, in sample C, all parts of the foot and leg in the after measurement were higher than before. The increased rate of relative skin temperature is shown in Figure 6, demonstrating higher values in sample A and C compared with sample B. Thus, wearing sample A and C was associated with

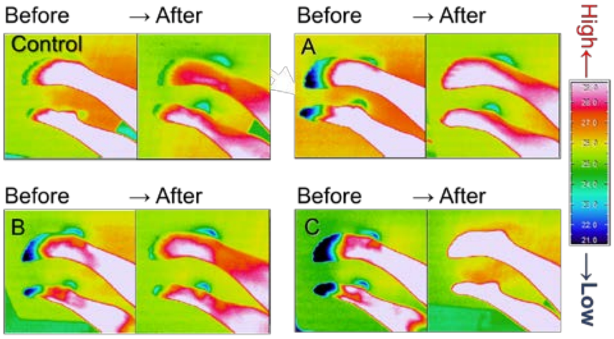

Figure 5. A typical example of thermo-gram

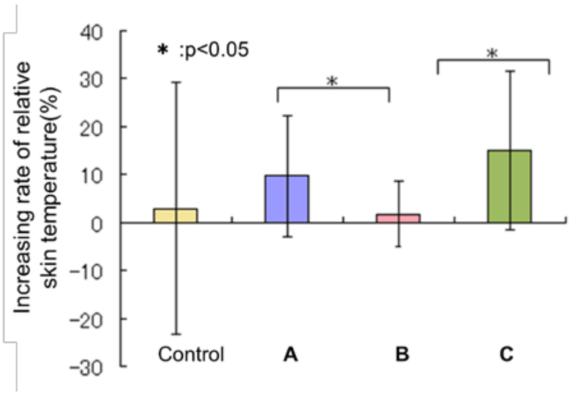

Figure 6. Increasing rate of relative skin temperature

increased skin temperature. It is preferable for clothing pressure to become higher centrifugally [5]. However, in sample B, because the clothing pressure of the ankle was high, as for the foot, the balance collapsed. Therefore, an inappropriate balance appeared to disturb the venous return. This finding suggests that the distribution of clothing pressure should be arranged highly centrifugally.

3.4 Correlation coefficients between clothing pressure and increased rate of skin temperature

Correlation coefficients between clothing pressure and increased rate of skin temperature are shown in Table 2. Clothing pressure was measured at 19 points, at intersections between four vertical lines (anterior/posterior midlines, inside/outside lines) and horizontal lines (under knee girth, maximum/minimum girths, arch/toe girths) and heel. Negative correlations were shown at the inside line under the knee (3.0–28.5 hPa), ankle (6.5–25.5 hPa) and toe (15.5–40.0 hPa) girths, and the outside line on the under knee girth (5.5–33.0 hPa). Thus, when the clothing pressure on the inside line was low, the increased rate of skin temperature was high. In contrast, the results revealed positive correlations at the inside (3.5–37.5 hPa) and outside (8.5–55.5 hPa) lines on arch girth. Thus, when the clothing pressure at the part of inside and outside lines from knee to ankle was low and the arch was high, the increased rate of skin temperature of the toe was high. The saphena and saphenous nerves are distributed over the inside surface from the knee to the ankle. When this region was under pressure by SKS, it is likely that the venous return was disturbed, and skin temperature fell because the bloodstream was inhibited, compared with subjects who worn light pressure SKS. The arch was relatively unaffected by pressure from the neighboring regions because blood vessels and nerves are located in the tarsal bone. Thus, humans may be relatively insensitive to centrifugal pressure, so a slight increase in high clothes pressure was found centrifugally, which would be expected to make it easier for blood to return to the heart. It will be necessary for future studies to examine bloodstream changes in more detail.

Table 2. Correlation coefficients between clothing pressure and an increased rate of skin temperature

Girth	Front		Inside		Back		Outside	
Under knee	-0.032	-	-0.368	*	-0.281	-	-0.358	*
Calf	-0.047	-	-0.153	-	-0.350	*	-0.087	-
Ankle	-0.088	-	-0.388	*	-0.112	-	-0.298	-
Arch	0.119	-	0.548	***			0.355	*
Toe	0.061	-	-0.401	*			0.279	-
Heel					-0.090	-		

*: P < 0.05,
**: P < 0.001,
n = 33

4. CONCLUSION

An online questionnaire among 1425 female Japanese consumers revealed that knee-high socks were the most desirable product for swelling body parts. Three sample SKSs were examined in the present study. We measured clothing pressure using a hydrostatic-pressure balanced method, while subjects wore SKSs in a standing position. Sample A (mean ± SD: 34.2 ± 12.3 hPa) was higher than B (27.1 ± 6.8 hPa) / C (18.5 ± 7.2 hPa) and sample B was higher than C significantly. Before-after skin temperature of the dorsal lower legs and feet were measured using a thermo-tracer while subjects wore SKSs for 4 hours in sitting position. Wearing sample A and C were associated with increased skin temperature. It is preferable for clothing pressure to become higher centrifugally. However, in sample B, because the clothing pressure of the ankle was high, as for the foot, the balance collapsed. The saphena and saphenous nerves are distributed over the inside surface from the knee to the ankle. When this region was under pressure by SKS, it is likely that the venous return was disturbed, and skin temperature fell because the bloodstream was inhibited, compared with subjects who worn light pressure SKS. The arch was relatively unaffected by pressure from the neighboring regions because blood vessels and nerves are located in the tarsal bone. Thus, humans may be relatively insensitive to centrifugal pressure, so a slight increase in high clothing pressure was found centrifugally, which would be expected to make it easier for blood to return to the heart. Our founding was the distribution of clothing pressure in a vertical position, with low clothing pressure on the inside part of the leg and high clothing pressure on the arch of the foot, promoted blood circulation.

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