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Preliminary communication

Exploration of Clothing Pressure for Compression Pants Measuring Blood Flow and Velocity

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Abstract: Older adults are staying active in health care and wearing compression products during exercise. Since most available products are developed for young people, it is necessary to develop those suitable for older adults. This study aimed to explore the optimum level of clothing pressure at each part of the lower limb for designing compression pants with positive effects on the blood flow of older adults. Calf sleeve (CS) and thigh sleeve (TS) were produced using the prototype pattern. Three types of CS and TS were produced to three levels of pressure: L1, L2, and L3. Eighteen participants in their 50 s and 60 s were given 12 experimental sleeves: three types of TS and nine combined types of CS and TS. The experimental sleeves were evaluated for pressure, blood flow, blood velocity, and perceived fit. The TS alone at ~ 9.8 mmHg thigh pressure led to increased blood flow and velocity with an outstanding perceived fit. Wearing CS and TS led to a significant increase in blood flow and velocity at the following pressure: ankle ~ 8.3 mmHg, calf ~ 10.5 mmHg, and thigh ~ 9.8 mmHg, with a significantly positive perceived fit. These results are meaningful in providing valuable data for the design of compression pants.

Keywords: blood flow; blood velocity; clothing pressure; compression pants

1 INTRODUCTION

With the advancement of economic status and health care technology, the population aged 65 years or older in South Korea reached 7,685,000 in 2019, accounting for 14.9% of the total population. The population of older adults is predicted to increase to 20.3% by 2025 to drive towards a super-aged society [1]. In line with this, the new silver generation has arisen, whereby older adults strive to enhance their quality of life through active physical exercise for healthy senescence. Recently, such exercises as Pilates and yoga have increased in popularity across the new silver generation, as they are known to be beneficial for improving physical fitness, metabolic activity, cognitive function, fatigue recovery, and muscular strength [2, 3]. The new silver generation is also highly interested in taking care of their appearance with a high preference for sportswear such as compression shirts and tights. However, most commercially available compression garments are developed for young and middle-aged individuals, with few products specialized for the silver generation.

Compression garments are primarily known to exhibit outstanding effects in enhancing blood flow. With a focus on cardiovascular and hemodynamic effects among the numerous effects of compression garments, the pressure exerted by the compression garment reduces the venous cross-sectional area to increase the venous blood velocity and pooling [4]. Graduated compression stockings, in particular, are known to improve blood circulation and velocity in patients with varicose veins. Wearing a graduated compression product delivers pressure from outside to the body to increase the hydrostatic pressure and redress the pressure balance between the deep and superficial veins to improve blood circulation in the lower limb [5]. In fact, the pressure of compression tights used for the prevention or treatment of cardiovascular diseases has been verified regarding their positive health effects [6].

According to one review [7], several stages were defined based on the level of disease in the United States, the United Kingdom, France, and Germany, to standardize the suitable clothing pressure for each stage within the range of 15-49 mmHg. Specifically, for the prevention and treatment of mild venous insufficiency, the first grade is described as 10-21 mmHg. The second grade, intended for moderate venous insufficiency accompanied by edema, ranges from 15-32 mmHg. The third grade, suitable for venous insufficiency associated with chronic venous insufficiency, venous thrombosis, skin changes, and ulcers, ranges from 20-46 mmHg. The fourth grade, designated for lymphedema, severe venous insufficiency, and deep venous thrombosis treatment, is described as 36-49 mmHg.

As such, in most reports, the effects of wearing a compression product were shown to prevent or treat lower limb vascular conditions in clinical practice. In several studies, however, the effects of wearing a compression garment were found to improve the blood flow of healthy individuals. The calf circumference after 30 min of standing, sitting, and walking was measured for individuals wearing or not wearing a below-knee compression stocking (16-20 mmHg) [8], and the results showed a fall in calf circumference to a significant level only in the group wearing the compression stocking. In another study with similar results, wearing a compression stocking of 12 mmHg clothing pressure at the ankle was shown to reduce the calf circumference in the group wearing the stocking compared to the control, after a long period of work sitting at the desk, to suggest a positive role in the prevention of edema. In addition, wearing a stocking of 18-29 mmHg pressure at the ankle and 15-23 mmHg at the calf reduced edema in the lower limb and enhanced quality of life [9]. The products applying 25-32 mmHg at the ankle, 18-22 mmHg at the calf, and 10-13 mmHg at the thigh were all shown to have positive effects on reducing edema and pain [10]. The findings collectively indicated that compression products with an optimum level of clothing pressure based on the characteristics of the user had positive effects on blood flow.

Nevertheless, whether these results obtained from individuals with a disease could be applied to healthy elderly subjects should be verified. Moreover, while the blood flow is critically influenced by clothing pressure, the subjective perception of the user regarding clothing pressure has been neglected in previous studies, where only the benefits of specific pressure levels on the blood flow were discussed. For designing sports compression garments targeting the elderly, it would be even more appropriate. This group may experience health issues such as degenerative joint diseases like osteoarthritis and cardiovascular disorders due to gradual musculoskeletal weakening and physiological decline, which can adversely affect their quality of life. The weakening of quadriceps and hamstring muscles and the repetitive and high dynamic loads on knee joints are said to exacerbate arthritis [11, 12]. Additionally, old age is a period when skin sensitivity increases, so the cognitive comfort aspect of a tight fitting garment should be handled sensitively. In designing special compression garments for the new silver generation that may be sensitive to pressure and feel discomfort more readily due to aging, the user's perception should be considered, unlike when designing compression garments for medical purposes. It is highly important to specify the research subjects and propose appropriate functional design elements for them when designing sports compression garments, as demonstrated in this manner.

Thus, this study determined the pressure of compression sportswear for a design that positively affects the perceived fit and blood flow of older women. In this study, the following research questions can be raised for the design of sports compression wear for healthy elderly individuals:

RQ 1: For knee-length pants, will the pressure level on the thigh affect blood circulation?

RQ 2: For full-length pants, will the pressure levels on the thigh, calf, and ankle affect blood circulation?

RQ 3: Do healthy elderly women have a subjective preference for pressure levels?

Based on these research questions, this study intended to explore the pressure level at which blood flow and velocity are improved. At the same time, the optimum level of pressure was sought by exploring the fit and comfort of these garments. The findings will provide valuable data for setting the pressure for compression pants for older women to ensure beneficial effects on blood flow. Furthermore, this study will provide information not only for the sportswear industry for older adults but also in the medical field to improve blood flow.

2 RELATED WORKS

Wearable compression products are made with clothing area smaller than the worn body area, and pressure increases on human tissues once worn. These products reduce the diameter of superficial or deep arrhythmias to prevent blood backflow, improve capillaries' microcirculation, and in some cases, are also used to treat aneurysms. The effectiveness of compression products in the medical field has been proven in many studies, and the recent studies are as follows. One study [13] reported that the cross-sectional area of blood vessels decreased, and the blood flow rate increased significantly when wearing compression underwear of about 25 mmHg (in a supine posture) and 50 mmHg (in an upright posture) for healthy people. According to another study [14], wearing compression garments with a pressure of 15-22 mmHg (at the calf) and sitting for 3 hours reduces venous pulling. Another study [15] reported that compression garments effectively reduced the cross-sectional area of blood vessels and improved venous disease in a standing position wearing medical stockings with a level of 21-35 mmHg at the ankle and 18-22 mmHg at the calf. In addition, three types of compression hosiery (low- [4-9 mmHg], moderate- [12-18 mmHg], and high-level [18-22 mmHg] at different ankle pressure levels for healthy people, were worn in the morning and morning. As a result of measuring leg volume using a Perometer® in the evening, the leg volume was significantly reduced to 54.9 mL for the moderate-level garments and 67.2 mL for the high-level garments.

In terms of wear sensation, the moderate level was well-tolerated, and the high level was not well-tolerated. It was reported that symptoms and swelling improved, and the degree of pressure in clothes with an excellent fit was moderate [16]. As the positive effects of compression products on blood flow have been proven, related products have been developed to recover from fatigue and improve exercise performance in sports. Their use has become popular over the last few decades, not only among professional sports players but also in the general public [17]. The following is a look at the related papers that have been recently published. According to one study [18], handball players wear compression bottoms with applied pressure of about 15 mmHg (at the calf) and controls applied pressure at about 5 mmHg. After exercise at 120 min of uphill running at 60% of VO_2 max, blood glucose, lactic acid and serum were significantly lowered when wearing compression wear products, suggesting they effectively promote fatigue recovery. Wearing different compression sportswear in basketball players increased venous return, muscle blood flow, and muscle oxygenation. Tight garments were the most effective because they compressed a large body area [19]. As a result of repeated-sprint exercises wearing lower-limb compression garments for recreationally active participants, it was confirmed that they helped the corresponding exercise ability related to local blood flow [20]. In addition, in a review [21] that qualitatively analyzed 183 studies on compression garments, 85 (46%) studies on blood and saliva markers were investigated. This review article stated that the discovery of compression garments could potentially increase arterial blood flow and reduce post-exercise pain and myalgia. It is noteworthy that information on compression ranges and mean pressures should be reported to improve future research in this field. Although some studies on compression sportswear design have made such attempts [22, 23], most are still mainly evaluation studies using existing products. Therefore, there are some areas in which the experiments did not proceed with well-controlled clothing. In addition, although it is most important to explore the level of pressure beneficial to the end user when developing compression wear, most studies are conducted on healthy adults, so it is difficult to apply the results of previous studies to a large population. On the other hand, when compression products are used for sports, the comfort level differs for each body part, so it is also essential to measure subjective sensations in various parts of the body [24].

3 METHODS

3.1 Research Design

The research design is illustrated in Fig. 1.

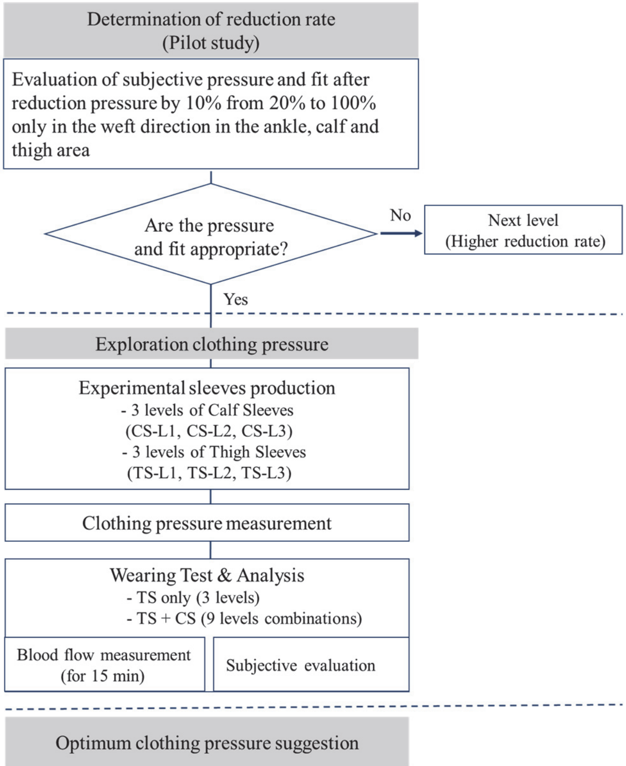

Figure 1 Research design

3.2 Subjects

This study was based on a subset of previous research data [25, 26]. Participants were recruited concerning a previous study of 18 healthy older people. All the subjects had normal blood pressure (systolic blood pressure [sBP] ≥ 140 mmHg) without a history of cardiovascular, neurological, or pulmonary diseases. The subjects in this study were 18 healthy female participants in their 50 s and 60 s (height: 156.7 ± 5.4 cm, weight: 57.8 ± 7.2 kg, mid-thigh circumference: 48.7 ± 3.6 cm, circumference at 6 cm below the patella's center point: 33.8 ± 2.5 cm, shin circumference: 36.2 ± 3.8 cm, and ankle circumference: 25.6 ± 2.1 cm) who did not have lower limb-related disorders including arthritis (institutional review board No. 201705-SB-022-01). The study goals, methods, and procedures were explained to the participants before starting the study, and those who agreed to participate were recruited.

3.3 Materials

Tricot, a type of fabric widely used in athleisure and sports compression wear, was selected as the material for the experimental sleeves in this study. The fabric composition was Nylon 77.2% and Polyurethane 22.8%, with 0.4 mm thickness. The fabric stretch was measured using the methods suggested in a previous study [27], and the measured stretch (Z-fabric stretch) had a warp of 16.5%, a weft of 22.5%, a bias of 20.5%, and a thickness of 0.55 mm.

3.4 Design of the Experimental Sleeves

To design the experimental compression sleeves, 3D human body scan data were converted to 2D data to set a nude prototype pattern, which was reduced to generate independent variables. For the nude prototype pattern, each of the calf sleeve (CS) and thigh sleeve (TS) designs was illustrated by applying the Geomagic Design X (3D systems, USA) program to the 3D data of mean body measurements of females in 50 s obtained from Size Korea (2016). The data were divided into blocks to be stored in a DXF format. The stored 3D blocks of triangle mesh were imported to the Pepakura Designer 3 program (Tama Software Ltd., Japan) following the methods in a previous study [28] for the conversion into 2D triangle pieces and using Yuka CAD (Youth Hitec, Japan), the apexes of the triangles were connected to complete the planar pattern of each block separated by the baseline. The block patterns were combined to develop the prototype pattern. Each subject's measured circumference and length were applied to the nude prototype pattern to develop individually customized prototype patterns. Using these prototype patterns to develop the reduced patterns, the pattern reduction rate was set based on the Z-fabric stretch according to Eq. (1). Through this equation, and using the pattern reduction and expansion function of the Yuka CAD software, the reduction in weft direction was applied to the *x* value to control the reduced pattern for completion.

$$\begin{aligned} &\textit{Pattern reduction rate}\ (\%) = 1 - [\%\ \textit{fabric stretch} \\ &/100 \times \textit{Z-applied percentage of fabric stretch}] \end{aligned} \qquad (1)$$

A pilot study was conducted on three subjects to finalize the reduction rate in this study. Using the prototype patterns and applying the reduction by 10% from 20% (pattern reduction rate of 3.5%) to 100% (pattern reduction rate of 21.5%) considering the Z-fabric stretch in the weft direction only at the ankle, calf, and thigh areas, the subjects were guided to describe the subjective perception of pressure and fit. The subjects reported that, for 20% Z-fabric stretch, almost no pressure was felt despite slight variations according to the area of application, with a level of tight adherence to the skin, and for 30% reduction, the fabric felt slightly more fitted, although the perceived pressure was not high. However, for the reduction by 50% (pattern reduction rate of 10.25%), the pressure was distinctly felt in each area, and for the 100% reduction, the perceived pressure was markedly high. Thus, the reduction rate was selected independently for the ankle, calf, and thigh areas between 25% (pattern reduction rate of 5%) and 85% (pattern reduction rate of 18%), and through different combinations, three pressure levels were set as shown in Tab. 1.

Table 1 Experimental compression sleeves

			Z-applied stretch / %	Pattern reduction rate / %
Experimental sleeves	L1	Ankle	25	5
		Calf	45	9
		Thigh	35	7
	L2	Ankle	45	9
		Calf	65	14
		Thigh	55	11
	L3	Ankle	65	14
		Calf	85	18
		Thigh	75	16

The final prototype patterns for the experimental sleeves, as shown in Fig. 2, combined the ankle and calf areas after independent reductions. A total of six patterns were produced for three calf sleeves; CS-L1, CS-L2, and CS-L3, and three thigh sleeves; TS-L1, TS-L2, and TS-L3. In this study, these experimental sleeves were evaluated based on quantitative measurements of clothing pressure, blood flow, and perceived fit. The subjects were given nine experimental sleeves to wear based on different combinations of three CSs (CS-L1, -L2, and -L3) and three TSs (TS-L1, -L2, and -L3). The control group was given short pants (clothing pressure < 0.5 kPa) with a length from the waist to the upper line of the TS. The experimental group was given short pants and an experimental sleeve of each combination as the variables in this study. The wearing of the experimental sleeve for all measurements and evaluations followed the Latin Square method to minimize the effect of the wearing order.

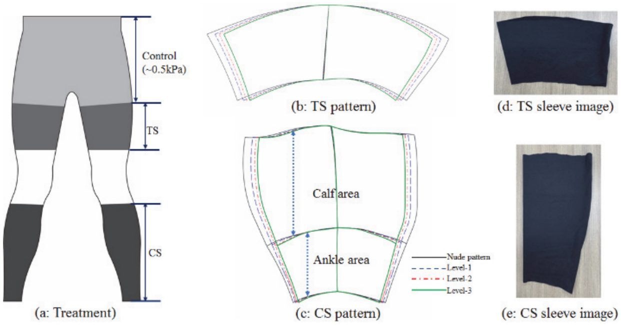

Figure 2 Experimental compression sleeves

3.4 Evaluation of the Experimental Sleeves

Based on a previous study [29], the clothing pressure was measured as follows: for the CS, the point 10 cm above the inner ankle towards the knee (Mp-1) and the point of maximum calf circumference (Mp-2) were selected. For the TS, the anterior-center point on the thigh (Mp-3) and the posterior-center point (Mp-4) were selected (Fig. 3). The measurements were taken while the subjects were in a straight standing position [30]. The time taken for measurement was one min at each point. The initial and final 10 s of the measured data were treated as noise, and the mean value for the remaining 40 s was obtained. An air-pack sensor (AMI3037-2, AMI Techno, Co., Ltd., Japan) was used to measure the clothing pressure.

To measure the blood flow, each subject entered the lab, took a 20 min rest, put on the experimental sleeve, and sat on the chair for measurement. The device used in this study was a Laser Doppler-Flowmeter (FLO-C1, OMEGAWAVE INC., Japan) for measuring blood flow and blood velocity. The device allowed the measurement of blood flow in microcirculation at approximately 1 mm beneath the skin's surface, which could be applied to any part of the body. The device is recommended to be applied to the tip of the middle finger of the right hand [31]. The time taken for blood flow measurement was set as 15 min, followed by a 20 min rest, based on previous studies where the same type of device was used [32, 33] and a study verifying the effect of a knee-length elastic stocking (15-25 mmHg) on the venous pumping function by measuring the venous output for 15 min [34]. The collected blood flow data were stored in a digitalized form via a data collector (HP Agilent 34970A) to generate independent blood flow and blood velocity datasets. The initial and final 1 min of the measured data were treated as noise, and the mean value for the remaining 13 min was obtained for the subsequent statistical analysis.

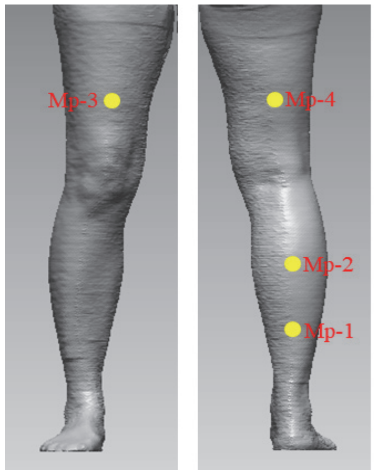

Figure 3 Clothing pressure measurement points

The subjective perception of fit was evaluated to identify the level of acceptability concerning perceived pressure, support, and comfort as the subjects wore experimental sleeves of varying pressure levels. For the comfort fit, the subjects were guided to focus the evaluation on pressure and support. Three evaluation items were used: "Is the pressure at an optimum level?", "Is the muscular support at an optimum level?" and "Is the comfort at an optimum level?" with each on a seven-point Likert scale (1: Strongly unacceptable [i.e., highly disliked]; 4: Moderately acceptable; 7: Strongly acceptable [i.e., highly preferred]).

3.5 Data analysis

The collected data were analyzed using the SPSS 26.0 statistical program (IBM Soft, USA). For the blood flow and perceived fit, the measured values were analyzed using repeated analysis of variance and a Duncan test at the level of significance of $p < .05$. The percentage change (%) was analyzed for the blood flow and blood velocity in wearing each experimental sleeve against the control.

4 RESULTS

4.1 Clothing Pressure

The CS and TS prototype patterns were applied, and the level of clothing pressure at the ankle, calf, and thigh was quantitatively evaluated. The results are presented in Tab. 2.

Table 2 Clothing pressure when wearing sleeves of three different compression levels in the lower body, Unit: mmHg

	CS Mean (Standard deviation)		TS Mean (Standard deviation)	
	Mp-1	Mp-2	Mp-3	Mp-4
L1	3.9 (1.3)	6.4 (2.8)	5.6 (2.2)	6.1 (2.9)
L2	8.6 (2.3)	10.7 (2.6)	9.5 (2.7)	10.4 (3.5)
L3	10.2 (2.1)	18.6 (3.2)	16.3 (2.3)	15.2 (3.2)

The measured range of clothing pressure according to the reduction rate was 3.9-6.4 mmHg for L1, 8.6-10.7 mmHg for L2, and 10.2-18.6 mmHg for L3, with the highest level. Hence, as the reduction rate increased, the measured clothing pressure increased. Notably, the clothing pressure for CS-L3 was approximately 18.5 mmHg for the calf area, and TS-L3 was ≥ 15.0 mmHg for the thigh area.

4.2 Change in Blood Flow
4.2.1 The Blood Flow Response in Wearing TS Alone

To examine the blood flow response while wearing the three TSs of different pressure levels, the blood flow and velocity were evaluated, as presented in Table 3. The blood flow was 23.08 mL/s/100 g in the control group, while wearing each of the three TSs led to increased blood flow compared to the control. The increase in blood flow was statistically significant for TS-L2 and TS-L3; the former led to a maximum increase of 38.4% and the latter to an increase of 22.0%. The blood velocity was 1.62 mm/s in the control group, while the wearing of TS-L2 and TS-L3 led to a significant increase. Notably, TS-L2 led to an increase of 33.8% to 2.17 mm/s compared to the control, and TS-L3 led to an increase of 19.1%, with less increase than TS-L2 but still a significant increase compared to the control.

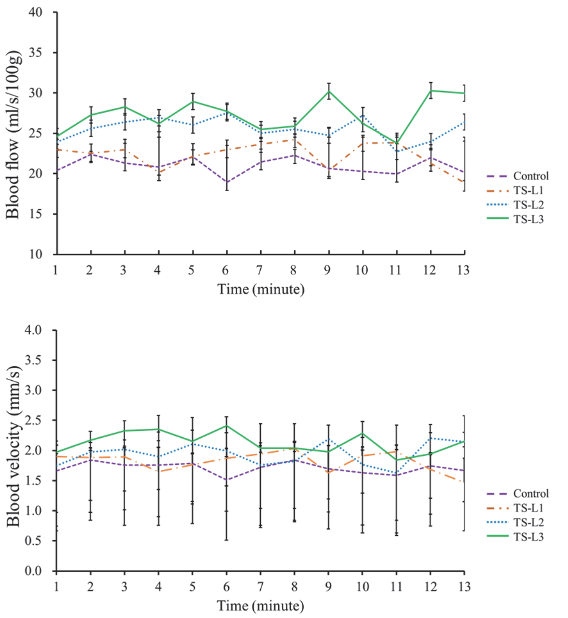

Figure 4 Variations of blood flow and blood velocity while wearing the TS alone (subject no. 8)

Fig. 4 shows the blood flow and velocity for 13 min in one subject according to clothing pressure. The time-dependent change in blood flow showed an overall increasing trend for wearing three TSs compared to the control, with a notably distinct increase in blood flow for TS-L2 and TS-L3. In addition, blood flow rapidly decreased and then restored while wearing the control or TS-L1 with the lowest clothing pressure.

A similar trend was found in blood velocity. While the measured values were similar between the control and TS-L1 with the lowest clothing pressure, the former showed a wave of rapid decrease and subsequent recovery in the blood velocity.

Table 3 Change in blood flow with thigh pressure

Treatment		Mean (Standard deviation)	Change / %	*F*-value
Blood flow / ml/s/100g	Control	23.08 (2.42)^{a}		32.258**
	TS-L1	24.22 (3.38)^{a}	5.0	
	TS-L2	31.93 (5.06)^{b}	38.4	
	TS-L3	28.16 (5.18)^{b}	22.0	
Blood velocity / mm/s	Control	1.62 (0.29)^{a}		8.087**
	TS-L1	1.81 (0.23)^{ab}	11.6	
	TS-L2	2.17 (0.45)^{c}	33.8	
	TS-L3	1.93 (0.38)^{bc}	19.1	

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .000$, Duncan's multiple range test: $a < b < c$

4.2.2 The Blood Flow Response While Wearing the CS and TS Simultaneously

The blood flow responses while wearing nine combined types of CS and TS are presented in Tab. 4. The control group's blood flow was 23.8 mL/min/100g. Wearing CS-L2+TS-L2 and CS-L2+TS-L2 showed an increase of 50% or more compared to the control, while an increase of 60% was found for CS-L3+TS-L1 and CS-L2+TS-L2, by 43.2% for CS-L3+TS-L3 and by 36.5% for CS-L2+TS-L1. Blood velocity displayed a maximum level of 72.8% for CS-L3+TS-L2, followed by 66% for CS-L2+TS-L2, 62.3% for CS-L3+TS-L1, and 50.0% for CS-L2+TS-L1, and an increase of 42.0%, and 32.1% for CS-L3+TS-L3 and CS-L2+TS-L3, respectively.

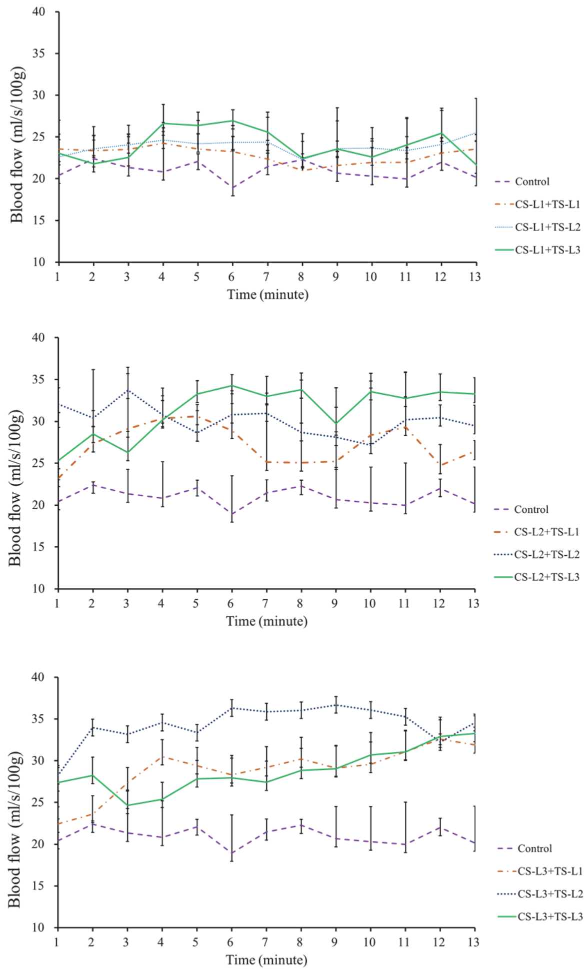

Figure 5 An example of the blood flow response in wearing the CS and TS simultaneously (subject no. 8)

Furthermore, to examine the change in blood flow over time, a graph was drawn for the blood flow response for 13 min of wearing the experimental sleeves in one subject. As Fig. 5 shows, the results of the combinations with CS-L1 with the lowest clothing pressure among CSs; CS-L1+TS-L1, CS-L1+TS-L2, and CS-L1+TS-L3, did not vary greatly from the results of the control. However, a distinct increase in blood flow compared to the control can be seen for CS-L2+TS-L1, CS-L2+TS-L2, and CS-L2+TS-L3, the combinations with CS-L2 of 8.6 mmHg clothing pressure at the ankle area and 10.7 mmHg at the calf area. In addition, a prominent increase in blood flow compared to the control can be seen for CS-L3+TS-L1, CS-L3+TS-L2, and CS-L3+TS-L3, the combinations with CS-L3 of 10.7 mmHg at the ankle area and 18.6 mmHg at the calf area.

Table 4 The blood flow response according to clothing pressure in wearing the CS and TS simultaneously

Treatments		Mean (Standard deviation)	Change / %	F-value
Blood flow / ml/min /100g	Control	23.08 (0.57)^{a}		22.688***
	CS-L1+TS-L1	24.47 (0.61)^{a}	6.0	
	CS-L1+TS-L2	25.55 (0.68)^{a}	10.7	
	CS-L1+TS-L3	27.9 7(1.10)^{ab}	21.2	
	CS-L2+TS-L1	31.50 (0.96)^{bc}	36.5	
	CS-L2+TS-L2	34.76 (1.58)^{d}	50.6	
	CS-L2+TS-L3	34.82 (1.30)^{cd}	50.9	
	CS-L3+TS-L1	37.26 (1.22)^{cd}	61.4	
	CS-L3+TS-L2	36.96 (1.47)^{d}	60.1	
	CS-L3+TS-L3	33.06 (1.11)^{cd}	43.2	
Blood velocity / mm/s	Control	1.62 (0.29)^{a}		31.899***
	CS-L1+TS-L1	1.70 (0.32)^{a}	4.9	
	CS-L1+TS-L2	1.76 (0.25)^{a}	8.6	
	CS-L1+TS-L3	1.82 (0.31)^{a}	12.3	
	CS-L2+TS-L1	2.43 (0.36)^{cd}	50.0	
	CS-L2+TS-L2	2.69 (0.41)^{e}	66.0	
	CS-L2+TS-L3	2.14 (0.29)^{b}	32.1	
	CS-L3+TS-L1	2.63 (0.40)^{de}	62.3	
	CS-L3+TS-L2	2.80 (0.39)^{e}	72.8	
	CS-L3+TS-L3	2.30 (0.29)^{bc}	42.0	

*p < .05, **p < .01, ***p < .000, Duncan's multiple range test: $a < b < c < d$

Fig. 6 shows a graph of one subject's blood velocity response for 13 min. The response for each level of clothing pressure showed that, compared to the control, the wearing of CS and TS simultaneously led to a distinct overall increase in blood velocity. Wearing CS-L3 and TS-L3 with relatively high levels of clothing pressure increased the blood velocity in an overall stable trend.

4.3 Subjective Evaluation of the Fit

4.3.1 Wearing TS Alone

A subjective evaluation was performed to determine the level of acceptability with respect to pressure, support, and comfort while wearing the TS alone. First, as shown in Fig. 7, the evaluation of perceived pressure based on each level of clothing pressure marked TS-L2 as the most preferred (a score of 6 points) experimental sleeve with the middle level of clothing pressure, followed by TS-L1 with the lowest clothing pressure (a score of 5) which was significantly preferred to TS-L3 with the highest clothing pressure (F = 56.064). However, although TS-L3 was given the lowest score, the score was still as high as 4 to indicate a moderate level of clothing pressure at 15.2-16.3 mmHg and not an unacceptable level.

Next, the evaluation of perceived support marked TS-L3 as the most preferred sleeve, followed by TS-L2, then TS-L1. The support was perceived as more outstanding with an increase in clothing pressure. Among the experimental sleeves, TS-L1, with the lowest clothing pressure, was least preferred at a score of 2. The significance level of the variation across the sleeves was high (F = 74.077). Lastly, the evaluation of perceived comfort with a focus on pressure and support marked TS-L2 as the most preferred sleeve, followed by TS-L1. The lowest score was given to TS-L1 with the lowest clothing pressure in comparison, and the level of significance of the variation across the sleeves was above the criteria (F = 48.199). The comfort fit, as previously mentioned, was evaluated with a focus on pressure and support. TS-L3, with the highest clothing pressure, received the lowest score for perceived pressure in terms of acceptability, and TS-L1 received the lowest score for perceived support. Although TS-L1 was given the lowest score for perceived comfort, at 6.1 mmHg clothing pressure, the pressure of approximately 9.8 mmHg on the thigh was shown to have a substantially positive effect on perceived comfort.

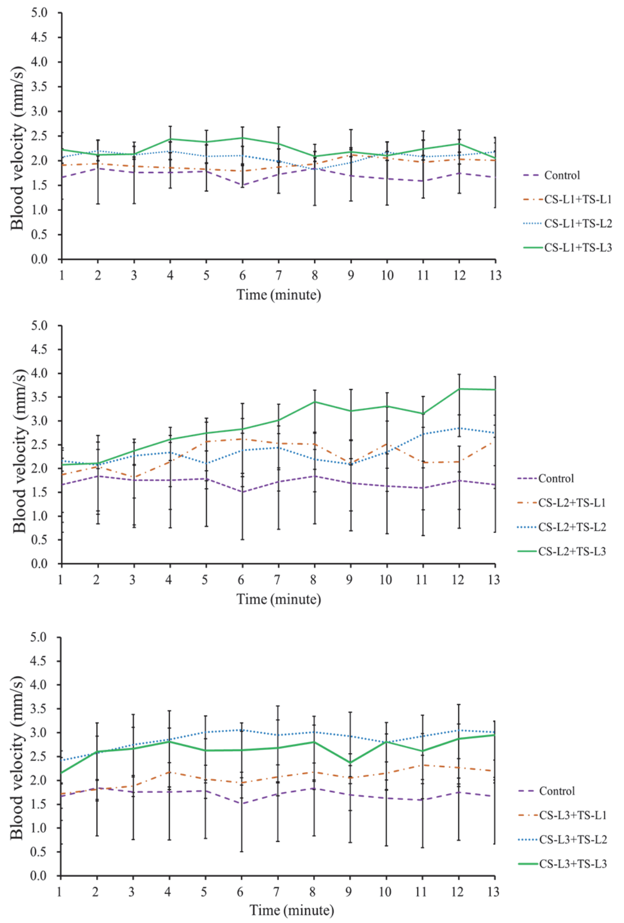

Figure 6 An example of the blood velocity response in combining CS-L1 with each of the three TS types; red represents TS-L1, green represents TS-L2, and blue represents TS-L3 (subject no. 8)

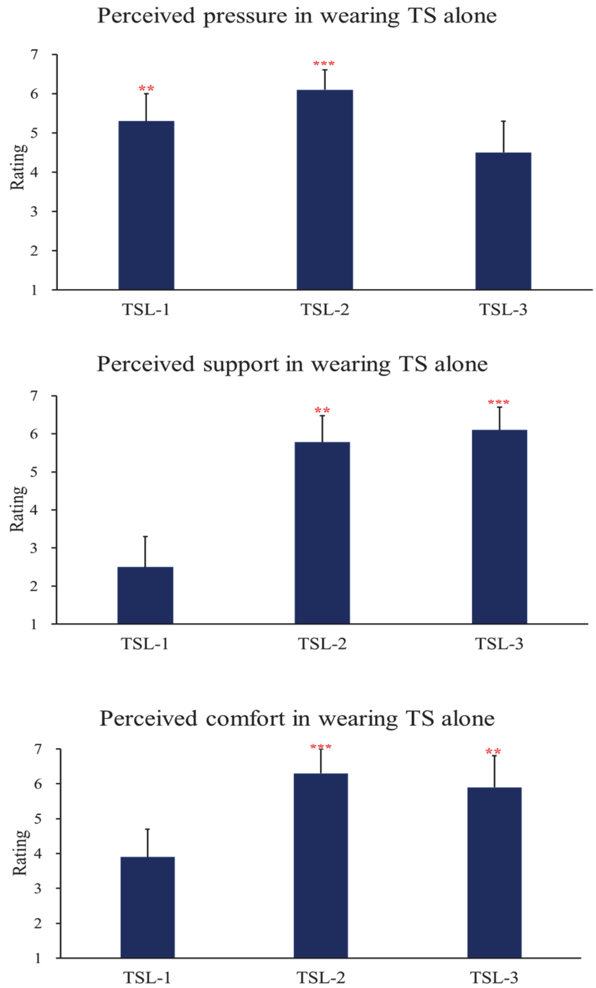

Figure 7 Subjective evaluation of the fit while wearing the TS alone

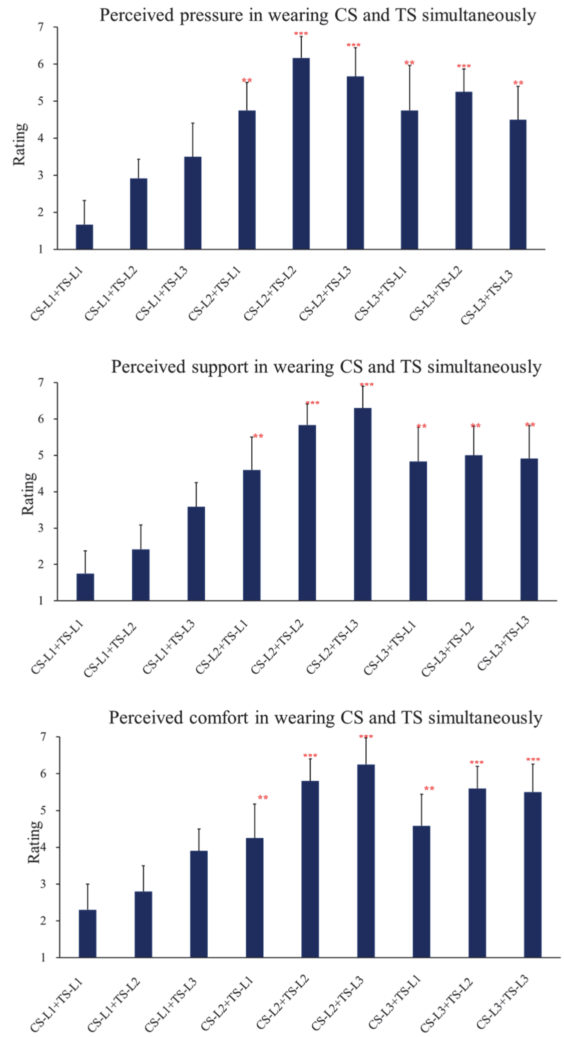

Figure 8 Rated acceptability of clothing pressure while wearing the CS and TS simultaneously

4.3.2 Wearing the CS and TS Simultaneously

The result of the subject evaluation on wearing the CS and TS simultaneously is shown in Fig. 8. The perceived pressure was acceptable for all experimental sleeves except the combinations of three TSs with CS-L1 with the lowest clothing pressure among CSs. Notably, the preferred sleeve combination was CS-L2+TS-L2, where both CS and TS exhibited a middle level of pressure, and the next preferred sleeve was the CS-L2+TS-L3 and CS-L3+TS-L2 combinations with markedly significant acceptability (F = 51.052). Next, the average perceived support in terms of acceptability was the highest for CS-L2+TS-L3, followed by CS-L2+TS-L2, while the preference level was similar for CS-L3+TS-L1, CS-L3+TS-L2, and CS-L3+TS-L3 with CS-L2+TS-L1. On the contrary, CS-L1+TS-L1, CS-L1+TS-L2, and CS-L1+TS-L3 were not preferred, with a significant variation across the sleeves (F = 41.593). Lastly, the perceived comfort was outstanding while wearing CS-L2+TS-L3, CS-L2+TS-L2, CS-L3+TS-L2, and CS-L3+TS-L3, the combinations of the CS and TS at L2, with the middle level of clothing pressure, and L3, with the highest level. In addition, CS-L2+TS-L1 and CS-L3+TS-L1 also scored 4 points at the moderately acceptable level. However, the remaining sleeves, CS-L1+TS-L1, CS-L1+TS-L2, and CS-L1+TS-L3, received low perceived comfort scores with a highly significant level of variation across the sleeves (F = 68.431).

4 DISCUSSION

This study aimed to determine the optimum clothing pressure on the lower limbs of older women to enhance their blood flow. The blood flow measurement and comfort fit evaluation were performed per the area and level of clothing pressure.

4.1 Blood Flow and Velocity on the Thigh

The experimental sleeves TS-L2 and TS-L3 with thigh pressures at 9.5-16.3 mmHg were shown to significantly enhance blood flow. On the contrary, TS-L1 with the thigh pressure at 5.6-6.1 mmHg was similar to the control and did not induce a positive change in blood flow. In a previous study [35], wearing of sports compression shorts with a level of clothing pressure on the thigh at 13.9-16.1 mmHg led to an increase in mean blood velocity by 42.4% and in the maximum value by 40.5% and a significant increase in blood flow by 43.9%, compared to the control with no clothing pressure.

4.2 Blood Flow/Velocity on Thigh and Calf

The evaluation of the blood flow and velocity responses according to clothing pressure while wearing the

CS and TS simultaneously showed a significant increase for the TS-L2+CS-L2 and TS-L2+CS-L3 combinations compared to the control and an improvement over TS alone. To be specific, the blood flow and velocity increased when the clothing pressure was 8.6-18.6 mmHg at the ankle and calf areas by CS and 9.5-16.3 mmHg at the thigh area by TS, while the blood flow and velocity were similar to the control when the clothing pressure at the ankle and calf areas ranged 3.9-6.4 mmHg. In other words, the blood flow was higher under a pressure of approximately 9.8 mmHg on the lower limb below the knee. The experimental sleeves in this study can be seen as a graduated compression type with a greater increase in clothing pressure on the calf than on the ankle. According to a study conducted on healthy male professionals in their 20 s who work sitting for 8 hours a day [36], wearing compression garments with pressures of approximately 11 mmHg on the ankles, 15 mmHg on the calves, and 11 mmHg on the thighs was found to be highly beneficial in improving or alleviating swelling and circulatory disorders associated with prolonged sitting. Although there are limitations in directly comparing these study findings to individuals of much lower age range. Considering the participants of this study were younger, it is possible to observe similar levels of meaningful garment pressure from a hemodynamic perspective. One of the studies that lent support to the results in this study [19] was conducted on basketball athletes, where wearing compression pants (ankle 15.2 mmHg, calf 21.8 mmHg, and thigh 15.5-17.1 mmHg) was compared to the control with no clothing pressure (0 mmHg). The mean and maximum blood velocity values in the calf area were increased by 57.3 and 58.9%, respectively, with an increase in blood flow of 98.6%, and the mean and maximum blood velocity values in the thigh increased by 45.4 and 46.4%, respectively, with an increase in blood flow of 40.3%. The muscle oxygenation in the calf and thigh also showed a significant increase of 82.4 and 24.4%, respectively. In another study [37] on patients with peripheral artery disease, the 30-day wearing of a graduated compression product with clothing pressure of 8 and 18 mmHg on the ankle and the calf, respectively, was shown to improve the disease's symptoms. These reports support the present study as they applied a higher level of clothing pressure at the calf than at the ankle.

In addition, another study [38] reported that, in workers sitting at a desk for 3 hours, wearing a compression garment led to a significant reduction in calf circumference compared to the control, when the applied clothing pressure was 15.7-16.4 mmHg at the ankle, 20.4-21.1 mmHg at the calf, and 15.6-16.5 mmHg at the thigh. The clothing pressure was high compared to the present study, but a partial agreement was found regarding the clothing pressure suggested in this study for edema prevention by reducing calf circumference. Furthermore, the clothing pressure applied by CS-L3 and TS-L2 (ankle: 10.7 mmHg, calf: 18.6 mmHg, thigh: 9.5-10.4 mmHg) in this study, with the results of the most significant increase in blood velocity, is of Class-1 (18-21 mmHg) in the prevention or early phase of vascular diseases of the lower limb in clinical practice [35]. In this light, the level of clothing pressure suggested in this study falls in the range of Class-1 clothing pressure to imply effectiveness in the prevention or early-phase treatment of relevant diseases. An additional study [39] tested the effect of four different compression socks with varying levels of clothing pressure on blood flow, muscle oxygenation, and fatigue before and after exercise and reported that the 15 and 20 mmHg pressure levels had positive effects on blood flow, muscle oxygenation, and fatigue. Another study [40] also reported that a calf-length sleeve with the clothing pressure at 11-21 mmHg was effective in improving the lower limb edema, and in connection with the present study, CS-L3 (10.2-18.6 mmHg) is likely to have a preventive role in lower limb edema. In conclusion, the level of pressure with a beneficial effect on blood flow identified in this study was similar to the levels suggested across previous studies, but lower by approximately 3.8 mmHg on average. This may be attributed to the subjects in this study being healthy individuals without any disease.

4.3 Subjective Sensation and Clothing Pressure

Meanwhile, the heightened sensitivity in senescence may cause significant discomfort due to the pressure offered by compression garments. The perceived fit as quantitatively evaluated in this study showed that the levels of perceived pressure, support, and comfort according to clothing pressure indicated a preference for 5.5-10.4 mmHg in the wearing of TS alone, while 15.2-16.3 mmHg was not preferred. In other words, female participants felt discomfort at a pressure ≥ 15.0 mmHg. On the other hand, wearing the CS and TS simultaneously led to a preference for CS-L2 (8.6-10.7 mmHg) combined with TS-L2 and TS-L3 (9.5-16.2 mmHg). This indicated that a higher pressure level on the thigh than on the area below the knee was preferred. In addition, compared to wearing the TS alone, additional pressure on the calf and ankle was shown to allow a level of pressure ≥ 15.0 mmHg to be felt as comfortable. Thus, in the development of compression pants for the new silver generation, the perceived support is likely to be satisfied when clothing pressure of a higher level is applied to the thigh compared to the ankle and calf.

4.4 Optimal Clothing Pressure

In summary, the level of clothing pressure that ensured a comfortable fit for the new silver generation and positive effects on the blood flow and velocity were TS-L2 (9.8 mmHg) for the thigh and CS-L2 (ankle: 8.3 mmHg and calf 10.5 mmHg) for the calf and ankle. While CS-L3 (ankle: 10.5 mmHg and calf: 18.8 mmHg) also positively affected the blood flow, its perceived fit score was relatively low. Likewise, the preference for TS-L3 (thigh: 16.5 mmHg) across varying combinations was also relatively low. To conclude, compared to the individuals with a disease, healthy individuals showed an improvement in blood flow and velocity at clothing pressure of 7.5-18.8 mmHg, a level approximately 3.8 mmHg lower, whereas a level of pressure ≥ 15.0 mmHg was not preferred in the subjective evaluation.

5 CONCLUSION

In this study, wearing sleeves with varying pressure levels on the calf and thigh areas of the lower limb in older women was evaluated concerning blood flow and perceived fit. The purpose was to determine the level of optimum clothing pressure with a positive blood flow response and an outstanding perceived fit to suggest the optimum clothing pressure for developing compression pants for older women. To conclude, blood flow and velocity increased with a pressure of approximately 8.6 mmHg (ankle), 10.7 mmHg (calf), and 9.8 mmHg (thigh) to indicate that the respective pressure level exerted a positive effect on blood flow. Moreover, the perceived fit was outstanding to predict that using the determined pressure level in the development of compression pants (with a length above the knee) for older adults would ensure the production of pants with health benefits. Meanwhile, when the thigh sleeve with a pressure of 5.8 mmHg was worn alone, it did not induce any blood flow response. However, when worn in combination with ankle sleeves of 8.6 mmHg and calf sleeves of 10.7 mmHg or ankle sleeves of 10.2 mmHg and calf sleeves of 18.6 mmHg, it showed positive effects on blood circulation. The blood flow response depends on the appropriate combination of pressure levels in different parts of the body, highlighting the significant role of the calf region as a variable that can induce positive blood flow responses.

The findings in this study are anticipated to serve as the basic data for developing health care products, including sportswear for the new silver generation. Notably, this study determined the level of clothing pressure with beneficial effects on the blood flow of individuals in a specific age group, while the systematic design of the experiment has led to the suggestion of the optimum clothing pressure suitable for end users. The limitations in this study may be that the blood flow was measured only in the sitting position and that the measurements were taken in a short time. A protocol should be designed to resolve these limitations in a follow-up study. At the same time, compression pants should be produced using the clothing pressure determined in this study, for which the performance should be evaluated with an extended scope that addresses physiological responses such as blood flow, mechanical perspectives, and subjective assessments.

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