THE EFFECT OF COMPRESSION STOCKING ON LEGS' GEOMETRY CHANGES WITHIN DIFFERENT MOVEMENT

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ABSTRACT

In this study, the changes in leg size and shape as well as pressure at different sites of a lower leg were investigated using advanced tools such as the Move4D scan system and Texsens pressure measuring device. The effect of the class of compression stocking, wearing time, and movement type was analyzed for one volunteer. It is the basis for the high-accuracy ready-to-wear compression stocking development based on the concept of personalization.

KEYWORDS

Compression stocking; 4D body scanning; Lower leg; Body size and shape; Dynamic position

INTRODUCTION

The demand for compression clothing and rehabilitation goods increases every year. Today's market for compression products is not limited to medical applications [1]. They are widely used in sports and everyday life. With the improvement of human needs and the development of technology, more and more attentions are paid to the comfort [2] and quality of the products used. Particular emphasis in this matter is on the items and products that can help maintain health levels [3]. It was stated [4] that satisfactory compression textiles should possess the following characteristics: compression comfort; biocompatibility; good dimensional stability; controlled elasticity, stiffness and hysteresis; dynamic and sustained pressure delivery; satisfied contractile perception in long-term use; moisture and thermo-physiological regulation.

The compression stockings are the most used compression garment because of spread such diseases as various types of chronic oedema, venous thromboembolism and venous ulcers, where compression therapy is widely used and had good results [5]. Many scientists and therapists paying a crucial attention to study stocking performance and pressure prediction. It was found that knitted structure [6] [7], as well as inlay yarn count [8] and amount [9] together with yarn nature [10] and treatment type affect the material properties and stocking performance [11] [12].

Simultaneously ensuring the necessary functional properties, namely the pressure level at different areas, and high levels of comfort of the compression clothing is problematic within the mass production of the products of standard sizes. Most of the research for compression stocking development was done for standard legs using in-vitro pressure measurements on extremities dummies [13] and/or virtual soft mannequins [14]. In-vivo measurement has been usually used in clinical research [15]. On the other side, the emerging technologies in the textile industry as 4D scanning [16], 3D design [17], and CAD systems enable manufacturers to produce bespoke textiles on demand [18]. Investigation of the geometry changes of body legs with compression stocking in the static position [19] showed that 3-4D scanning allows the quick estimation of the compression clothes functionality and it can be a promising means for assessing the dimensional changes of the body parts.

This research aims to study the changes in sizes and shapes of the lower legs within the wearing time of compression stockings and different activities as well as changes in pressure that occurred at the same time. The research results are the basis for the development of a tool for high-accuracy ready-to-wear compression garment design.

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MATERIALS AND METHODS

Compression stockings

Conventional knee-high 40 den stockings and two classes of compression stockings (I CCl and II CCl) of the same manufacturer were used. 85 % nylon and 15 % spandex are the yarns composition provided by manufacture. One volunteer took the part in the study. He is using compression stockings of size 3 [20] according therapist prescription. He did their usual routine activity between scanning without any limitations.

Scanning procedure

The MOVE 4D system from Valencia Polytechnic University at ITM TU Dresden was used for the investigation of the changes in the size and shape of the lower legs. Five following movements were performed: walking, stepping, bending over, sitting down, and rising on tiptoes. The scanning time for each movement was 4 seconds with a frequency of 15 frames per sec (Fig. 1). Scans were made for the control leg (without stocking) and within stocking wearing: just after putting on stockings (0 hour) and after wearing time of 1 and 4 hours.

The 4D scanning data gives a possibility for a quick comparison of the legs. The evaluation can be done not only by leg circumference and cross-sectional area at certain sites but by the contours as well. The slicing of the legs scans and data transfer were done by ParaView 5.11.0, and MeshLab 2022.02 was used for the planar section (Fig. 2 b), area and circumference measurements. The left and right legs were studied separately.

Pressure measurement

The Texsens force and pressure measuring device [21] was used for pressure investigation. Measurement time was 60 sec (1 min) with 0.02 sec frequency. The measurements were done just after putting on stockings (0 hour) and after the first and fourth hours of wearing during all activities. The measurements were performed according RAL-GZ 387/1 [20] at three levels recommended by this standard: B (ankle), B1 (lower calf) and C (calf), They were fixed for the volunteer at 10, 23 and 30 cm from the floor (Figure 2.a). These levels were marked on the legs and on the stockings because within activity the distance between them is changed.

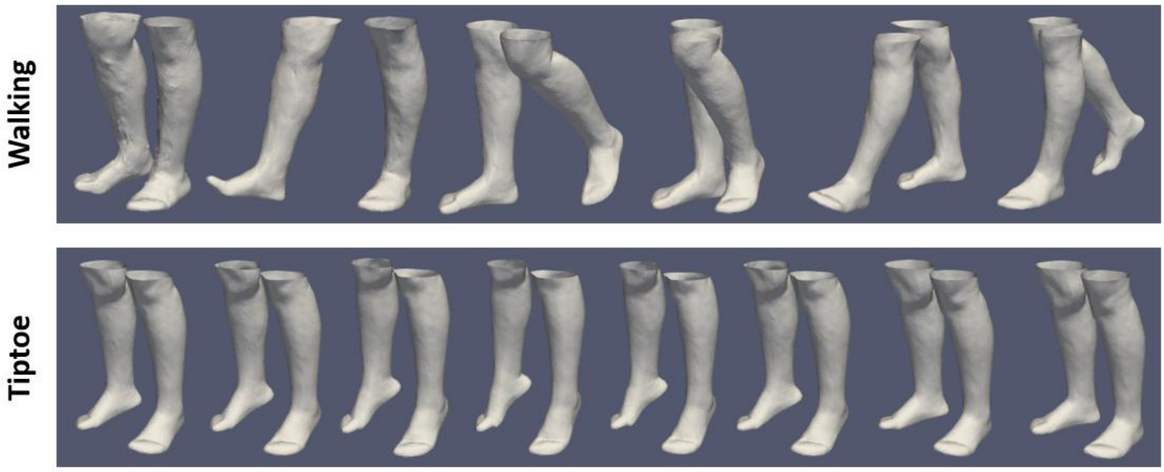
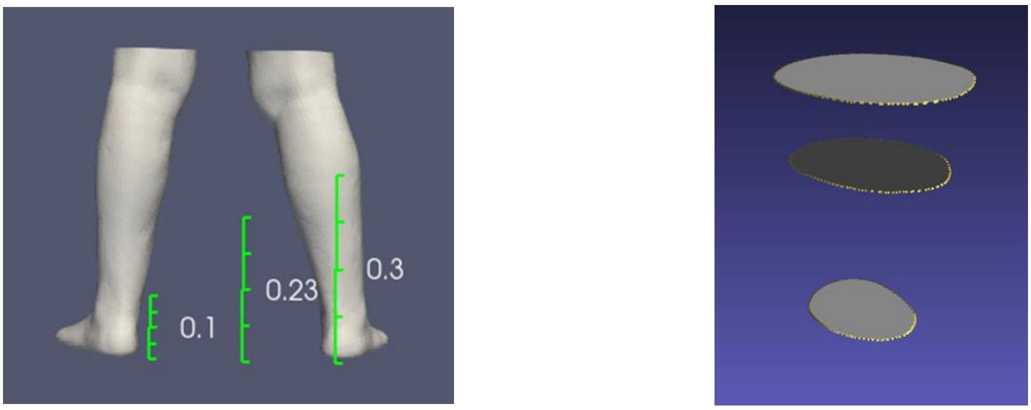


Figure 1. Example of a scan captions during different movements.



(a) (b)

Figure 2. Legs scan processing: (a) measurement levels; (b) the leg‘s slicing.

RESULTS AND DISCUSSION

The research was conducted in a few steps. Firstly, the leg shapes and sizes as well as their changes over time and used stocking's type were studied in static position. The values of existing changes at three levels were calculated and analyzed. Then, the effect of compression stocking and wearing time on the lower legs' sizes was studied during five different activities. After that the pressure level of stockings were analyzed as well.

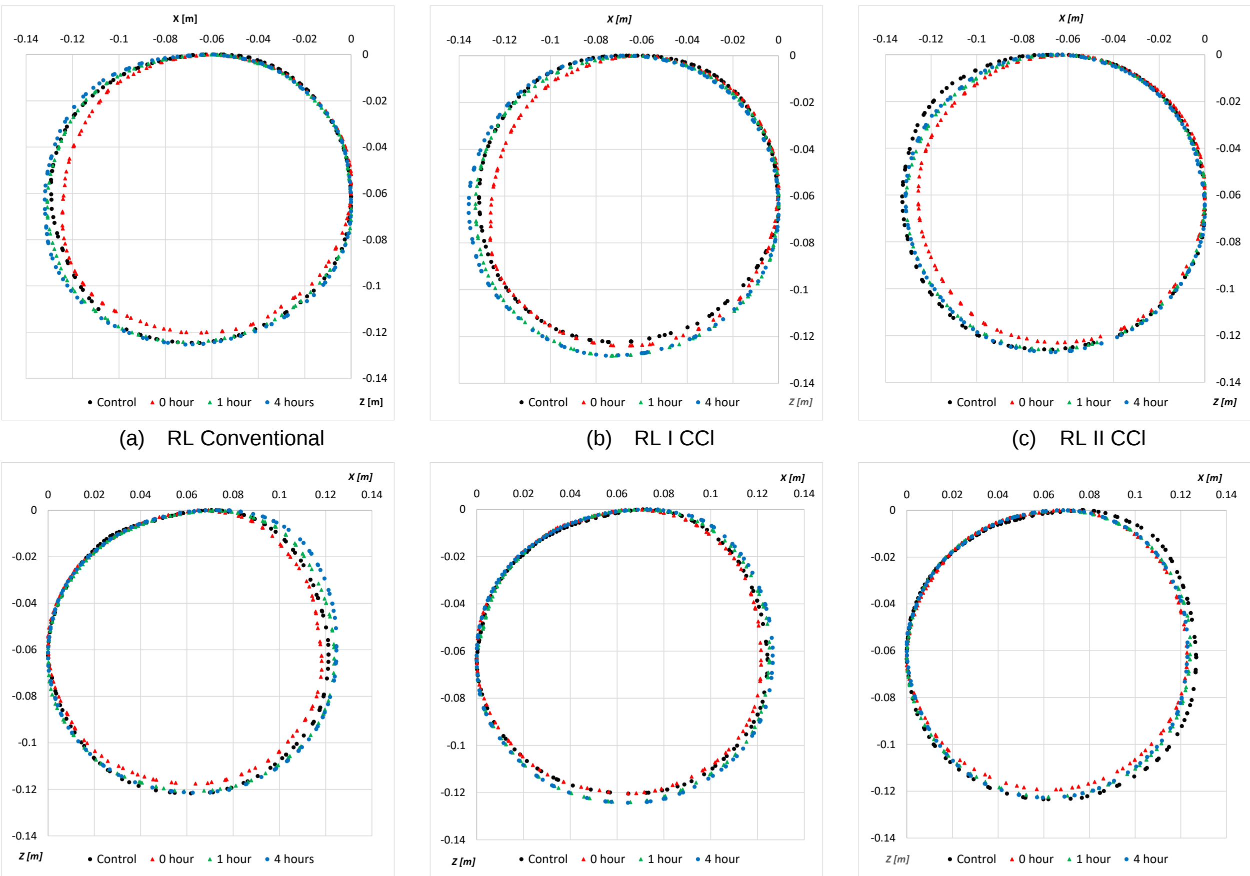
Lower leg's size at static position

There is an increasing in leg's size within wearing time of conventional stocking due to legs swelling. In our previous study [19] was confirmed differences in left and right legs due to body's asymmetry. The example of cross-sectional contours at 30 cm level for both right (RL) and left (LL) legs are presented in Fig. 3. The cross-section area increases up to 11 % at the calf and up to 17 % at the ankle after 4 hours of conventional stockings wearing. The values for circumference increasing are smaller and are up to 5.3 % and 7.6 % respectively. It can affect the pressure delivered by compression stocking within wearing time. Using II CCl stockings are more effective for scanned person: the leg's circumference and cross section area were kept at initials value at all studied levels for both legs.

Lower leg's size during movement (conventional stockings)

It is clear that leg shape and volume are changing during different movement due to muscles volume changes [22]. Thus, the greatest changes will be at level. An example of measurements of legs circumference at 30 cm level during bending over and rising on tiptoe are presented in Figure 4. The differences in the left and right legs are observed. The right leg is thicker by 10 mm in circumference. The changes in legs' size are within 10 mm for both movements. Both legs are swelling but the right leg swells more which is clear when comparing the control leg with the leg after 4 hours conventional stockings wearing during bending over (Fig. 4 a). The plots in Fig. 4 b give clear understanding how the legs circumference changes within one cycle of movement, namely rising on tip toe and back to initial position.

The research result for changes (Δ) in the leg cross section area (S) compared to control leg is presented in Table 1. The right leg and 30 cm level were chosen for presentation because of its higher swelling and data representativity. The presented data show that leg's size changes not only over time but during different activities as well. The highest changes of



(a) RL Conventional (b) RL I CCl (c) RL II CCl

(d) LL Conventional (e) LL I CCl (f) LL II CCl

Figure 3. Changes in the legs' shape at 30 cm level at the static position within wearing time for different stockings.

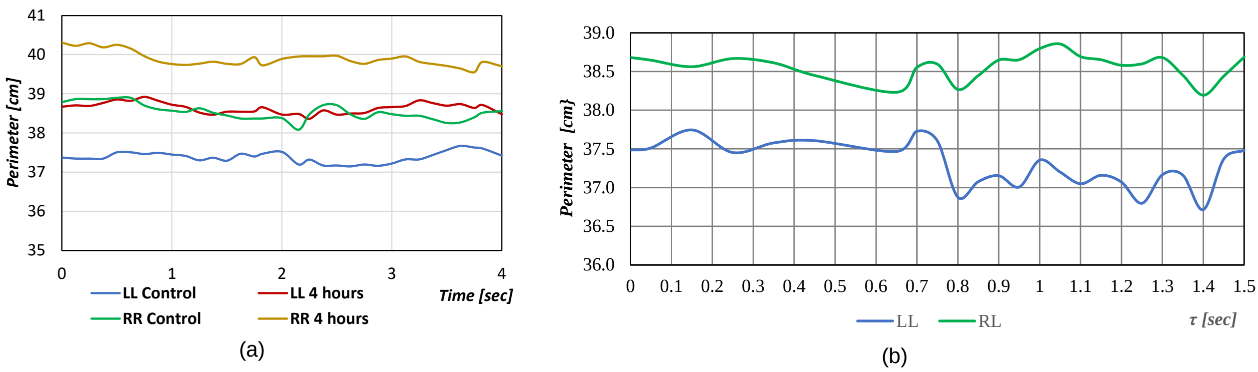


Figure 4. Legs circumference changes at 30 cm level during bending over (a) and rising on tiptoe (b).

Table 1. Right leg cross section area (maximal value) at 30 cm level.

Conditions		**Type of stocking**					
Activity	***Wearing time***	***Conventional***		***I CCL***		***II CCl***	
		S [cm²]	*Δ* [%]	*S* [cm²]	*Δ* [%]	*S* [cm²]	*Δ* [%]
Static	Control leg	119	-	128	-	134	-
	0 hour	119	0.0	126	- 1.9	124	- 7.9
	1 hour	130	9.1	136	6.3	131	- 2.1
	4 hours	133	11.1	138	7.5	131	- 2.4
Walking	Control leg	119	-	128	-	129	-
	0 hour	119	0	126	- 1.6	126	- 2.3
	1 hour	130	9.2	133	3.9	127	- 1.6
	4 hours	132	10.9	135	5.5	131	1.6
Rising on tiptoes	Control leg	118	-	122	-	128	-
	0 hour	118	0	121	- 0.8	123	- 3.9
	1 hour	127	7.6	130	6.6	127	- 0.8
	4 hours	128	8.5	131	7.4	127	- 0.8
Stepping	Control leg	118	-	124	-	126	-
	0 hour	118	0	120	- 3.2	122	- 3.2
	1 hour	124	5.1	130	4.8	128	1.6
	4 hours	127	7.6	133	7.2	127	0.8
Bending over	Control leg	116	-	124	-	125	-
	0 hour	116	0	122	- 1.6	121	- 3.2
	1 hour	123	6.0	129	4.0	125	0
	4 hours	125	7.8	131	5.6	125	0
Sitting down	Control leg	151	-	155	-	162	-
	0 hour	151	0	154	- 0.6	159	- 1.8
	1 hour	166	9.9	164	5.8	159	- 1.8
	4 hours	167	10.6	164	5.8	163	0.6

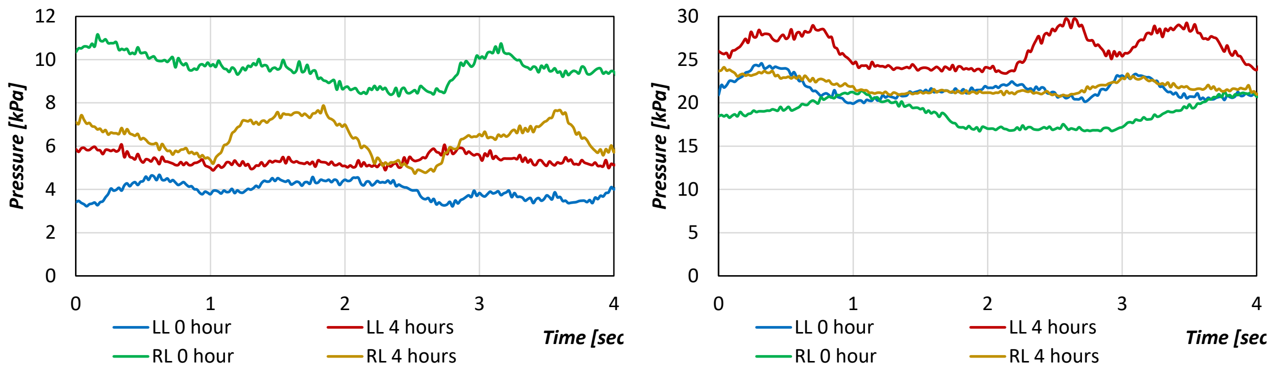
legs cross section areas after 4 hours of conventional stocking wearing were fixed during walking and sitting down with 10.9 % and 10.6 % correspondently. The I CCl stockings reduce values up to twice mostly. The I CCl stockings reduce swelling and values decrease, but the best results have been got with the usage of II CCL stockings. No swelling was fixed even after 4 hours of stockings wearing. Thus, obtained results give the clear opportunity for evaluation of compression stockings effectiveness.

Pressure value

The change in the leg's size leads to changes in stocking pressure on a lower limb. As we can see in Fig. 5 the pressure during bending over is changing within 3 kPa for I CCL and 5 kPa for II CCL stockings. The differences in pressure exerted to left and right legs are due to differences in their sizes. The pressure delivered by II CCl stocking is 2 times higher than those by I CCl stocking.

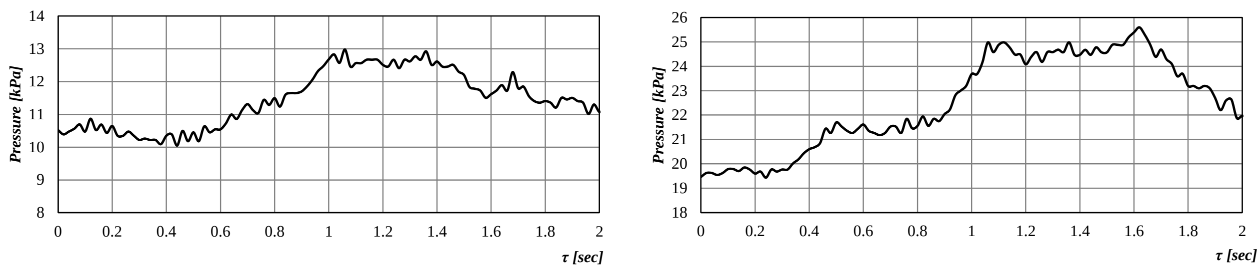
Thus, for left leg with 1 CCl stocking the pressure during bend over was from 3.2 to 4.5 kPa just after stocking wearing and in the 3.9-5.2 kPa range within 1 hour of wearing. The pressure rose to 5-6 kPa (over 50% increase) after 4 hours of wearing due to leg swelling. For the right leg there is different tendency: the delivered pressure is decreasing withing wearing time. This is probably because the stocking is not fitting well and slipping during wearing time.

The II CCl stocking with a higher level of delivered pressure keeps it more stable (Fig. 5 b). The changes in pressure during bend over just after stocking wearing was within 5 kPa, but after 1 hour of wearing it was only 2 kPa with similar mean values. After 4 hours of wearing the pressure goes up due to leg swelling and necessity to keep legs in initial state. The increase is within 20 %. The tendencies are similar for both legs. The differences in pressure value for left and right legs is due to their different size and swellings.



(a) (b)

Figure 5. Pressure at 30 cm level within bending over for compression stockings: (a) I CCl; (b) II CCl.



(a) (b)

Figure 6. Pressure at 30 cm level within rising on tiptoe just after compression stockings wearing (0 hour): (a) I CCl; (b) II CCl.

The plots in Fig. 6 show how the pressure value on right leg changes within one cycle of movement, namely rising on tip toe and back to initial position. It is clear that highest value is at the top position and it correlates with circumference changes (Fig. 4 b). There is the similarity in plots for I CCl (Fig. 6 a) and II CCl (Fig. 6 b), the different is only in pressure values.

The plots for legs sizes changes and for delivered pressure for correspondent movements show similarity in tendencies thus 4D scan data can be used for the evaluation of compression stocking performance for certain persons and future development of high-quality personal products.

CONCLUSION

The investigation of the geometry changes of lower legs with compression stockings of two classes during wearing time and different activity confirmed that the shape and size of lower leg increased over time due to legs swelling and over different activity due to muscles volume changes. It was found that for studied volunteer the right leg is bigger and has higher swelling level. The highest changes in leg circumference at calf level was occurred during bending over and rising on tip toe (10-15 mm). The leg area increases up to 11 % at calf level, that were obtained after 4 hours at static position and during both walking and sitting down.

The conducted research has shown a correlation between the leg size (circumferences and areas) and the pressure level delivered by compression stockings. By processing data, it was clarified the compression stocking of which class more effective and more useful for scanned person. It could be concluded that the 4D scanning allows the quick estimation the compression stockings functionality.

The study results with stockings of two compression classes within wearing time and different activity are the basis for future development the algorithm for a customization of compression stocking to individual body geometry.

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