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Investigation of the geometry changes of body legs with compression stocking in static position

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ABSTRACT

The high speed (4D) body scanning provides technical possibility for accurate measurements of the body geometry and can be applied not only for moving objects, but as well for evaluating the changes of static geometry with time. This information is important for compression socks, because it provides data regarding the relaxation processes of the textile product and of the human leg. In this work, changes of the body geometry after 1 and 4 hours with compression socks are investigated. Up to 9% changes of the cross section areas and up to 5.5% of changes of the circumference between the position at the starting point and after 4 hours are detected. Additionally the differences between the both legs of the investigated person and of the different (upper- and bottom) part of the leg are observed. It is the first step to the digitalization of the personal compression stocking design.

Keywords
compression clothes,
stocking,
lower leg,
body size and shape,
body scanning

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1 Introduction

Pressure garment is the main element of compression therapy [1] that is a mean of treatment and prevention of many diseases [2]]. The main principle of this therapy is the application of a certain pressure on the tissues surrounding the affected area. Depending on the applied pressure, compression clothes can affect the internal volume of veins, arteries, and lymphatic vessels [3]. Compression clothing should suit different body types and exactly follow the contours of the body as well as should have controlled elasticity and extensibility. It is necessary to strictly observe the conditions of interaction between textiles and the body, because differences in sizes and shapes are crucially important for the treatment of each individual [4].

At the beginning of the therapy, the appropriate girths and lengths are collected with a measuring tape (for example, for the leg), and then the compression garment is selected according to the compression level and the size table of the current standard [5]. Ready-to-wear or pre-sized garments are available from a number of commercial companies. They are available in a variety of styles and sizes for all body parts, but they do not normally fit patients perfectly. Custom-made pressure garments are widely considered to be the most effective for pressure therapy, but are more expensive as well.

The degree of pressure produced by a compression garment is determined by a complex interrelation between clothes and body. From the clothing point of view the principle factors are the design and fit of the garment, the structure and physical properties of its materials. As for the body they are the size and shape of the body's part to which it is applied and the nature of the activity undertaken [6]. Scientists around the world are working to improve understanding the main points of designing compression clothing. One of the main priorities is to create a high accuracy model to predict the pressure at the intended points on the human body.

A huge part of research on compression stockings is related to their medical usage [7-9] and published in medical scientific journals [9-11] because of medical aspects' study. It was found that the pressure profile exerted by elastic stockings varies with the posture [12] and exercise [13]. Furthermore, the changes in pressure vary from side to side of the leg. Compression stockings are effective not only for preventing diseases [14] but for enhancing the performance during the submaximal and maximal running exercise as well [15].

From the textile point of view, the main developments are new products of different compression classes [16,17] with graduated pressure [18] and improved comfort properties [19,20]. Important aspects are the prediction the compression value [21] and its mathematical modeling [22]. The development of reliable full body scanning has provided a new tool for compression garment design [23] and the study of the interaction between the body and clothing fit in active positions [24]. The exploration of system "body-compression garments" is the most important stage of compression garment design and this stage is less studied despite a lot of works in the area. It is complex research with different targets. Starting from studying the individual geometry of the patient's body and the changes of sizes and shapes of body parts within wearing time and different activity, it is followed by the investigation the actual pressure level and its changes within both wearing time and different activity. The study the changes of elastic materials' properties within usage and the recognition of body areas most affected by clothes pressure are very important as well.

The correct adaptation of compression garment to the individual geometry of the patient's body is an important aspect of compression therapy to achieve the desired therapeutic success. On the other side, the measurement accuracy of body shape and size leads to improvement compression clothes development. In this case, the 3D/4D body scanning can be an appropriate tool. The investigation of the leg geometry and its changes within time and wearing different stockings is the purpose of this research. The research data as well as an avatar of scanned legs is the initial point to the digitization of the compression stocking design with the accent on the product personalization. Lower legs were chosen as study object because of widespread diseases such as various types of chronic oedema, venous thromboembolism and venous ulcers, were compression therapy is widely used. The data obtained by a scanning system for the static body position were transferred into different software in order to find the optimum way for the evaluation of the result.

2 Methods

2.1 Body scanning

A modular photogrammetry-based 3D/4D capture and analysis system MOVE 4D from Valencia polytechnic university at TU Dresden was used for body scanning. It consists of a set of synchronised 4D scanning modules and software that automatically processes the captured point clouds to provide dense watertight 3D meshes [25]. The homologous export function enables new possibilities for analysis and optimization of clothes [26]. The standardized or custom digital markers that are enabled by the homologous model allow quick physical assessments [27].

Only one person was scanned because of the idea of an individual concept. The scans were made for the control leg (without stockings) and a leg wearing stockings. Two types of compression stockings were used (Table 1). The scanning was done before (control) and just after putting on the stockings (0 hour), after 1 and 4 hours wearing. Within the 4 hours between scanning moments, the person did their usual activity without any restriction and obligation. The measurements were performed at every 1 cm between ankle and calf. Three points (at 10, 23 and 30 cm from the floor) were chosen to be presented in the paper as most important for pressure measurement and control (Fig.1). These points were marked on the legs and on the stockings because within activity (walking, running, bending over etc.) the distance between them changed. This will simplify future measurements of the legs' shape changes within different activity

Table 1. Circumferences of pre-sized stockings.

Measurement point	I compression class	II compression class
10 cm	186 mm	190 mm
23 cm	228 mm	224 mm
30 cm	270 mm	266 mm

Fig. 1 Stockings and measurement points.

2.2 Data processing

After the scanning and data processing by MOVE 4D, a large list of obj files with the body geometry is available, but requires another software and algorithms for its evaluation [28].

In this study, the following software was used for data processing:

1. Geomagic Design X – for a comparison of leg shapes and an analyses of changes;
2. MeshLab 2022.02 – for planar section (Fig. 2a) and for area or/and circumference measurements, five parallel measurements were done and a mean value was used for analysis;
3. ParaView 5.11.0 – for slices (Fig. 2b) and data transfer in CSV and TXT formats;
4. Excel 2016 – for data sorting, organizing and calculation.

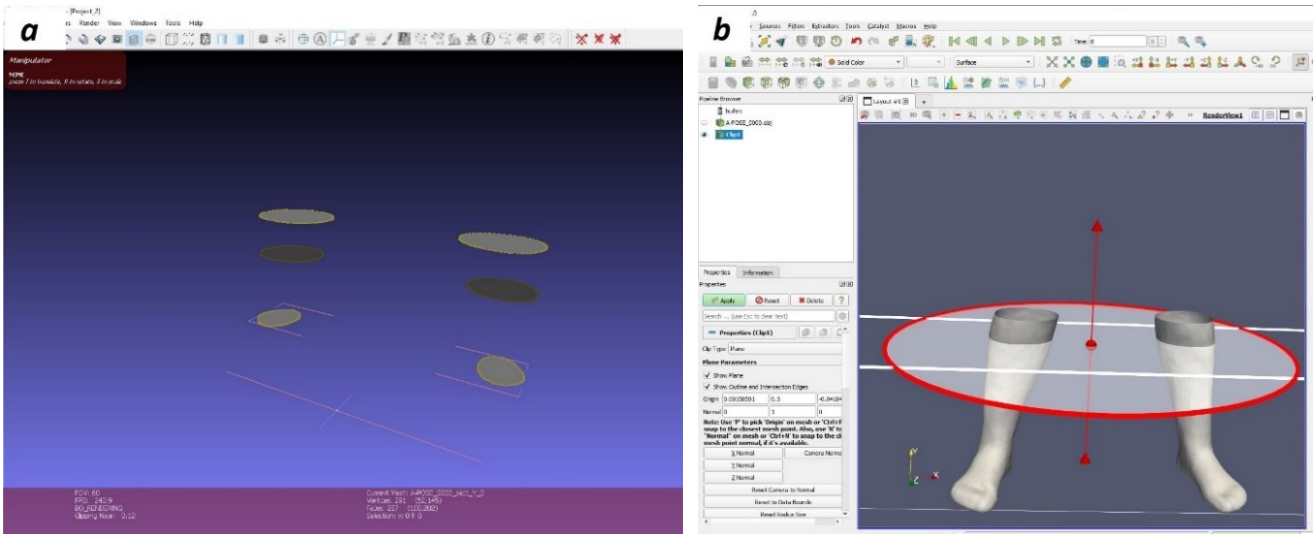

Fig. 2 Used software capture (a) MeshLab; (b) ParaView.

3 Results and discussion

3.1 Lower leg shape changes

Firstly, a comparison of the scanned legs was conducted to assess which parts of the leg change most over time, as well as how the use of compression stockings affects such changes. The analysis shows that, as predicted, the shape and volume of the legs increase over time due to swelling. The inner and back lower leg parts swell most. The legs' volume decreases slightly immediately after wearing the compression stockings (Fig. 3a), but over time it recovers and even increases partially (Fig. 3b). This applies to the calf area especially.

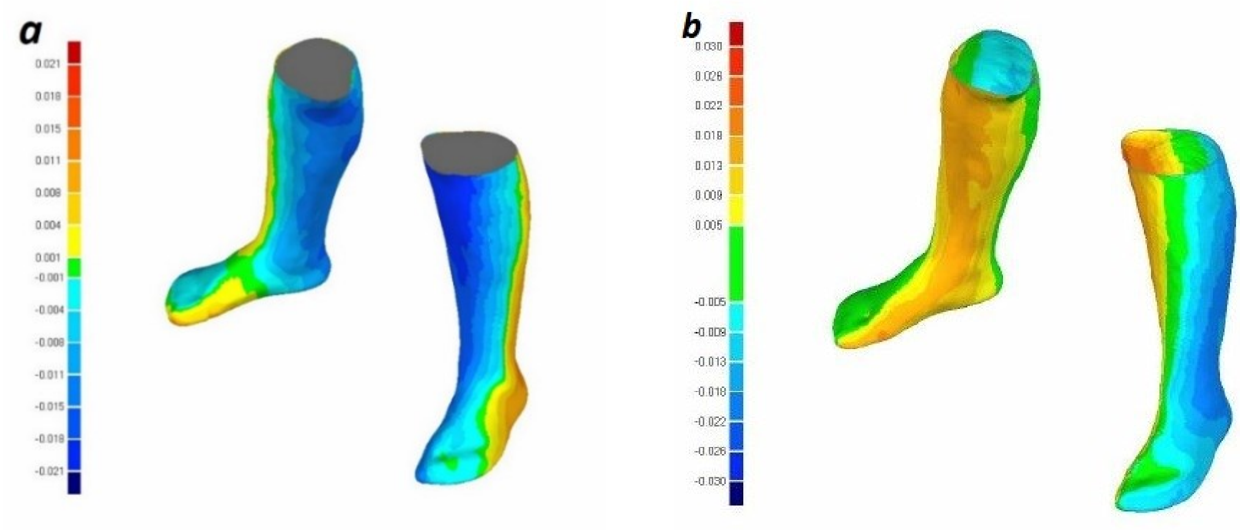

Fig. 3 Geomagic Design X comparison of leg shapes wear compression stockings class I (a) 0 hour to control; (b) 4 hours to 0 hour.

Comparative analysis of scanned legs using Geomagic Design X software (Fig. 3) showed the possibility of its application only at the initial stage of research in order to determine the areas with the greatest changes. As can be seen from the presented examples, there are shape increases and decreases at the same level. This certainly does not reflect the real picture because it is a consequence of different body positions. It is practically impossible to get two identical scans of the same person, especially after a time interval.

3.2 Leg size changes

To investigate real changes in the shape and size of the legs, slices were made at three levels (10 cm, 23 cm, and 30 cm) using ParaView software. Data arrays were converted into Excel files and processed. The obtained cross-sectional contours are presented in Fig. 4.

It is clear from the results that the legs are different. The right leg is larger than the left due to the asymmetry of the human body. The girths of the legs increased over time due to leg swelling. The right leg swells more.

The results of calculating the mean values of the circumferences and cross-sectional areas of the lower legs obtained by using the MeshLab software are presented in Table 2.

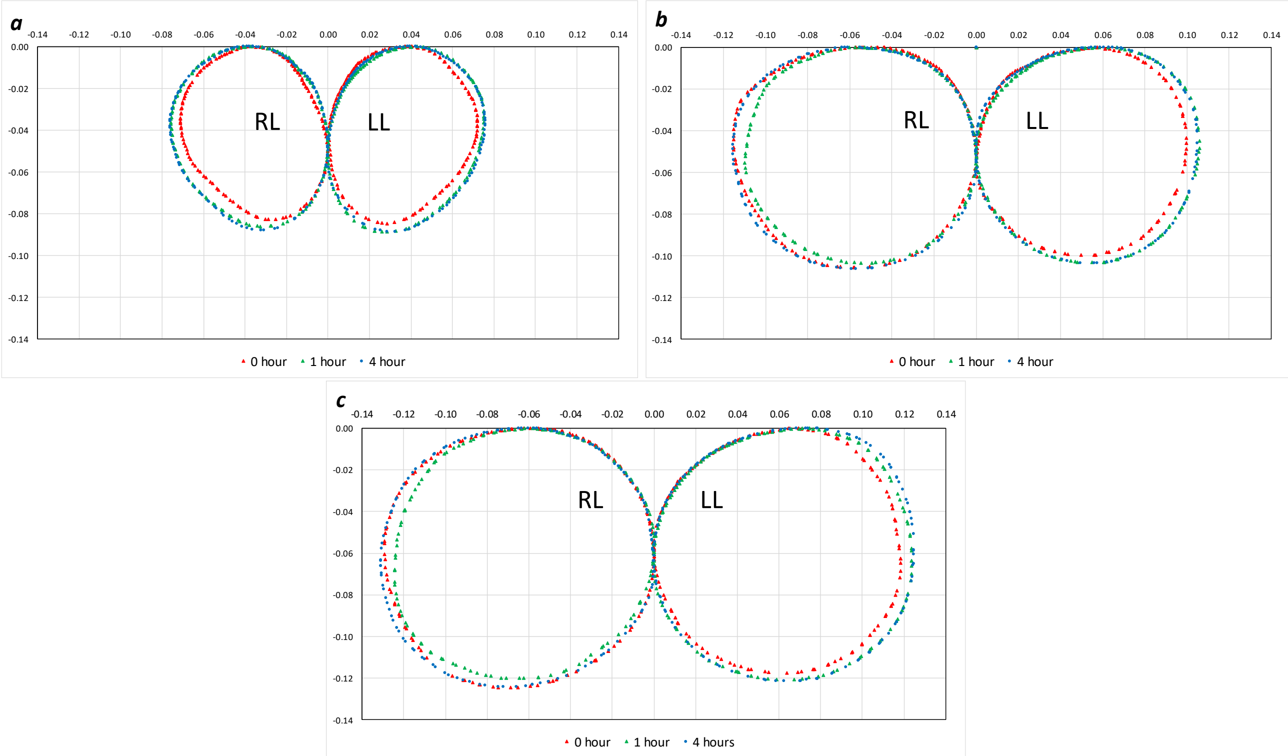

Fig. 4 Lower leg shape changes at levels (a) 10 cm; (b) 23 cm; (c) 30 cm.

Table 2. Leg sizes changes.

Leg level	Time	Circumference (mm)				Area (cm^2)			
		RL	Δ (%)	LL	Δ (%)	RL	Δ (%)	LL	Δ (%)
10 cm	0 hour	239	–	244	–	44	–	46	–
	1 hour	254	6.4	258	5.9	50	14.7	51	12.5
	4 hours	257	7.6	259	6.2	51	16.8	52	13.8
23 cm	0 hour	339	–	319	–	91	–	80	–
	1 hour	355	4.7	332	4.0	99	9.4	87	8.3
	4 hours	357	5.4	332	4.0	101	10.8	87	8.3
30 cm	0 hour	389	–	375	–	119	–	111	–
	1 hour	406	4.3	389	3.7	130	9.1	120	7.6
	4 hours	409	5.3	392	4.6	133	11.1	122	9.5

The obtained data confirm that the right leg is larger than the left, especially in the calf area. Leg circumference increases over time and reaches 4.6-5.4% at the calf and 6.2-7.6% at the ankle after 4 hours. The area’s increase is 9.5-11.1% at the calf and 13.8-16.8% at the ankle. It is obvious that the legs swelling is more pronounced at the ankle. These results clarify the above conclusions.

3.3 Compression stocking class I

To investigate real changes in the shape and size of the legs within compression stockings class I usage, the legs without stockings were scanned as control. The cross-sectional contours obtained from scan data of legs are presented in Fig. 5. The results of calculating the mean values of the circumferences and cross-sectional areas are presented in Table 3.

The study result shows that after putting on stockings the changes are more visible for the right leg and at the calf level (Fig. 5). It could be stated that the pre-sized stockings matched left leg better. Within the wearing time, both legs were swollen, but the swelling was less than without stockings.

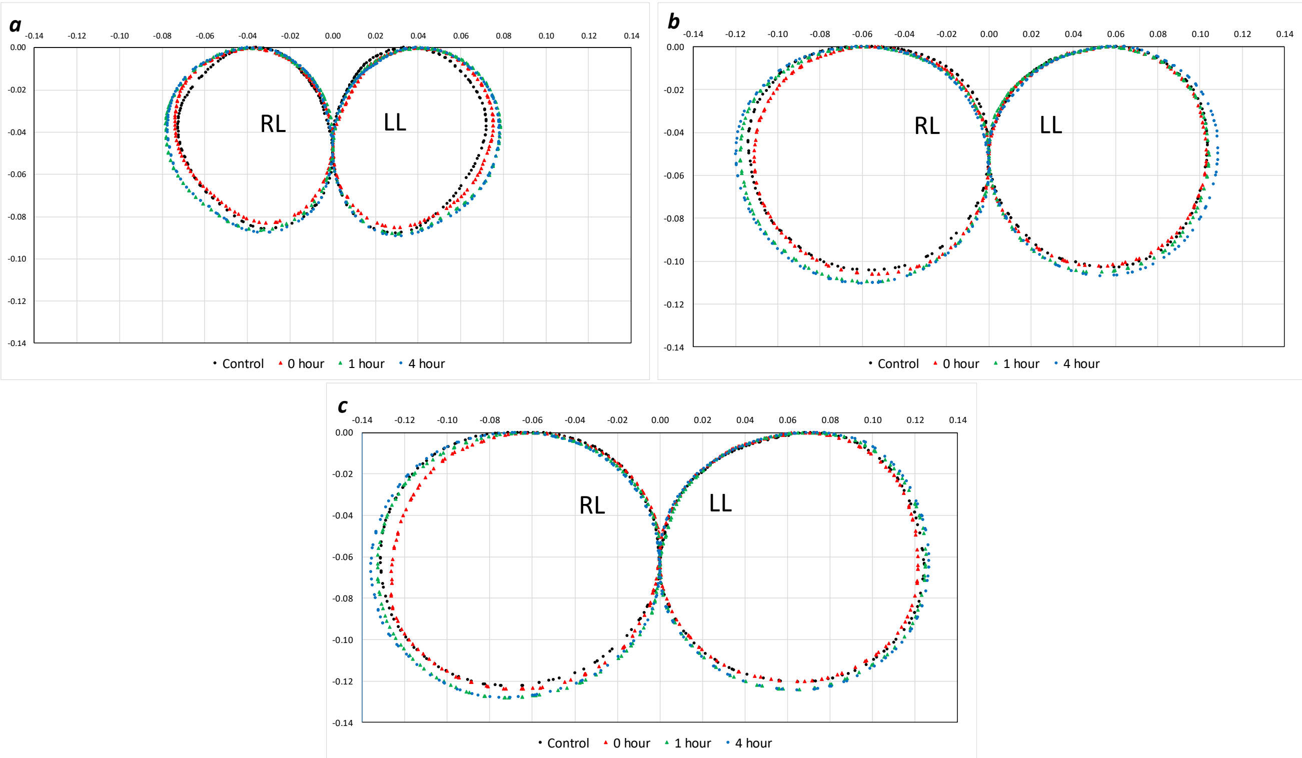

Fig. 5   Lower leg shape changes with compression stockings class I at levels (a) 10 cm; (b) 23 cm; (c) 30 cm.

Table 3. Leg sizes changes with compression stockings class I.

Leg level	Time	Circumference (mm)				Area, cm^2			
		RL	Δ, %	LL	Δ, %	RL	Δ, %	LL	Δ, %
10 cm	Control	246	–	250	–	47	–	48	–
	0 hour	246	0.0	250	0.0	47	1.2	49	1.4
	1 hour	258	5.2	262	4.8	52	12.4	54	11.3
	4 hours	259	5.4	262	4.8	53	12.9	54	11.6
23 cm	Control	347	–	325	–	95	–	84	–
	0 hour	346	-0.5	325	0.0	95	-0.5	84	0.4
	1 hour	361	3.8	333	2.4	103	8.1	88	5.1
	4 hours	361	4.5	338	4.1	104	9.6	91	8.7
30 cm	Control	402	–	385	–	128	–	117	–
	0 hour	399	-0.9	384	-0.3	126	-1.9	117	-0.4
	1 hour	414	3.0	393	2.6	136	6.3	124	5.5
	4 hours	416	3.6	398	3.3	138	7.5	125	6.8

Leg circumference increases over time and reaches up to 4% at the calf and 4.8-5.4% at the ankle after 4 hours (Table 3). The area's increase is 8.7-9.6% at the calf and 11.6-12.9% at the ankle. It is obvious that the legs swelling is less than without stockings. This is a confirmation for the necessity of compression stockings.

3.4 Compression stocking class II

The cross-sectional contours obtained from scan data of legs within compression stockings class II wearing are presented in Fig. 6. It is clear that using compression stockings class II leads to decreasing in the girths of the legs immediately after putting on the stockings. The original size and shape of the legs restored at the calf's level and was kept smaller than the original values at the ankle level within the wearing time.

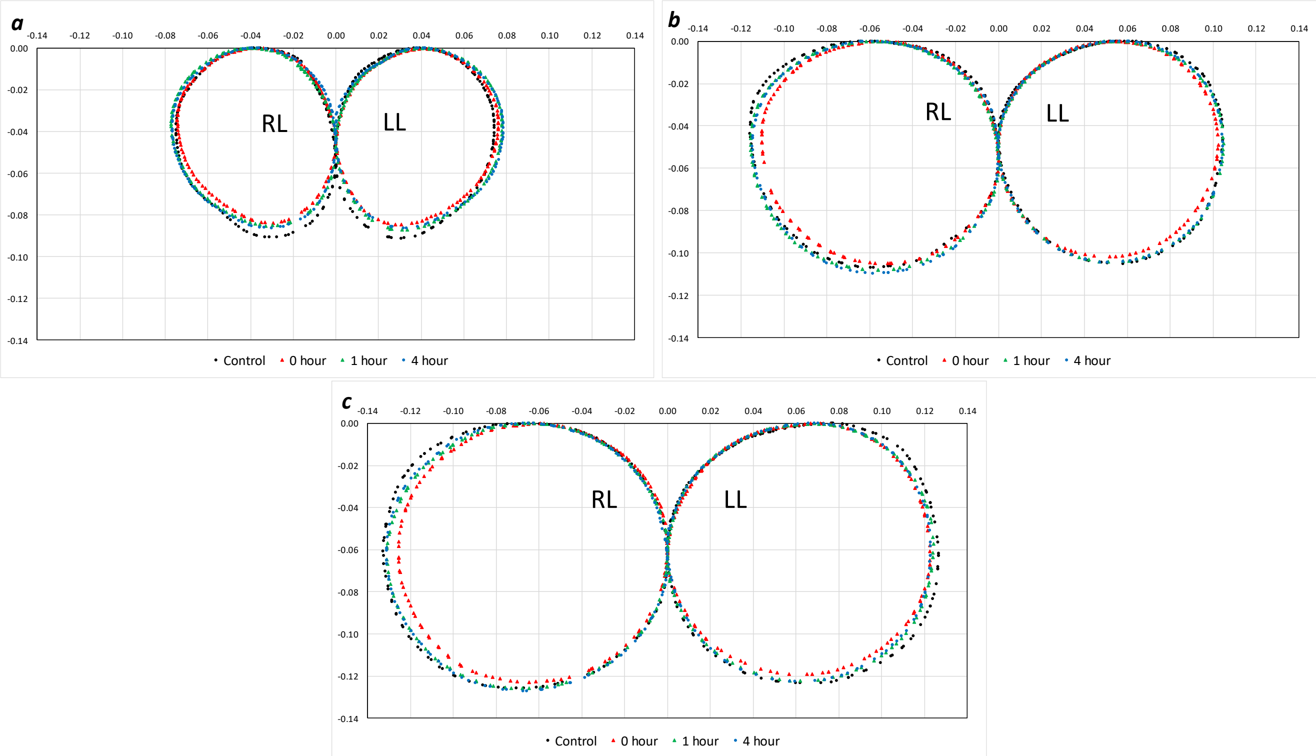

Fig. 6 Lower leg shape changes with compression stockings class II at levels (a) 10 cm; (b) 23 cm; (c) 30 cm.

Table 4. Leg sizes changes with compression stockings class II.

Leg level	Time	Circumference (mm)				Area (cm^2)			
		RL	Δ (%)	LL	Δ (%)	RL	Δ (%)	LL	Δ (%)
10 cm	Control	262	–	262	–	53	–	53	–
	0 hour	247	-5.5	250	-4.4	48	-9.4	49	-7.7
	1 hour	255	-2.6	258	-1.4	51	-3.6	52	-1.8
	4 hours	257	-1.8	257	-1.8	52	-1.9	52	-2.4
23 cm	Control	354	–	332	–	99	–	87	–
	0 hour	341	-3.6	323	-2.8	92	-6.5	83	-5.1
	1 hour	355	0.3	330	-0.5	100	1.2	86	-0.6
	4 hours	354	-0.1	330	-0.6	99	0.4	86	-0.9
30 cm	Control	411	–	398	–	134	–	125	–
	0 hour	394	-4.1	382	-4.1	124	-7.9	116	-7.6
	1 hour	407	-1.1	391	-1.9	131	-2.1	121	-3.4
	4 hours	406	-1.3	389	-2.4	131	-2.4	120	-4.3

This statement is fully confirmed by the results of calculating the mean values of the circumferences and cross-sectional areas as well as their changes during wearing time, as presented in Table 6. Thus, it can be stated that compression stockings class II are more suitable for the scanned person. They provide compression at the level sufficient to keep the volume of the legs within normal limits.

4 Conclusions

During the investigation of the geometry changes of lower legs with compression stocking in static position, the following results were found:

- the right leg of the scanned person is larger than the left due to the asymmetry of the human body;
- the shape and size of the lower legs increased over time due to legs swelling;
- the pre-sized compression stocking fitted better to the left leg;

- compression stockings class II were more effective.

To summarize the results, it can be asserted that 3-4D scanning is a promising means for assessing the dimensional changes of the body parts. It allows the quick estimation of the compression clothes functionality. The study of the changes of the legs' shape and size during different activity and the development of an algorithm for transforming data obtained during 4D scanning into processing data software are future stages. They will be the basic for the individual design of knitted compression products according to the patient's needs.

Author Contributions

O. Kyzymchuk: conceptualization, methodology, investigation; Y. Kyosev: supervision, writing – review and editing; L. Melnyk: formal analysis, writing – original draft preparation; N. Sadretdinova: visualization, data curation, validation. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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