Comparison and testing of compression stockings for sport activities in the laboratory

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Abstract. This work is about comparing and testing compression stockings and their influence on the human body. In this paper the basics of compression in the medical area as well as in the sportive field will be presented. The sportive compression works the same way like the compression therapy of the medicine area and has the same conditions for a healthy and correctly using. The sportswear with compression effect has an anatomically adjusted pressure profile, which based on a pair of pants, is most powerful at the ankle and decreases continuously up to the thigh. The closer one gets to the heart, the less pressure is required. There are many different types of socks for specific sport fields and it does not matter if it is an outdoor or indoor sport or for summer or winter. Five compression stockings were tested. In order to choose the right socks, a detailed inquiry about the currently available compression stockings on the market was conducted. The stockings were tested with several testing equipment existing in our facilities of the Center of Textile Sciences and Technology. The lab tests show that the stockings B and D has the best performance. The weakest in all test is stocking E. We can conclude that the compression effect of the stockings stabilizes the muscles and because of this the musculature isn´t so much stressed, increasing the recovery of the muscles.

1. Introduction

Compression therapy is a therapy that performs local pressure on the venous leg vasculature to increase blood flow velocity. This pressure may be produced by taping with the leg-compression bonding or by special socks [1]. Through development and guarantee of a permanent pressure, the venous leg vessels are constricted. For this reason the flow rate of the blood increases [2]. Compression therapy reduces the circumference of the conductive blood vessels of the body, which are below the compression dressing. For physical reasons the flow velocity of the blood increases because it has to pass through a lower space [3]. The return of the blood to the heart increases, edema is reduced and annealed toxins will be carry away.

The sportive area wants to use the effect of the compression for the improvement of the performance and a faster regeneration. If the blood circulation runs faster because of the pressure then there is more oxygen in the blood. The improved oxygen supply could boost the performance, increase the concentration and stimulate a faster regeneration. Furthermore, the musculature could be stabilized better and the pressure could reduce the vibration of the muscles. Above this the compression socks could prevent injuries because of the additionally muscle support. The sportive compression works the same way like the compression therapy of the medicine area and has the same conditions for a healthy and correctly using [4].

The performed pressure defines the so called compression class of the compression stockings.

Compression class I: The lowest pressure of 18 to 21 mmHg is used for prophylaxis of thrombosis, removal of heaviness or fatigue in the legs and is used for varicose veins with a lower risk of edema.
Compression class II: The pressure of 23 to 32 mmHg, is used for pregnancy varicose veins, after vein stripping, with swelling of the legs and after healing minor ulcerations as well as to prevent relapse of healed ulcers.
Compression class III: The strong compression with a pressure of 34 to 46 mmHg is used for thrombosis, post-thrombotic sequelae of venous insufficiency and a pronounced risk of edema.
Compression class IV: The very strong compression describes a pressure above 49 mmHg for lymphedema or elephantiasis [5].
The sportswear with compression effect has an anatomically adjusted pressure profile, which based on a pair of pants, is most powerful at the ankle and decreases continuously up to the thigh. The closer one gets to the heart, the less pressure is required. [6]
A very important material for compression stockings is the elastane. Without this the socks would not extensible in the necessary dimensions and could not be tightened. In addition, the stockings would exert any pressure when the elastane would not go back to its original shape and thus there would be no compression effect. The more elastane per area is used, the more elastic the material is.
There are many different types of socks for specific sport fields and it does not matter if it is an outdoor or indoor sport or for summer or winter. The various sport types for which one can use specific sport socks are Biking: Road bike and mountain bike; Running: Running and Nordic walking; Winter sports: Alpine skiing, cross country skiing, ski touring and snowboard; Outdoor: Hiking, trekking and mountaineering; Team sports: Basketball, soccer and ice hockey; Motorsports: Car racing and motorcycle racing; Hunting; Trend sports: Skateboarding, fitness and inline skating; Rackets sports: Golf and tennis and Horse riding.
In this paper the basics of compression in the sportive field will be presented. Five compression stockings were tested. In order to choose the right socks, a detailed inquiry about the currently available compression stockings on the market was conducted. The most important details and facts as well as the results of the laboratory investigations will be presented in this paper.

2. Materials and methods

The compressions stockings of this study were produced with weft knitting, using special circular machines and are described in Table 1.

Table 1. Sport compression stockings technical specifications, obtained from the manufacturer's information.

	Material	***Technical Composition***	***Pressure gradient***	***Retail Price***
A	86% Nylon, 10% Polypropylene, 4% Elastane	32% Nylon, 30% Skin NODOR®, 24% Robur™, 10% Mythlan™, 4% Elastane	High compression	55,00 €
B	72% Nylon, 28% Elastane	No special technical compositions	20-30 mmHg	49,95 €
C	86% Nylon, 10% Polypropylene, 4% Elastane	32% Nylon, 30% Skin NODOR®, 24% Robur™, 10% Mythlan™, 4% Elastane	Mid compression	55,00 €
D	85% Polyamide, 15% Elastane	No special technical compositions	20-22 mmHg	27,50 €
E	81% Polyamide, 12% Elastane, 7% Polyester	53% Polyamide, 24% Polyamide Tactel®, 12% Elastane, 7% Polyester, 4% Polyamide Nanoglide	19-22 mmHg	40,00 €

2.1. Dynamometer

With the dynamometer the force that exists in an object can be measured. On the one hand there is the traction and on the other hand the pressure force. For the compression stockings only the traction is important because the socks will be stretched while wearing as well as the fabric will be pulled. For this reason, it is very interesting to know how strong the socks have to be pulled to suit on the leg of the test person. Every stocking was pulled from the dynamometer at the ankle, in the middle between the ankle and the strongest calf point, and at the strongest calf point. The socks were stretched on every of the three points in ten cycles.

Some parameters, which must set on the computer for the dynamometer, are for every stocking the same and some parameters needed to change from sock to sock. The following list shows the not changing parameters:

- Load range: 200N - The maximum strength of the dynamometer;
- Extension range: 200mm - The size of the diagram window;
- Speed: 400mm/min - The speed of the pulling tools;
- Preload: 0,1N - The start point of the measurement.

The changing parameters are the gauge length and the extension length. The first one is about the setting of the pulling tools. The tools need to be set in the right distance to each other. For this distance the width of every sock must be measured at the three measurement points (ankle, middle, calf). The tools needed to set one centimetre closer than the measurements so that they could grab the socks about five millimetres from the edge of each side. The second changing parameter, the extension length, is about how far the socks should be pulled by the dynamometer. Here it is necessary to measure the perimeters of a female leg at the ankle, the strongest calf point and in the middle. After this the width of the ankle minus one centimetre must be subtracted from the perimeter of the ankle to get the right extension length for this measurement point. The machine pulls the sock ten times to the extension length and after this the computer shows the curves as a result.

2.2. Deformation sensor

The *StretchSense* sensor is an elastic capacitor made of laminated polymer structure. The capacitance of the structure changes when the sensor is stretched or pushed and the change will be measured and related to deformation, which will allow to measure the compression applied by the stockings.

The figure 1 shows the so called „Evaluation-Kit“ with the battery, two sensors, the USB battery charger and the five channel sensing circuit. With this test the acting pressure on the leg can be measured. The sensor can be put in the stocking while wearing and the changing capacitance will be sent via Bluetooth to a mobile phone or tablet. On this mobile device the results can be observed with the StretchSense App.

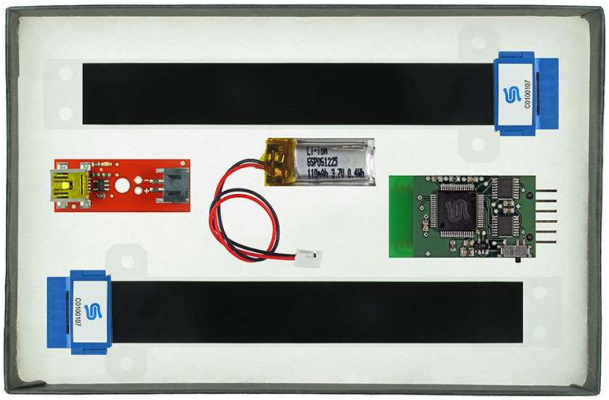

Figure 1 - : StretchSense „Evaluation-Kit, with the sensor bands (black stripes), the processing unit (right), battery (center) and USB adapter (left).

Every sock was tested at two spots, first above the ankle and second at the strongest point of the calf. At the ankle the pressure should be strongest and decrease up to the calf about 20-40%. Because of this the measurements at the ankle are set as 100% to calculate the decreasing pressure. The results were given as the changing capacitance so the stockings can be compared with each other but there is no information about the exact pressure gradient. For the mmHg value the sensor had to be calculated with weights to know how high the capacitance is changing at which pressure.

2.3. Air permeability

The testing of the air permeability is a very important thing for sportswear, especially for sport socks because the feet are one of the most sweating and heat developing area of the human body. If the fabric of the socks is not breathable enough then the socks are not suitable as sportswear. The sweat and water vapour could not pass through the fabric anymore and the feet would heat up to an unhealthy point.
The standard DIN EN ISO 9237: 1995 describes the test and its parameters. The test apparatus used is the Textest Instruments FX3300 and as testing head the size is selected because it is small enough so that no air flows past the side of the sock. Because the test is about clothing the standard recommends a test pressure of 100 Pa for clothing. The shaft and the footbed was measured 3 times so a statistically more correct value was obtained. The results are given in the unit liter divided by square meter per second (l/m2/s).

2.4. Thickness

The measurements of the thickness of the stockings were made with the Digital Thickness Gauge from SDL International. Every sock were measured on three different spots.
Every sock were measured on three different spots. The thickness was measured on each spot 3 times for a statistically more correct value.

3. Results

3.3.1 Dynamometer

The table 2 shows the maximum force values measured by the dynamometer for each stocking and for the three measured spots.

Table 2. Maximum forces measured using the dynomometer.

Stockings	***Measured Spot***		
	Ankle	***Middle***	***Calf***
A	16 N	19 N	19 N
B	21 N	26 N	33 N
C	13 N	15 N	12 N
D	23 N	24 N	24 N
E	6 N	14 N	29 N

The stocking B and D are the ones with the strongest force at almost all measurement points. These numbers support the official manufacturer´s instructions. The stocking E is one of the weakest of all socks, as it is in the official manufacturer's instructions too. At the area of the calf it is one of the strongest, but this is not because of the compression force of the sock, it is because of the not so elastic socks bund. It is conspicuous that the measurements regarding to the ankle have the lowest numbers but theoretically these values should be the strongest ones because the pressure should decrease in direction to the heart. It is possible due to human anatomy that a lower degree of force is necessary for higher pressure in the area of the ankle because this part of the leg consists of bones and less tissue.

3.2 Stretch Sensor

The table 3 shows the results of the changing capacitance of the StretchSense test. The unit is picoFarad (pF).

Table 3. Pressure force measured by Stretchsense system. The unit is picoFarad (pF).

Stockings	Ankle	Calf
A	224,2 (100%)	164,6 (73,4%)
B	229,4 (100%)	167,8 (73,1%)
C	220,3 (100%)	165,8 (75,3%)
D	237,8 (100%)	183,7 (77,2%)
E	219,4 (100%)	155,4 (70,8%)

The stocking with the lowest change of capacitance and so the lowest pressure force at the ankle as well as at the calf is the stocking E. The stocking with the highest change of capacitance and so the highest pressure force at the ankle as well as at the calf is the stocking D. The sock B has also a very high change of capacitance. However the stocking C is the weakest ones with an official „Mid compression"value and the results of the StretchSense supports this. All stockings have a decreasing change of capacitance from the ankle to the calf and so a decreasing pressure force about 29,2% to 22,8% from the ankle to the calf. This is like it should be for a healthy using of the tested stocking.

3.3 Air Permeability

The following table 4 shows the results regarding air permeability.

Table 4. Air permeability. The unit is $l/m^2/s$.

	Measured Spot	
Stockings	***Leg***	***Foot***
A	223,7	172,3
B	126	146
C	194	170
D	105,7	116,3
E	281	203,7

The results show that the Stockings E has the highest air permeability. As the dynamometer and the StretchSense tests showed, these stockings are the ones with the lowest compression force. Because of this it is logical that the loop structure is not so tight like the structure of the other socks and this is why the stockings E has the highest results for air permeability. The loose structures allow more air to stream through the knitting structure. On the other side the results of stockings B and D are the lowest air permeability due their tightest loop structure and so the air cannot stream so easily through the socks. The dynamometer and the StretchSense tests showed that the stockings B and D has the highest compression force so it is also logical that the results for this socks are the lowest for the air permeability. The results of stockings A and C are in the middle like their results of the compression force tests. Almost all socks have a higher air permeability in the leg area than at the footbed, except stocking B and D.

3.4 Air Thickness
The following table 5 shows the results regarding thickness measured in millimetre (mm).

Table 5. Thickness (mm)

Stockings	***Measured Spot***
A	9,13
B	3,67
C	9,23
D	5,80
E	5,03

The table shows that the socks A and C have the highest thickness. It is very interesting that the sock B, one of the socks with the highest compressions, are the ones with the thinnest material. The stockings with the lowest compression force should have the thinnest knitting structure and therefore the weakest material in regard to the pressure.

4. Conclusions
Regarding to compression stockings on the market there are many different types for specific uses, for example running socks and nowadays also recovery socks after running. Some of the stockings have built in features like toe protectors, cooling channels or ankle protection pads.
The lab tests showed that the strongest ones are the stockings B and D. The weakest in all test is stocking E. If we compare the retail price, the stocking with the best behaviour is also the cheapest one, almost half the price of the other studied socks.
It is perceptible that the measurements of the pressure should decrease in direction to the heart. It is possible due to human anatomy that a lower degree of force is necessary for higher pressure in the area of the ankle because this part of the leg consists of bones and less tissue.
All stockings have a decreasing change of capacitance from the ankle to the calf and decreasing pressure from the ankle to the calf. This is like it should be for a healthy use of the tested stocking.

5. References

[1] Xiong Y and Tao X 2018 *Polymers* 10, p 663
[2] Felty C L and Rooke T W 2005 *Seminar Vascular Surgery* 18 pp 36-40
[3] Liu R et al 2008 *Advances in Therapy* 25 p 465
[4] Available from http://omotion.eu/de/kompression/medizinischer-hintergrund.html
[5] Available from http://www.sigvaris.de/de/sigvaris-medical/erfahren-sie-mehr/was-ist kompressionstherapie
[6] Grundmeier A. M. 2011 *Bekleidung und Gesundheit*. Baltmannsweiler: Schneider Verlag Hohengehren

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