Comparison of compression stockings in the laboratory and by wear trial

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ABSTRACT: This work is about compression stockings and their influence on the human body together with the sportive performance. In this paper the basics of compression in the medical area as well as 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 stockings were tested with the dynamometer and pressure sensor in the laboratory and furthermore all the socks were tested by running trials in the gym on the treadmill. The most important details and facts as well as the results of the laboratory investigations and the running tests will be presented in this paper.

Keywords: compression stocking; medical area, sportive field, laboratory tests, wear trial.

1. INTRODUCTION

1.1 *Compression stockings*

Compression therapy is a therapy that performs local pressure on the venous leg vasculature to increase blood flow velocity (Xiong et al, 2018). This pressure may be produced namely by taping with the leg-compression bonding or by special socks. Compression therapy is used in a variety of conditions, for example for pregnancy edema and venous insufficiency. In addition, the compression therapy is also used as prevention for diseases where there is a risk of thrombosis and for immobile patients who develop congestions such as paresis of the legs (Rabe et al, 2018). Through development and guarantee of a permanent pressure, the venous leg vessels are constricted. For this reason, the blood's flow rate increases (Felty et al, 2005). For physical reasons the flow velocity of the blood increases because it has to pass through a lower space (Liu et al, 2008). The return of the blood to the heart increases, edema is reduced and annealed toxins will be carry away. Other desirable effects are speeding up the healing of wounds and the prevention against thrombosis. The performed pressure defines the so called compression class of the compression stockings. The following list shows the compression classes.

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 (Sigvaris,2018).

In the sportive area the pressure should promote the blood flow and the resulting increased oxygen level in the body can maintain the concentration longer during exercise, which is very important especially for very fast and dangerous sports such as motorcycle racing or alpine skiing. In addition, the improved

oxygenation helps enhance performance and the pressure reduces undesirable muscle vibration. After physical exertion compression garment has a regenerating effect, it accelerates recovery and prevents muscle soreness (Stanek, 2017). 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 (Grundmeier, A. M;2011).

2. MATERIALS AND METHODS

All compressions stockings are produced with the knitting technology. Some stockings use special fibers like the SkinNodor® fiber, which is a microfiber made of polyamide 6.6 with silver ions or the Robur™ fiber, which is a hollow bodied fiber made from polyamide 6.6 as well (Table 1).

Table 1

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

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 circles. 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 centimeter closer than the measurements so that they could grab the socks about five millimeters 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 centimeter must be subtracted from the perimeter of the ankle to get the right extension length for this measurement point. The same must be calculated for the calf and the middle. When all parameters are set, the socks must be inserted between the pulling tools of the dynamometer machine at one of the three measurement points and then the test can start. The machine pulls the sock ten times to the extension length and after this the computer shows curves as a result. After this the test need to be repeated on the other two measurement points.

2.2 *Stretch 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 (Stretchsense, 2018). The following figure shows the so called „Evaluation-Kit“with the battery, two sensors, the usb battery charger and the five channel sensing circuit.

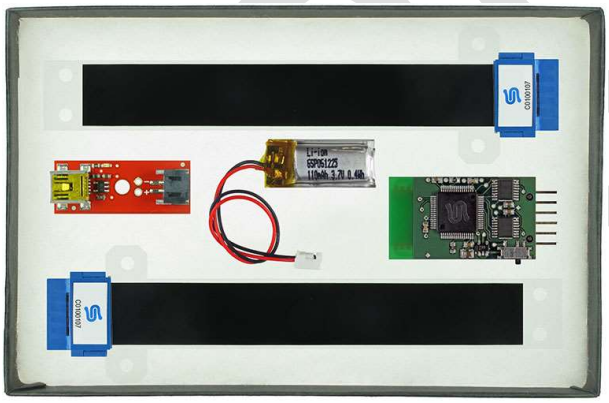

Figure 1 - : StretchSense „Evaluation-Kit

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 seen with the StretchSense-App.

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. The following table shows the results of the changing capacitance of the StretchSense test.

2.3 Wear trial

The wear trial was performed by a female athlete. There were two runs with the same stocking, one in the morning at 10 a.m. and the second one in the evening at 7 p.m. All runs were two kilometers long and executed at the gym on the same treadmill and after the runs the athlete answered questions regarding to the run she did. At the beginning she did two runs as comparative runs without wearing a compression stocking so that all the other tests with the stockings could be compared to the normal level. The running time for the comparative run in the morning is 14 minutes and 15 seconds and the running time in the evening is 14 minutes and 49 seconds.

3. RESULTS AND DISCUSSION

3.1 Dynamometer

The table 2 shows the maximum dynamometer values for each stocking.

Table 2

Stockings	***Female Version***		
	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 following table shows the results of the changing capacitance of the StretchSense test.

Table 3

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.

3.3 Evaluation of the wear trial

The athlete never wore compression stockings before and so it was very uncomfortable to wear them the first time. But the more often she wore the stockings the better was the feeling. The runs in the morning are always the better ones. Maybe the body is more efficient in the morning or the body was kind of exhausted after the morning run so the second one in the evening could not be as good as the first one. The following table shows the results of the running tests for all stockings.

Table 4

Stockings	Morning run in minutes	Evening run in minutes
Without stockings	14:15	14:49
A	14:52	15:04
B	14:04	14:38
C	13:57	14:08
D	14:05	14:22
E	14:16	14:43

Almost all runs with stockings were a little bit faster than without. Except the sock A, because of the painful feeling while the running and the sock E because there was no feeling of pressure at all. However, the athlete did not have the feeling that the stockings improved her performance even when the running times with the socks where a little bit faster. The continuous running enhanced her capacity more than wearing the compression stockings. Furthermore, when the pressure was really uncomfortable like it was with stocking B or D socks the running time was a little bit slower. On this way the stockings had a bad effect on the performance. But the running times of the sock E, the ones with no feeling of pressure, is almost the same as the running times of the comparative runs. So, the pressure maybe has a little influence on the performance but without blood tests to determine the lactate value and the oxygen level in the blood as well as a thermal imaging of the muscles there will be no sure answer about the influence of compression stockings to the performance. But regarding to the recovery of the muscles the athlete thinks that the stockings have a positive effect. The athlete never had heavy legs or muscle hangovers or cramps after running or the days later. So, the compression effect of the stockings stabilizes the muscles and because of this the musculature is not stressed so much.

4. CONCLUSIONS.

Regarding to compression stockings on the market there are many different types for specific use, for example recovery socks or beginner socks. Some of the stockings have built in features like toe protectors, cooling channels or ankle protection pads. There are many research studies about compression and the effectiveness of using compression pressure for sportive action or recovery as we could see in the Introduction.

All stockings were tested in the laboratory and by wear trial. The tests in the laboratory were the dynamometer, the StretchSense sensor, which captured the pressure of each stocking while wearing. The running tests were performed on a treadmill. There were two runs per sock, one in the morning and one in the evening. To compare the results two runs without compression stockings were performed from the athlete as well.

The lab tests and the experience of the athlete show that the strongest ones are the stockings B and D. The weakest in all test is stocking E. The Stocking A was the slowest in the wear trial. And the runs with stocking C were the fastest during wear trial, maybe because they felt the most comfortable for the athlete without a painful feeling, while wearing. Regarding to the recovery of the muscles the athlete felt a positive effect, therefore we can conclude that the compression effect of the stockings stabilizes the muscles and because of this the musculature wasn´t so much stressed.

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