Clinical Study

Compression Stockings for Treating Venous Leg Ulcers

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Background. In order to treat venous leg ulcers, it is recommended to use high pressure compression (30–40 mmHg at the ankle). Compression stockings which are not operator dependant could be the best option because of their pressure control. However 30–40 mmHg compression stockings are often hard to put on. Putting two lower pressure compression stockings over each other could be a good therapeutic alternative. **Objectives.** To compare the *in vitro* pressures given by the manufacturers of 2 antiulcer kits with the *in vivo* interface pressures measured in healthy subjects and to evaluate the stiffness and friction indices from those kits based on the interface pressure in order to assess their clinical properties. **Material and Methods.** Using a Kikuhime pressure device, interface pressure was measured in 12 healthy subjects at the reference point B1. One stiffness index (Static Stiffness Index (SSI)) and a friction index have been calculated. **Results.** Mediven Ulcer kit gets the recommended pressures whereas Jobst's Ulcer Care kit does not for treating a venous leg ulcer. Jobst's Ulcer Care transmits entirely the pressure in relation to a friction index close to 1. **Conclusion.** This antiulcer kit study underlines that *in vivo* and *in vitro* pressures can be different (Jobst's Ulcer Care kit and Mediven Ulcer kit). In order not to lose pressure, it is important to take into account the friction index when superimposing two stockings.

1. Background

Compression increases ulcer healing rates compared with no compression [1, 2].

Thus to improve the healing process (recommendation grade 1B) it is recommended to treat venous or mixed venous ($0.6 > \text{ABI} < 0.9$) with high pressure. A pressure between 30 and 40 mmHg should be obtained at the ankle (professional agreement).

Multicomponent systems are more effective than single-component systems. Multicomponent systems containing an elastic bandage appear more effective than those composed mainly of inelastic constituents. Two-layer stockings appear more effective than the short-stretch bandage [3]. In fact, there are no clear differences in the effectiveness of different types of high compression.

Putting on the bandages requires a great experience and the respect of the bandage stretching rules. A pressure level from 30 to 40 mmHg may not be easy to achieve. The main criticism that can be made against the use of a multilayer bandage or short stretch is linked to bandage slippage.

Slippage is a cause of adverse effects: pain, aggravation of ulcer ulceration, and necrosis [4].

The use of compression stockings seems to be the best option because of the pressure control it allows for and it is not operator dependant. However 30–40 mmHg compression stockings are often hard to put on, especially for the elderly. In this case a donning and doffing aid could be useful.

According to Amsler et al. [5] putting two lower pressure compression stockings on top of each other is the best option to get the desired pressure level. In terms of healing process, pain level, and nursing cares, compression stockings are better than bandages.

Concerning the pressure under 2 stockings on top of each other, Cornu-Thenard et al. [6] showed that the *in vitro* pressure, in such conditions, is equal to the sum of the pressures that each stocking induces separately.

The pressure is different *in vivo*.

For Partsch et al. [7], the pressure under 2 stockings on top of each other is slightly inferior to the sum of the pressures that each stocking induces separately.

Benigni et al. [8] came to the same conclusions in regard to the *in vivo* pressures and the stiffness indices.

Rastel and Lun [9] agree that the loss of pressure can be explained by the added pressure resulting from two elastic yarns on top of each other. Concerning compression stockings, the yarns go on top of each other in the remaining free areas (Figure 1). Yarns do not rub uniformly on top of each other. Friction forces need to be taken into account in order to understand the loss of pressure transmitted.

The interface pressures and the *in vivo* kits stiffness must be known. By analogy with bandages they could allow to anticipate the expected clinical effects. Moreover pressure loss happening by superimposing needs to be linked with friction consequences. A better understanding of this process should result in improved kits.

2. Objectives

The aim of this paper is as follows:

- (1) to compare *in vivo* interface pressures at B1 measured in healthy subjects with *in vitro* pressures of two different superimposed antiulcer 40 mmHg kits,
- (2) to calculate their stiffness and friction indices based on the *in vivo* interface pressures, in order to appreciate the outcome.

3. Material and Methods

Twelve healthy subjects participated in the study (4 men and 8 women). They were aged between 52.1 ± 12 years, with an average height of 169 ± 6 cm, an average weight of 69.0 ± 8 kg with ankles of 22 ± 0.9 cm at point B and of 29 ± 3 cm at point B1. Healthy patients were randomized in 2 groups of 6.

The interface pressures were measured at point B1 (Figure 2). This point is described in the CEN document [10]. Measurements have been done both at rest and then in a standing position [11].

3.1. Compression Ulcer Kits. Mediven Ulcer Kit (Medi Bayreuth) compression stockings (kit 1) were as follows:

- (i) a Mediven ulcer understocking with an ankle pressure of 20 mmHg (point B). This stocking is to be worn day and night. It is made of 71% polyamide, 28% elastin, and 1% silver (antimicrobial texture),
- (ii) a Mediven ulcer plus overstocking also with an ankle pressure of 20 mmHg (point B) only to be worn during the day. It is made of 75% polyamide and 25% elastan.

In vitro pressure Mediven Ulcer kit (manufacturer) 40 mmHg at point B.

Jobst's Ulcers Care, (Jobst) compression stockings (kit 2) were as follows:

- (i) an understocking for protection, made of 78% nylon/polyamide and 22% Spandex/elastane,

- (ii) an overstocking with a zipper. It is made of 85% Nylon/polyamide and 15% Spandex/elastane.
- (iii) *in vitro* Jobst's Ulcer Care pressure (manufacturer): 40 mmHg at point B.

The sizes of stockings were selected accordingly to the circumferences measured at ankle level (point B).

3.2. In Vivo Interface Pressure Measurements. The interface pressures were measured using the Kikuhime system (TT Medi Trade, Soledet 15, DK 4180 Soro), which is composed of the following:

- (i) a Kikuhime device (Figures 3 and 4),
- (ii) this system uses two identical, oval-shaped measuring sensors, 30×38 mm, 3 mm thick when calibrated to 0 mmHg.

At point B1, the interface pressures were measured on the 12 healthy subjects' right leg in 2 positions (at rest and standing up). Each measurement was repeated 3 times as follows: with the understocking, then the overstocking alone, and finally the two on top of each other. 216 measurements were completed.

3.3. Stiffness Index Calculation. Static Stiffness Index (SSI) reflects the difference in interface pressures between the lying and standing positions.

We consider that a compression is stiff when the SSI is higher than 10 mmHg [11].

3.4. Friction Index Calculation. When on top of each other and moving, the knitting yarns rub each other. When stretching the two knitted pieces, the threads are not superimposed anymore and the transmitted pressures become smaller.

This index equals 2 superimposed stockings stiffness index (SI^{sup}) divided by the sum of the stiffness indices of the 2 stockings used separately (SI^{alone}):

$$IF = \frac{SI^{superimposed}}{SI^{alone} + SI^{alone}}. \quad (1)$$

4. Statistical Analysis

Measurement of the coefficient of variation, comparison of means for the interface pressure, and the Stiffness Index were performed using the Student's *t*-test.

Statview version 5 statistics software was used to perform the calculations.

5. Results

The 2 groups were comparable for sex, age, and leg circumferences.

5.1. In Vivo Pressure Measurements in mmHg and Stiffness Indices Calculation. For the kit 1 (Table 1), the *in vivo* interface pressures at B1, in the 2 situations, are within the

FIGURE 1: Compression stockings superimposition (yarn of wool and stitch, picture obtained by 2 stockings numeric superimposition).

FIGURE 2: Point B1 (virtual dissection of the leg with a CT scan and a 3D reconstruction without contrast medium. G: medial gastrocnemius muscle; S: soleus muscle).

FIGURE 3: Kikuhime device.

limits of pressures recommended to treat a venous ulcer. On the other hand the pressures of the kit 2 stay under 30 mmHg at rest. They only exceed 30 mmHg when there is a muscular activity (Table 2).

For the kit 1, the pressures measured *in vivo*, when superimposing, are smaller than the sum of the two stockings used separately. As for kit 2, there is no significant difference.

All the pressures measured under the 2 understockings are low; hence the understockings can be kept on the leg during night, even in patients with peripheral arterial occlusive disease (with an ABI > 0.6) without ischemic risks.

The bigger the pressures get, the more the Stiffness Index (SSI) increases. Our analysis goes along previous publications [7, 8].

For the two tested kits the comparison between the *in vivo* average pressure at rest shows a noticeable difference but inferior to 10 mmHg (Table 3). None of the 2 kits are stiff.

None of the two kits are stiff between the resting and standing positions (SSI).

Concerning the kit 1, the stiffness indices are lower than the sum when the two stockings are superimposed, whereas for the second, the kit 2, there is no difference

FIGURE 4: Pressure sensor.

between the results of the sum of the two pressures and the superimposition.

The calculation of a friction index is necessary to explain these differences.

5.2. Friction Index. The kit 2 friction index is 1 (SSI). In other words, the kit 2 transmits all of the two stockings pressure.

TABLE 1: Average and standard deviation of the kit 1 of *in vivo* pressures at point B1 and stiffness indices.

<i>In vivo</i>	Overstocking	Understocking	Theoretical sum	Superimposition measured
At rest	19.0 (3.9)	16.8 (3.3)	35.8	33.0 (4.7)**
Standing up	25.1 (3.4)	22.2 (3.2)	47.3	41.9 (5.5)**
SSI	6.1	5.4	11.5	8.9

** $P < 0.05$.

TABLE 2: Average and standard deviation of the kit 2 of *in vivo* pressures at point B1 and stiffness indices.

<i>In vivo</i>	Overstocking	Understocking	Theoretical sum	Superimposition measured
At rest	15.7 (3.4)	8.3 (0.8)	24	24.2 (4.5)**
Standing up	19.8 (4.5)	12.2 (2.3)	32	32.2 (5.3)**
SSI	4.2	3.9	8.1	8.1

** $P < 0.05$.

TABLE 3: Comparison of the stiffness indices measured with 2 kits and the stiffness indices calculated based on the sum of pressures, $P < 0.05$.

	Kit 1	Kit 2	Kit 1 versus Kit 2
SSI 2 CS superimposed	8.9 (4.1)	8.1 (3.9)	NS
SSI sum	11.5 (4.7)**	8.1 (3.9)**	$P < 0.05$

TABLE 4: Friction indices.

Friction index	Kit 1	Kit 2
SSI	0.77	1

However the other kit, whose friction index is 0.77 for kit 1, underlines that they only transmit the pressure partially. The pressure loss is about 20% for this kit.

In this kit, the two superimposed stockings fibers do not come on top of each other when stretched, in contrast to kit 2 (Table 4).

6. Discussion

This underlines the importance of the friction index. In order to understand it better, one should go back to the laws of friction for materials. Pierre-Gilles de Gennes summarizes them as follow [12].

“Leonard da Vinci’s work imposed itself as a cornerstone in this field. He observes that if an object—a piece of wood—is on a surface that is then raised up, it will slide along it up from a certain angle. This is a feature of static friction. In 1699, Guillaume Amontons repeats the experience and comes to the same conclusion. It is only in 1950 that the British school (T. P. Bowden and David Tabor) explained why a small surface has the same properties as a big one: the tight contact results from asperities and bumps. When using a small surface, the pressure applied increases; hence the decrease in surface is compensated by a higher density on the contact zone. The same result is obtained than on a bigger surface”.

The kit 2 has the biggest friction index possible: 1 for the SSI. There is no loss of pressure, during a muscle contraction

FIGURE 5: Stitch of the understocking from kit 2.

FIGURE 6: Stitch of the overstocking from kit 2.

when superimposing, in relation with the number of asperities between the two stockings, although the pressures applied are smaller.

In this kit, the stitch of the overstocking is very dense. Because there are a lot of asperities, the friction of the understocking on the overstocking is high. There is no free space between the yarns of wool; hence a friction index equals to 1 (Figures 5 and 6 numeric microscope).

The knitting of the other kit is completely different. There are fewer asperities; hence the friction indexes are smaller by approximately 20% (Figures 7 and 8). In the stitch, the

TABLE 5: Selection criteria for compression.

	Size of ulcer	Dressing stage of the wound	Dysmorphic leg	Presence of significant edema
Compression stocking kit	Small size	Granulation/epithelialisation	–	–
Bandages	Large size	Exudative/debridement	+	+

FIGURE 7: Stitch of the understocking from kit 1.

FIGURE 8: Stitch of the overstocking from kit 1.

yarns of wool are superimposing because of the remaining free space between them.

Therefore when superimposing stockings, using the kit 1, the real (*in vivo*) pressures obtained at rest and standing up are similar to the ones given by the manufacturers (*in vitro*).

However the kit 2 shows differences when tested at rest.

Practical Consequences. The short stretch or multilayer bandages represent an ideal in terms of pressure and stiffness. But sliding, high variation of pressures, poor interoperator and intraoperator reproducibility, and cost-effectiveness are obstacles to their daily use.

Compression stocking kits marketed must come closer to the ideal of bandages without its flaws. This trial provides a reference for an “ideal” antiulcer kit by compression stockings. Their pressure at the ankle must be higher than 30 mmHg, stiffness greater than 10 mmHg, and the pressure of the kit should be equal to the sum of the pressures of each stocking measured separately (friction index = 1).

On the other hand, an important issue to tackle is the donning of the kit. The kit 2 understocking is easy to put on. However the overstocking is not, it is hard to zip it up.

However, the choice between compression stockings and bandages cannot be reduced to a pressure problem. Some other factors play a role (Table 5):

- (i) the size of ulcer,
- (ii) the dressing applied depending on the stage of the wound,
- (iii) the presence or absence of musculoskeletal deformities of knees, feet, or other dysmorphia,
- (iv) the importance of edema.

The size of ulcer is important in the choice. A large ulcer will require a dressing that may slip or come off when threading a stocking. It is preferable to use a multitype or a short stretch bandage easier to install. If the ulcer is small, the dressing with the hand when threading can be easily maintained.

At the exudative phase, the risk of leakage and odors requires the use of a secondary absorbent dressing. The thickness of two dressings makes difficult to apply one or two stockings in superimposition. In contrast during the granulation/epithelialisation phase, wound no longer flows, the primary dressing is usually thin and changed less frequently. The use of a kit is then fully justified.

The remark is similar in case of dysmorphic leg. A bandage is more suitable.

A significant edema is a problem of a different nature.

In the initial phase of edema reduction, the use of a stiff bandage (multilayer or short-stretch) allows a rapid reduction of swelling but the bandage may slip and lose all effectiveness or sliding may cause skin disorders. The bandage should be removed every two or three days to adapt it to the volume of the leg. If the swelling is small, the compression stockings find its natural place.

7. Conclusions

This antiulcer compression stocking study underlines that *in vivo* and *in vitro* pressures can be different (Jobst’s Ulcer Care kit).

In order not to lose pressure, it is important to take into account the friction index when superimposing two stockings. To that end it is more important to increase the number of asperities between the two antiulcer stockings, through their knitting, rather than considering the actual pressure applied.

In the future, bandages will only be used during the initial oedematous phase of venous leg ulcer treatment. The kits’ two superimposed stockings will be used during the maintenance phase.

Disclosure Agreement

No fees paid by manufacturers to authors. The concerned laboratories provided only the necessary stockings for measurement purposes.

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