ARTÍCULO ORIGINAL

Compression stockings for treating venous leg ulcers

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Abstract

Background: In order to treat venous leg ulcers, it is recommended to use high pressure compression (30-40mmHg at the ankle), particularly multilayer bandage. Its use depends on an operator and the pressure level can not be guaranteed. 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 difficult to put on, especially for the elderly people. To put two lower pressure compression stockings over each other could be a good therapeutic alternative. In Europe, anti-ulcer kits are available in order to solve that issue. Their *in vivo* properties must be specified: interface pressure and stiffness index. A better understanding of friction coefficient could allow to obtain better kits.

Objectives: To compare the *in vitro* pressures given by the manufacturers of 3 anti ulcer kits with the *in vivo* interface pressures measured in healthy subjects. To evaluate the stiffness and friction indexes from those kits based on the interface pressure and to assess their clinical properties.

Material and Methods: Using a Kikuhime pressure device, interface pressure was measured in 18 -healthy- subjects at the reference point B1. Two stiffness indexes (Static Stiffness Index [SSI] and the Dorsi Flexion Stiffness Index [DFSI]) and a friction index have been calculated.

Results: Both Hartmann's Saphenamed UCV and Medi's Mediven Ulcer kits get the recommended pressures whereas Jobst's Ulcer Care kit does not. The 3 kits are rigid only when a strong muscular contraction occurs (DFSI). Jobst's Ulcer Care transmits entirely the pressure in relation to a friction index close to 1.

Conclusion: This trial confirms that it is feasible to get the recommended stiffness index above 10 mmHg using two-layer compression stockings. It provides a reference for an "ideal" anti-ulcer kit by compression stockings.

Key Words: Compression Ulcer Kit. Superposition. Interface Pressure. Stiffness Index. Friction Index.

Resumen

Medias de Compresión para el Tratamiento de las úlceras Venosas de las Piernas

Antecedentes: A fin de tratar a las ulceras venosas de las piernas, se recomienda el uso de compresión de alta presión (30-40mmHg en el tobillo), particularmente el vendaje multicapa. Su uso depende de un operador sin poder garantizar la presión. Las medias de compresión que no dependen de un operador pueden convertirse en la mejor opción debido al control de su presión. Sin embargo, las medias de compresión de 30-40 mmHG son frecuentemente difíciles de colocar, especialmente para ancianos. Colocar las medias de compresión de presión más baja una sobre la otra puede ser una buena alternativa terapéutica. En Europa, los *kits* anti úlceras se encuentran disponibles a fin de resolver este tema. Sus propiedades in-vivo se pueden especificar: presión interfase e índice de rigidez. Un mejor comprendimiento del coeficiente de fricción podría permitir obtener mejores *kits*.

Objetivos: Comparar las presiones *in vivo* dadas por los fabricantes de 3 *kits* anti ulceras con presiones interfases *in vivo* medidas en personas sanas. Para evaluar tanto la rigidez como los índices de fricción de aquellos kits que se basan en la presión interfase y afirmar sus propiedades clínicas.

Material y Métodos: Utilizar un dispositivo de presión Kikuhime la presión interfase se midió en 18 pacientes sanos en el punto de referencia B1. Se han calculado dos índices de rigidez (el Índice de Rigidez Estático [SSI] y el Índice de Rigidez Dorsi Flexion [DFSI]).

Resultados: Ambos *kits* el de Hartmann's Saphenamed UCV y Medi's Mediven poseen las presiones recomendadas mientras que el kit de Jobst no. Los 3 *kits* son rígidos solamente cuando se produce una fuerte contracción muscular (DFSI). El cuidado de la úlcera de Jobst transmite la presión en forma completa en relación a un índice de fricción cercano a 1.

Conclusión: este Studio confirma que es factible obtener el índice de rigidez recomendado por sobre 10mmHg utilizando las medias de compresión multicapa. Provee una referencia para un *kit* anti úlcera "ideal" por medio de las medias de compresión.

Palabras Claves: Kit de compresión de la úlcera. Superposición. Presión interfase. Índice de rigidez. Índice de Fricción.

Background

Compression increases ulcer healing rates comparing 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> ABI < 0.9) with high pressure. A pressure between 30 and 40 mmHg should be obtained at the ankle (professional agreement).

Multi-component systems are more effective than single-component systems. Multi-component systems containing an elastic bandage that appear to be more effective than those ones composed mainly of inelastic constituents. Two-layer stockings seem to be more effective than the short-stretch bandage(3).

To put on the bandages requires a great experience as well as to respect the bandage's strechting rules. A pressure level from 30 to 40 mmHg may not be easy to achieve.

The use of compression stockings seems to be the best option due to the pressure control; it is not operator-dependant. However, 30-40 mmHg compression stockings are often hard to put on especially for the elderly people.

According to F. Amsler(4), putting two lower pressure compression stockings on top of each other is the best option to get the desired pressure level. According to the healing process, to the pain level and to nursing cares, compression stockings are better than bandages.

Concerning to the pressure under 2 stockings on top of each other, A. Cornu-Thenard et al.(5) have shown that the *in vitro* pressure in such conditions is equal to the sum of the pressures that each stocking induces in a separate way. The pressure is different *in vivo*.

For H. Partsch et al(6), the pressure under 2 stockings on top of each other is slightly inferior to the sum of the pressures that each stocking induces separately.

J. P. Benigni, A. Cornu-Thenard et J. F. Uhl(7) have come to the same conclusions in regard to the *in vivo* pressures and the stiffness indexes.

D. Rastel, et B. Lun(8) agree that the loss of pressure can be explained by the added pressure resulting from two elastic yarns on top of each other. Concerning to

compression stockings, the yarns go on top of each other in the remaining free areas *(Picture 1)*. Yarns do not rub on the top of each other in an uniform way. Friction forces need to be taken into account to understand the loss of pressure transmitted.

The *in vivo* pressure kits do not reach the "dose expected effect". 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 super-imposing, needs to be linked with friction consequences. A better understanding of this process should result in improved kits.

Objectives

The aim of this report is:

1. To compare in vivo interface pressures at B1 measured in healthy subjects with in vitro pressures of 3 different superimposed anti-ulcer 40 mmHg kits.

2. To calculate their stiffness and friction indexes based on the in vivo interface pressuresr to appreciate the outcome.

Material and Methods

18 healthy subjects have participated in this study (6 men and 12 women). They were aged between 53.1 +/- 12.9 years, with an average height of 168 +/-8 cm, an average weight of 69.8+/- 10 kg with ankles of 22+/-22.9 cm. at point B and of 29+/- 3 cm. at point B1. Healthy patients were randomized in 3 groups of 6 patients.

The interface pressures were measured at point B1 (Picture 2). This point is described in the CEN document(9). Measurements have been done both at rest and at work(11) in a lying position and then in a standing position(10).

Compression Ulcer Kits

Mediven Ulcer Kit (Medi Bayreuth) compression stockings :

-A Mediven ulcer understocking with an ankle pressure of 20 mmHg (Point B). This stocking is to be worn during the day and the night. It is made of 71% polyamide, 28% elastan and 1% silver (antimicrobial texture).

- 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.

Saphenamed UCV (Hartmann) compression stockings:

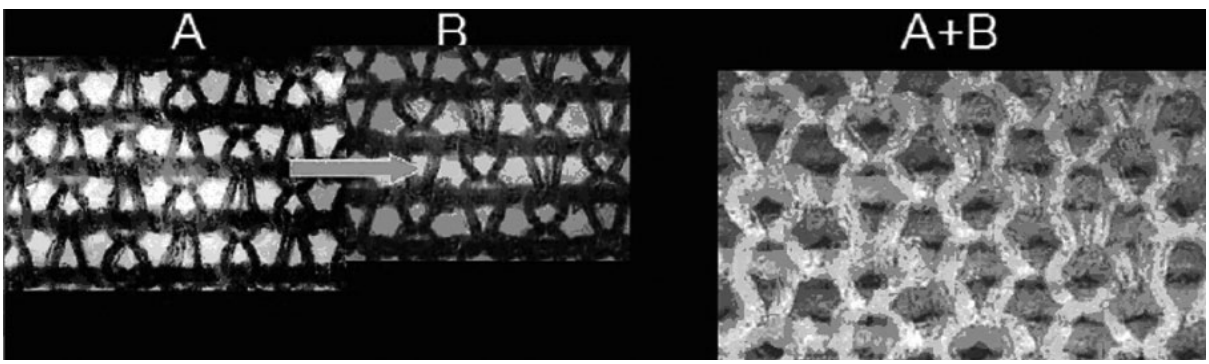
- A microfiber understocking to facilitate the application made of 3 % Lyocell and SeaCell (seaweed et cellulose), 9% cotton, 18% elastan and 70% polyamide also generate a optimum pressure on the ulcer area and keep a low graduated pressure from the ankle to the calf. It is made of smooth yarns and they do not put pressure on the feet.

- An overstocking open foot. It is made of 61% polyamide, 28% elastane, 8% coton and 3% Lyocell® *in vitro* pressure Saphenamed UCV (manufacturer): 40 mmHg at Point B.

Jobst UlcerCare (Jobst) compression stockings:

- An understoking for protection made of 78% nylon/polyamide and 22% Spandex/elastane.

- An overstocking with a zipper. It is made of 85%



Picture 1. Compression stockings super-imposition (yarn of woof and stitch, picture obtained by 2 stockings numeric super-imposition).

Nylon/polyamide and 15% dSpandex/elasthane.

- *In vitro* Jobst UlcerCare pressure (manufacturer): 40 mmHg at point B.

The sizes of stockings were selected accordingly to the manufacturer's recommendations, depending on the circumferences measured at ankle level (Point B).

In vivo Interface Pressure Measurements

The interface pressures were measured using the Kikuhime system (TT Medi Trade, Soleddet 15, DK 4180 Soro), which is composed by:

- A Kikuhime device (Picture 3).
- This system uses two identical: oval-shaped measuring sensors, 30 x 38 mm, 3 mm thick when calibrated to 0 mmHg.

At Point B1, the interface pressures were measured on the 18 healthy subjects' right leg in 3 positions (at rest and at work in a lying position then standing up). Each measurement was repeated 3 times as follows: with the understocking, then with the overstocking alone and finally with the two on top of each other. 486 measurements were completed.

Stiffness Index Calculation

Static stiffness index (SSI) reflects the difference in interface pressures between the lying and standing positions.

In France another stiffness index is used: the DFSI (Dorsi Flexion Static Index). It reflects the difference in interface pressures between the lying positions at rest and after a complete foot dorsiflexion(11). We consider a compression is stiff when the SSI is higher than 10 mmHg(10).

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 to: 2 superimposed stockings stiffness indexes (SI^{sup}) divided into the sum of the stiffness indexes of the 2 stockings used separately (SI^{alone}) (Formula).

Statistical analysis

Measurement of the coefficient of variation, comparison of means for the interface pressure and the stiffness index were performed using the Student *t* test.

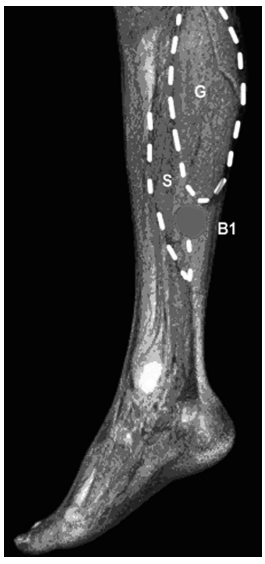
Statview version 5 statistics software was used to perform the calculations.

Results

The 3 groups were comparable for sex, age, leg circumferences.

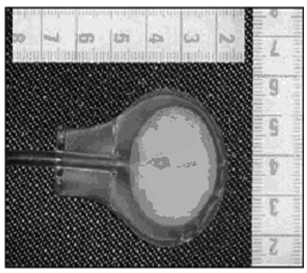
In vivo Pressure Measurements in mmHg and Stiffness Indexes Calculation

For the Saphenamed UCV (Hartmann) (Table 1)



Picture 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)

Picture 3. Kikuhime device.



Picture 4. Pressure sensor.

$$IF = \frac{SI^{superimposed}}{SI^{alone} + SI^{alone}}$$

Formula

and Mediven Ulcer kit (Medi) (Table 2) kits, the *in vivo* interface pressures at B1, in the three situations are within the limits of pressures recommended to treat a venous ulcer. On the other hand, the pressures of Jobst's superimposed stocking kit tay under 30 mmHg at rest. They only exceed 30 mmHg when there is a muscular activity (Table 3).

For the Saphenamed UCV (Hartmann) and the Mediven Ulcer Kit (Medi) kits, the pressures measured *in vivo*, when superimposing ones are smaller than the sum of the two stockings used separately. As for Ulcer Care (Jobst) there is no difference.

All the pressures measured under the three 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 pressures get the most the stiffness indexes (SSI and DFSI) increase. Our analysis goes along previous publications(6,7).

For the three tested kits, the comparison between the *in vivo* average pressure at rest and at work (DFSI) shows a noticeable difference superior to 10 mmHg ($p<0.05$) associated with an auto-massage effect necessary to reduce an edema on walking. Under these conditions, the Mediven Ulcer kit is significantly stiffer than Jobst's Ulcer Care kit.

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

Concerning to Saphenamed UC of Hartmann and Mediven Ulcer kits, the stiffness indexes are lower than the sum when the two stockings are superimposed, whereas for the third Jobst's Ulcer care kit there is no difference 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.

In vivo	Overstocking	Understocking	Theoriticalsum	Superimposition Measured
At rest	19,2 (1,5)	17, (1,3)	36,4	34,8 (5,4)* **
Dorsiflexions	26,1 (2,4)	25,1 (3,9)	51,2	47,3 (8,8)*
Standing up	24,4 (2,1)	23,1 (3,9)	47,5	43,6 (9,2)**
SSI	**5,2**	**5,8**	11	**8,7**
DESI	**6,8**	**7,9**	14,7	**12,4**

* **p<0,05

Table 1. Average and standard deviation of the Saphenamed UCV® kit of in vivo pressures at point B1 and stiffness indices

In vivo	Overstocking	Understocking	Theoritical sum	Superimposition Measured
At rest	19,0 (3,9)	16,8 (3,3)	35,8	33,0 (4,7)* **
Dorsiflexions	28,9 (5,0)	26,8 (4,8)	55,7	48,2 (5,4)*
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**
DFSI	**9,9**	**10,1**	20	**15,2**

* **p<0,05

Table 2. Average and standard deviation of the Mediven Ulcer Kit® of in vivo pressures at point B1 and stiffness indices

In vivo	Overstocking	understocking	Theoritical sum	Superimposition Measured
At rest	15,7 (3,4)	8,3 (0,8)	24	24,2 (4,5)* **
Dorsiflexions	22,4 (6,3)	12,8 (3,0)	35,2	35,3 (6,5)*
Standing up	19,8 (4,5)	12,2 (2,3)	32	32,2 (5,3)**
SSI	**4,2**	**3,9**	8,1	**8,1**
DFSI	**6,7**	**4,6**	11,2	**11,3**

* **p<0,05

Table 3. Average and standard deviation of the Jobst Ulcer Care® kit of in vivo pressures at point B1 and stiffness indices

Friction Index

Jobst's Ulcer Care® friction indexes are 0.99 (DFSI) and 1 (SSI). In other words, the kit transmits all of the two stockings pressure.

However, the other two kits, whose friction indexes were 0.84 and 0.79 for Saphenamed UCV and 0.76 and 0.77 for Mediven Ulcer kit underline that they only transmit the pressure in a partial way. The pressure loss is about 20% for these two kits.

In these two kits, the two superimposed stockings fibers do not come on top of each other when stretched, in contrast with Jobst's Ulcer Care kit.

Discussion

Therefore, when superimposing stockings using either Saphenamed UCV® (Hartmann) or Mediven Ulcer Kit® (Medi) kits, the real *(in vivo)* pressures obtained at rest, at work and standing up are similar to the ones given by the manufacturers *(in vitro)*.

However, the Ulcer Care® (Jobst) shows differences when they are tested at rest.

Medi's Mediven Ulcer Kit® has the highest DFSI. Hence, this kit is stiffer than the other two and it should theoretically has a better massaging effect.

But one should not get confused between the stiffness and the friction indixes. Even if the kit is stiff the pressure loss, when superimposing stockings, can be important. Mediven Ulcer Kit (Medi) kit is the stiffest out of the three ones studied but there is still a 20% pressure loss when it is superimpoed. The Ulcer Care® (Jobst) kit, even though less stiff, transmits all the pressure.

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(13): 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 he 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.

Jobst's Ulcer Care kit has the biggest friction pressure possible: 1 for the SSI and 0.99 for the DFSI. There is no loss of pressure during a muscle contraction when superimposing in relation to 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 woof, hence a friction index equals to 1 (Pictures 5 and 6 numeric microscope).

The knitting of the other two kits is completely

	Saphenamed	Mediven	Jobst	Saphena Vs Mediven	Saphena Vs Jobst	Mediven Vs Jobst
SSI 2 CS superimposed	8,7 (4)	8,9 (4,1)	8,1 (3,9)	NS	NS	NS
SSI sum	11 (4,6)	11,5 (4,7)	8,1 (3,9)	NS	p<0,05	p<0,05
DFSI 2 CS superimposed	12,4 (4,9)	15,2 (5,5)	11,2 (4,6)	NS	NS	p<0,05
DFSI sum	14,7 (5,4)	20 (6,7)	11,3 (4,6)	p<0 ,05	p<0,05	p<0,05

Table 4. Comparison of the stiffness indexes measured with 3 kits and the stiffness indexes calculated based on the sum of pressures, with α=5 % one-sided p<0,05.

Friction Index	Saphenamed UCV® (Hartmann)	Mediven Ulcer® kit (Medi)	Ulcer care® (Jobst)
SSI	0.79	0.77	1
DFSI	0.84	0.76	0.99

Table 5. Friction indexes

different. There are fewer asperities; hence the friction indexes are smaller by approximately 20% (Pictures 7 and 8). In the stitch, the yarns of woof are superimposing because of the remaining free space among them.

Putting the Stockings on

Our last but not less important issue: to tackle is the putting on phase for those three kits.

Jobst's Ulcer care understocking is easy to put on. However, the overstocking is not, it is hard to zip it up.

The lack of heel on the understocking makes the other kits be easier to put on.

Hartmann's Saphenamed UCV kit probably is the best one to use to put it on an ulcer bandage. Indeed, both the understocking, with its low graduated pressure and the overstocking with its open foot are easy to put on. Overall this kit was the easiest to one to use.

Conclusions

This anti-ulcer compression stocking study underlines that *in vivo* and *in vitro* pressures can be different (Jobst's Ulcer care® kit).

The three kits stiffness are superior to 10 mmHg during a muscle contraction (DFSI) close to walking.

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

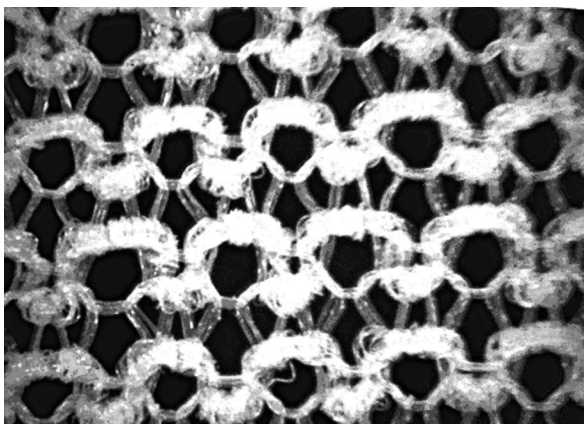


Photo 5: Stitch of the understocking from Jobst's Ulcer Care®.

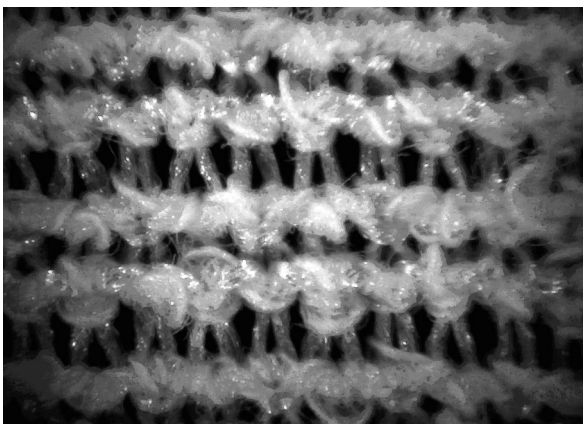


Photo 7: Stitch of the understocking from Saphenamed UCV® (Hartmann)

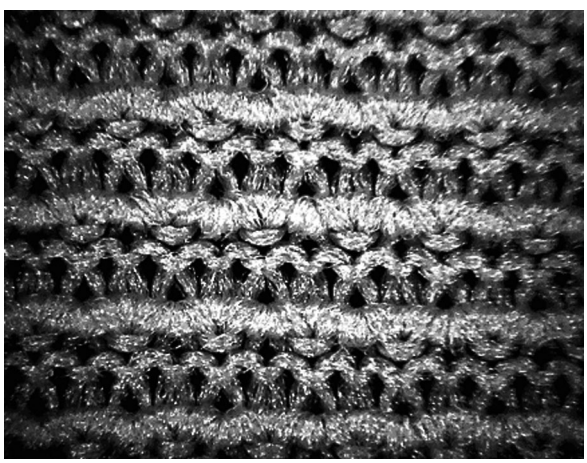


Photo 6: Stitch of the overstocking from Jobst's Ulcer care®.

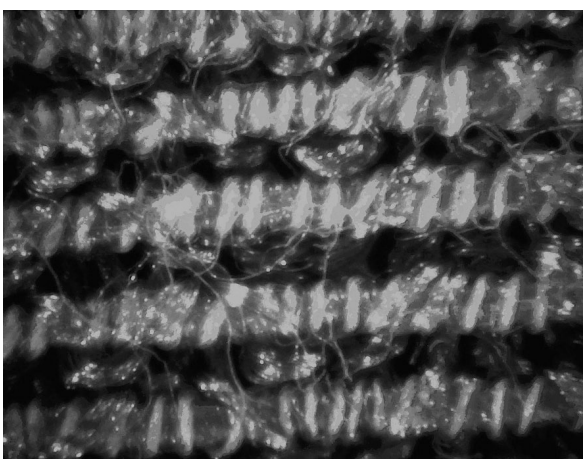


Photo 8: Stitch of the overstocking from Saphenamed UCV® (Hartmann)

The ideal anti-ulcer compression stocking kit should have the following features:

- low pressure understocking, between 10 à 15 mmHg at Point B,
- easy to put on the foot (bump on the back of the foot or lack of pressure on the foot),
- an open foot overstocking with a pressure of about 25 mmHg at Point B,
- when superimposed and at rest, a pressure between 30 a 40 mmHg at Point B1,
- an upper stiffness superior to 10 mmHg for both the le Static Stiffness Index and the Dorsiflexion Stiffness Index,
- a friction index close to 1 thanks to an increased number of asperities on both of the stockings in relation to an efficient knitting.

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

The low pressure understocking will safely treat the patients with peripheral arterial disease (with an ABI> 0,6), especially in elderly people. The care will then be provided by the patient's family. Hence significant savings for the community can be expected.

Disclosure agreement

The concerned laboratories provided the necessary stockings for measurement purposes.

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