Do we still need compression bandages? Haemodynamic effects of compression stockings and bandages

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Abstract

Objective: To compare haemodynamic data obtained with elastic compression stockings and inelastic compression material applied with different pressure ranges on the lower extremities.

Methods: Haemodynamic effects of compression therapy were demonstrated by measuring venous flow velocity, venous volume, venous reflux and venous pumping function using radioisotopes, phlebography, water displacement volumetry, duplex, air plethysmography, foot volumetry and phlebodynamometry.

Results: Light-compression stockings are able to increase venous blood flow velocity in the supine position and to prevent leg swelling after prolonged sitting and standing. In the upright position an interface pressure of more than 50 mmHg is needed for an intermittent occlusion of incompetent veins and for a reduction of ambulatory venous hypertension during walking. Such high interface pressures may rather be achieved by short-stretch, multilayer bandages than by an elastic stocking.

Conclusion: Elastic compression stockings exerting interface pressures up to 40 mmHg are effective in preventing or reducing oedema. Multilayer compression bandages with a pressure over 40 mmHg additionally improve severely disturbed venous pumping function.

Phlebology 2006; **21:** 132–138

Keywords: Compression therapy; bandages; interface pressure; stiffness; ambulatory venous hypertension

Introduction

During the past few years several studies have shown that medical compression stockings may successfully be used for indications that traditionally have been assigned to compression bandages. Especially in the field of venous ulcers, the classical domain for bandages, some recent studies revealed satisfying healing rates in comparison with bandages.[1,2] Also regarding the reduction of pain and oedema in patients with acute deep vein thrombosis, good compression stockings (30–40 mmHg) achieved similar results compared with bandages.[3]

The use of compression stockings versus bandages has enabled the patient to be more independent from a medical staff, which can improve compliance and reduce the cost of therapy.

Therefore, the question if we still need compression bandages has considerable practical actuality.

The following presentation will review acute experiments that show substantial differences between the haemodynamic effects of compression stockings and that of bandages in patients with chronic venous disorders.

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Accepted 28 June 2006

Methods

The following parameters had been investigated with and without different types of compression stockings and bandages:

Venous diameter and venous volume

Phlebography[4] and duplex investigations had been used to demonstrate the narrowing of superficial and deep veins by external compression.

The diameter of superficial and deep veins on the lower leg[5] and on the thigh[6] under increasing pressure had been measured by duplex using a blood pressure cuff with an ultrasound-permeable window (Echo-cuff®, VNUS Technologies, Sunnyvale, CA, USA).

Changes of venous volume under compression had been measured by whole-body scintigraphy after injection of labelled autologous erythrocytes[7] and by using air plethysmography (APG).[8]

Venous flow velocity

Venous circulation time was assessed by injection of radioactive tracers into a dorsal foot vein with and without thromboprophylactic stockings. These investigations were performed on the healthy leg of patients with suspected unilateral deep vein thrombosis.[9]

Venous refluxes

The venous filling index (VFI) measured by APG allowed for a quantitative assessment of the global reflux in a leg. Measurements were made in patients with venous ulcers and deep venous refluxes using elastic and inelastic bandages applied with varied pressures as measured by an Oxford monitor[8] on the distal leg.

Venous pumping function

Foot volumetry and measurement of the intravenous pressure in a dorsal foot vein (phlebodynamometry) had been used to assess the venous pumping function under standardized exercises with and without different forms of compression.[10,11]

Compression material

Mild, moderate and strong custom-made compression stockings from different European companies have been used. Compression bandages were always multilayer bandages, either with inelastic material (e.g. zinc paste, short-stretch bandages) or four-layer bandages.

Different devices were used to measure the interface pressure of the compression material on the leg: Oxford Pressure Monitor (Talley Ltd, UK), MST tester (Salzmann Medico, Switzerland), Juzo Tester (Elcat, Germany), Kikuhime tester (Meditrade, Soro, Denmark).

The increase of interface pressure due to an increase in the leg circumference by standing up or walking defines the stiffness of the material. This parameter characterizes the elastic property of a compression device. With the same resting pressure, multilayer bandages show higher stiffness than elastic stockings.[12,13]

Statistics

Median values with quartiles and ranges are given. For comparing multiple matched groups, the nonparametric Friedman test was used. The Kruskall–Wallis test was taken to compare unpaired groups.

Results

Venous diameter and venous volume

Venous diameter

Using the Echo-cuff as a model for inelastic bandages in 18 lower legs of volunteers showed that the external pressure to occlude superficial and deep veins was 20–25 mmHg in the supine position, 50–60 mmHg in the sitting and about 70 mmHg in the standing position. A narrowing of the veins in the upright position could be observed only with pressures above a pressure of 30 mmHg in average.[5]

At thigh level in the sitting position, a statistically significant reduction of the diameters of the great saphenous and of the femoral vein could only be obtained when the cuff pressure was higher than 40 mmHg ($P < 0.001$).[6]

Measuring the interface pressure of thigh-length compression stockings with an ankle pressure of 28 mmHg using an MST instrument in a group of 12 ulcer patients, values of around 15 mmHg were found at mid-thigh level, while adhesive short-stretch bandages revealed a pressure of more than 40 mmHg.[6]

Figure 1 shows that a pressure bandage applied to the thigh exerting a pressure of 60 mmHg was able to reduce the diameter of the femoral vein in the standing position.

Figure 1 Phlebography of the femoral vein without (left) and with an adhesive compression bandage on the thigh exerting a local pressure of 60 mmHg. The bandage narrows the deep vein to a thin cord

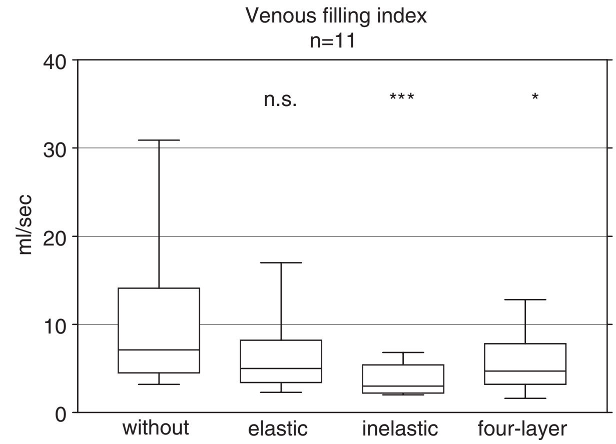


Figure 2 Measurement of venous reflux by air plethysmography (APG) in 11 patients with venous ulcers and deep vein incompetence. Lack of reflux is characterized by a venous filling index (VFI) of <2.2 mL/s. With the same interface pressure of 30 mmHg, elastic material achieves only a modest, non-significant reduction of venous refluxes unlike the inelastic (*** = $P<0.001$) and four-layer bandages (* = $P<0.05$). (Friedman's test)

Venous volume

Whole-body scintigraphy performed in 10 patients showed that external pressure of 40 mmHg applied to the legs reduced the local blood volume by 30% and, at the same time, increased the blood volume over the trunk demonstrating a shift of blood towards the abdomen and thorax.[7] In the supine position, no significant difference was seen with an external pressure of 20 versus 40 mmHg.

Ten patients with venous ulcers and deep venous refluxes investigated by APG showed no significant reduction of venous volume in the standing position when wearing either elastic and inelastic bandages exerting a pressure of 20 mmHg on the distal leg. However, a significant reduction of venous volume could be achieved with a pressure of 40 mmHg or more. Additionally it was seen that when the same pressure was applied, material with high stiffness, either inelastic bandages or four-layer bandages, was more effective than elastic materials.[8]

Venous flow velocity

In 13 patients investigated by isotopic phlebography, the venous velocity calculated by measuring the mean transit time of the tracer between the dorsum of the foot and the groin was 1.3 ± 0.7 cm/s without and 2.1 + 1.0 with a light thigh length stocking exerting a pressure of 15 mmHg on the distal lower leg ($P<0.001$).[9]

Venous refluxes

In 11 patients with venous ulcers and deep venous refluxes, the median initial VFI was 7.1 mL/s (range 3.2–30.9 mL/s, normal values <2.0). With the same resting pressure of 30 mmHg, inelastic bandages and four-layer bandages achieved a significant reduction of venous reflux while elastic bandages were much less effective (Figure 2).[8]

Venous pumping function

In 20 patients presenting with oedema and/or skin changes according to CEAP classes C3–C4, foot volumetry showed an expelled volume (EV) of 5.9 ± 2.1 mL (normal >12 mL). Knee-length elastic compression stockings whose interface pressure was measured by MST led to a slight increase of EV with increasing interface pressure up to 8.0 ± 3.5. However, this increase was statistically significant only with stockings exerting a pressure on the distal lower leg of 34 mmHg and more.[10] Intravenous pressure on the dorsum of the foot during standardized knee-bending exercises was measured in 13 patients with CEAP classes C3–C4, all with an incompetent great saphenous vein, without compression, with one light stocking (14.3 mmHg), with a second applied over the first (30.8 mmHg), with one loosely applied short-stretch bandage (23.2 mmHg) and two strong short-stretch bandages (53.6 mmHg). A statistically significant reduction of ambulatory venous hypertension could be achieved only with the strongly applied short-stretch bandage but not with the stockings.[11] Figure 3 shows one example.

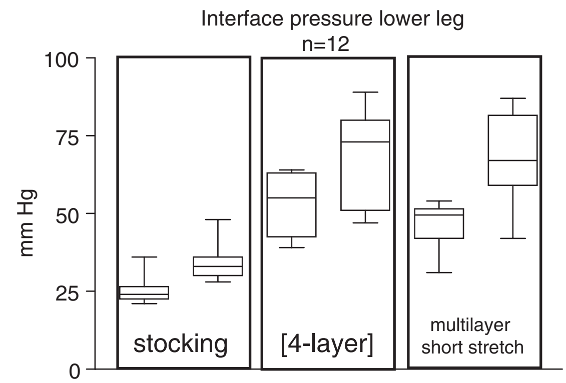
Discussion

Haemodynamic effects of compression therapy depend mainly on the exerted pressure, the stiffness of the device and on the body position.

As it is shown in Figure 4, multilayer bandages applied even with moderate pressure[12] exert a significantly higher interface pressure on the distal lower leg than medium-range compression stockings.

In the supine position, light stockings with a pressure range on the distal leg of 10–20 mmHg are able to narrow the veins and to increase venous blood flow velocity.[9] This has been seen to be effective in preventing deep vein thrombosis in non-ambulatory patients.

In the upright position, compression stockings exerting a pressure of 10–30 mmHg are able to counteract oedema[14] and to increase blood flow velocity in the microcirculation.[15] The pressure in the lower leg veins is 60–80 mmHg while standing and about 30–50 mmHg in the sitting position. Therefore the narrowing effect of a compression device exerting a pressure of 30 mmHg will be minimal. However, a small reduction of the venous



X Labels	L	St	L	St	L	St
Minimum	21.00	28.00	39.00	47.00	31.00	42.00
25% Percentile	22.50	30.00	42.50	51.00	42.00	59.00
Median	24.00	33.00	55.00	73.00	49.50	67.00
75% Percentile	26.50	36.00	63.00	80.00	51.50	81.50
Maximum	36.00	48.00	64.00	89.00	54.00	87.00

Figure 4 Interface pressure measured on the medial distal lower leg using a small Kikuhime pressure transducer in the lying (L) and standing (St) positions. Four-layer bandages and multilayer short-stretch bandages applied with moderate strength exert a significantly higher pressure than medium-range compression stockings (Kruskall–Wallis test, $P<0.001$). The pressure increase by standing up from the supine position is higher under the bandages than under the stocking

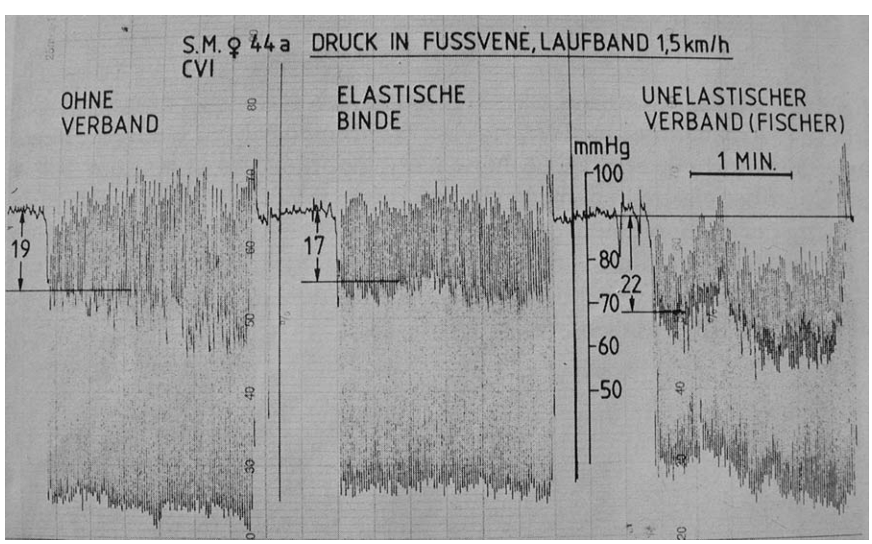


Figure 3 Venous pressure measurement in a dorsal foot vein during walking on a treadmill in a patient with venous ulceration due to deep and superficial venous incompetence. The curves should be read from the right to the left. During muscle systole (pressure peaks), there is no pressure fall without bandage (left) and with elastic bandage (middle). An inelastic zinc-paste bandage exerting an interface pressure on the distal leg of 60 mmHg (Fischer bandage, right) shows a fall of the venous pressure peaks below the resting pressure

diameter as it was demonstrated also by other authors[16] may cause an over-proportional reduction of venous volume explaining the beneficial effects as reported in several plethysmographic studies.[10,17,18]

In order to achieve a more pronounced narrowing of the leg veins, much higher pressures are necessary. A complete occlusion of a vein will only be obtained when the external pressure is higher than the intravenous pressure. A multilayer bandage applied with moderate strength achieves a pressure on the distal leg around 50 mmHg in the supine position and of 60–70 mmHg when the patient stands up[12] (Figure 4). The interface pressure under a 20–30 mmHg stocking is significantly lower (non-parametric Kruskall–Wallis test: $P < 0{,}001$) and will only slightly increase during standing (Figure 4). When applying elastic material with the same resting pressure, the pressure increase during standing and ankle movement is much less with elastic than with inelastic material (Figure 5). The pressure peaks exerted by inelastic material with each muscle contraction may intermittently override the intravenous pressure in the lower leg resulting in an intermittent occlusion of the veins. This effect can be demonstrated by the Echo-cuff containing an ultrasound-transparent window through which the leg veins can be visualized using Duplex.

In severe stages of chronic venous disease, this intermittent venous occlusion during exercise is able to create an artificial valve mechanism that can reduce ambulatory venous hypertension. A convincing model is the rare condition of a congenital absence of venous valves. In such patients who develop severe skin changes on the distal lower leg and venous ulcers at an early age, we have measured the intravenous pressure on the dorsum of the foot.[19] During walking on a treadmill, no pressure fall was observed, but a blood pressure cuff with 80 mmHg on the thigh led to a distinct reduction of ambulatory venous hypertension, most likely due to an intermittent interruption of venous reflux. Lower degrees of external pressure did not improve ambulatory venous hypertension. This is in agreement with phlebodynamometric measurements that were not able to demonstrate an improvement of ambulatory venous hypertension by compression stockings.[20]

These findings underline the principle differences between medical compression elastic stockings and inelastic compression bandages concerning their haemodynamic efficacy.

Stockings with a pressure lower than 20 mmHg enhance venous blood flow velocity in bedridden patients and are therefore successfully used especially for preoperative prevention of deep vein thrombosis.[21] It could be demonstrated that light stockings in a range of 10–20 mmHg are also useful for preventing oedema after long sitting or standing[14] and to improve subjective symptoms of patients with mild venous disorders.[22,23]

The pressure range of ready-made stockings prescribed for venous patients is between 20 and 40 mmHg at the ankle. As stockings have to be pulled over the heel, they are made of elastic material with high extensibility in order to facilitate the application. During walking they adapt to the changes of the leg shape and give way when the muscle contracts. Therefore, their interface pressure during walking ('working pressure') has been shown to be only about 5–10 mmHg higher than the

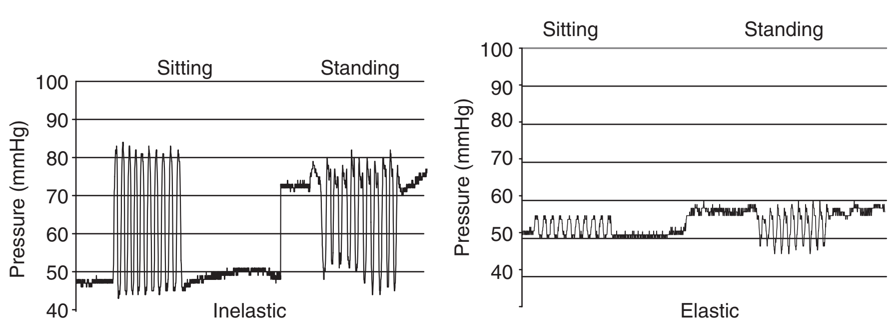


Figure 5 Measurement of interface pressure at the distal medial lower leg using a Kikuhime pressure transducer with a data logger. The resting pressure in the sitting position is close to 50 mmHg, both for the inelastic (left) and for the elastic bandage (right). With up and down movement of the feet, much higher pressure peaks are observed with the inelastic than with the elastic material. Standing up from the sitting position is followed by a pressure increase of more than 20 mmHg with the inelastic and of 8 mmHg with the elastic material. Tip-toeing shows much higher pressure amplitudes under the inelastic than the elastic bandage. The higher pressure difference between standing and supine with the inelastic material characterizes its higher stiffness

resting pressure.[24,13] The resulting total pressure maximally achieved by a compression stocking will reduce oedema and act at the microcirculatory level of the skin. However, the narrowing effect on large veins will be minimal.

Compression bandages are usually applied with a pressure of 40 mmHg and higher (Figure 4). During standing and walking, interface pressure will rise to values of 60 mmHg and more[12,13] which will lead to an intermittent narrowing or occlusion of the veins. In addition, they will provide the same benefit to the before-mentioned effects on oedema and microcirculation.

Both, elastic and inelastic bandages lead to an immediate reduction of the leg volume.[25] While elastic material is able to adapt, there is a pressure loss with short-stretch material of about 25% in the first 2 h after application. A short-stretch bandage designed to exert 40 mmHg should therefore be applied with a pressure of 60 mmHg. When the patients lies down, the pressure will immediately fall to one-half.[25]

When bandages are applied in several layers, the elastic property of the final bandage will shift towards inelastic due to friction of the single layers,[26] even when the single components are rather elastic like in the four-layer bandage. Such bandages have a relatively high working pressure but do not loose their pressure as fast as inelastic material.[27] Therefore, care has to be taken that the pressure in the supine position is not too high in order to avoid pain and skin damage. In our experiments using APG, we have observed a reduction of venous volume and of venous refluxes when using four-layer bandages coming close to the effect of inelastic bandages.[8]

What are the consequences of these different haemodynamic effects of compression stockings and bandages concerning their clinical indications?

For prevention and treatment of oedema and less severe CVI symptoms, compression stockings are effective and widely sufficient.[3,14] For the treatment of patients with chronic venous hypertension, it is desirable to achieve interface pressures that come close to the individual level of ambulatory venous hypertension during walking but that are comfortably tolerated during lying down. These preconditions may be fulfilled by multilayer bandages or devices with inelastic properties (high stiffness) applied with a resting pressure of 50 mmHg or more. The main disadvantage of inelastic bandages is the fact that the application technique is not easy and has to be learned.

Venous ulcers are the most important indication in which the reduction of ambulatory venous hypertension is a basic goal. Recent randomized controlled trials comparing bandages and specially designed stockings for ulcer healing have shown equal or even better results with compression stockings.[1,2] It has to be stressed, however, that in these trials the bandage application in the control group was not optimal explaining the poor healing rates that were much lower than those from reports with strong multilayer bandages[28] In order to achieve comparable and repeatable results, the *in vivo* interface pressure of compression devices should, therefore, be measured in future trials.[13]

Conclusions

Multilayer compression bandages with high stiffness applied with a pressure higher than 50 mmHg have beneficial haemodynamic effects in severe stages of venous incompetence that cannot be achieved by elastic compression stockings with a maximum pressure of 30–40 mmHg. This may explain the fact that the best healing rates of venous ulcers have been reported with bandages.

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