**Original article**

# Inelastic compression increases venous ejection fraction more than elastic bandages in patients with superficial venous reflux

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## Abstract

***Aim*:** To investigate the influence of compression bandages, manufactured using materials with different elastic properties, on the impaired venous pumping function in patients with venous insufficiency.

***Methods*:** Ejection volume (EV) and ejection fraction (EF) were measured using strain gauge plethysmography distal from the patella without and with elastic and inelastic compression bandages in a total of 30 patients with major venous reflux in the great saphenous vein. The interface pressure of the bandages was measured simultaneously in the medial gaiter area. Normal values of EV and EF were obtained from 15 healthy controls.

***Results*:** Patients with venous insufficiency showed a statistically significant reduction of EV and EF compared to controls. Elastic bandages with an average pressure of 42 mm Hg in the supine position achieved a moderate increase of EV and a significant improvement of EF ($p < .01$), while inelastic bandages applied with comparable resting pressure (41 mm Hg) raised EV and EF into a normal range ($p < .001$). The improvement of the ejection fraction correlates well with the pressure differences between standing and lying (Static Stiffness Index) and between muscle systole and diastole during exercise (Pearson $r = 0.69$ and 0.74 respectively, $p < .001$). Elastic bandages applied with high stretch in order to achieve standing pressures comparable to those of inelastic bandages (>60 mm Hg) led only to a minor improvement of the venous pumping function.

***Conclusions*:** Ejected volume and ejection fraction, which are severely reduced in venous insufficiency, can be increased by compression therapy. Inelastic compression is much more effective than elastic bandages, and is able to normalize venous pumping function. With elastic bandages EV and EF always remain below the normal range even when applied with high stretch producing a resting pressure that is barely tolerable.

**Keywords:** varicose veins; bandaging; elastic and inelastic compression; venous pumping function; venous reflux

## Introduction

Venous incompetence is characterized by varying and complex haemodynamic mechanisms. However, a decreased ejected volume (EV) and a reduced ejection fraction (EF) from the lower leg during exercise are the constant pathophysiological key parameters.[1] Compression therapy is believed to improve haemodynamic impairment. In particular, it has been proved effective in reducing venous volume (VV), reflux, oedema and ambulatory hypertension.[2–8] The aim of this work was to measure EV and EF in patients with venous insufficiency, to investigate whether compression therapy is able to improve these parameters and if there is a difference in effect between elastic and inelastic bandages.

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## Methods

### Subjects

Thirty patients (13 men and 17 women with a mean age of 59.9 ± 11.9 years) affected by severe reflux in the great saphenous vein (GSV) (clinical, aetiological, anatomical and pathological elements [CEAP] C2–C5), all of them waiting for surgery, and 15 healthy volunteers (six men and nine women with a mean age of 58.8 ± 10.5 years) as a control group (CEAP C0–C1) participated in this study.

### Inclusion criteria

All patients had severe superficial venous insufficiency of the GSV, including terminal and preterminal valve incompetence diagnosed using a Duplex scanner (Esaote Technos with linear probe 7.5–10 MHz; Esaote s.p.a., Genoa, Italy). The venous diameter in standing position 2 cm below the junction was >1 cm and venous reflux time after manual calf compression was longer than 3 seconds. None of these patients was affected by deep venous insufficiency or obstruction. The clinical signs according to the CEAP classes were C0–C1 in the 15 normal volunteers, C2 in six, C3 in 14, C4 in eight and C5 in two cases (Table 1).

### Exclusion criteria

Patients with competent terminal and preterminal valve; with the venous diameter in standing position 2 cm below the junction <1 cm, with venous reflux time shorter than 3 seconds, with restricted mobility or with a body mass index >30 or with an ankle brachial pressure index below 0.8 measured using the Doppler, were excluded from the study.

All individuals were informed about the investigation and gave their written informed consent.

They were examined in the mid-morning in a quiet room, with a constant temperature of about 22°C.

### Plethysmography

VV, EV and EF were measured using a recently described method in which the transducer is placed proximal to the compression device.[9] Strain gauge plethysmography (Angioflow2, Microlab, Padua, Italy) with an indio-gallium alloy probe was used to measure the changes of the leg volume. The strain gauge is suitable to record volume changes of the leg segment to which it is applied.[10,11] The probe was placed 5 cm distal to the patella in supine position. After calibration, the examined leg was elevated above heart level in order to empty the leg veins and to obtain a minimum blood volume in the leg. After 2 minutes, when a new stable baseline was recorded, the patient was asked to stand up with the weight placed on the opposite leg until a stable signal was achieved. The resulting volume increase after refilling of the veins is defined as VV. Then, the patient was asked to perform 20 standardized steps in 20 seconds and to return to the original position. The resulting volume decrease corresponds to the EV (Figure 1). In the healthy volunteers, the test was repeated three times with a 30 minute interval to assess the reproducibility of the procedure.

### Bandage application and interface pressure measurement

In patients with venous reflux, the procedure was repeated after application of an elastic, long stretch bandage (Dauerbinde K®; Lohmann & Rauscher GmbH & Co KG, Rengsdorf, Germany) and then after a multilayer, multicomponent inelastic bandage made up of Mollelast® (Lohmann & Rauscher GmbH & Co KG), a cohesive, short stretch bandage on top of cotton padding. Both bandages were applied in a spiral fashion with 50% overlapping between the layers from the base of the toes up to 1 cm below the strain gauge. The interface pressure (IP) between the compression bandage and the skin was measured continuously during bandaging in order to produce the same

**Table 1** Venous volume (VV), ejected volume (EV) and ejection fraction (EF) in healthy legs and legs with venous signs (CEAP C2–C5) (median and interquartile range)

| | Normal legs | CEAP C2 | C3 | C4 | C5 | All patients C2–C5 |
|---|---|---|---|---|---|---|
| *n* | 15 | 6 | 14 | 8 | 2 | 30 |
| VV (mL%) | 4.4 (3.9–5.1) | 6.3 (4.7–6.9) | 5.0 (3.7–5.9) | 5.1 (4.8–5.8) | 5.3 (3.0–6.7) | 5.1 (4.2–6.3) |
| EV (mL%) | 3.0 (2.5–3.4) | 2.1 (1.9–2.5) | 1.3 (1.1–3.6) | 1.9 (1.4–2.0) | 1.9 (1.3–2.5) | 1.6* (1.3–2.1) |
| EF% | 65.0 (63.7–67.8) | 39.6 (30.6–41.2) | 27.5 (24.9–33.3) | 33.8 (29.8–37.3) | 35.1 (33.1–37.1) | 33.1* (27.0–38.3) |

Mann-Whitney rank sum test (normal versus C2–C5): *$P < 0.0001$

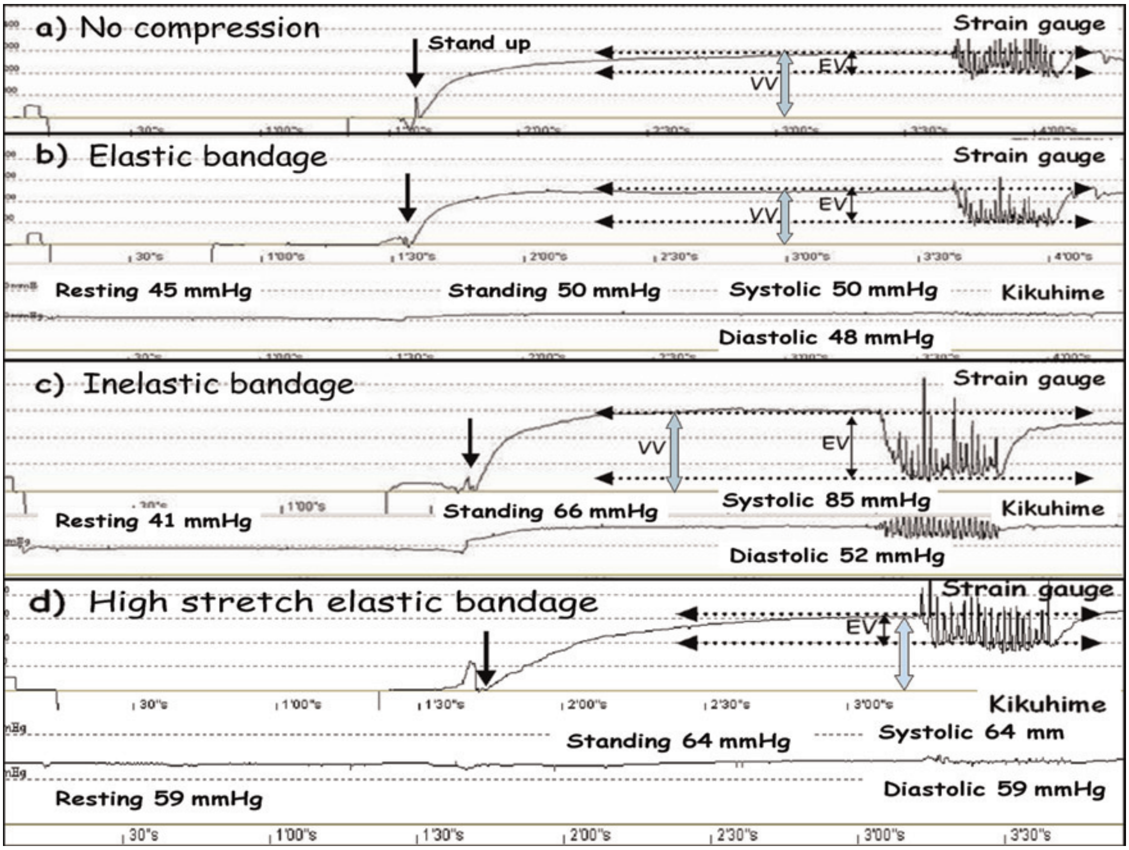


**Figure 1** Simultaneous recordings of strain gauge plethysmography and interface pressure (Kikuhime) in a patient without compression ([a], baseline), with elastic compression (b), with an inelastic bandage (c) and with elastic compression with high stretch. After leg elevation the patient stands up, which causes an increase of VV and of interface pressure. During exercise the decrease of volume reflects the ejected volume which is highest with the inelastic bandage. Note that the pressure fluctuations and expelled volume are much higher with the inelastic than with the elastic bandage applied both with the same supine and standing pressure

final resting pressure of 40 mmHg. In 15 patients, the elastic bandage was also applied with higher stretch in order to produce the same standing pressure of about 60 mmHg as the inelastic bandage.

The IP exerted by each bandage was measured in supine and standing position, and during the active movements by means of a Kikuhime® measuring device with the small air-filled pressure transducer measuring 3 cm in diameter (TT Medi Trade, Soleddet 15, DK 4180 Soro). The transducer was placed at the medial aspect of the leg where the tendinous part of the gastrocnemius muscle turns into its muscular part (point B1)[10] and connected through a data-logger to a computer for continuous data recording. Pressure and volume changes were recorded simultaneously (Figure 1).

The following parameters were calculated:

(1) EF according to the formula $EF = 100 \times EV/VV$
(2) Static stiffness index (SSI) as the difference between standing and supine pressure
(3) Systolic–diastolic difference (SDD) as the difference between systolic and diastolic IP during movement.

## Statistics

To characterize the reproducibility of the plethysmographic measurement, the coefficient of variance was calculated ($100 \times SD/mean$). For comparisons between the different treatment groups, the non-parametric Mann-Whitney rank sum test and Kruskal-Wallis statistics with Dunn's multiple comparisons were used. The Wilcoxon test was used for the comparison of pairs and the Spearman rank test was taken as a non-parametric method for quantifying correlations. Differences with a $P < 0.05$ were considered statistically significant.

The graphs and the statistical evaluations were generated using Graph Pad Prism, version 4, software (Graph Pad, San Diego, CA, USA).

## Results

### Baseline measurements

The plethysmographic parameters in normal legs and in the legs with venous pathology, according to their clinical CEAP classes, were compared (Table 1).

There was no significant difference for VV in the different classes; EV and EF were significantly lower in venous insufficiency compared with normals.

The variation coefficients for VV, EV and EF, assessed by repeating the measurements three times in eight individuals from the control group were 8.6%, 9.7% and 7.5%, respectively.

### Influence of bandages applied with the same resting pressure in the supine position

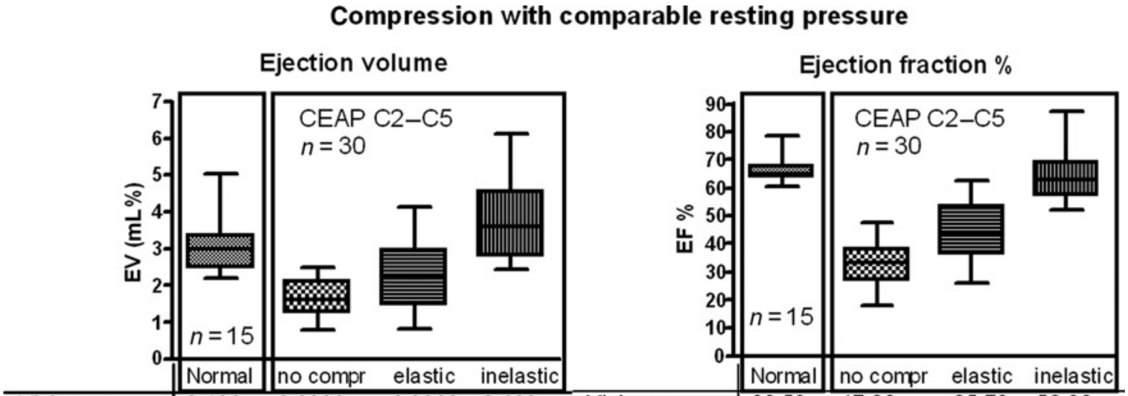
Compression bandages did not change VV significantly, but improved the venous pumping function as demonstrated by an increase in EV and EF (Figures 1 and 2). Elastic bandages showed a moderate increase of EV and a significant improvement of EF ($P < 0.01$), whereas inelastic bandages led to a highly significant increase of both, EV and EF into the normal range ($P < 0.001$). The higher VV with inelastic bandage seen in the example of Figure 1 could be explained by the non-yielding material prohibiting an increase of the calf distal to the measuring site when the patient stood up.

The IP of elastic and inelastic bandages measured in the supine position was in the same range of 41.5–42 mmHg. By standing up, the pressure raised to 46 mmHg with an elastic and to 62 mmHg with an inelastic bandage (median values, $P < 0.001$). The pressure difference that has been termed 'SSI' was 4.0 and 20.5 mmHg, respectively.[12,13] The SDD during exercise was 4.0 with elastic and 23.5 mmHg with inelastic bandages (median values, $P < 0.001$ for both parameters) (Table 2).

### Influence of bandages applied with the same resting pressure in the standing position

In a subgroup of 15 patients, the elastic bandage was applied with high stretch in order to achieve the same standing pressure (median value 63 mmHg) exerted by the inelastic bandage. The corresponding pressure values in the supine position were 58 mmHg for the elastic bandage applied with high stretch and 42 mmHg for the inelastic bandage ($P < 0.001$). With elastic high-stretch bandages SDD was five versus 30 mmHg with inelastic bandages (median values, $P < 0.001$) (Table 3).

An increase of EV and EF into the range of normal values can be achieved by inelastic bandages



| | Normal | no compr | elastic | inelastic |
|---|---|---|---|---|
| Minimum | 2.190 | 0.8000 | 0.8300 | 2.460 |
| 25% Percentile | 2.500 | 1.285 | 1.485 | 2.810 |
| Median | 3.000 | 1.615 | 2.245 | 3.610 |
| 75% Percentile | 3.360 | 2.120 | 2.980 | 4.565 |
| Maximum | 5.050 | 2.500 | 4.160 | 6.140 |

| | Normal | no compr | elastic | inelastic |
|---|---|---|---|---|
| Minimum | 60.50 | 17.90 | 25.70 | 52.30 |
| 25% Percentile | 63.70 | 26.95 | 36.40 | 57.30 |
| Median | 65.00 | 33.10 | 43.85 | 62.70 |
| 75% Percentile | 67.80 | 38.30 | 53.75 | 69.05 |
| Maximum | 78.60 | 47.50 | 62.50 | 87.40 |

**Figure 2** Inelastic bandages increase the ejection volume (EV) and ejection fraction (EF) highly significantly ($P < 0.001$), whereas the elastic bandages applied with the same resting pressure in a supine subject produce only a moderate increase of EV and a more pronounced improvement of EF ($P < 0.01$). The box and whisker plots show median values, interquartile ranges (boxes), and minimal and maximal values. The corresponding numeric data are given below the graphs

**Table 2** Interface pressure (mmHg) measured on the distal lower leg in the supine and standing position, and pressure differences standing-supine static stiffness index (SSI) and systolic–diastolic difference (SDD) (mmHg) ($n = 30$, median and interquartile ranges)

| | Elastic bandage | Inelastic bandage | Statistical difference (Wilcoxon test) |
|---|---|---|---|
| Supine | 42.0 (39.0–43.0) | 41.5 (38.5–43) | n.s. |
| Standing | 46.0 (43.5–49) | 62.0 (59.0–65.5) | $P < 0.001$ |
| SSI | 4.0 (3.0–5.0) | 20.5 (18.0–25.0) | $P < 0.001$ |
| SDD | 4.0 (2.0–6.5) | 23.5 (16–23) | $P < 0.001$ |

**Table 3** Interface pressure (mmHg) measured on the distal lower leg in the supine and standing position, and pressure differences standing-supine static stiffness index (SSI) and systolic–diastolic difference (SDD) (mmHg) in those patients in whom elastic bandages were applied with high stretch in order to achieve a standing pressure comparable with inelastic bandages ($n = 15$, median and interquartile ranges)

| | Elastic bandage | Inelastic bandage | Statistical difference (Wilcoxon test) |
|---|---|---|---|
| Supine | 58.0 (55.0–64.0) | 42.0 (40.0–43.0) | $P < 0.001$ |
| Standing | 63.0 (60.0–69.0) | 63.0 (60.0–68.0) | n.s. |
| SSI | 5.0 (2.0–8.0) | 22.0 (20.0–25.0) | $P < 0.0001$ |
| SDD | 5.0 (3.0–7.0) | 30.0 (22.0–33.0) | $P < 0.0001$ |

($P < 0.001$). Maximally stretched elastic bandages increase EV ($P < 0.05$) and EF ($P < 0.01$) much less in spite of being applied with the same high standing pressure (Figure 3).

## Correlation between ejection fraction and bandage pressure

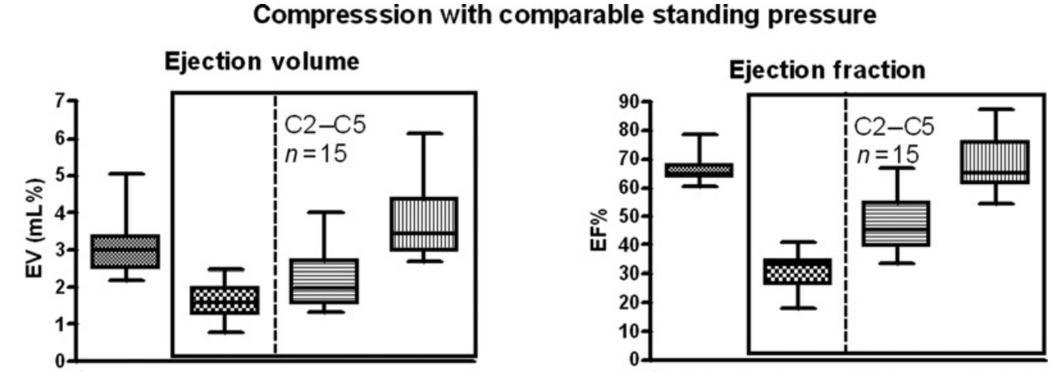
There is a statistically highly significant correlation between EF and the sub-bandage pressure only in the standing ($P < 0.001$, Pearson $r = 0.69$) but not in the supine position (Pearson $r = -0.027$) (Figure 4).

Significant correlations can be shown between EF and the pressure increase when a subject stands up from the supine position (SSI) ($P < 0.001$, Pearson $r = 0.69$) (Figure 5 left). The amplitudes of sub-bandage pressure during walking (SDD) also show a significant correlation with EF ($P < 0.001$, Pearson $r = 0.74$) (Figure 5 right). Even though elastic bandages were applied at high pressure with high stretch (Figure 5, symbols $\Delta$) only small pressure differences were achieved by standing (SSI) and exercise (SDD), which correlated with low values of EF.

## Discussion

Compression therapy is able to improve the haemodynamic impairment of venous insufficiency: venous reflux and ambulatory venous hypertension may be reduced and EV and EF are enhanced.[2–8]

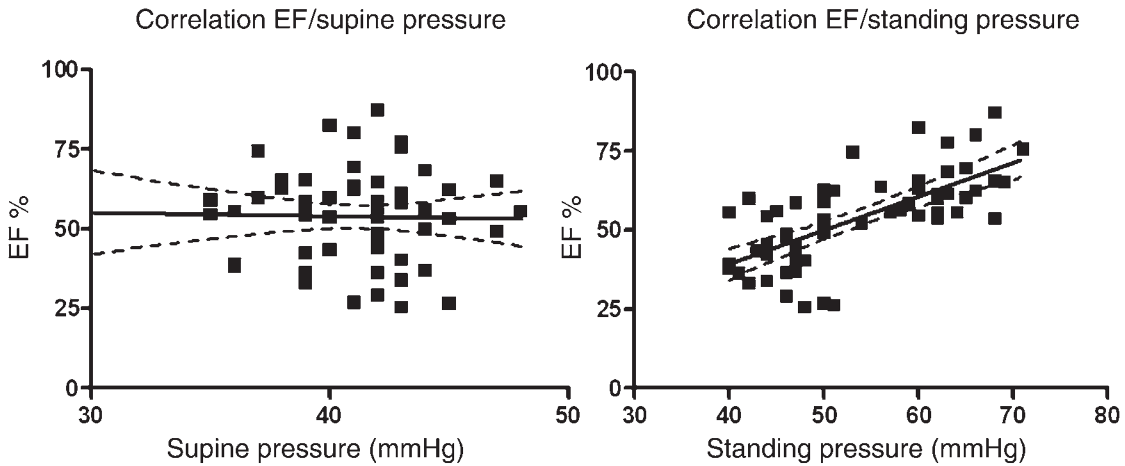
Among the different parameters mentioned, the influence of compression on venous reflux measured by air plethysmography has been reported in several studies.[11,14–16] There is a general agreement among different authors on the accuracy and reproducibility of venous filling



| | Normal | No compr | el stretch | inelast |
|---|---|---|---|---|
| Minimum | 2.190 | 0.8000 | 1.330 | 2.660 |
| 25% | 2.500 | 1.280 | 1.570 | 2.980 |
| Median | 3.000 | 1.590 | 1.980 | 3.430 |
| 75% | 3.360 | 1.970 | 2.700 | 4.350 |
| Maximum | 5.050 | 2.490 | 4.000 | 6.140 |

| | Normal | No compr | el stretch | inelast |
|---|---|---|---|---|
| Minimum | 60.50 | 17.90 | 33.60 | 54.60 |
| 25% | 63.70 | 26.40 | 39.60 | 61.30 |
| Median | 65.00 | 33.10 | 45.10 | 65.10 |
| 75% | 67.80 | 34.50 | 54.70 | 75.80 |
| Maximum | 78.60 | 40.70 | 66.60 | 87.40 |

**Figure 3** Ejection volume and ejection fraction in 15 patients in whom the elastic bandage was maximally stretched in order to achieve a standing pressure comparable with the inelastic bandage (64 mmHg). Both parameters are increased up to a normal range by inelastic, but not by an elastic material. The box and whisker plots show median values, interquartile ranges (boxes), and minimal and maximal values. The corresponding numeric data are given below the graphs

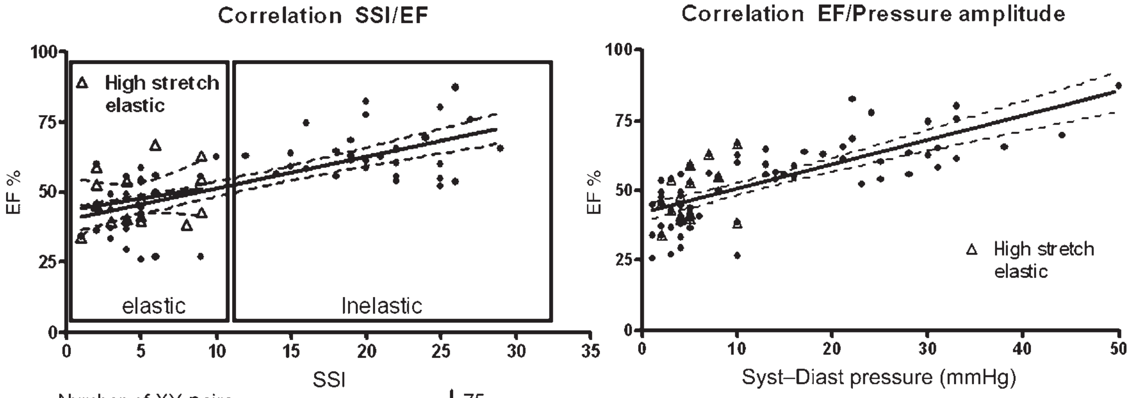


| | |
|---|---|
| Number of XY Pairs | 60 |
| Pearson *r* | −0.02712 |
| 95% confidence interval | −0.2792 – 0.2284 |
| *P* value (two-tailed) | 0.8370 |
| *P* value summary | ns |

| | |
|---|---|
| Number of XY Pairs | 60 |
| Pearson *r* | 0.6924 |
| 95% confidence interval | 0.5319 – 0.8048 |
| *P* value (two-tailed) | $P < 0.0001$ |
| *P* value summary | *** |

**Figure 4** Good correlation, highly significant, between ejection fraction and the interface pressure of the bandages in the standing (right), but not in the supine position (left)

index allowing a reasonable assessment of global venous reflux. EF, measured by air plethysmography seems to be less reliable, both in discriminating between normal subjects and patients with vein disease, and between different degrees of venous insufficiency.[15–19] This could be due to the need to place the plethysmographic air chamber over the bandage, and to measure EV and EF directly over the pumping segment. Measurement of these parameters can be influenced by the reduction of the basic volume under compression taking place in the region of the calf pump. With the method we used, the measuring probe is placed proximally to the bandage directly on the skin; therefore, the measured volume changes reflect changes of the leg and not of the bandage. In the original description of the method, Poelkens *et al.*[9] have measured EV and EF in healthy subjects



| | |
|---|---|
| Number of XY pairs | 75 |
| Pearson *r* | 0.6921 |
| 95% confidence interval | 0.5517 – 0.7943 |
| *P* value (two-tailed) | $P<0.0001$ |
| *P* value summary | *** |
| Is the correlation significant? (alpha = 0.05) | Yes |
| *R* squared | 0.4789 |

| | |
|---|---|
| Number of XY pairs | 75 |
| Pearson *r* | 0.7471 |
| 95% confidence interval | 0.6263 – 0.8328 |
| *P* value (two-tailed) | $P<0.0001$ |
| *P* value summary | *** |

**Figure 5** Correlation between EF and the sub-bandage pressure difference when a subject stands up from supine (static stiffness index, left) and between systolic and diastolic pressure during walking (right). The data from the 15 patients, in whom additional elastic bandages with high stretch were applied (8), are included

proximal to a plaster and showed an increase of both parameters depending on the filling condition of water pads located under the plaster. We have adopted this method for patients with venous pumping insufficiency and were able to show that an improvement of reduced values of EV and EF can be obtained by calf compression (Figures 1–3). VV of the non-compressed calf segment, where the plethysmographic measurement takes place, does not show significant changes with different bandages, in contrast to EV and EF. These parameters discriminate between normal subjects and venous patients, and show a significant improvement of the venous pump by bandages depending on the material used. However, it may happen that the reflux into the lower leg is prevented by the higher pressure provided by inelastic bandages thereby producing an increase of the volume of the calf segment (VV) proximal to the bandage (Figure 1). Those patients with venous reflux showed values of EF that were significantly lower than normal ($P < 0.001$), independently of their CEAP classes (Table 1). This may be explained by our selection of patients who all had major reflux in the GSV being candidates for venous surgery.

Our data indicate that compression bandages are able to increase EV and EF. Although the improvement of venous pumping function after elastic bandages is only moderate, inelastic bandages applied with the same resting pressure raise the values of EV and EF into a normal range (Figure 2).

One important difference between elastic and inelastic bandages, both applied with the same supine pressure, is the high pressure increase in the upright position and during exercise with inelastic in contrast to elastic material (Table 2). Even when both bandages are applied with the same standing pressure inelastic material shows a significantly higher pressure increase during exercise compared with elastic material (Figure 1; Table 3).

EF is correlated significantly with the standing, but not with the supine pressure (Figure 4).

Based on these findings one would expect to see a similar improvement of venous pumping function when both bandage materials are applied with the same high pressure in the standing position. As demonstrated in Figure 3, inelastic bandages with a standing pressure of 64 mmHg are able to normalize the venous pumping function, whereas this is not the case for elastic bandages applied with the same standing pressure. Moreover, the interface pressure of the highly stretched elastic bandages between 50 and 70 mmHg in the lying position was reported to be rather painful by the patients. Therefore, these bandages could be endured only in the laboratory for the short time necessary for the test.

These experiments quite clearly show that the static IP is not the only important determinant for improving the venous pump function, but also, that, in addition, the elastic property of the compression material plays a critical role.

Stiffness characterizes the distensibility of a textile and determines the performance of a compression device during standing and walking.[12]

Inelastic material does not give way when the calf muscle contracts. This explains the highly significant rise of the sub-bandage pressure when a subject stands up from the supine position. It has been proposed that this pressure difference measured in the gaiter area should be called the SSI.[12,20,21] The standing pressure shows an excellent correlation with the peak pressure during walking, the so-called working pressure.[12,22] Compared with an elastic bandage, a stiff bandage produces higher standing and working pressure, and a higher difference between systolic and diastolic pressure during calf muscle contraction (SDD)[12,22] (Figure 1). As demonstrated in Figure 5, both parameters, SSI and SDD, show a highly significant correlation with EF. The high increase in pressure, especially under inelastic material can be explained by the fact that the pressure transducer is positioned on the medial gastrocnemius-tendon, which protrudes during standing and intermittently during walking.[12] These pressure peaks under a stiff bandage parallel the changes in tissue pressure that are obviously the deciding effector of the improved venous pump function.

These findings are in accordance with previous reports showing that inelastic bandages are much more effective than elastic bandages, even when starting from the same resting pressure.[12,13,19]

How can the haemodynamic superiority of inelastic compression material be explained?

The high-pressure amplitudes of an inelastic bandage during walking act like an intermittent pneumatic pressure pump exerting a massaging effect on the leg, so promoting an increase of both EV and EF.

Furthermore, it may be speculated that during walking, the sub-bandage pressure peaks, induced by muscle systole, may overcome the intravenous pressure fluctuations and thereby causing short periods of intermittent occlusion of the leg veins. Such short phases of venous occlusions during muscle systole could be observed by the Duplex using stiff cuffs on the leg (Partsch H, unpublished). This may block venous reflux intermittently like an artificial valve and may explain the reduction of ambulatory venous hypertension that can be measured under inelastic bandages applied with high pressure, but not with elastic material.[23,24]

In summary, in this study the best haemodynamic improvement in patients with chronic venous insufficiency could be demonstrated with inelastic compression material that allows a relatively low, well tolerable resting pressure and, at the same time, pressure increases during standing and walking to a range which is high enough to counteract gravity. The attempt to achieve a better haemodynamic effect by applying an elastic bandage with higher pressure does not provide any further functional benefit, but is associated with patient discomfort.

Future studies should investigate the improvement of the venous pumping function depending on various pressure ranges of different compression devices.

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