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Compression Stockings with a Negative Pressure Gradient Have a More Pronounced Effect on Venous Pumping Function than Graduated Elastic Compression Stockings

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Abstract *Objectives:* To measure the effect on the venous pumping function of a stocking providing a negative pressure gradient with higher pressures over the calf in comparison to a conventional graduated elastic compression stocking (GECS) in patients with advanced venous insufficiency.
Design: Experimental study.
Material: 30 patients with severe superficial chronic venous insufficiency were enrolled. Two elastic stocking designs exerting a pressure at ankle between 15 and 25 mm Hg were compared; a conventional GECS and a stocking exerting a higher pressure over the calf than over the ankle producing a "progressive" increase in compression (PECS).
Method: the venous calf pumping function was assessed by measuring the ejection fraction (EF) from the lower leg by a plethysmographic method during a standardised exercise. Interface pressure of the 2 compression devices was simultaneously recorded both at B1 = 12 cm above ankle, C = just above widest part of calf.
Results: The mean increase of EF produced by PECS was +75% (95 CI 48,7-101,3) compared with +32% (95%CI 16,8-48,6) with GECS ($P < 0.001$). There was a significant correlation between EF and the stocking pressure measured at calf level during standing and walking.
Conclusion: Stockings exerting a higher pressure on the calf than on the ankle show a greater efficacy in increasing the venous ejection fraction from the leg.

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Graduated elastic compression stockings (GECS) providing a decreasing pressure profile from distal to proximal (degressive gradient) have become a cornerstone of standard care, both concerning thromboprophylaxis and management of venous and lymphatic disorders. Although some discrepancies between the theoretical pressure profile indicated by the stocking producers and measurements on the human leg have been reported,[1,2] a continuous pressure reduction from distal towards proximal is generally considered an important quality criterion for producing compression hosiery in different regulations.[3–5]

Recently, a new concept of stockings providing a higher compression pressure over the calf than over the ankle region, inversely graduated or 'progressive' elastic compression stockings (PECS), has been proposed. Beneficial results have been reported in sports applications[6] as well as in venous disease patients.[7] In a double-blind multicenter randomised controlled trial in patients with mild chronic venous insufficiency (CEAP C0s—C2s), it was demonstrated that PECS are equally effective as conventional stockings concerning an improvement of subjective symptoms. Additionally, they reported that PECS were easier to put on, were more comfortable to wear and had a better compliance compared to GECS.[7]

Although these results are encouraging, objective data concerning an improvement of the venous haemodynamics in venous disease patients have not yet been presented.

The aim of our work was to measure the impact of a PECS providing higher pressures over the calf versus the ankle area on the venous pumping function in patients with advanced venous insufficiency in comparison to a conventional compression stocking with standard degressive graduation.

Material and Methods

Thirty patients with chronic venous insufficiency (18 female, 12 male, average age: 57.2 years), presenting with significant reflux in the great saphenous vein (GSV), all candidates for varicose vein surgery, were enrolled into this study.

Inclusion criteria:

- CEAP between C2 and C5 (C2 11 patients, C3 12 patients, C4 3 patients, C5 4 patients).
- Significant GSV insufficiency with incompetent terminal and pre-terminal valves, diameter at the level of the junction >10 mm shown by Duplex and reflux longer than 1 s.
- Good joint mobility enabling patients to perform the exercises requested by the protocol.

Patients who did not fulfil the inclusion criteria and patients who were unable to perform the exercise test described below were excluded.

Patients were informed about the details of the examination and gave their written consent.

With the patient in the standing position, Duplex investigation of the superficial and deep veins of the lower extremity was performed in longitudinal view for detecting venous reflux during Valsalva manoeuvre. Reflux time more than 1 s was considered to be pathological. A cross-sectional view was used to measure the diameter of the GSV in the groin and 5 cm distal.

Compression devices

Two different kinds of ready-made, knee-length, elastic stockings, both with a pressure at ankle between 15 and 25 mmHg were applied in a randomised order to the leg for which varicose vein surgery was planned.

The standard stocking was supposed to exert a higher pressure at ankle and a 'degressive' pressure profile, lower by 20% at calf level (provided by Pierre Fabre, Castres, France). The other stocking (Progressiv® N'System, Pierre Fabre, Castres, France) exerting a lower pressure at the ankle was supposed to exert a pressure at calf level about 50% higher than that at the ankle so realising a negative, 'progressive' gradient (PECS).

Interface pressure measurement

The pressure of each garment was continuously measured at two sites of the leg using a newly developed instrument connected with a data logger by a special computer program (Picopress®, Microlabitalia, and Padua, Italy). The pressure transducer consists of a flat plastic pressure probe (diameter 5 cm) that is filled with 2 ml of air for the pressure measurement. Fluctuations of pressure on this probe are transformed into electronic signals (Statham-element) that can be recorded continuously. Two probes were used to measure pressure simultaneously: one at the distal leg, about 12 cm proximal to the inner ankle (B1 point, which is defined by the transition of the muscular part of the medial gastrocnemius into the tendinous part) and one proximally at the maximal calf circumference (C point).[3,4] Sub-stocking pressure was measured continuously in the supine, the standing position and during the exercise program.

Measurement of ejection fraction of the venous calf pump

Using strain-gauge plethysmography (Angioflow2, Microlabitalia, Padua, Italy), ejection fraction (EF) was assessed following the method described by Poelkens et al.[8] An indium—gallium alloy gauge (diameter of 1 mm) is placed around the leg in the supine position 5 cm distally from the patella and proximally to the elastic stockings. The investigation starts, after calibration of the device, by elevating the examined leg in order to empty the veins and to record the minimal volume of the leg segment. Then the patient stands up and the volume increase of the calf segment encircled by the strain-gauge probe, reflecting venous filling, is measured continuously. Venous volume (VV) is defined as the difference between empty and filled veins. During a standardised exercise (walking on spot with 20 steps in 20 s) the amount of blood that is expelled towards the heart (EV = expelled volume) reflects the quality of the venous pump. EF is calculated according to the formula $100 \times EV/VV$.

As it was demonstrated in previous reports,[9–12] this method is able to assess the haemodynamic efficacy of several compression products in a completely non-invasive manner.

The experiments were carried out in baseline condition without compression and repeated with the two stockings applied in a randomised sequence to all patients.

All tests on every patient were done on the same day with an interval of 15 min between each measurement. The measurements were performed 5 min after stocking application with the patient resting in the supine position in a quiet room with constant humidity and temperature.

Statistics

Determining the power of a completed experiment and comparing EF with and without a compression stocking from a previous study with a sample size of 20 in each group,[10] a 95% power to detect a difference between means of 7.91 with a significance level (alpha) of 0.05 (two-tailed) was calculated (Graph Pad StatMate, San Diego, CA, USA). The same kind of analysis performed in the presented experiments carried out on 30 pairs of comparisons revealed a 99% power to detect a smallest average difference between pairs of 12.52 with a significance level of 0.05 (two-tailed). The actual difference between the mean values of the two stocking types was 12.17.

In the present work, median values and interquartile ranges (IQRs) are given. One-way analysis of variance (ANOVA) was used to compare the repeated measurements of EF under different compression systems with the baseline. 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 statistically evaluations were generated by using Graph Pad Prism and Graph Mate software (Graph Pad, San Diego, CA, USA).

Results

Ejection fraction

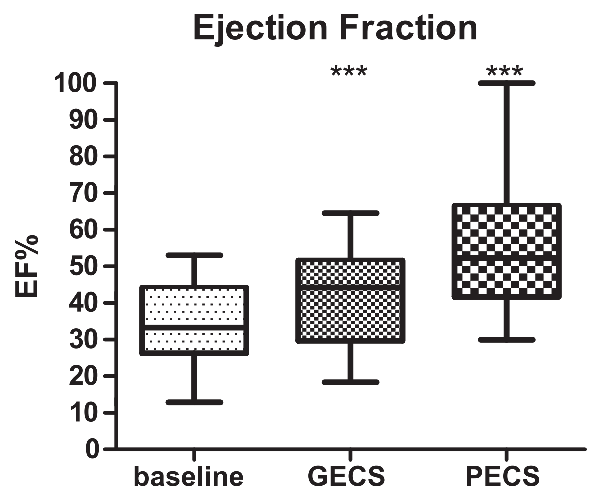
Without compression EF was 33.29% (IQR: 26.26–44.21), which is significantly lower than our normal values from healthy volunteers [median 65% (IQR: 63.7–67.8)].[9]

EF increased significantly to 44.5% (+32.7%, 95% CI: 16.8–48.6) with GECS ($P < 0.001$) and to 52.54% (+75%, 95% CI: 48.6–101.3) with PECS ($P < 0.001$) (Fig. 1).

Pressure measurements

The exerted pressure and the pressure gradients exerted by the conventional GECS and the new PECS in the supine position are completely opposite. Compared with PECS, GECS exerted a higher pressure at ankle level between 18 and 27 mmHg (median 22 mmHg; IQR: 20–24) and showed a decrease of the median pressure by 14% between the distal leg (point B1) and the calf (point C).

PECS starting from a lower pressure at ankle level between 11 and 23 mmHg (median 18.5 mmHg; IQR: 16–20) exerted a pressure increase between points B1 and C by



	baseline	GECS	PECS
Minimum	12.91	18.35	29.97
25% Percentile	26.26	29.75	41.72
Median	33.29	44.50	52.54
75% Percentile	44.21	51.66	66.56
Maximum	53.01	64.51	100.0

Figure 1 Ejection fraction which is severely reduced in patients with venous insufficiency (baseline) increases significantly with traditional stockings (GECS) and, much more, with progressive stockings (PECS). *** = $P < 0.001$ compared to baseline.

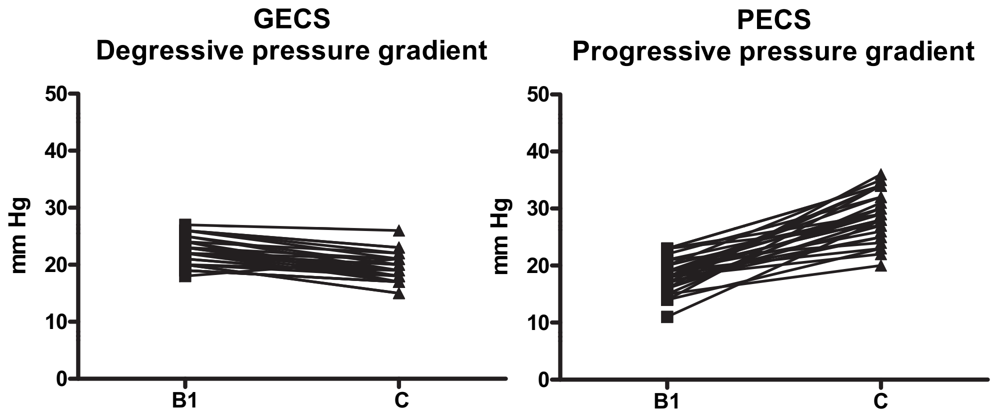
57%; both differences (at point B1 and C) are statistically significant ($P < 0.0001$) (Fig. 2).

These pressures increased only slightly by standing up (Fig. 3) and during exercise. The highest median pressures were recorded at C point with progressive stockings in standing position (31.5 mmHg) and during exercise (32 mmHg).

EF showed a significant correlation with the standing pressure (Spearman $r = 0.43$, $P < 0.001$) and the maximal pressures during exercise (Spearman $r = 0.406$, $P < 0.01$) at position C, but not at B1 (Fig. 4).

Discussion

One of the main targets of compression therapy in venous insufficiency is to counteract venous hypertension. Venous pressure in the leg veins corresponds to the weight of the column of blood between the right heart and the point of measurement. The amount of external pressure required to counteract the venous pressure diminishes progressively towards proximal as the hydrostatic pressure decreases. The concept that any kind of external compression of the extremity needs to be graduated or 'degressive' is based on the assumption that under physiological conditions flow will always go from a distal point with higher pressure to a proximal point with lower pressure and that creating a reverse pressure gradient by applying higher proximal compression will disturb venous return. Although this assumption could be valid for the resting position, in which a proximal flow hindrance due to an inverse pressure



	B1	C
Minimum	18.00	15.00
25% Percentile	20.00	17.75
Median	22.00	19.00
75% Percentile	24.25	21.00
Maximum	27.00	26.00

	B1	C
Minimum	11.00	20.00
25% Percentile	16.00	25.75
Median	18.50	29.00
75% Percentile	20.25	32.50
Maximum	23.00	36.00

Figure 2 Conventional GECS (left) show a decreasing pressure profile from B1 to C points; stockings with a progressive pressure gradient (right) show a lower pressure in B1 and an increasing pressure profile between B1 and C.

gradient should be avoided, this is obviously not the case for the complex situation in a moving individual when muscle contractions will physiologically induce very high intravenous pressure peaks creating inverse pressure gradients with every step.

Phases of venous outflow obstruction may even occur during the muscle contraction. The pressure increase due to muscle contraction is much higher in the deep veins compared to the superficial veins. However, simultaneous pressure measurements performed in superficial veins showed a greater ambulatory venous pressure reduction in the foot versus in the calf veins, in both in normals and patients with superficial venous incompetence.[13]

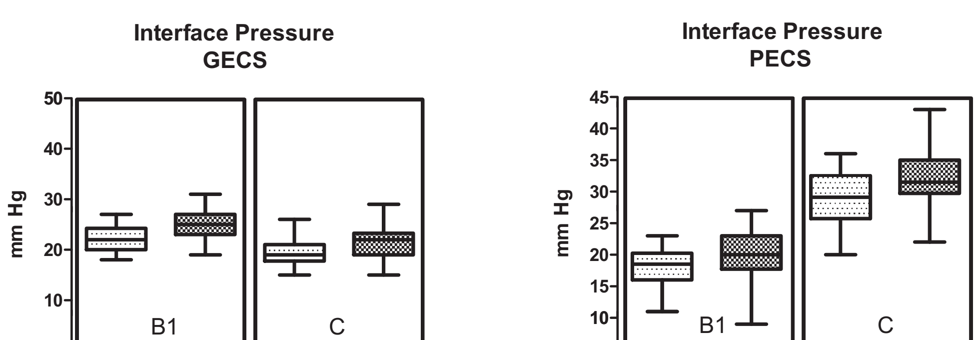
This demonstrates that during walking there are phases with a proximal intravenous pressure higher than distal and that a continuous intravenous pressure gradient is not a general physiological principle.

External compression over the calf exerted by a PECS will increase the pressure exerted on the local veins during muscle systole and the great amount of blood pooled in the calf will be squeezed out more rigorously compared to the ankle area, which is covered by lower compression.

In a previous study assessing local blood volume in the leg by radioscintigraphy using labelled autologous erythrocytes, it was demonstrated that in the upright position the highest amount of blood volume is located in the mid-calf area while the content of blood in the distal parts of the leg is rather poor.[14]

Our data show a positive correlation between the EF and the standing and peak pressure in the calf area (C point) but not in the ankle area (B1 point) (Fig. 4).

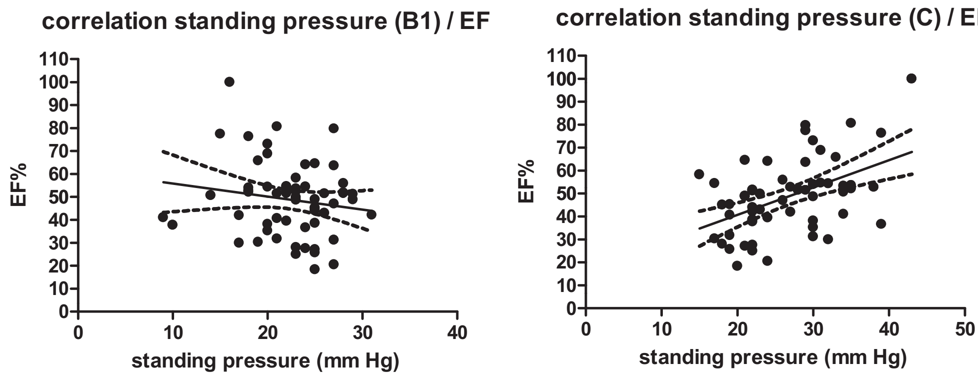
Following stocking manufacturing standards,[3,4] the pressure profile of a compression stocking exerting 20 mmHg in the ankle position should be graduated as follows:



	supine	standing	supine	standing
Minimum	18.00	19.00	15.00	15.00
25% Percentile	20.00	23.00	17.75	19.00
Median	22.00	25.00	19.00	22.00
75% Percentile	24.25	27.00	21.00	23.25
Maximum	27.00	31.00	26.00	29.00

	supine	standing	supine	standing
Minimum	11.00	9.000	20.00	22.00
25% Percentile	16.00	17.75	25.75	29.75
Median	18.50	20.00	29.00	31.50
75% Percentile	20.25	23.00	32.50	35.00
Maximum	23.00	27.00	36.00	43.00

Figure 3 Supine and standing pressure at B1 and C points for GECS (left) and PECS (right).



Number of XY Pairs	60
Spearman r	-0.1460
95% confidence interval	-0.3922 to 0.1197
P value (two-tailed)	0.2657
P value summary	ns

Number of XY Pairs	60
Spearman r	0.4312
95% confidence interval	0.1917 to 0.6223
P value (two-tailed)	0.0006
P value summary	***

Figure 4 Ejection Fraction correlates with standing pressure at C (right) but not with that at B1 (left).

ankle (position B): 20 mmHg (100%) about 12 cm
above (position B1): 14—20 mmHg (70—100%)
calf (position C): 10—14 mmHg (50—70%).

Following this regulation, a pressure of 44—60 mmHg at the ankle would be needed in order to achieve a pressure of 30 mmHg at calf level. Based on our results, we cannot exclude that such a conventional GECS could lead to the same or to an even a higher degree of improvement of the venous pump. However, such high pressure in the ankle region would make donning very difficult and could be rather uncomfortable in the resting position. Actually, the comparison between GECS and PECS in a randomised controlled trial has clearly shown that GECS with a resting pressure of about 20 mmHg at the ankle are more difficult to be put on and are less comfortable than PECS with a lower ankle pressure, but with a higher calf pressure.[7]

External compression of the calf region will increase the venous pumping function, which can be quantified by measuring the amount of expelled volume and of EF using different plethysmographic methods including foot volumetry and air plethysmography.[15,16] Some of these studies have shown an increase of venous pumping by increasing compression pressure[10] and better results with inelastic compared to elastic material.[9]

The presented improvement of EF under GECS is in agreement with previous reports from our group using the same methodology in comparable patients with venous insufficiency.

In our present study, it was shown that the significantly higher pressures over the calf achieved by the PECS (29 mmHg in supine, 33.5 mmHg during walking) are significantly more effective than lower pressures in improving a disturbed venous pumping function. Despite this significant improvement, PECS are not able to restore a normal EF from the lower leg as it happens using inelastic bandages exerting comparable resting pressures.[9]

One weakness of measuring EF following the described technique is the variability in performing the walking exercises. However, since the measurements are repeated on the same individual without changing the plethysmographic detector, a satisfactory reproducibility was achieved in previous experiments (variation coefficients of 7.5%).[8]

The significantly improved efficacy of PECS stockings on the venous calf pump may not be extrapolated to other effects of such stockings like thromboprophylaxis, chronic oedema or lymphoedema reduction and deep venous damage following DVT. Further studies are needed to clarify a potential value of PECS in these indications.

Ethical Issues

Our work complies with the principles laid down in the Declaration of Helsinki. Our Ethical Committee was informed of the study but according to Italian regulations formal approval was not required. Nevertheless, patients gave informed consent.

Conflict of Interest

No conflict of interest.

References

1 Liu R, Kwok YL, Li Y, Lao TTH, Zhang X, Qun X. Objective evaluation of skin pressure distribution of graduated elastic compression stockings. *Derm Surg* 2005;**31**(6):615—24.
2 Partsch H, Partsch B, Braun W. Interface pressure and stiffness of ready made compression stockings: comparison of in vivo and in vitro measurements. *J Vasc Surg* 2006;**44**(4):809—14.
3 *European Committee for Standardization (CEN): adopted European Prestandard: medical compression hosiery*. Brussels: ENV 12718; 2001. CEN. Quality Assurance.
4 RAL-GZ 387/1. Medical Compression Hosiery. *Deutsches Institut für Gütesicherung und Kennzeichnung*. Berlin: E.V. Beuth Verlag; January 2008.

5 British Standards Institution. *British standards specification for graduated compression hosiery* (BS 6612.). London: The Institution; 1985.
6 Garreau C, Pibourdin JM, Nguyen Le C, Boisseau MR. Elastic compression in golf competition. *J Mal Vasc* 2008 Dec;**33**(4—5):250—1.
7 Couzan S, Assante C, Laporte S, Mismetti P, Pouget JF. Booster study: comparative evaluation of a new concept of elastic stockings in mild venous insufficiency. *Presse Med* 2009;**38**(3):355—61.
8 Poelkens F, Thijssen DH, Kersten B, Scheurwater H, van Laarhoven EW, Hopman MT. Counteracting venous stasis during acute lower leg immobilization. *Acta Physiol* 2006;**186**(2):111—8.
9 Mosti G, Mattaliano V, Partsch H. Inelastic compression increases venous ejection fraction more than elastic bandages in patients with superficial venous reflux. *Phlebology* 2008;**23**(6):287—94.
10 Mosti G, Partsch H. Is low compression pressure able to improve venous pumping function in patients with venous insufficiency? *Phlebology* 2010 Jun;**25**(3):145—50.
11 Mosti G, Partsch H. Inelastic bandages maintain their hemodynamic effectiveness over time despite significant pressure loss. *J Vasc Surg* 2010;**52**(4):925—31.
12 Mosti G, Partsch H. Measuring venous pumping function by strain-gauge plethysmography. *Int Angiol* 2010;**29**(5):421—5.
13 Stranden E, Ogreid P, Seem E. Venous pressure gradients in patients with chronic venous disease. *Phlebology* 1986;**1**:47—50.
14 Partsch H, Lofferer O, Mostbeck A. Zur Beurteilung der Lymph- und Venenzirkulation am Bein mit und ohne Kompression. In: Zeitler E, editor. *Aktuelle Probleme in der Angiologie*. Bern, Stuttgart, Wien: Hans Huber Verlag; 1973. p. 169—75.
15 Norgren L. Elastic compression stockings: an evaluation with foot volumetry, strain-gauge plethysmography and photoplethysmography. *Acta Chir Scand* 1988;**154**(9):505—7.
16 Ibegbuna V, Delis KT, Nicolaides AN, Aina O. Effect of elastic compression stockings on venous hemodynamics during walking. *J Vasc Surg* 2003;**37**(2):420—5.