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Lower Limb Deep Vein Diameters Beneath Medical Compression Stockings in the Standing Position

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WHAT THIS PAPER ADDS

This study clarifies the reasons why results from previous studies on lower limb deep vein changes under compression are discordant. Deep vein diameter reductions observed under compression in the standing position are caused by isometric muscle tension during weight bearing and not the compression effect of the stocking. This is contrary to previous studies that imply that medial compression stockings alone are able to compress deep veins in the standing position.

Objectives: The mechanism by which compression therapy works is still discussed, especially at calf level. Whether lower limb deep vein diameters change under compression stockings is a matter of debate: no change versus great change. New study material helps to address this question.

Methods: This was an experimental single centre controlled study on nine selected patients with mild to moderate superficial venous disease. A total of 34 deep vein segments were examined. A new hybrid (elastic + non-elastic materials) cuff pressure device enabled the deep vein diameter changes from baseline to occlusion similar to that which could be observed under stockings. The deep vein diameters were measured through the device with the patients in a standing position and their body weight distributed equally on both legs. This was compared to a 20–35 mm Hg medical compression stocking. The diameter change when patients put their whole body weight on the tested leg was also measured.

Results: A pressure of 25.3 ± 6.4 mm Hg (mean, SD) was required to ovalise lower leg deep veins and a pressure of 43.1 ± 16.2 mm Hg (mean, SD) to occlude them. Both pressures were significantly different from baseline: $p = .003$ and $p < .0001$, respectively. No diameter reduction was achieved when the stockings were worn, and occlusion of deep veins occurred when the patients transferred their body weight onto the examined leg.

Conclusion: In the standing position, deep vein diameter reduction is not caused by compression stockings but may be due to the isometric muscle contractions required to support the patient's body weight.

Keywords: Lower limb, Compression stockings, Deep vein, Calf pump

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INTRODUCTION

One of the key treatments of deep and superficial venous insufficiency is compression therapy.[1] It has been shown that compression therapy reduces intravenous pressure by improving calf venous pump function.[2–6] Although these effects have been known for a long time, the way bandages and medical compression stockings (MCSs) can enhance the calf pump remains unclear.[7,8] One of the hypotheses is that MCSs improve venous pumping by reducing the venous cross sectional diameters.[9]

In a standing position, it has now been clearly shown that MCS cannot drastically reduce superficial vein diameters.[10] The authors demonstrated that deep vein diameters are either not or only very slightly reduced by compression stockings.[11,12]

Using a cuff device on 11 deep vein segments, it was demonstrated that a mean of 40 mmHg was necessary to narrow the veins and 68 mmHg to a totally collapse them.[10]

Quite paradoxically, more recent works using new investigation techniques have explained that MCSs cannot reduce the diameter of superficial veins, but that they can reduce the lumen of deep veins.[14,15] No explanation was given for these results which are contrary to the two previously mentioned studies.

Moreover, a most recent digital model approach involving finite element calculations drew the conclusion in favour of the absence of any effect of moderate to strong compression on the reduction of vein diameters, and especially deep veins.[16] Consequently, the question remains unresolved and the issue of deep vein diameter reduction under external

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compression using a new hybrid compression device has been addressed.

METHODS

The study was an experimental controlled single centre trial. Deep vein diameters were measured from no pressure up to the pressure under which the vein ovalised then totally collapsed. Pressure was applied to the calf using a newly designed compression device which enabled a Laplacian type pressure to be exerted, namely a pressure phenomenon similar to MCS effects, at any desired level. The device was wrapped around the leg using a Velcro system, and angularly positioned on the calf in order to provide good quality ultrasound examination access for the investigator. On the opposite part of the device, a sphygmomanometer (Spengler, Issoudun, France) was inserted between the tibial edge of the calf and the wrapping device. The pressure exerted by the wrapping device (hybrid cuff) was calculated based on two parameters: the circumference of the leg at the level of the investigated vein in combination with the material tension. That tension was defined by the distances between the two vertical lines on the stretched fabric (Fig. 1).

The veins were localised and measured through the knitted fabric that is part of the posterior side of the device using B mode ultrasound. A 3.5—5.0 MHz probe was used (Esaote MyLab 25 Gold, Genoa, Italy). To improve the repeatability of the measurement process, the area of the leg to be investigated was precisely located by a repositionable laser pointer moving along a vertical stick. Once the image froze, the lumen which is the internal diameter between the anterior and posterior intimal layers of the vein, was measured by the available specific function on Esaote machine. The mean of three consecutive measurements was recorded.

The aim was to study at least 30 deep vein cross sections. The posterior tibial, fibular, and soleus veins were used and the measurements were made at mid-calf level.

Recruitment was not done randomly but performed according to the capability of the investigator to perfectly scrutinise the entire shape of the vein, irrespective of its diameter (Fig. 2).

Therefore, nine patients were recruited during a phlebological consultation and had a clinical venous examination as well as a colour flow duplex examination in the standing position. This study, being legally held under the scope of the French Medical Devices Vigilance System activities (official organisation depending on the *Agence Française de Sécurité du Médicament*), only required formal written informed consent, which was obtained from all included patients.

The patients were selected in an age range of 30—65 years, and presented with, as a minimum, telangiectasias.

Patients suffering from healing or healed ulcers, lipodermatosclerosis, or with acute or chronic deep venous disorders were excluded.

Deep veins were located and imaged while the patients were standing. Vein measurement sessions started after 2 min of standing. At basal conditions, the patient was requested to equally distribute his/her body weight on each leg. As a control step, patients were asked to wear French graduated class 3 MCS (Sigvaris, St-Just-St-Rambert, France) exerting a 21—35 mmHg at ankle level and 18—22 mmHg at calf level; correct MCS fitting was checked. The diameters of the same deep vein portions were measured through the stockings in the standing position while the body weight was equally distributed on both legs. The volunteers were then asked to remove the MCSs and the same vein calibres were again measured under “without stocking” conditions.

An additional measurement was made in order to have any possible biases under control.

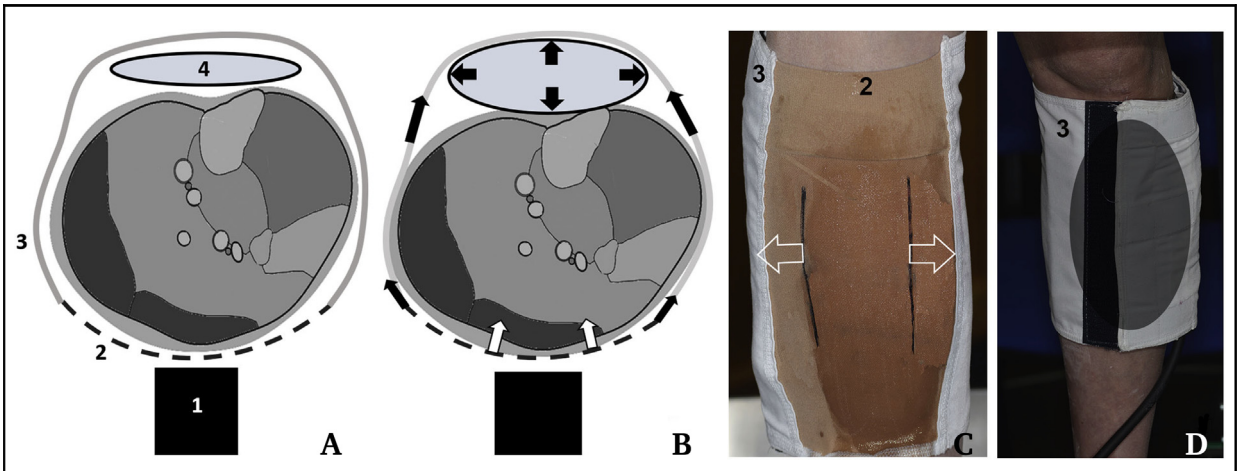

Figure 1. Hybrid cuff-knitted fabric device used in the trial. (A) device with deflated cuff. 1, ultrasound probe; 2, knitted fabric (dotted line); 3, rigid wrapping which is sewn to the knitted fabric; 4, inflatable cuff. (B) device with inflated cuff and resulting forces. (C) the posterior aspect of the device; the arrows indicate the displacement of the vertical black lines when the cuff is inflated and the knitted fabric stretched. (D) anterior aspect, the oval grey transparent zone represents the location of the air pressure cuff underneath the rigid wrapping.

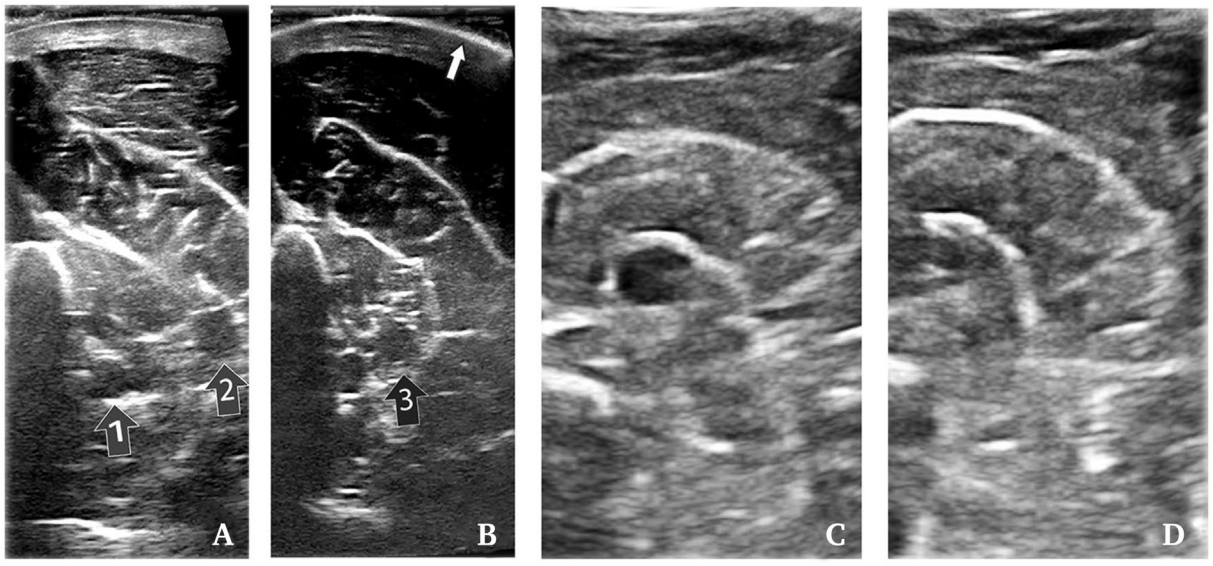

Figure 2. Examples of sonography of calf deep veins in different situations. (A) Stocking free calf; at the same slice, a clearly visible and measurable fibular deep vein (arrow 1) and a less clearly, poorly visible soleal vein (arrow 2). (B) Calf with stocking (white arrow); two fibular veins are visible but one of the two is not clearly visible and will not be chosen for measurement (arrow 3). (C,D) the same patient with a clearly visible soleal vein without muscle contraction and totally collapsed under body weight transfer to the examined leg (C and D, respectively).

Patients were examined in the standing position and were requested to transfer their body weight onto one leg only, while the other leg which was the examined leg was totally free of muscle contractions. Then, afterwards, the same deep veins were measured again after the body weight was equally distributed on both legs and finally with the weight transferred to the examined leg. This operation created two standardised muscle conditions: no contraction versus necessary contraction to support the body load.

A repeatability test was also carried out on three deep vein segments, each of them being measured 10 times.

Statistics

The descriptions use standard statistical parameters: mean, standard deviation, quartiles, and ranges for quantitative variables, and percentages for qualitative variables. Comparisons between groups were conducted by the Student *t*-test for quantitative criteria. A p value < 0.05 was considered statistically significant.

RESULTS

The patients were three males and six females whose mean age was 48 years old, ranging from 30 to 61 years. Nine legs were tested. One leg had distal Grade 2 ankle to foot lymphoedema and six others legs had superficial venous disease. According to the CEAP classification of venous diseases, three legs were classified C1EpAsPn, one leg was C1,2EpAsPr, and five were C1,2,3EpAsPr. None of the patients wore compression stockings on a daily basis.

The average calf circumference at the largest point was 35.9 cm, ranging from 31 to 42 cm, and the diameter of all deep veins tested was 4.5 $\pm$ 0.91 mm (mean, SD), consisting of seven segments of posterior tibial vein, 10 segments of fibular vein, and 17 segments of soleus vein. At the site of vein testing there was no significant difference, at inclusion, between muscular and intermuscular calf deep vein diameters.

The repeatability of the deep vein measurements was carried out on one fibular vein and two soleus veins. Each vein was measured 10 times; the mean was considered as the final measurement. The results showed a standard deviation of 0.48 mm for the fibular vein, 0.33 mm on the first and 0.30 mm on the second soleus vein tested; average diameters were 4.4 mm, 6.4 mm and 5.8 mm, respectively.

The variation of the vein shape under compression using the hybrid system showed the same pattern as already published with an ovalisation, an “eight shape” and full collapse.[9]

On the 34 different deep vein segments tested, a 32.3 $\pm$ 11.9% (mean, SD), ranging from 18% to 72%, deep vein diameter percentage reduction was obtained with a pressure of 25.3 $\pm$ 6.4 mmHg (mean, SD), ranging from 14.9 to 34.4 mmHg. Total collapse of deep veins was achieved with 43.1 $\pm$ 16.2 mmHg (mean, SD), ranging from 22.3 to 84.6 mmHg (Fig. 3). Compared with baseline values the difference was significant with $p = .003$ at ovalisation and $p < .0001$ at occlusion. The pressures at occlusion were 46 $\pm$ 18.8 mmHg, 42 $\pm$ 8.2 mmHg, 42 $\pm$ 17.7 mmHg (mean, SD) for the fibular, posterior tibial, and soleus veins, respectively (Fig. 4). A summary is provided in Table 1. No sub-group comparison was made due to the small number of vein segments in some groups. Vein diameters without and with French Class 3 stockings (20—

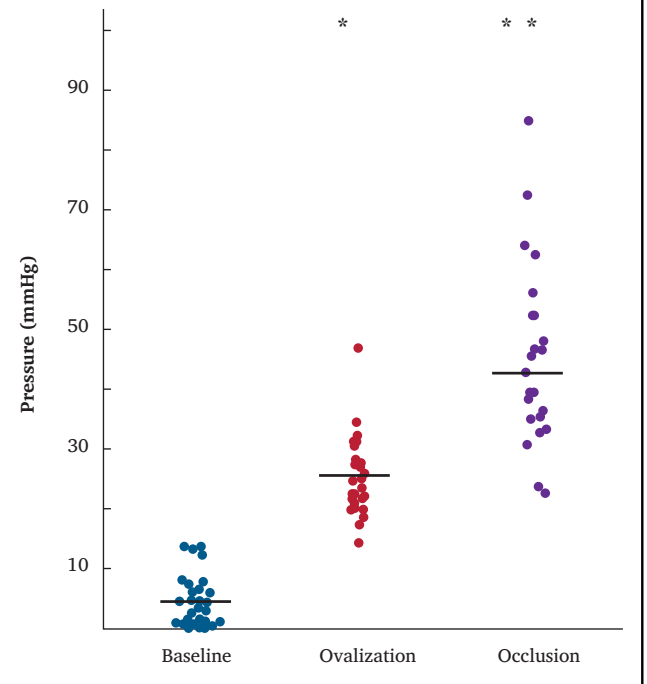

Figure 3. Deep vein diameter changes with pressure at baseline, ovalisation and occlusion. Body weight equally distributed on both legs. The horizontal bar represents the mean. The difference from baseline is significant. * $p = .003$, ** $< .0001$.

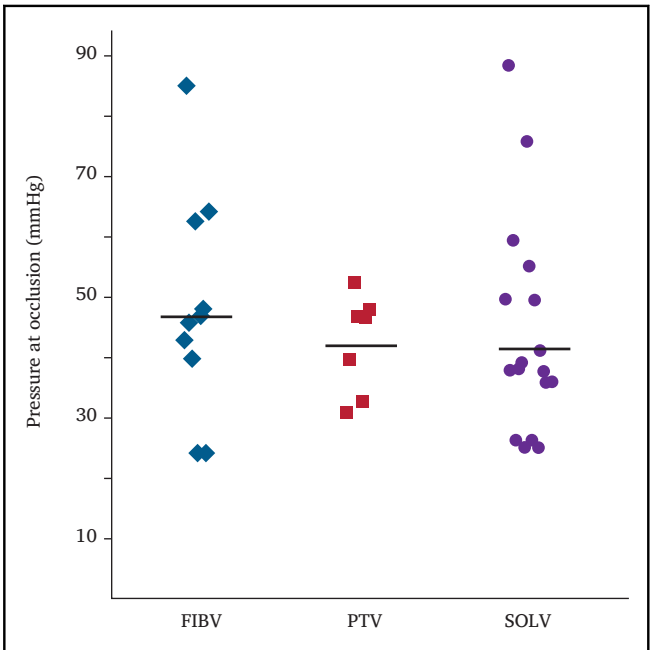

Figure 4. Deep vein diameter changes with pressure at occlusion according to the type of vein. Body weight equally distributed on both legs. FIBV for fibular vein, PTV for posterior tibial vein, SOLV for soleus vein. Horizontal bar represents the mean. No significant difference between groups.

35 mmHg at the ankle) were measured on seven volunteers representing 16 different deep vein sections. The diameter of deep veins without stocking was 4.0 ± 2.3 mm, and with stockings 4.1 ± 1.8 mm (mean, SD). There was no statistical difference in deep vein diameter changes under MCSs (Fig. 5).

Table 1. Pressure at baseline (initial stage), ovalization and occlusion of different deep vein segments

Pressure (mmHg)	Initial	Ovalization	Occlusion
All ($n = 34$)	5.1 ± 3.8	25.3 ± 6.4	43.1 ± 16.2
FIBV ($n = 9$)	4.4 ± 2	27.4 ± 8.6	46 ± 18.8
PTV ($n = 7$)	4.5 ± 2.3	25.3 ± 6	42 ± 8.2
SOLV ($n = 18$)	6.5 ± 4.3	24.2 ± 5.2	42 ± 17.8

Data are presented as means ± standard deviation. All = all veins; FIBV = fibular vein; PTV = posterior tibial vein; SOLV = soleus vein.

For the additional measurement, six legs were tested on six volunteers representing nine soleus, three fibular, and three posterior tibial vein sections. First, the deep vein diameters, measured when the examined leg was not loaded, were 5 ± 1.4 mm. Then, when the body weight was equally distributed on both legs, the average reduction of the vein section was 11.8%, ranging from 0 to 54%; the difference was statistically significant with $p = .009$ (Fig. 6). Finally, for each patient when asked to transfer his/her body weight on the examined leg all of the deep veins had completely closed under this isometric contraction (Fig. 2). Differences between soleus and other deep veins were not significant. A summary of the vein diameter values under the different situations is summarised in Table 2.

DISCUSSION

The main results of this research can be summarised in three points: (1) the average pressure required to fully close

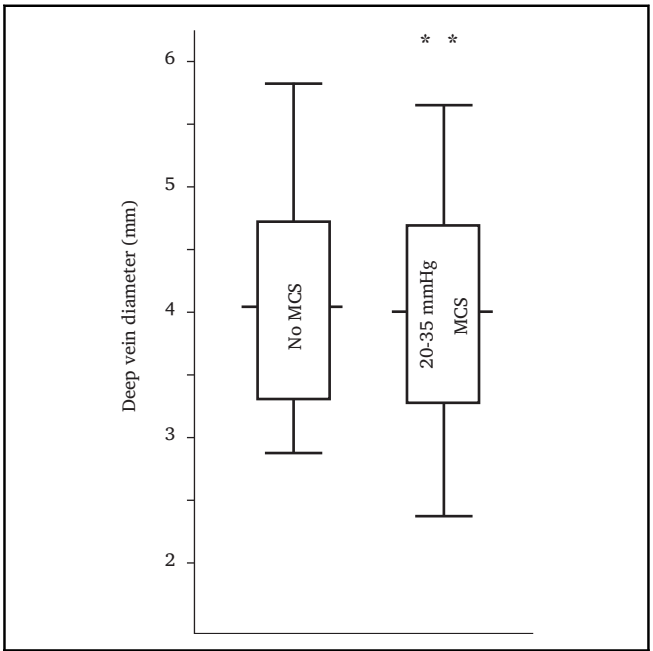

Figure 5. Change in deep vein diameters under French Class 3 medical compression stocking exerting 21 – 35 mmHg compared with baseline without stockings. Body weight equally distributed on both legs. ** No significant differences. Mean (horizontal bar), 25th and 75th percentiles (block), and range. MCS = medical compression stocking.

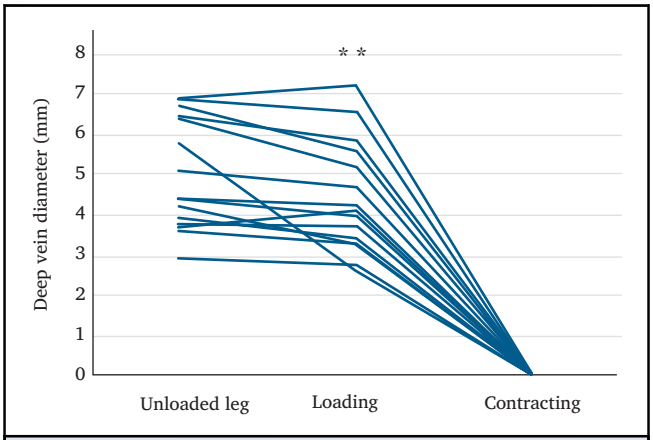

Figure 6. Deep vein diameter changes when the examined leg is not loaded, weight equally distributed on both legs (loading), and when weight is transferred to the examined leg (contracting). ** Difference between unloaded leg and loading is significant ($p < .009$).

the deep veins was 43.0 mmHg, which is much higher than any calf pressure exerted by commercially available Class 3 MCS at least in France; (2) in the standing position, the deep vein diameter reduction achieved by wearing a commercially available MCS compared with no stockings and when the body weight was evenly distributed on the two lower limbs, was not significant; (3) finally, when the calf muscles get contracted by transferring the body weight onto the examined leg, the deep veins totally collapsed. Subsequently, it is assumed that the cause of deep vein diameter reduction cannot be the external compression.

The two first trials which addressed the question did not highlight any effect of compression on vein luminal cross sectional area reduction.[4,11] The one which specifically focused on calf deep veins in 30 volunteers, 13 of whom were affected by a great saphenous vein incompetence, demonstrated that while wearing 20—30 mmHg MCSs and moving from a supine to a standing position, the maximum diameter reduction was 13% for saphenous veins and 5% for deep veins, which was not significant.[11] The absence of effect of MCSs on deep vein diameters was also clearly mathematically explained by finite element modelling, which summarised and improved any of the previous models elaborated to imitate the effect of compression on the different compartments of the leg and whose results also led to the same conclusion.[16] Previous modelling experiments did not find similar results but these did not use ultrasound as was the case in the study by Rohan et al.[16,17]

It has already been shown that diameters of calf deep veins cannot be collapsed by standard MCSs and that the reduction of the diameter starts only at a much higher pressure than that delivered to the limb by standard commercially available MCSs.[10]

In a clinical study including nine healthy patients and five patients suffering from superficial venous insufficiency, the authors showed, in 11 deep vein segments, that an external compression of 30—40 mmHg led to a moderate decrease in the posterior tibial deep vein cross sectional area.[10]

In a different approach, based on a panel of data from 12 individuals, the number of deep vein segments studied being unknown, the authors reported, that using magnetic resonance imaging (MRI), there was a reduction of deep vein diameters by compression and they argued that diameters of deep veins were reduced even with the moderate pressure of MCSs, but this was not the case for superficial veins. That led them to put forward the hypothesis of paradoxical behaviour under compression stockings.[13—15] One of these experiments showed that on 10 legs from five healthy volunteers, the interface pressure provided by the cuff pressure was restored to normal inside the muscle, the muscle pressure being measured by a needle pressure device inserted in the superficial muscle compartment.[13] A linear correlation was found between external interface pressure and intramuscular pressure and they concluded that external compression led to a narrowing of the lower leg deep veins.[13]

In contrast, Murthy et al.[18] observed a modest 3%—7% increase in intramuscular pressure in the standing position when strong external compression was applied to the leg.

An important aspect of compression therapy that has not been addressed in the literature so far is the influence of postural muscle contraction on the response of deep veins to external compression. The results of the current study provide a complementary explanation for the different findings and contribute to understanding why diameters of deep veins in the standing position are sometimes reduced, and at other times not much or not at

Table 2. Summary of deep vein diameter changes under various conditions

Diameters (mm)	Device	All	FIBV	PTV	SOLV
Initial	Hybrid cuff	4.5 ± 0.9 [34]	4.5 ± 1.1 [9]	5.2 ± 0.6 [7]	4.2 ± 0.8 [18]
Ovalization	Hybrid cuff	3.1 ± 0.8 [34]	3.1 ± 0.8 [9]	3.6 ± 0.4 [7]	2.9 ± 0.9 [18]
Unloaded leg	No	5.0 ± 1.4 [15]	3.7 ± 0.7 [3]	4.5 ± 1.1 [3]	5.6 ± 1.3 [9]
Loaded leg	No	4.4 ± 1.4 [15]	3.7 ± 0.8 [3]	3.2 ± 0.5 [3]	5.1 ± 1.4 [9]
No stockings	No	4.1 ± 0.9 [16]	4.7 ± 1.0 [5]	4.1 ± 0.8 [4]	3.5 ± 0.7 [7]
Stockings	21—35 mmHg	4.0 ± 1.0 [16]	4.6 ± 0.7 [5]	4.5 ± 0.8 [4]	3.3 ± 1.0 [7]

Data are presented as means ± standard deviation with numbers of measured venous segments in square brackets. All = all veins; FIBV = fibular vein; PTV = posterior tibial vein; SOLV = soleus vein.

all, with a mean reduction of 69% according to Downie et al.'s results.[19]

It was recently shown that calf muscle pumping can be reproduced while standing simply by weight transfer from limb to limb.[20] This manoeuvre is more efficient than the classical tiptoe method, and it is hypothesised that the results from the literature and the current results can be explained by mild muscle contractions permanently acting to maintain immobile standing posture. The deep vein diameters can be reduced by a maximum of 54%.

It is hypothesised that all the results of the previous studies can be explained by involuntary muscle contraction while standing, which is necessary to control body balance.

The collapse of veins when patients in the standing position put their weight on the leg being measured also explains the MRI results. It was clearly noted by Uhl et al.[15] that the long static MRI acquisition time reduces the number of slices. This could interfere with the ability to exactly find the patients in the same posture with and without stockings but it did not ensure that static muscle contraction would not occur to maintain a standing position. It is assumed that the MRI results on deep veins are a result of moderate calf muscle contractions and are not due to stockings.

Mathematical modelling involving advanced physical laws explains that when pressure is applied to the external part of a soft body a loss of pressure is expected at the internal part. This loss of pressure varies according to the thickness and softness of the body; this could also explain why MCSs could not directly be active at depth. Surprisingly and without any explanation, no loss of pressure was reported in recent work.[13]

Generally speaking, the lower leg venous pumping effect is measured using plethysmography and is improved by compression stockings.[21–23] The pumping function was more efficient with higher pressures on the calf than lower pressures.[22] Not all patients had their pumping function improved; 25% of them with the highest calf compression had a similar ejection fraction to the 75% of patients with no compression at all.[22] This result would favour the role of compression as a modifier of lower leg muscle activity, perhaps through a body neuronal response and not of a direct effect on veins, the muscle activity being the only parameter that was not under control in those studies.[24] Interestingly, in further works and experiments, recording muscle activity through surface electromyography would be of great help.

The study was limited by the use of a device instead of stockings of different pressure values and the small number of vein segments limiting the comparison between the different deep veins.

CONCLUSIONS

In the standing position, deep vein diameter reduction is not caused by compression stockings but may be due to isometric muscle contractions required to support the patient's body weight.

The improvement of calf pumping function due to compression has still to be clearly explained.

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CONFLICTS OF INTEREST

None.

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REFERENCES

1 Wittens C, Davies AH, Baekgaard R, Brohlom A, Cavezzi A, Chastanet S, et al. Management of chronic venous disease. Clinical practise guidelines of the European Society for Vascular Surgery (ESVS). *Eur J Vasc Endovasc Surg* 2015;**49**:678–737.
2 Partsch H. Besserung der venösen pumpleistung bei chronischer veneninsuffizienz durch compression in abhängigkeit von andruck und material. *VASA* 1984;**1**:58–64.
3 Partsch B, Meyer W, Partsch H. Improvement of ambulatory venous hypertension by narrowing of the femoral vein in congenital of absence of venous valves. *Phlebology* 1992;**7**:101–4.
4 Mayberry JC, Moneta GL, De Frang RD, Porter JM. The influence of elastic compression on deep venous hemodynamics. *J Vasc Surg* 1991;**13**:99–100.
5 Horner J, Fernandes J, Fernandes E, Nicolaides AN. Value of graduated compression stockings in deep venous insufficiency. *Br Med J* 1980;**22**:820–1.
6 Christopoulos DG, Nicolaides AN, Szendro G. Air-plethysmography and the effect of elastic compression on venous hemodynamics of the leg. *J Vasc Surg* 1987;**5**:148–59.
7 Somerville JJF, Brow GO, Byrne PJ, Quill RD, Fegan WG. The effect of elastic stockings on superficial venous pressures in patients with venous insufficiency. *Br J Surg* 1974;**61**:979–81.
8 Partsch H. Mechanism and effects of compression therapy. In: *The vein book*. London: Elsevier; 2007. p. 103–9.
9 Partsch H. Compression therapy: clinical and experimental evidence. *Ann Vasc Dis* 2012;**5**:416–22.
10 Partsch B, Partsch H. Calf compression pressure required to achieve venous closure from supine to standing positions. *J Vasc Surg* 2005;**42**:734–8.
11 Lord RSA, Hamilton D. Graduated compression stockings (20–30 mmHg) do not compress leg veins in the standing position. *ANZ J Surg* 2004;**74**:581–5.
12 Jeanneret C, Karatolios K, von Planta I. Impact of compression stockings on calf-vein diameters and on quality of life parameters in subjects with painful legs. *VASA* 2014;**43**:268–77.
13 Uhl JF, Begnini JP, Cornu-Thénard A, Fournier J, Blin E. Relationship between medical compression and intramuscular pressure as an explanation of a compression paradox. *Phlebology* 2015;**30**:331–8.

14 Partsch H, Mosti G, Mosti F. Narrowing of leg veins under compression demonstrated by magnetic resonance imaging (MRI). *Int Angiol* 2010;**29**:408–10.
15 Uhl J-F. 3D multisclice CT to demonstrate the effects of compression therapy. *Int Angiol* 2010;**29**:411–5.
16 Rohan CP, Badel P, Lun B, Rastel D, Avril S. Prediction of the biomechanical effects of compression therapy on deep veins using finite element modelling. *Ann Biomech Eng* 2015;**43**:314–24.
17 Dai G, Gertler JP, Kamm RD. The effects of external compression on venous blood flow and tissue deformation in the lower leg. *J Biomech Eng* 1999;**121**:557–64.
18 Murthy G, Ballard RE, Breit GA, Watenpaugh DE, Hargens AR. Intramuscular pressures beneath elastic and inelastic leggings. *Ann Vasc Surg* 1994;**8**:543–8.
19 Downie SP, Raynor SM, Firmin DN, Wood NB, Thom SA, Hughes AD, et al. Effects of elastic compression stockings on wall shear stress in deep and superficial veins of the calf. *Am J Physiol Heart Circ Physiol* 2008;**294**:2112–20.
20 Lattimer CR, Franceschi C, Kalodiki E. Optimizing calf muscle pump function. *Phlebology* 2018;**33**:353–60.
21 Ibegbuna V, Delis KT, Nicolaides AN, Aina O. Effect of elastic compression stockings on venous hemodynamics during walking. *J Vasc Surg* 2003;**37**:420–5.
22 Mosti G, Partsch H. Improvement of venous pumping function by double progressive compression stockings: higher pressure over the calf is more important than a graduated pressure profile. *Eur J Vasc Endovasc Surg* 2014;**47**:545–9.
23 Williams KJ, Ayekoloye O, Moore HM, Davies AH. The calf muscle pump revisited. *J Vasc Surg Venous Lymphat Disord* 2014;**2**:329–34.
24 Narracott AJ, John GW, Morris RJ, Woodcock JP, Hose DR, Lawford PW. A Validated model of calf compression and deep vessel collapse during external cuff inflation. *IEEE Trans Biomed Eng* 2009;**56**:273–80.