Calf compression pressure required to achieve venous closure from supine to standing positions

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Background: **Compression therapy needs to narrow the veins of patients with venous disorders to achieve a hemodynamic effect. This study investigated the external pressure necessary to narrow and occlude leg veins in different body positions.**
Methods: **In nine healthy volunteers and five patients with incompetent small saphenous veins, the diameter of the small saphenous veins and of one posterior tibial vein was measured at the mid level of the calf by duplex ultrasound scans in sitting, standing, and supine positions. A modified blood pressure cuff with an acetate window that permitted ultrasound visualization of the veins was gradually inflated, and the pressures needed to narrow or occlude the veins were recorded.**
Results: **Initial narrowing occurs with a median pressure of between 30 and 40 mm Hg in the sitting and standing positions. Complete occlusion of superficial and deep leg veins occurs with 20 to 25 mm Hg in the supine position, between 50 and 60 mm Hg in the sitting position, and at about 70 mm Hg in the standing position. The difference between sitting and standing, and between standing and supine, was statistically significant ($P < .01$ and $P < .001$, respectively).**
Conclusion: **The external pressure has to exceed the hydrostatic pressure in the vein to compress leg veins effectively. Higher external pressures than can be expected to be delivered by elastic compression stockings are required to achieve the collapse of lower-extremity veins in the upright position. (J Vasc Surg 2005;42:734-8.)**

Narrowing of leg veins is considered a basic mechanism of compression therapy. In the supine position, a reduction of vein diameter will accelerate blood flow velocity, aiding deep vein thrombosis prevention.[1] In the upright position, external compression is supposed to counteract the hydrostatic pressure. Because of gravity, higher pressures are necessary when standing than in the supine position to achieve the same effect. Accordingly, it could be demonstrated that high-pressure bandages were able to reduce ambulatory venous hypertension in patients with chronic venous insufficiency in contrast to compression stockings exerting a lower pressure.[2]

Perhaps surprisingly, few studies have attempted to determine the optimal pressure to compress leg veins in different body positions. In the following investigation, the diameters of superficial and deep veins of the lower leg were measured by duplex ultrasound scans. Narrowing and occlusion of the short saphenous vein and of one posterior tibial vein was obtained by a blood pressure cuff with a transparent acetate window for ultrasound visualization.

PATIENTS AND METHODS

Eighteen lower legs of nine healthy volunteers and five legs of patients with incompetent small saphenous veins (SSV) were investigated. Incompetence of the SSV was defined by refluxes with a duration >1 second after distal manual compression. All volunteers were C0 to C1 according to the CEAP classification. There were four women and five men aged 28 to 66 years (mean, 53.1 years). The patients with SSV incompetence were in clinical stage C6 (n = 2), C4 (n = 1), and C2 (n = 2). There were four women and one man with an age 52 to 88 years (mean, 59.4 years). All individuals were informed about the procedure and gave their consent to participate in the study.

A 17-cm-wide pneumatic blood pressure cuff with a transparent 10-cm-wide acetate window (VNUS Medical Technologies, Inc of Sunnyvale, Calif) was placed around the largest segment of the lower leg. Ultrasonic gel was applied below and above the window, and the transverse diameters of the SSV and a posterior tibial vein (PTV) were measured by using an 11-MHz linear transmitter (GE LOGIQ 400 CL, Milwaukee, Wisc).

Repeated measurements of the interface pressure of the cuff using a pressure transducer (Kikuhime, Soleddet 15, DK4180 Soro, Denmark) revealed pressure readings under the acetate window that were between 5 and 8 mm Hg higher than the values obtained from adjacent positions on the medial and lateral aspect of the leg segment. This may be explained by the smaller radius of the leg segment over the mid calf compared with the flat portions on the medial and lateral aspect of the leg and proves that the window is not a region of lower or absent compression.

The SSV was visualized by placing the window and the ultrasound probe on the dorsal aspect of the calf by using the characteristic interfascial location (Fig 1)—the "Egyptian eye sign"—as a marker. After rotating the cuff in order to place the ultrasound window and probe over the mediodorsal aspect of the leg, the PTVs and artery were found near the tibia. The vein best visualized was chosen for measurement. The duplex probe was positioned in the center of the acetate window (Fig 2), and the vein diameters were measured (Fig 3). The cuff pressures were gradually increased over a period of 30 seconds and the pressures causing initial narrowing and complete occlusion

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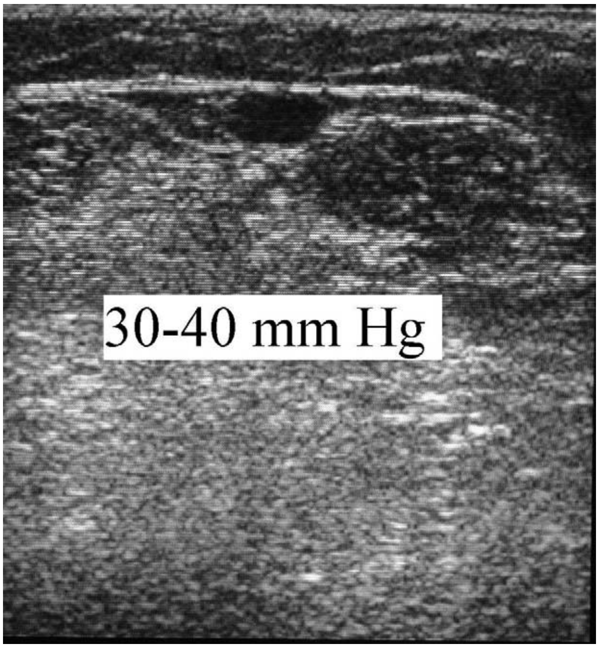


Fig 1. Initial narrowing of the small saphenous vein.

Fig 2. Test arrangement with the modified blood pressure cuff with transparent acetate window.

were noted (Fig 1, 4). The pressure values were rounded to values of 5 mm Hg increments in a similar fashion to routine blood pressure measurement.

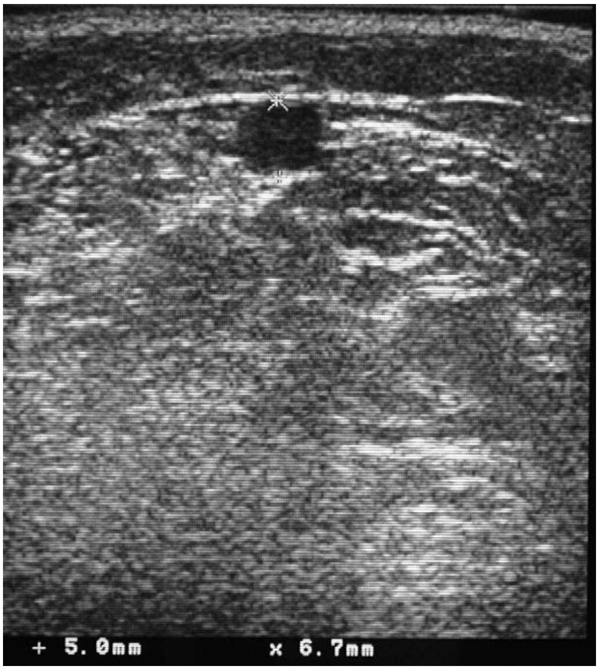


Fig 3. Duplex ultrasound of the interfascial small saphenous vein. Measurement of diameter and depth from the skin surface.

The measurements were performed in the sitting, standing, and supine positions. Not every vein could be optimally visualized in every position, so the number of measurements is not the same for each body position.

Statistics. Median values and interquartile ranges are given. The nonparametric Kruskal-Wallis test was used for comparisons. Two-sided P values of $< .05$ were considered to be statistically significant.

RESULTS

Initial narrowing. This was investigated in the sitting and standing positions but not in the supine position when veins are partly collapsed. Fig 5 shows that initial narrowing occurs with a median pressure of between 30 and 40 mm Hg in the sitting and standing positions.

Complete occlusion. As demonstrated in Fig 6, complete occlusion of superficial and deep leg veins occurred with 20 to 25 mm Hg in the supine position. In the sitting position, the median values were between 50 and 60 mm Hg and in the standing position, about 70 mm Hg. For the SSV diameter, statistically significant differences were found between sitting and standing ($P < .01$) and between the standing and supine position ($P < .001$). For the PTV, significant differences were found between sitting and supine ($P < .001$) and between standing and supine ($P < .001$). There were no statistically significant differences between the diameters of SSV and PTV in the different positions.

The patients with a larger diameter of the SSV (median diameter in the sitting position, 7.7 mm) needed a higher pressure to occlude the vein (median, 65 mm Hg) than

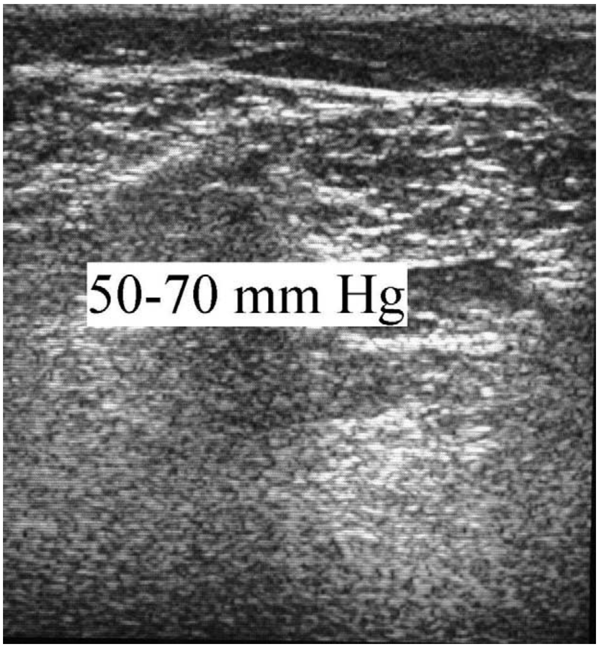
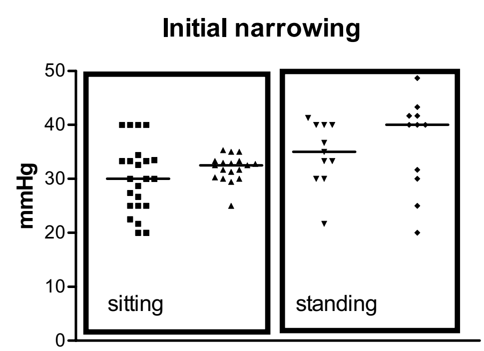


Fig 4. Complete occlusion of the small saphenous vein.



X Labels	SSV	TPV	SSV	TPV
Minimum	20.00	25.00	21.67	20.00
25% Percentile	25.00	30.15	31.67	30.84
Median	30.00	32.50	35.00	40.00
75% Percentile	33.95	33.33	40.00	42.50
Maximum	40.00	35.33	41.33	48.67

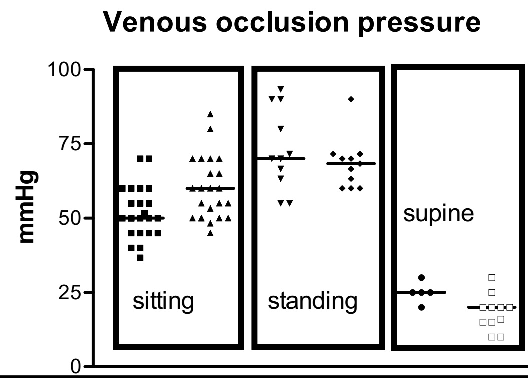
SSV – short saphenous vein

PTV – posterior tibial vein

Pressures necessary for initial narrowing of the SSV, and PTV in the sitting and standing position.

Fig 5. Pressures necessary to cause initial narrowing of the short saphenous vein *(SSV)* and the posterior tibial vein *(PTV)* in the sitting and standing positions. No significant differences were found, either for the diameters in the different body positions or for the comparison between SSV and PTV.

normals (diameter, 2.3 mm; occlusion pressure, 50 mm Hg). However, the pressure differences were not statistically significant. In the small number of investigations, no



X Labels	SSV	PTV	SSV	PTV	SSV	PTV
Minimum	36.67	45.00	55.00	60.00	20.00	10.00
25% Percentile	45.00	50.00	65.00	61.67		15.00
Median	50.00	60.00	70.00	68.33	25.00	20.00
75% Percentile	60.00	70.00	90.00	71.67		22.50
Maximum	70.00	85.00	93.33	90.00	30.00	30.00

SSV – short saphenous vein

PTV – posterior tibial vein

Pressures necessary for venous occlusion of the SSV, and PTV in the sitting, standing and supine position.

Fig 6. Pressures necessary for venous occlusion of the short saphenous vein *(SSV)* and the posterior tibial vein *(PTV)* in the sitting, standing, and supine position.

significant correlation was found between occlusion pressure and vessel diameter. No significant correlation could be found in our small cohort between the height of the individuals and the occlusion pressure during sitting and standing.

DISCUSSION

Narrowing of veins is considered to be a basic purpose of compression therapy, yet few clinical studies using visualizing methods have demonstrated that venous diameters can be reduced by external compression. Phlebographic investigations have shown a considerable reduction in the diameter of superficial and deep veins in the standing position with strong compression bandages.[3]

Duplex measurements, which have mainly been performed with thromboprophylactic stockings in the supine position, showed a decrease of venous diameter and an acceleration of venous blood flow velocity.[4,5] In the upright position, no[6] or only minimal venous narrowing[7] could be observed using class II compression stockings. In these investigations, the veins were insonated by ultrasound through the stockings, which may obscure the duplex picture, especially when stockings made from strong fabrics are used.

Using an approach similar to a previous study on thigh veins,[8] we applied a blood pressure cuff with an acetate window, which offered two advantages. First, by putting ultrasound gel above and below the window, unimpeded pictures of the superficial and deep veins can be obtained.

Second, narrowing and occlusion of the veins can be observed when a clearly defined pressure is applied in the cuff encircling the leg segment of interest.

The cuff was inflated stepwise, and changes in venous diameter were observed. The pressure that induced a visible compression of the vein in cross-section was defined as *initial narrowing pressure*. The pressure that led to a total compression of the vein was termed *venous occlusion pressure*. In addition to intravenous pressure, several other factors may influence these pressures: the distance of the vein from the skin surface, the diameter of the vein, the mechanical properties of the vein wall, the consistency of the surrounding and underlying tissue, and the circumference of the calf.

The results of our investigation agree with basic physical principles: the hydrostatic pressure in a vein represents the weight of the blood column between the measuring point and the right atrium of the heart. In the resting position, healthy individuals have the same intravenous pressure as patients with venous insufficiency. If a vein is to be totally occluded by compression, the applied external pressure has to overcome the pressure inside the vein. The values for complete venous occlusion correspond with figures found with intravenous pressure measurement in the different body positions, which is about 70 mm Hg at calf level in the standing position.[9] Less pressure is needed to obtain a narrowing of the veins.

What are the practical implications of these results? Under static conditions, a persistent occlusion of the superficial veins may be desirable after sclerotherapy or after varicose vein surgery to reduce hematoma. As can be seen from our results in the standing position, this can only be achieved by applying an external pressure of about 70 mm Hg at calf level, which is much higher than the pressure of a medical compression stocking.[6] This shortcoming can be overcome by applying pads or rolls to increase the local pressure. By locally decreasing the radius of the leg, a stocking pressure of 30 mm Hg may be sufficient to occlude the underlying vein.[10]

Persistent occlusion of deep veins is not necessarily a therapeutic goal; however, intermittent occlusions during walking may decrease ambulatory venous hypertension.[2,8] In patients with congenital absence of valves, it was demonstrated that a rigid cuff applied with 70 mm Hg on the thigh did not increase the pressure measured in a dorsal foot vein while standing. But as soon as the patient started to walk, a fall of ambulatory venous hypertension was observed due to intermittent occlusion of the incompetent veins leading to a segmentation of venous refluxes. We named this effect the *artificial valve mechanism*.[11]

A similar mechanism may explain the observation that in a group of patients with severe ambulatory venous hypertension, venous pressure during walking could be decreased significantly by short stretch bandages that exert a resting interface pressure on the distal lower leg of >50 mm Hg, but not by elastic stockings.[2] Short stretch bandages are characterized by an extensibility of the textile of <100%, whereas elastic stockings have an extensibility in the circumferential direction of >100%. In contrast to the material of highly elastic stockings, which gives way during walking, short stretch material may exert systolic pressure peaks during walking that are 20 to 30 mm Hg higher than the resting pressure in the upright position. In a patient with ambulatory venous hypertension, these pressure peaks may, for short moments of the walking cycle, override the elevated intravenous pressure fluctuations and lead to an intermittent shortening of refluxes. There is a more pronounced efficacy of short stretch, compared with long stretch material applied with the same pressure, to counteract deep venous distension. This could be demonstrated in a study on patients with deep venous refluxes using air plethysmography (APG), which showed venous volume and venous filling index to be significantly more reduced with short stretch than with long stretch material.[12]

The data presented on narrowing and occlusion of the superficial and deep veins may explain some of the discrepancies in the literature concerning the efficacy of external compression on the disturbed venous pumping function in patients with chronic venous insufficiency. Most studies that use peripheral venous pressure measurements were performed with compression stockings and could not find an improvement of ambulatory venous hypertension.[13,14] This is not surprising, since the pressure of stockings in the upright position is not high enough to counteract the pressure in the deep veins.

On the other hand, many plethysmographic investigations could demonstrate a beneficial effect of compression stockings on the venous pumping function.[14-18] Higher compression pressure led to a more pronounced improvement of expelled volume measured by foot volumetry,[16,17] but light compression stockings were also demonstrated to have a positive effect on the venous pump.[18] This may be explained by the fact that a minimal reduction of the venous diameter [7] will already lead to an overproportional reduction of the venous volume. Assuming a circular cross-section of a vein in the upright position, a narrowing from a diameter of 4.5 mm to 4.0 mm (–11%) will lead to a reduction of the area and hence of the volume by 22%. This is a dimension that can easily be measured by plethysmography. Furthermore, even light stockings have a beneficial effect on the relief of symptoms,[19] the microcirculation of the skin,[20] and on preventing and reducing edema,[21] effects that are beyond the scope of our investigation.

CONCLUSION

In the upright position, an external pressure of about 30 to 40 mm Hg is necessary to narrow the leg veins. A complete occlusion of the leg veins occurs with a pressure of 20 to 25 mm Hg in the supine position, with 50 to 60 mm Hg in the sitting position, and with about 70 mm Hg in the standing position.

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