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Relevance of stiffness of compression material on venous hemodynamics and edema

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Abstract

Elastic and inelastic stockings or bandages may provide the same degree of compression pressure in the resting supine position but inelastic material provides much greater compression pressure in the standing or working position. For elastic compression to have the same effect in the standing or exercising state would require a degree of compression in the resting position that would be intolerable. Studies have shown that this applies to reduction of reflux and improved venous pumping although both appear to have a similar effect for reducing edema.

Introduction

Stiffness and its importance on venous disease

Venous reflux, obstruction and reduced venous pumping function from the lower leg during exercise are the main pathophysiological parameters of venous disease.[1] Compression therapy can improve hemodynamic impairment. In particular compression has been proven effective in reducing venous volume, reflux, venous pumping function, edema and, consequently, ambulatory venous hypertension.[2-8] Compression may be applied to the leg by different materials: elastic stockings, elastic and inelastic bandages, and/or velcro-band-devices. The main differences between these materials are the exerted pressure and the elastic properties which can influence their hemodynamic effects. The resting pressure produced by a stocking rarely exceeds 40 mmHg[9] while the resting pressure exerted by a bandage depends mainly on the strength of application. When applied by means of inelastic bandages, which must be applied under full stretch, or of velcro band devices which are completely inelastic and inextensible, the exerted pressure is usually higher than 60 mmHg. Nevertheless, the pressure increase when moving from the resting supine to the standing position represents the main difference between elastic and inelastic material, even more important than resting pressure. The pressure increase by standing characterizes the stiffness of the material[9] and can be measured *in vivo*[10] just by subtracting supine from standing pressure. This difference has been termed static stiffness index (SSI) and the cut off in distinguishing elastic from inelastic material is 10.[11,12] Elastic material gives way to the muscle volume increase during muscle contraction achieving a pressure increase in the standing position only slightly higher than supine resting pressure and always lower than 10 (Figure 1).

Inelastic material doesn't give way to the muscle expansion and the exerted pressure will rise significantly; SSI will always be higher than 10. Other parameters of stiffness are the maximal working pressure, the pressure peaks and pressure amplitudes during walking (the difference between systolic and diastolic pressure).[13] When inelastic material is correctly applied with full stretch exerting a pressure of 50-60 mmHg in supine position, the significant pressure increase to 70-90 mmHg with standing will produce a significant vein narrowing or occlusion (Figure 2). Also elastic material could exert this very strong pressure and narrow or occlude the veins but, due to its elastic characteristics, it must be applied with similar strong pressure even at rest which will make the bandage painful and intolerable (Figure 3).[14] Narrowing/occlusion of veins by external compression devices is a prerequisite for their hemodynamic efficacy and can be observed with phlebography, Duplex ultrasound or magnetic resonance imaging. The amount of narrowing depends on the body position and the range of compression pressure. In the supine position a pressure of about 20 mmHg is able to narrow the veins while in the upright position, a pressure range of 70-80 mmHg will be necessary to counteract the standing intravenous pressure and to narrow up to near occlusion of the vein lumen.[15,16] Similar vein narrowing may occur while walking with inelastic materials that produces pressure peaks which overcome the intravenous pressure with every step and leads to an intermittent narrowing of the veins[15] thus restoring a kind of artificial valve mechanism.[17] Elastic material or elastic stockings cannot achieve similar results because in order for the compression to be tolerable the exerted pressure range can never exceed 50 mmHg. This degree of compression can slightly influence the venous diameter but certainly cannot produce significant vein narrowing.[18]

Relevance of stiffness on reflux and venous pumping function in venous disease

Effect on reflux

Reflux has been shown to be abolished both in patients with post-thrombotic syndrome[19] and severe superficial venous incompetence[20] by using different methods that produce similar results. In the first study,[19] the authors used air-plethysmography and were able to show a progressive reduction up to the abolishment of venous reflux by increasing the pressure of compression devices. At every pressure range inelastic material was able to reduce reflux more than elastic material. Only with very strong pressure of 60 mmHg does elastic and inelastic material provide similar result.

In patients with severe reflux of the great saphenous vein[20] similar results could be demonstrated using Duplex ultrasound: increasing leg compression led to a progressive reduction of reflux, with inelastic always more effective than elastic material.

Reflux reduction up to abolition is due to external pressure which progressively reduces the venous reservoir of the lower leg. The superiority of inelastic compared with elastic material can be explained by higher standing pressure exerted by inelastic material starting from the same supine pressure of 20 or 40 mmHg. This produces a more pronounced narrowing of leg veins, a greater reduction of their reservoir capacity leading to a greater decrease of venous reflux.

A very high pressure will occlude the leg veins irrespective of the elastic properties of materials used; therefore venous reflux is blocked by both elastic and inelastic devices.

Nevertheless it is necessary to take into account that elastic material applied with this strong pressure can be used only for the short period of time of a laboratory test but not in clinical practice because such pressure is barely tolerated by patients.[14,20]

In conclusion reflux abolition depends only on the standing pressure necessary to narrow the veins but it is only theoretically independent from the elastic properties of the compression material: elastic material can produce a pressure strong enough to narrow the vein diameter but this pressure will be painful and impossible to use in the clinical practice.

Effect on venous pumping function

Effects of compression on venous pumping function maybe demonstrated by different plethysmographic techniques, such as foot volumetry, air plethysmography or strain gauge plethysmography.[8,19,21-28]

With this method we could demonstrate that the ejection fraction (EF) from the lower leg is reduced in patients with chronic venous insufficiency and that it can be improved by external compression.[28] Inelastic compression material is able to increase EF from the lower leg and restore normal venous pumping function. The increased EF achieved by inelastic is significantly higher than by elastic material applied with the same pressure. Elastic material never restores the normal function even if applied with high stretch producing a very strong pressure higher than 60 mmHg. Therefore not only pressure but also elastic properties of the compression devices play an important role in increasing venous pumping function. In particular the difference between systolic and diastolic pressure during walking (the so called massaging effect) seems to play a deciding role squeezing blood from the leg. The significant correlation between ejection fraction and sub-bandage pressure during standing and walking and between ejection fraction, static stiffness index and walking pressure amplitudes confirm the hemodynamic superiority of inelastic material.[29]

Furthermore inelastic material has been shown to be effective even when applied with a low pressure of 20-30 mmHg, (in a range where elastic stocking are unable to increase the ejection fraction) and demonstrated a positive correlation with an increasing application pressure.[30]

Finally inelastic materials are claimed to lose effectiveness as they lose pressure overtime. It was proved that this material is able to maintain its effectiveness over time (one week) even despite significant pressure loss.[31]

Edema

Edema develops because of a complex interaction that involves the permeability of the capillary wall and the hydrostatic and oncotic pressure gradients that exist between the blood vessels and the tissues.[32] As almost all interstitial fluid is removed by the lymphatic circulation,[33] edema will form when net capillary filtration exceeds lymphatic drainage capacity. Compression counteracts edema formation by increasing the tissue pressure[34] and lymphatic drainage in the initial stage of lymphatic damage.[35]

Edema is always reduced by compression and the beneficial effect of compression on edema is so clear that only relatively few studies were performed to investigate this effect. Edema is effectively treated by inelastic material applied with very strong pressure and by elastic stockings of moderate pressure (in the range of 23-32 mmHg).[36] The inelastic bandage seems to be slightly more effective without statistical significance.

If elastic and inelastic materials are equally effective in treating edema we could conclude that, so far, stiffness does not seem to play a role in treating leg edema.

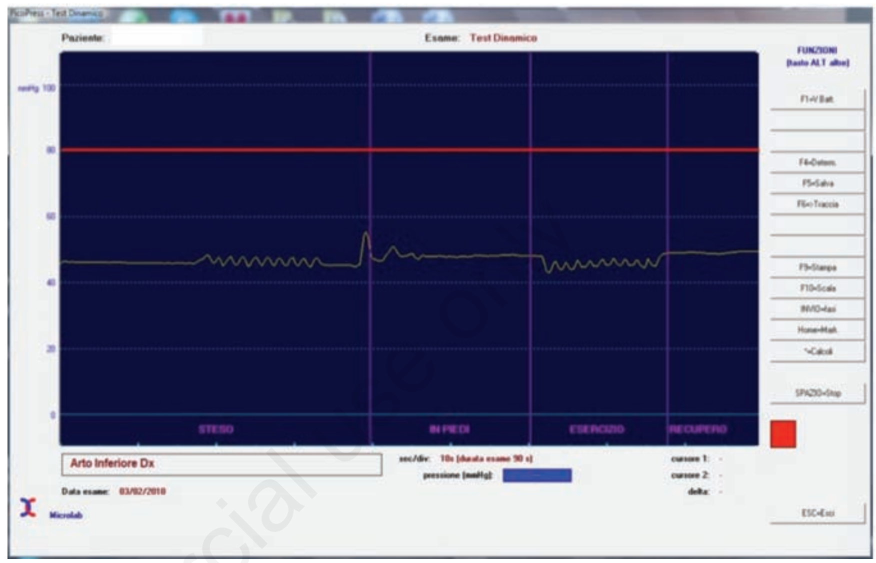

Figure 1. Interface pressure of an elastic compression device applied with 50% stretch and 50% overlapping of each layer. The exerted pressure always (during dorsiflexion in the supine position, standing, walking in place) remains well below the intravenous pressure (red line) which would be necessary to compress or occlude the veins.

Figure 2. Interface pressure of an inelastic compression device applied with full stretch and 50% overlapping of each layer. The exerted pressure always (during dorsiflexion in the supine position, standing, walking in place) overcomes the intravenous pressure (red line) narrowing/occluding the veins thus restoring a kind of valve mechanism.

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Conclusions

There is clear evidence that compression exerted by inelastic materials with high stiffness are able to achieve a very strong pressure starting by low and comfortable pressure at rest. This strong pressure can narrow and even occlude the venous system. This leads to a reduction or even abolition of venous reflux and an improvement or normalization of the venous pumping function. When the supine resting position is resumed the compression pressure is lower and comfortable for the patient, but still effective when ambulation is resumed.

Elastic materials with low stiffness are unable to get strong pressure during standing and ambulation and are much less effective than inelastic with a statistically significant difference. Stiffness plays a deciding role in the hemodynamic effects of compression.

The effect of stiffness in reducing leg edema doesn't seem very relevant so far.

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