Compression and Venous Surgery for Venous Leg Ulcers

Giovanni Mosti, MD

KEYWORDS

• Compression therapy • Elastic compression • Inelastic compression • Venous reflux • Venous pumping function • Venous surgery

KEY POINTS

- Randomized controlled studies comparing surgery and compression point out that surgery and compression have similar effectiveness in producing ulcer healing but surgery is more effective in preventing recurrence.
- There is evidence that compression is better than no compression, compression with strong pressure is better than compression with mild to moderate pressure, and compression exerted by multi-component devices is better than compression by mono-component devices.
- Elastic stockings exerting the highest pressure that can be tolerated by the patient must be used after ulcer healing to prevent recurrence.

INTRODUCTION

In more than 70% of patients,[1,2] leg ulcers are caused by venous diseases, such as superficial or deep venous insufficiency and deep vein obstruction (**Fig. 1**). Venous reflux and reduced venous pumping function result in ambulatory venous hypertension (AVH).

The hydrostatic venous pressure in the lower leg in the standing position is about 70 to 80 mm Hg both in healthy individuals and in patients with venous disease, because it depends on the pressure exerted by the column of blood from the right heart to the ankle.

In the normal individual this pressure decreases significantly during active movement (eg, walking) because of venous pumping and the valvular function that fragments the blood column and reduces hydrostatic venous pressure.[3] In patients with venous insufficiency or obstruction, pressure decreases much less or may even increase because of reduced pumping function and valvular incompetence, and this condition is termed AVH.

The pathophysiological mechanisms leading from venous hypertension to skin changes and ulcer formation are still unclear and could be caused by varied mechanisms. Fibrin cuff formation around the microvessels, impaired exchange of gases (O_2, CO_2),[4] the entrapment of white cells[5] in the microvessels causing skin necrosis, and the inhibition of growth factors[6] causing stagnation of the healing process are responsible for skin breakdown and delayed healing.

In the treatment of venous ulcers, the main aim is to counteract AVH, the most important cause of the skin damage. This is done by compression therapy, by elevating the leg, by walking, by the abolition of reflux by means of surgery (including ablation of superficial incompetent veins or perforator veins, catheter dilatation, and stenting or valve reconstruction of deep veins), or by more conservative methods, (endovascular procedures, such as laser therapy, radiofrequency ablation, foam sclerotherapy, or hemodynamic correction of venous insufficiency).

The author declares no conflict of interest.
Angiology Department, Clinica MD Barbantini, Via del Calcio 2, 5510 Lucca, Italy
E-mail address: jmosti@tin.it

Clin Plastic Surg 39 (2012) 269–280
doi:10.1016/j.cps.2012.04.004

Fig. 1. Venous ulcers are typically located at the medial aspect of the leg in the supramalleolar area. Their size and ulcer bed condition are variable depending on ulcer duration and treatment. The periwound skin can be brown colored and is usually hard because of dermatosclerosis typical of venous insufficiency. Scaling is another typical feature of venous ulcers. Edema is present every time the ulcer is not treated by compression.

Compression therapy is able to narrow or occlude the leg veins[7] by applying appropriate external pressure to induce a valvular mechanism that reduces venous reflux[8,9] and increases the calf pumping function.[10]

The appropriate timing for compression and venous surgery and the choice of the compression most useful for the healing of ulcers, remain unclear (**Box 1**).

COMPRESSION OR VEIN SURGERY FOR ULCER HEALING

Several uncontrolled and nonrandomized studies have shown the beneficial effect of surgical procedures on venous ulcer healing.

Great saphenous vein crossectomy and stripping are claimed to improve venous function and heal leg venous ulcers without compression bandaging, if the deep veins are normal. Compression is always necessary when a deep venous insufficiency coexists.[11,12]

Perforating vein interruption, sometimes associated with great saphenous vein stripping, has been performed to promote ulcer healing.[13–17] This procedure is reported to result in rapid ulcer healing, improvement in quality of life, and significant reduction of ulcer recurrence. Studies[13–17] conclude that "nihilism has no place in the management of venous disease in the 21st century",[14] that "surgery is indicated before an ulcer is intractable to treatment,"[14] and that "standard surgical methods can be applied for the therapy of venous leg ulcers at any stage."[17]

However, 2 different meta-analyses on compression therapy demonstrated significant effectiveness in ulcer healing.[18,19]

A prospective but not randomized study showed that, compared with compression, great saphenous vein surgery did not deliver better results in the ulcer healing rate; although a lower recurrence rate at 1–, 2–, and 3 years[20] was reported.

In controlled and randomized studies[21–23] the conclusions were similar[22]:

- Chronic venous leg ulceration was managed by compression treatment, elevation of the leg, and exercise
- Addition of ablative superficial venous surgery did not affect ulcer healing, but reduced ulcer recurrence.

In one study, the treatment of venous insufficiency by hemodynamic surgery was more effective than compression, both in healing and lowering the recurrence rate.[24]

In conclusion, there is almost general agreement that compression and surgery are equally effective in producing ulcer healing and improving quality of life; surgery is more effective than compression only in preventing ulcer recurrence.[25]

Endovascular procedures showed a beneficial effect in the ulcer healing process, in uncontrolled nonrandomized studies. However, no comparison with traditional surgery or compression proved the greater effectiveness of these procedures.[26–29]

Foam sclerotherapy was also used to speed the healing process in venous leg ulcers.[30–32] Foam in adjunct to compression, proved to be effective and demonstrated outcomes similar to surgery.[30,31] It seemed to accelerate the healing process.[32] Because foam sclerotherapy is almost always associated with compression therapy, studies comparing these 2 methods in ulcer healing do not exist (**Box 2**).

Box 1
Initial approach to leg ulcers

- Leg ulcers are frequently (in more than 70% of cases) caused by venous disease causing AVH.
- The first step to promote ulcer healing is to counteract AVH.
- This is done conservatively by compression therapy, by elevating the leg, by walking, or by ablating the vein by means of surgery, endovascular procedures, and foam sclerotherapy.

Box 2
Compression or vein surgery for ulcer healing

- Several uncontrolled and nonrandomized studies showed the beneficial effect of surgical procedures, such as great saphenous vein crossectomy and stripping and/or perforating vein interruption, on venous ulcer healing.
- Compared with compression, venous surgery did not reveal better results in the ulcer healing rate, but did reveal a lower recurrence rate at 1–, 2–, and 3 years.
- Uncontrolled, nonrandomized studies showed beneficial effect for endovascular procedures (laser and radiofrequency) and foam sclerotherapy in the ulcer healing process. Controlled randomized studies comparing these techniques with compression do not exist.
- There is an almost general agreement that compression and surgery are equally effective in ulcer healing and improving the quality of life; surgery is more effective than compression only in preventing ulcer recurrence.

CHOICE OF COMPRESSION IN THE TREATMENT OF ULCERS

The prerequisite for the effectiveness of compression on venous hemodynamics is a significant narrowing of the veins with short phases of intermittent occlusion during walking to prevent venous reflux, increase the venous ejection fraction and reduce AVH.

To narrow or occlude the venous system, the compression pressure must be higher than the intravenous pressure. This depends on the body position because venous pressure varies in different body positions. It has been shown that it is possible to narrow or occlude the veins with an external pressure of 20 mm Hg in the supine position, 50 mm Hg in the sitting position, and 70 mm Hg in the standing position.[33] It was also demonstrated that in the sitting position a pressure of 40 mm Hg was enough to narrow (but not occlude) the calf veins; but when the patient was asked to do foot dorsiflexions with an inelastic cuff, the pressure increased to 60 mm Hg, resulting in vein occlusion. These data were confirmed by magnetic resonance imaging studies, which showed that in the standing position, a pressure of 40 mm Hg was not able to occlude the veins, that were only completely occluded with a pressure of 80 mm Hg (**Fig. 2**).[7]

In conclusion standing venous pressure can be modified by an external compression pressure higher than 60 mm Hg (defined as very strong in a recent consensus paper).[34]

Compression materials are classified into elastic and inelastic categories. Both categories exert pressure on the leg that depends on the stretch applied to the bandage, the number of turns in the bandage, and the radius of the leg segment (Laplace law).[35]

An intelligent compression system should exert a very strong pressure in the standing position and a low and comfortable resting pressure in the supine position. It should have a large difference between standing and resting pressure. This difference has been termed Static Stiffness

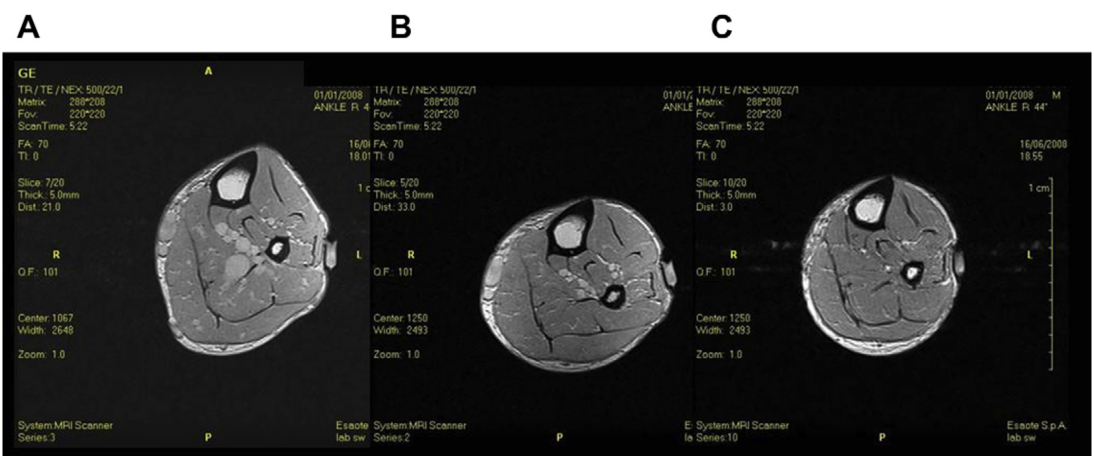


Fig. 2. In the standing position the superficial and deep leg veins are significantly dilated (*A*). An elastic stocking exerting a standing position of 38 mm Hg has no effect on the superficial veins whereas it occludes the muscle veins (*B*); an inelastic bandage exerting a pressure of 81 mm Hg occludes both superficial and deep veins (*C*).

Index (SSI) and it is one of the most important indicators of the stiffness of the bandage.[36,37] Elastic material gives way to muscle expansion that results in a very low difference between the resting pressure and the pressure in standing position or during functional activities. For elastic material, the SSI is usually less than 10 mm Hg. During muscular activity, the difference between systolic and diastolic pressure termed walking pressure amplitude (WPA), another indicator of the stiffness of the bandage, is very low.

In addition elastic material tends to return to its original length when extended and its return power is directly related to the stretch applied to the bandage (squeezing effect). As a consequence, in order to produce the strong standing pressure necessary to counteract AVH, an elastic bandage must be applied at full stretch. This application method exerts a very strong pressure also in the supine position (**Fig. 3**). The resulting bandage will be painful and intolerable to the patient and should be avoided in the clinical setting.

An elastic bandage should be applied at 50% of its total extensibility to avoid being painful. In this condition the supine pressure is not higher than 40 to 45 mm Hg, resulting in a standing pressure not higher than 45 to 50 mm Hg, which is not enough to occlude the veins (**Fig. 4**).

An inelastic bandage, made up of a short stretch of inextensible material, exerts its effect by resisting the increase of muscle volume during muscular contraction in the upright position and during functional activities (the leg gives way) and it does not exert any elastic return effect.

Inelastic bandages are well tolerated at rest even when applied with strong initial pressure, because the leg volume reduces immediately due to the reduction of physiological oedema,

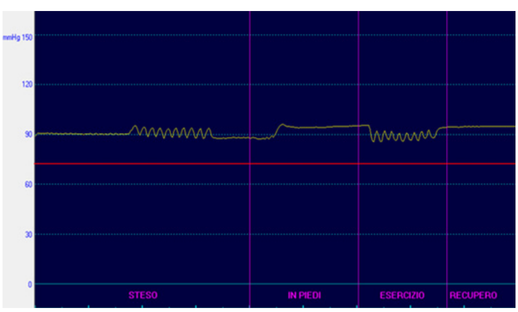


Fig. 3. Pressure curve of an elastic bandage applied with high stretch to exert a strong standing pressure. The supine pressure must be strong to guarantee a strong standing pressure. This sustained pressure can be painful.

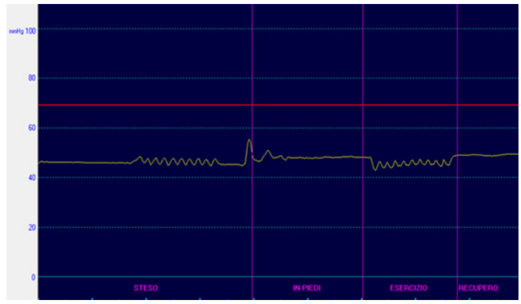


Fig. 4. Pressure curve of an elastic bandage correctly applied; the supine pressure is 43 mm Hg resulting in a standing pressure of 46 mm Hg that is not enough to occlude the veins.

resulting in a very fast pressure loss into a tolerable range. At the same time, it exerts a much higher pressure during standing (SSI always >10) and strong or very strong pressure peaks during muscular exercise, higher than 70 mm Hg, enough to intermittently occlude the veins and restore a kind of valvular mechanism starting from a fairly low and tolerable resting pressure. For these reasons the inelastic bandage system comes close to the criteria for an ideal compression system (**Box 3**, **Fig. 5**).[38]

Box 3
Choice of compression material for treatment of venous ulcers

- The pre-requisite for the effectiveness of compression on venous hemodynamics is a significant narrowing or occlusion of the vein lumen. An external pressure higher than 60 mm Hg is necessary in the standing position to occlude the veins.
- Compression materials are classified into elastic and inelastic materials.
- Elastic material is not able to achieve strong pressure in the standing position when properly applied.
- Inelastic material exerts a very high standing pressure and strong or very strong pressure peaks during muscular exercise. This pressure is able to intermittently occlude the venous lumen.
- For these reasons the inelastic bandage has a hemodynamic effect, is able to reduce AVH and should be preferred in ulcer treatment.

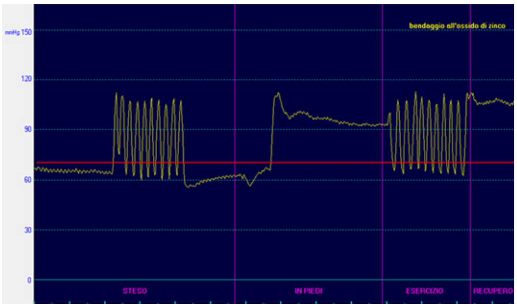


Fig. 5. Pressure curve of an inelastic bandage. It can be applied with full stretch exerting a supine pressure of 60 mm Hg, not painful because the material has no elastic return. The standing or working pressure is easily more than 70 mm Hg (the venous pressure in the leg in the standing position), restoring a kind of valvular function.

THE PRACTICAL CONSEQUENCES OF DIFFERENT COMPRESSION PRESSURE PROFILES ON VENOUS REFLUX AND IMPAIRED VENOUS PUMPING FUNCTION

Effect on Venous Reflux

Inelastic material is more effective than elastic material in reducing venous reflux in venous insufficiency. In a previous study,[9] in patients with deep venous insufficiency, the air plethysmographic parameters venous volume (VV) and venous filling index (VFI) were reduced by increasing external pressure; the reduction was significantly greater with inelastic than with elastic compression materials because the former achieved a much higher standing pressure starting from the same supine pressure. The investigators concluded that, "using the same bandage pressure, inelastic compression material is more effective at reducing deep venous refluxes than elastic bandages, in patients with venous ulcers."

In a more recent work we came to the same conclusion in patients affected by superficial venous insufficiency, by measuring the reflux volume automatically calculated by the Duplex scanner.[8]

Twelve patients were examined in the standing position by means of the Duplex scanner Esaote Mylab 60 (Esaote, Florence, Italy) with a specially designed finger-like probe (Esaote IOE323 Intraoperative, Linear Array 4–13 MHz) without any compression and after the application of different compression devices from the base of the toes to the knee. This probe finger-like 12 MHz probe was fixed with tapes at the mid-thigh, on the incompetent GSV along the longitudinal axis and its position was never changed during the experiments. The reflux was elicited by tip-toe maneuvers and measured when the patient returned to the upright relaxed position after tip-toeing. After recording the baseline measurements without any compression, the authors applied elastic and inelastic devices at the same supine pressure of 20–, 40–, and 60 mm Hg. The resulting standing pressures were significantly higher with inelastic material compared with elastic and inelastic material resulted in significantly higher reduction of venous reflux. Only when the authors applied elastic bandages with 60 mm Hg pressure, the reflux was reduced to an extent similar to inelastic compression, but this high pressure was intolerable to the patient and was used only for the short duration of the laboratory test and not in daily practice.

Effect on Venous Pumping Function

Inelastic material is more effective than elastic material in improving venous pumping function that is severely reduced in venous insufficiency. In different experiments conducted on 68 patients affected by major reflux in the great saphenous vein (CEAP C3-C5 classification), the authors measured the ejection fraction (EF) of the venous calf pump by means of strain gauge plethysmography[10,39–41] according to a previously described protocol (Poelkens and colleagues).[42] The investigation started with leg elevation to empty the veins. The minimal volume of the leg segment proximal to the bandage was registered by the strain gauge. Then the patient stood up and the volume increase of the calf segment that reflected venous filling, was measured continuously. Venous volume (VV) is defined as the difference between empty and filled veins. During a standardized exercise (20 steps on a 20 cm high stair in 20 seconds) the volume of blood that is expelled toward the heart (EV) reflects the quality of the venous pump. The proportion of EV in relation to VV expressed as a percentage, is the EF (**Box 4**).

Box 4
Effects of elastic and inelastic compression materials on the venous pumping function

- Compared with elastic material, inelastic material is more effective in reducing venous reflux and increasing the venous pumping function in patients with superficial and deep venous insufficiency.
- These effects occur independently from the pressure at application and even at a low pressure of 20 mm Hg.
- Inelastic material maintains its positive effect up to 1 week despite a significant drop in pressure over time.

After the baseline measurements without any compression, the authors applied compression with elastic and inelastic materials at the same pressures of 20–, 40–, and 60 mm Hg. After patients stood up, the pressures increased significantly with the use of inelastic material compared with elastic material, and the EF increased slightly but significantly with elastic material and was restored to the normal range only by the inelastic material (**Table 1**).[10,39]

In these series of experiments 3 findings were noteworthy:

1. Elastic material does not improve the venous pumping function at the same extent as inelastic material, not even when applied with maximal stretch to exert a standing pressure of 60 mm Hg. Despite this high pressure, the increase of EF was always modest and significantly lower than the improvement achieved by inelastic material. Furthermore, this pressure was hard for the patient to tolerate and was applied only for short durations. The EF improvement showed significant correlation with the standing pressure, the pressure differences during movement (massaging effect), and especially with the pressure peaks (working pressure).[10]
2. This significant superiority of inelastic material was also seen at a very low pressure of 20 mm Hg. At this pressure the elastic material barely showed a hemodynamic effect, whereas inelastic material increased the EF values almost into the normal range.[40] This finding has significance in the use of inelastic compression systems with reduced pressure in the treatment of mixed arterio-venous ulcers.
3. Despite a significant pressure drop, the effect of inelastic material was maintained over time. The authors measured the EF not only immediately after elastic and inelastic bandage application but also after 7 days of wearing time. They observed that the pressure of inelastic material dropped significantly, whereas with the elastic material the pressure drop was much less. Nevertheless, the stiffness and the efficacy of the inelastic bandage was maintained over time as demonstrated by high SSI and WPA (that were substantially unchanged after 1 week) and EF remained still in the normal range. The effect of elastic material, which was poor immediately after application, continued to be poor after 7 days.[41]

Table 1
Percentage improvement in EF increase with elastic and inelastic material applied with different pressures

	20 mm Hg	40 mm Hg	60 mm Hg
Elastic material	+19%	+32%	+37%
Inelastic material	+63%	+83%	+86%

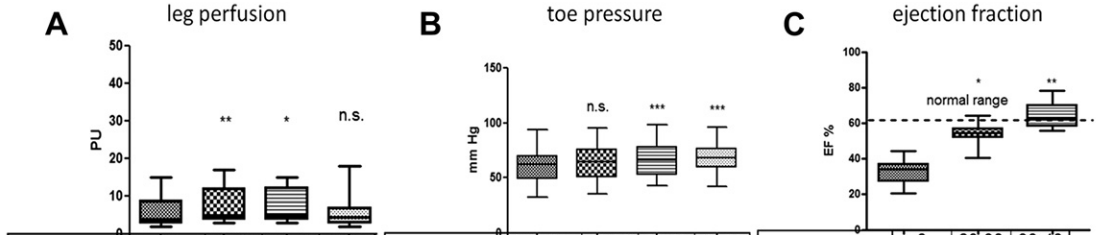
Data from Mosti G, Partsch H. Measuring venous pumping function by strain-gauge plethysmography. Int Angiol 2010;29(5):421–5.

INELASTIC COMPRESSION AND MIXED LEG ULCERS

About 15% to 20% of patients with venous leg ulcers have arterial impairments that cause retarded healing. In these patients, compression improves venous hemodynamics but could impair arterial inflow.

In 25 patients (10 men, 15 women), aged 76 years,($\pm$ 4 to 10 years) with mixed ulcers presenting a mean ankle brachial pressure index (ABPI) value of 0.57($\pm$ 0.09), the authors tried to define a range of compression pressures that did not impede arterial flow but was still able to improve the venous pumping function.[43] The skin flow in the peri-wound area and in the plantar surface of the first toe and toe pressure were assessed by means of laser doppler flowmetry. Trancutaneous oxygen pressure on the foot dorsum distal to the bandage was measured. The measurements were taken in baseline conditions and after inelastic bandages were applied with pressure ranges of 20 to 30 mm Hg, 30 to 40 mm Hg, and 40 to 50 mm Hg. Bandage pressure was continuously measured by a pneumatic device. The venous pumping function was assessed by strain gauge plethysmography measuring the EF from the lower leg in baseline conditions and after application of reduced compression.

Skin perfusion around the ulcer increased significantly with bandage pressures of 20 to 30 mm Hg and 30 to 40 mm Hg and returned to the baseline level with a bandage pressure of 40 to 50 mm Hg (**Fig. 6**A). Toe perfusion showed minor insignificant decrease with bandage pressures of 20 to 30 mm Hg and 30 to 40 mm Hg but registered significant reduction with 40 to 50 mm Hg pressure. Toe pressure increased with every pressure step, showing significant differences compared with baseline values with bandage pressures of 30 to 40 mm Hg and 40 to 50 mm Hg (see **Fig. 6**B). EF increased significantly with a bandage pressure of 20 to 30 mm Hg and was restored to the normal range with bandage pressure of 30 to 40 mm Hg (see **Fig. 6**C).



	baseline	20-30	30-40	40-50
Minimum	2.000	3.000	3.000	2.000
25% Percentile	3.000	4.000	4.000	3.000
Median	4.000	5.000	5.000	4.500
75% Percentile	8.750	12.00	12.25	7.000
Maximum	15.00	17.00	15.00	18.00

	baseline	20-30	30-40	40-50
Minimum	32.00	35.00	43.00	42.00
25% Percentile	49.00	50.00	52.25	59.00
Median	62.00	64.50	66.00	68.50
75% Percentile	70.00	75.50	78.00	76.25
Maximum	94.00	95.00	98.00	96.00

	0	20-30	30-40
Minimum	20.50	40.20	55.90
25% Percentile	27.33	51.90	58.40
Median	33.95	54.35	62.60
75% Percentile	36.80	56.80	70.28
Maximum	44.30	64.10	78.50

n.s.= not significant; *=*P*<.05; **=*P*<.01; ***=*P*<.001

Fig. 6. In mixed ulcers skin perfusion increases significantly with bandage pressures of 20–30 mm Hg and 30–40 mm Hg and start to decrease with 40–50 mm Hg (*A*). Toe pressure increases with every pressure step (*B*). EF increases significantly with a bandage pressure 20–30 mm Hg and is restored into the normal range with 30–40 mm Hg (*C*).

In conclusion, external compression up to 40 mm Hg significantly increased arterial flow, (even in patients with very low ABPI values and venous EF) and may be considered the basic treatment modality in managing patients with mixed ulceration.

In this experiment the authors avoided elastic material because elastic return power could be painful for patients with reduced arterial inflow, even when applied with low compression pressure. In addition, they took advantage of the hemodynamic superiority of inelastic bandages demonstrated in their previous studies (**Box 5**).[10]

ELASTIC OR INELASTIC BANDAGES FOR PATIENTS WITH LEG ULCERS AND RESTRICTED MOBILITY?

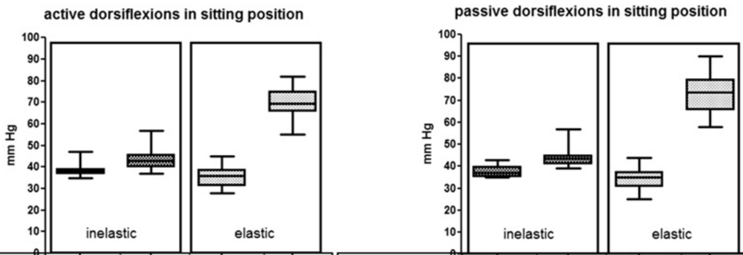
Some old textbooks claim that inelastic material only works during exercise and is therefore ineffective for patients with restricted or absent mobility of the ankle joint. If a patient is completely immobile and bedridden, a simple antiembolic stocking exerting a pressure of about 20 mm Hg is enough to narrow the veins. But if the patient is able to move some steps and sit in a chair, a pressure of 50 mm Hg is necessary to influence the vein lumen in the sitting position and 70 mm Hg in the standing position. Elastic material is not able to exert this strong or very strong pressure. Moreover simple ankle movements either active or induced by a physiotherapist, produce intermittent peaks (massaging effect), which are much higher with an inelastic bandage than with an elastic bandage (**Fig. 7**) and result in a stronger effect on the venous pumping function. Daily experience shows that wheelchair-bound patients presenting with swelling and leg ulceration benefit dramatically from inelastic bandages, which may stay on the leg for several days and nights, needing to be changed only when they become very loose.[44,45]

Box 5
Inelastic compression for mixed leg ulcers

- Inelastic material with a reduced pressure of 30 to 40 mm Hg was safely used in patients with mixed ulcerations without affecting and even improving the arterial inflow.
- Inelastic material showed a better effect on pressure amplitude and, as a consequence, on reflux and pumping function, and also in patients with reduced mobility.

Relationship between Hemodynamic Efficacy and Ulcer Healing Rate

When inelastic bandages are correctly applied and the intended pressure is achieved, the outcomes on venous ulcers can be spectacular with a healing rate close to 100%, as shown in a recent trial[46] that compared 2 inelastic bandage systems used in the treatment of venous ulcers. In this trial, both compression systems were applied with pressures higher than 40 mm Hg. Pressure was measured at bandage application to ensure that the correct pressure range was applied with both systems and also measured at bandage removal to check the bandage pressure loss. Because of the strong pressure at application and the maintenance of high SSI values over time, all the patients except one (who withdrew because of an ulcer infection) healed in both compression groups and 92 out of 99 patients healed within 3 months.



Active	inelastic diastolic	inelastic systolic	elastic diastolic	elastic systolic
Minimum	35.00	37.00	28.00	55.00
25% Percentile	37.00	40.00	31.25	66.00
Median	38.00	43.00	36.00	69.50
75% Percentile	39.00	45.75	38.75	75.00
Maximum	47.00	57.00	45.00	82.00

Passive	inelastic diastolic	inelastic systolic	elastic diastolic	elastic systolic
Minimum	35.00	39.00	25.00	58.00
25% Percentile	35.25	41.00	31.00	65.75
Median	37.00	43.50	35.00	73.50
75% Percentile	39.75	45.00	37.50	79.50
Maximum	43.00	57.00	44.00	90.00

Fig. 7. Active (*left side*) and passive (*right side*) dorsiflections in a patient with reduced mobility in sitting position. Inelastic material produces much higher pressure peaks starting from similar diastolic values both in active and passive exercise.

Many investigators have claimed the superiority of elastic material (both elastic stockings and elastic bandages) compared with inelastic material. This contradicts all the reported data showing more favourable hemodynamic effects for inelastic material.

Unfortunately the clinical studies reporting the superiority of elastic material have major flaws.

Limitations of Studies of Elastic and Inelastic Bandages

1. The pressure exerted by compression devices was almost never measured in studies comparing different compression devices, although compression pressure is considered the "dosage" of compression and the main determinant of its effect. When the compression pressure produced by a compression device is not measured, there is no information on the principal determinant of its effectiveness. Furthermore, when compression pressure is not measured, it is difficult to determine if bandages were correctly applied, if the intended pressure for a specific bandage was achieved, and if the exerted pressure is consistent in different centers or in different bandages applied by the same bandager. The absence of sub-bandage pressure measurements in older studies was caused by the lack of effective, simple, inexpensive, and reproducible measurement devices. This is no longer the case and such devices are now available.[47,48] They were used in all the author's investigations.
2. In the published articles comparing elastic and inelastic bandages,[49–51] the prototype of the elastic material was Profore® (Smith and Nephew, UK), which works like an inelastic bandage. Profore® is made up of 4 different mainly elastic components but the overlapping of different textiles changes the elastic properties of the final bandage, especially because of the friction between the layers. This may explain why Profore® has an SSI that is close to the Rosidal sys® (Lohmann Rausscher, Germany) bandage that is mainly composed of inelastic textiles.[52]
3. In effect, all the studies report comparison between 2 different inelastic bandages and not between an elastic and an inelastic bandage.It is possible that the "different" but actually very similar compression devices had similar results.
4. The so-called elastic material may have delivered the best outcomes because of the better expertise of the bandagers applying this compression device (**Box 6**).

COMPARISON BETWEEN ELASTIC STOCKINGS AND INELASTIC BANDAGES

A recent meta-analysis reported that "leg compression with stockings is clearly better than compression with bandages, has a positive impact on pain, and is easier to use."[53] Unfortunately this meta-analysis contains errors in the reporting of some quoted studies (**Box 7**).

1. The elastic stockings used for comparison were actually elastic kits or tubular devices exerting a high supine pressure of 40 mm Hg or more and higher stiffness (although always in the recommended range of stiffness for elastic material), because of the friction between 2 components.[54–58]
2. Neither sub-bandage pressure measurements nor bandagers' skills in applying the inelastic bandage were reported. Without pressure

Box 6
Comparison of elastic and inelastic bandages on venous ulcer outcomes

- When correctly applied and the intended pressure achieved, the outcomes of inelastic bandages on venous ulcers are extremely positive (healing rate close to 100%).
- Studies claiming the superiority of elastic material (both elastic stockings and elastic bandages) compared with inelastic materials were almost always performed without measuring the pressure of the compression devices.
- Pressure represents the "dosage" of compression and when not measured, make the results of these studies unreliable.
- The bandage almost always used as the elastic comparision in these studies is actually inelastic.

measurements, only the pressure of elastic kits as declred by the manufacturer was available and there was no information on the pressure of the inelastic bandage, which can be extremely variable[59–61] because it is wholly dependent on the stretch applied to the bandage by the bandager. In one study, the patients were even allowed to remove the bandage in the evening and re-apply it on the following morning.[55] The variability of bandage pressure is high even when the bandages are applied by expert doctors and nurses and it is conceivable that variability is even higher when patients or relatives reapply the bandage.

Box 7
Comparison of elastic stockings with inelastic materials

- A meta-analysis reporting the comparison between elastic stockings and inelastic material has some errors.
- The elastic stockings taken into consideration for comparison were actually elastic kits or tubular devices exerting a high supine pressure of 40 mm Hg or more with greater stiffness.
- Neither sub-bandage pressure measurements nor bandagers' skills in applying the inelastic bandage have been reported.
- In one study the patients or their relatives were even allowed to remove the bandage in the evening and reapply it on the following morning.
- In a few studies that measured compression pressure, it was demonstrated that the higher the pressure of the bandage, the higher was the healing rate. This conclusion is clearly in favor of bandages that, when correctly applied, exert a compression pressure definitely higher than elastic stockings or kits.
- Elastic stockings exerting the highest pressure tolerable to the patients, should be used after ulcer healing to prevent recurrence.

All these elements make it difficult to understand if the bandages were correctly applied and certainly a good elastic kit could work better than a poorly applied bandage (both elastic and inelastic). In a few studies (some of them also referenced in the meta-analysis) that measured compression pressure,[57,58,62,63] it was demonstrated that the higher the pressure applied the higher was the healing rate. This conclusion is clearly in favor of bandages that, when correctly applied, exert a compression pressure definitely higher than elastic stockings or kits.

COMPRESSION AFTER ULCER HEALING

After ulcer healing, compression must be continued to prevent ulcer recurrence. This is the best indication for elastic stockings. Because the higher the compression pressure applied the lower is the recurrence rate, the highest pressure tolerated by the patients is recommended.[64]

SUMMARY

- Treatment of leg ulcers must be based first on the correction of hemodynamic impairment. This can be done conservatively by means of compression, walking and leg elevation, or by surgical removal of venous reflux.
- To achieve the best results, compression therapy must be correctly applied. It should exert a high pressure in standing and working conditions to counteract venous hemodynamic impairment (venous reflux, reduced venous pumping function), starting from a lower and tolerable supine pressure.
- Venous surgery has been shown to be as effective as compression therapy in promoting ulcer healing and improving quality of life. Surgery is more effective than compression in preventing ulcer recurrence. Many surgical procedures have been proposed, from crossectomy and stripping to perforator interruption and endovascular procedures (laser, radiofrequency). More conservative procedures to abolish venous

reflux (foam sclerotherapy, conservative hemodynamic treatment) have also been proposed in ulcer treatment.
- There is convincing evidence that inelastic compression material is more effective than elastic compression material in reducing venous reflux and in improving the venous pumping function and that it is more tolerable at rest. Inelastic material is more effective at every pressure range (mild, medium and strong) and is effective over time. It is more effective even in patients with reduced mobility and it is able to improve (rather than decrease) the sub-bandage and periwound flux in patients with arterial impairment, if applied with reduced pressure. There is proof that inelastic material, applied with the same initial pressure, is significantly more effective than elastic material in improving the hemodynamic impairment of venous insufficiency. This results in the higher effectiveness of inelastic material in promoting ulcer healing, when properly applied.
- The so-called multilayer bandages consisting of several elastic components are in the end, stiff because of the friction between the layers, so that the designation "elastic" is inadequate. The "elastic" bandage very often considered as the material for comparison in these studies is actually an inelastic bandage, making the comparison inconsistent with the aim of the studies.
- Clear clinical evidence confirming the superiority of inelastic bandages compared with elastic bandages in promoting ulcer healing is lacking because of major flaws reported in the clinical studies.
- A multicentre randomized study, with experienced bandagers and sub-bandage pressure measurements to ensure the correct application of the bandage and achieve the intended pressure range, is highly recommended.

REFERENCES

1. Adam DJ, Naik J, Hartshorne T, et al. The diagnosis and management of 689 chronic leg ulcers in a single-visit assessment clinic. Eur J Vasc Endovasc Surg 2003;25(5):462–8.
2. Baker SR, Stacey MC, Singh G, et al. Aetiology of chronic leg ulcers. Eur J Vasc Surg 1992;6(3): 245–51.
3. Arnoldi CC. Venous pressure in the leg of healthy human subjects at rest and during muscular exercise in the nearly erect position. Acta Chir Scand 1965;130(6):570–83.
4. Browse NL, Burnand KG. The cause of venous ulceration. Lancet 1982;2(8292):243–5.
5. Coleridge Smith PD, Thomas P, Scurr JH, et al. Causes of venous ulceration: a new hypothesis. Br Med J (Clin Res Ed) 1988;296(6638):1726–7.
6. Falanga V, Eaglstein WH. The "trap" hypothesis of venous ulceration. Lancet 1993;341(8851):1006–8.
7. Partsch H, Mosti G, Mosti F. Narrowing of leg veins under compression demonstrated by magnetic resonance imaging (MRI). Int Angiol 2010;29(5):408–10.
8. Mosti G, Partsch H. Duplex scanning to evaluate the effect of compression on venous reflux. Int Angiol 2010;29(5):416–20.
9. Partsch H, Menzinger G, Mostbeck A. Inelastic leg compression is more effective to reduce deep venous refluxes than elastic bandages. Dermatol Surg 1999;25(9):695–700.
10. 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.
11. Scriven JM, Hartshorne T, Thrush AJ, et al. Role of saphenous vein surgery in the treatment of venous ulceration. Br J Surg 1998;85(6):781–4.
12. Bello M, Scriven JM, Hartshorne T, et al. Role of saphenous vein surgery in the treatment of venous ulceration. Br J Surg 1999;86(6):755–9.
13. Gloviczki P, Bergan JJ, Rhodes JM, et al. Mid-term results of endoscopic perforator vein interruption for chronic venous insufficiency: lessons learned from the North American subfascial endoscopic perforator surgery registry. The North American Study Group. J Vasc Surg 1999;29(3):489–502.
14. Iafrati MD, Pare GJ, O'Donnell TF, et al. Is the nihilistic approach to surgical reduction of superficial and perforator vein incompetence for venous ulcer justified? J Vasc Surg 2002;36(6):1167–74.
15. Roka F, Binder M, Bohler-Sommeregger K. Mid-term recurrence rate of incompetent perforating veins after combined superficial vein surgery and subfascial endoscopic perforating vein surgery. J Vasc Surg 2006;44(2):359–63.
16. Nelzén O, Fransson I. True long-term healing and recurrence of venous leg ulcers following SEPS combined with superficial venous surgery: a prospective study. Eur J Vasc Endovasc Surg 2007;34(5): 605–12.
17. Obermayer A, Göstl K, Walli G, et al. Chronic venous leg ulcers benefit from surgery: long-term results from 173 legs. J Vasc Surg 2006;44(3):572–9.
18. Cullum N, Nelson EA, Fletcher AW, et al. Compression for venous leg ulcers. Cochrane Database Syst Rev 2001;2:CD000265.
19. Partsch H. Evidence based compression therapy. VASA 2003;32(Suppl 63):3–39.

20. Barwell JR, Taylor M, Deacon J, et al. Surgical correction of isolated superficial venous reflux reduces long-term recurrence rate in chronic venous leg ulcers. Eur J Vasc Endovasc Surg 2000;20(4):363–8.
21. Guest M, Smith JJ, Tripuraneni G, et al. Randomized clinical trial of varicose vein surgery with compression versus compression alone for the treatment of venous ulceration. Phlebology 2003;18:130–6.
22. Barwell JR, Davies CE, Deacon J, et al. Comparison of surgery and compression with compression alone in chronic venous ulceration (ESCHAR study): randomised controlled trial. Lancet 2004;363(9424):1854–9.
23. van Gent WB, Hop WC, van Praag MC, et al. Conservative versus surgical treatment of venous leg ulcers: a prospective, randomized, multicenter trial. J Vasc Surg 2006;44(3):563–71.
24. Zamboni P, Cisno C, Marchetti F, et al. Minimally invasive surgical management of primary venous ulcers vs. compression treatment: a randomised clinical trial. Eur J Vasc Endovasc Surg 2003;25(4):313–8.
25. Howard DP, Howard A, Kothari A, et al. The role of superficial venous surgery in the management of venous ulcers: a systematic review. Eur J Vasc Endovasc Surg 2008;36(4):458–65.
26. Sufian S, Lakhanpal S, Marquez J. Superficial vein ablation for the treatment of primary chronic venous ulcers. Phlebology 2011;26(7):301–6.
27. Teo TK, Tay KH, Lin SE, et al. Endovenous laser therapy in the treatment of lower-limb venous ulcers. J Vasc Interv Radiol 2010;21(5):657–62.
28. Sharif MA, Lau LL, Lee B, et al. Role of endovenous laser treatment in the management of chronic venous insufficiency. Ann Vasc Surg 2007;21(5):551–5.
29. Marrocco CJ, Atkins MD, Bohannon WT, et al. Endovenous ablation for the treatment of chronic venous insufficiency and venous ulcerations. World J Surg 2010;34(10):2299–304.
30. Pang KH, Bate GR, Darvall KA, et al. Healing and recurrence rates following ultrasound-guided foam sclerotherapy of superficial venous reflux in patients with chronic venous ulceration. Eur J Vasc Endovasc Surg 2010;40(6):790–5.
31. Darvall KA, Bate GR, Adam DJ, et al. Ultrasound-guided foam sclerotherapy for the treatment of chronic venous ulceration: a preliminary study. Eur J Vasc Endovasc Surg 2009;38(6):764–9.
32. O'Hare JL, Earnshaw JJ. Randomised clinical trial of foam sclerotherapy for patients with a venous leg ulcer. Eur J Vasc Endovasc Surg 2010;39(4):495–9.
33. Partsch B, Partsch H. Calf compression pressure required to achieve venous closure from supine to standing positions. J Vasc Surg 2005;42:734–8.
34. Partsch H, Clark M, Mosti G, et al. Classification of compression bandages: practical aspects. Dermatol Surg 2008;34:600–9.
35. Thomas S. The use of the Laplace equation in the calculation of sub-bandage pressure. EWMA J 2003;1:21–3.
36. Partsch H. The static stiffness index: a simple method to assess the elastic property of compression material in vivo. Dermatol Surg 2005;31:625–30.
37. Partsch H. The use of pressure change on standing as a surrogate measure of the stiffness of a compression bandage. Eur J Vasc Endovasc Surg 2005;30:415–21.
38. Partsch H. Compression therapy of venous ulcers. EWMA J 2006;2:16–20.
39. Mosti G, Partsch H. Measuring venous pumping function by strain-gauge plethysmography. Int Angiol 2010;29(5):421–5.
40. Mosti G, Partsch H. Is low compression pressure able to improve venous pumping function in patients with venous insufficiency? Phlebology 2010;25(3):145–50.
41. Mosti G, Partsch H. Inelastic bandages maintain their hemodynamic effectiveness over time despite significant pressure loss. J Vasc Surg 2010;52(4):925–31.
42. Poelkens F, Thijssen DH, Kersten B, et al. Counteracting venous stasis during acute lower leg immobilization. Acta Physiol (Oxf) 2006;186(2):111–8.
43. Mosti G, Iabichella ML, Partsch H. Compression therapy in mixed ulcers increases venous output and arterial perfusion. J Vasc Surg 2012;55(1):122–8.
44. Mosti G. La terapia compressiva nel paziente con lesioni trofiche degli arti inferiori immobile o con mobilità limitata. Acta Vulnologica 2009;7(4):197–205 [in Italian].
45. Partsch H. Quelle compression sur des patients immobiles: allongement court ou allongement long? Geriatrie et Gerontologie 2009;155:278–83 [in French].
46. Mosti G, Crespi A, Mattaliano V. Comparison between a new, two-component compression system with zinc paste bandages for leg ulcer healing: a prospective, multicenter, randomized, controlled trial monitoring sub-bandage pressures. Wounds 2011;23(5):126–34.
47. Mosti G, Rossari S. L'importanza della misurazione della pressione sottobendaggio e presentazione di un nuovo strumento di misura. Acta Vulnol 2008;6:31–6 [in Italian].
48. Partsch H, Mosti G. Comparison of three portable instruments to measure compression pressure. Int Angiol 2010;29(5):426–30.
49. Franks PJ, Moody M, Moffatt CJ, et al. Randomised trial of cohesive short-stretch versus four-layer bandaging in the management of venous ulceration. Wound Repair Regen 2004;12:157–62.
50. Callam MJ, Harper DR, Dale JJ, et al. Lothian Forth Valley leg ulcer healing trial—part 1: elastic versus

non-elastic bandaging in the treatment of chronic leg ulceration. Phlebology 1992;7:136–41.
51. Duby T, Hofman D, Cameron J, et al. A randomized trial in the treatment of venous leg ulcers comparing short stretch bandages, four layer bandage system, and a long stretch-paste bandage system. Wounds 1993;5:276–9.
52. Mosti G, Mattaliano V, Partsch H. Influence of different materials in multicomponent bandages on pressure and stiffness of the final bandage. Dermatol Surg 2008;34:631–9.
53. Amsler F, Willenberg T, Blättler W. Management of venous ulcer: a meta analysis of randomized studies comparing bandages to specifically designed stockings. J Vasc Surg 2009;50:668–74.
54. Mariani F, Mattaliano V, Mosti G, et al. The treatment of venous leg ulcers with a specifically designed compression stocking kit. Phlebologie 2008;37: 191–7.
55. Junger M, Partsch H, Ramelet AA, et al. Efficacy of a ready-made tubular compression device versus short stretch bandages in the treatment of venous leg ulcers. Wounds 2004;16:313–20.
56. Jünger M, Wollina U, Kohnen R, et al. Efficacy and tolerability of an ulcer compression stocking for therapy of chronic venous ulcer compared with a below-knee compression bandage: results from a prospective, randomized, multicentre trial. Curr Med Res Opin 2004;20(10):1613–23.
57. Horakova MA, Partsch H. Compression stockings in treatment of lower leg venous ulcer. Wien Med Wochenschr 1994;144(10–11):242–9.
58. Brizzio E, Amsler F, Lun B, et al. Comparison of low-strength compression stockings with bandages for the treatment of recalcitrant venous ulcers. J Vasc Surg 2010;51:410–6.
59. Partsch H. Variability of interface pressure exerted by compression bandages and standard size compression stockings. Proceedings of 20th Annual Meeting of American Venous Forum. Charleston (SC), February 20–23, 2008.
60. Moffat C. Variability of pressure provided by sustained compression. Int Wound J 2008;5(2):259–65.
61. Keller A, Müller ML, Calow T, et al. Bandage pressure measurement and training: simple interventions to improve efficacy in compression bandaging. Int Wound J 2009;6(5):324–30.
62. Milic DJ, Zivic SS, Bogdanovic DC, et al. A randomized trial of the Tubulcus multilayer bandaging system in the treatment of extensive venous ulcers. J Vasc Surg 2007;46:750–5.
63. Milic DJ, Zivic SS, Bogdanovic DC, et al. The influence of different sub-bandage pressure values on venous leg ulcers healing when treated with compression therapy. J Vasc Surg 2010;51(3):655–61.
64. Nelson EA, Bell-Syer SE, Cullum NA. Compression for preventing recurrence of venous ulcers. Cochrane Database Syst Rev 2000;4:CD002303.