6 Use of Compression Therapy

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HISTORICAL DEVELOPMENT

The oldest known illustration of compression bandages dates back to the Neolithic Age (5000–2500 BC) (Fig. 6.1).[1] The ancient Hebrews, Egyptians, Greeks and Romans used compression therapy for treatment of wounds and ulcers, as described in the Smith Papyrus (1650–1552 BC) and in the Book of Isaiah (Isaiah 1:6), eighth century BC.[2] Hippocrates wrote about compression treatment in the fourth century BC, and this was followed by further refinements from Celsus and Virgo. Roman soldiers who marched for days at a time quickly learned that applying tight strappings to the legs reduced leg fatigue. The knowledge concerning the beneficial effects of compression was rediscovered by physicians during the Middle Ages, including Guy de Chauliac (1363), Giovanni Michele Savonarola (1440) and Fabrizio d'Aquapendente (1537–1619). They used compression bandages, plaster dressings and laced stockings made from dog leather.[3]

Ambroise Paré (1510–1590), Richard Wiseman (1622–1676), Christian Anton Theden (1714–1787) and Thomas Baynton (1797) were pioneers, especially in the treatment of leg ulcers, who recommended different kinds of compression material that were mainly inelastic. In 1885, the dermatologist Paul Unna introduced his zinc paste boot for the treatment of venous dermatitis, and in 1910 his pupil, Heinrich Fischer, recommended firmly applied 'Unna boots' for treating venous thrombosis.[3,4]

The use of elastic compression occurred with the development of elastic stockings in the mid 1800s and the discovery by Charles Goodyear in 1839 of a vulcanizing process for rubber that would increase its elasticity and durability. In 1839, John Watson, MD, reported on the usefulness of an elastic stocking in treating varicose veins in a 23-year-old woman with Klippel–Trenaunay syndrome.[5] However, these stockings, made exclusively from rubber threads, were uncomfortable. It was not until Jonathan Sparks patented a method for winding cotton and silk around the rubber threads that elastic stockings became comfortable and popular.[3]

During the late 1800s and early 1900s, technical advances in the manufacturing process led from the development of the frame-knitting to the flat-knitting method, which increased production efficiency in addition to providing a proper fit. Stockings became even more comfortable and better looking when ultra-fine rounded latex yarns became available, which permitted the construction of seamless stockings. Two-way stretch stockings were developed next, which led to easier application of the stocking. Finally, the development of synthetic elastomers in the 1960s gave rise to latex-free compression stockings. Synthetic (spandex, polyurethane and nylon) stockings are still the ideal form of material to use today because of the relative resistance to moisture from sweat and other environmental factors and also the very fine threads and stretch–contraction characteristics that lead to the production of fine stockings.

Today there are more than 200 different brands of graduated compression stockings. As a complete discussion comparing all of the available stockings is beyond the scope of this chapter, concepts are discussed that are central to all forms of compression stockings, and information is given on the more commonly used and available brands.

MECHANISM OF ACTION

EDEMA

By increasing the tissue pressure, compression works against filtration, which is the basis of both prevention and removal of edema. Occupational leg swelling in sitting and standing professions can be prevented by light compression stockings,[6] which are also able to reduce mild edema.[7,8] Reduction in intradermal edema has been measured with 20-MHz ultrasound in patients with chronic venous insufficiency (CVI) and lipodermatosclerosis.[9] Application of class I or II graduated compression stockings decreased dermal edema by 17% in 4 days with no statistical difference between the two classes of compression. It could be demonstrated that stockings with a pressure of about 20 mmHg are quite effective in reducing leg edema and that this effect can be maintained by donning a second stocking over the first.[10]

Compression may also exert beneficial effects in nonphlebologic causes of edema, such as inflammatory edema (arthritis, cellulitis), cardiac edema, dysproteinemic edema, renal edema, lymphedema and cyclic idiopathic edema.[11] A study by Arpaia et al[12] showed an improvement in the quality of life (QOL) in patients with chronic CVI who wore class I graduated compression stockings.

LYMPH DRAINAGE

Several beneficial mechanisms of compression therapy on the swollen extremity may be explained by its effects on the lymphatic system[13]:

- Reduction of capillary filtration
- Increase of capillary reabsorption
- Shift of fluid into noncompressed parts of the body

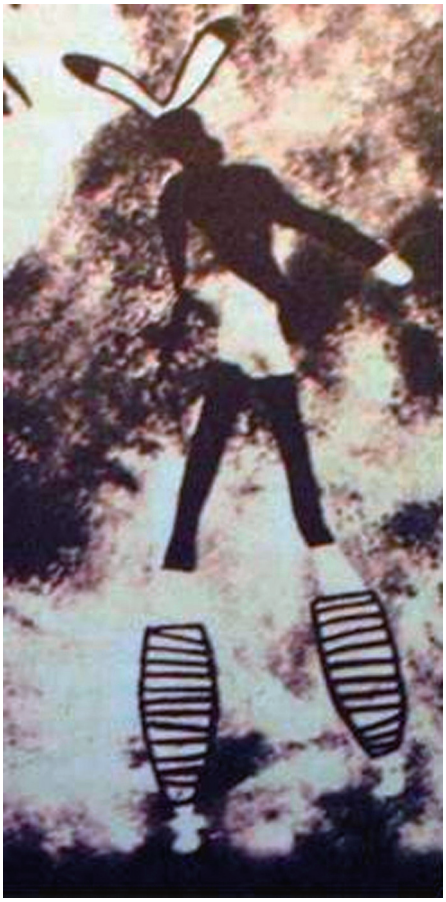

Figure 6.1 Mural paintings in the Tassili caves (Sahara), 5000–2500 BC. (From Partsch H, Rabe E, Stemmer R. Compression therapy of the extremities. Paris: Editions Phlébologiques Françaises; 1999.)

- Increase of lymphatic reabsorption and lymphatic transport
- Breakdown of fibrosclerotic tissue
- Down regulation of proinflammatory cytokines and receptors for growth factors[14]

One mechanism of central importance is the restriction of capillary filtration, which corresponds to the amount of the lymphatic load. With compression, the skin and dermal tissues are in closer contact with the superficial capillary network, which is otherwise separated by a pericapillary halo of protein-rich edema fluid.[15]

Compression removes more water than protein from the tissue, thereby increasing oncotic tissue pressure and reinforcing the need for sustained compression. Therefore, in chronic edema, success is dependent on continued compression.[16]

Compression together with movement enhances the contraction of the lymphatic system. Olszewski was able to demonstrate that both compression and exercise stimulated the movement of stagnating lymph through the lymph collector in lymphedema patients whose lymphatic trunks were filled.[17,18] This is probably one explanation for the reduction in intralymphatic hypertension obtained by complex decongestive therapy as demonstrated by Franzeck and co-workers by lymph capillary pressure measurements.[19]

Figure 6.2 Indirect lymphography by subdermal infusion of water-soluble contrast into lipodermatosclerotic skin above the medial malleolus. Before treatment (1984), irregular lymphatics with dermal backflow and extravasation can be seen. After compression therapy, with removal of edema and normalization of the skin changes (1986), normal lymph drainage is obtained. (From Partsch H. J Dermatol Surg Oncol 1991;17:799.)

Intermittent pneumatic compression enhances prefascial lymph drainage.[15] Unna boots are able to increase subfascial lymph transport, which is reduced in postthrombotic syndrome.[20] Consequent compression leads to a morphologic improvement of pathologic initial lymphatics in patients with lipodermatosclerosis, which can be demonstrated by indirect x-ray lymphography (Fig. 6.2).[21]

VENOUS SYSTEM

Depending on the exerted pressure and the body position, external compression is able to narrow or occlude superficial and deep leg veins.[22] In the supine position an external pressure of 10 to 15 mmHg is enough to decrease the venous diameter. This results in an increase in blood flow velocity as shown by measuring the circulation time with isotopes,[23] and is the rationale for recommending light compression stockings for thromboprophylaxis in bedridden patients. A graduation in pressure (18 mmHg at the ankle, falling to 8 mmHg at the thigh) leads to a significantly increased velocity in the deep femoral vein flow.[24]

In the upright position, such low pressure will have only a minimal effect on decreasing the diameter of the leg veins.[25,26] However, a very small decrease of venous diameter will result in an over-proportional decrease of the local blood volume as demonstrated by several plethysmographic studies.[27–34] Stockings with an ankle pressure of around 20 mmHg have been shown to improve the venous pump.[27,32,33] Elastic compression stockings with low pressure have also been found to significantly reduce symptoms of CVI in patients during daily work activity.[35–38]

Bandages may provide much higher pressure in the upright position. Magnetic resonance imaging (MRI) is able to show that during standing deep veins will be narrowed by an external pressure of 42 mmHg and nearly occluded by a pressure of 82 mmHg[26] (Fig. 6.3). During ankle movements and walking with stiff bandages, pressure peaks of this magnitude will lead to an intermittent occlusion of the veins (Fig. 6.4). Such high pressure may be tolerated only with inelastic (not with elastic) material.

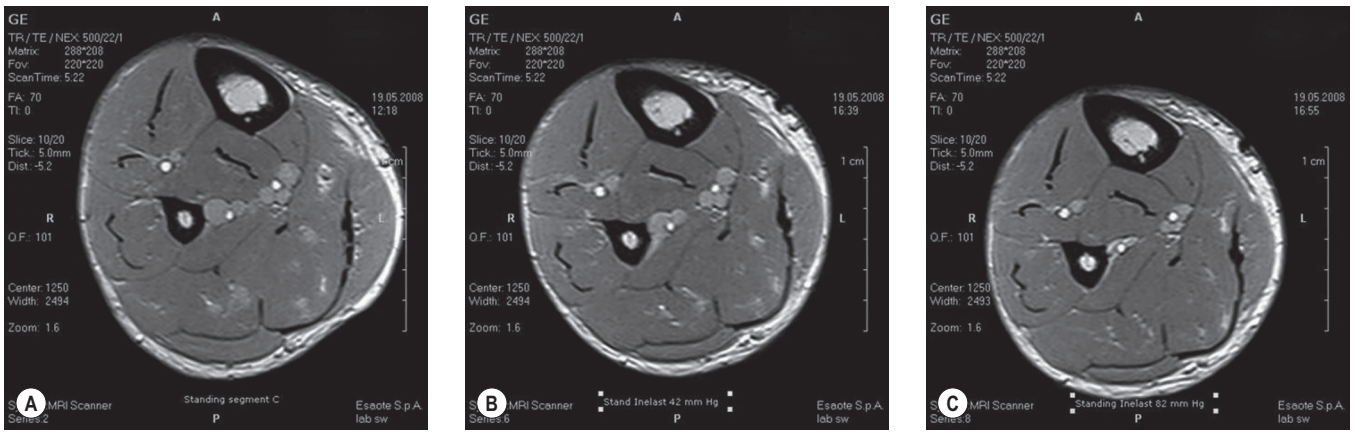

Figure 6.3 Magnetic resonance imaging of a crosssection through the largest calf segment in the standing position. **A,** Without compression; **B,** with a short-stretch bandage exerting a local pressure of 42 mmHg; **C,** with a pressure of 82 mmHg. A diameter reduction of the deep tibial posterior and peroneal veins can clearly be seen with increasing pressure. (Investigations together with G. Mosti at the laboratory of ESAOTE, Genova, Italy).

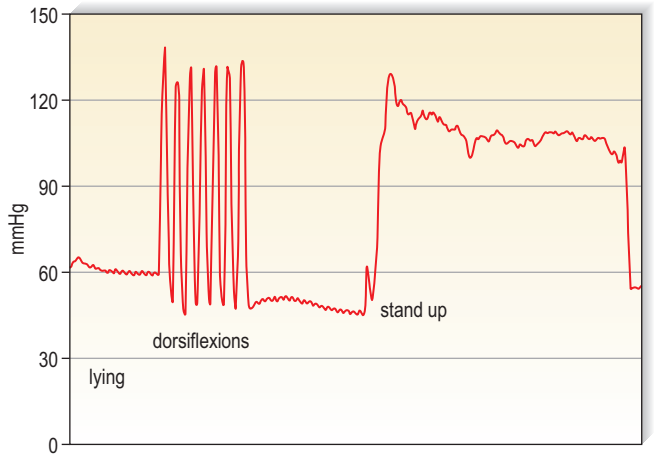

Figure 6.4 Interface pressure measured 12 cm above the inner ankle after application of a tight, zinc paste bandage aiming to produce a very strong bandage. The initial pressure in the lying position *(left)* is 60 mmHg. Ankle movements performing maximal dorsiflexions produce pressure peaks up to 120 mmHg. By standing up *(right)* the pressure rises to 100 mmHg. During the next 2 h there was a pressure drop to 25 mmHg in the supine and to 60 mmHg in the standing position.

The compression pressure when starting to walk counteracts the lateral expansion and dilation of leg veins during muscle contraction by encasing the veins in a semirigid envelope.[39,40]

The application of an external pressure with a blood pressure cuff blown up to 40 to 60 mmHg to various portions of the leg containing incompetent valves led to an abolishment of reflux.[41,42] This effect was directly associated with a decreased vein diameter. Reduction of venous refluxes and improvement of ambulatory venous hypertension by external compression could be demonstrated even in patients without any valves (avalvulia), indicating that this effect is not necessarily explained by coaptation of distended valve leaflets, but rather seems to be owing to increasing the resistance to retrograde flow.[43] Increasing external pressure in the upright position increases the ejection fraction of the calf muscle pump function.[44]

Conflicting results have been reported concerning an improvement in ambulatory venous hypertension by using compression stockings.[39,45] One study showed a significant decrease of such hypertension with short-stretch bandages applied with a resting pressure on the distal leg of more than 50 mmHg, but no decrease with elastic compression stockings exerting a pressure of 30 to 40 mmHg.[40] This may be explained by the fact that inelastic short-stretch bandages lead to an intermittent short venous occlusion during the muscle systole while walking. In patients with venous ulcers resulting from deep venous incompetence, short-stretch bandages are able to impede venous reflux more effectively than are elastic stockings exerting the same resting pressure.[46] Patients with severe stages of CVI benefit more from high compression pressure, whereas lower pressure is sufficient for milder stages such as varicose veins.[47]

The key mechanism of compression therapy to reduce ambulatory venous hypertension in patients with severe CVI is an intermittent occlusion of the veins during walking. In contrast, continuous obliteration of veins by external compression may be desirable after varicose vein surgery to stop bleeding and after sclerotherapy to prevent refilling of blood.

To achieve complete occlusion of superficial veins the external pressure should be higher than the intravenous pressure, and this depends on the body position. It was shown that occlusion of the leg veins can be obtained with an external pressure in the range of 20 mmHg in the supine position, but that in the sitting and standing positions the pressure has to be between 50 and 70 mmHg.[22,26] With compression stockings, such pressure ranges can only be achieved when rolls or pads are applied over the vein, thereby increasing the local pressure by reducing the local radius (law of Laplace, see later). Such rolls may be especially useful if local compression over treated veins on the thigh is intended.[48]

MICROCIRCULATION

Compression accelerates blood flow in the enlarged capillary loops and reduces capillary filtration because of enhanced tissue pressure. Improvements are seen in normalization of

venular flow, volume and velocity, improved distribution of microcirculation blood flow and normalization of leukocyte adhesion.[49–55] Different studies using electron microscopy were able to show a restoration of the structural changes in the media myocytes in stripped veins[56] and a tightening of intercellular junctions.[57] Laser Doppler flux measured a 29% increase in blood cell velocity in patients with CVI and lipodermatosclerosis.[52] Even in patients with mixed arterial–venous ulcers an increase of laser Doppler fluxmetry could be demonstrated up to a compression pressure of 40 mmHg.[58] Increasing flow velocity may reduce the likelihood of white blood cells interacting or sticking to endothelium with release of various factors. Effects on mediators involved in the local inflammatory response may explain both the immediate pain relief that occurs with good compression and ulcer healing.[59] Studies in patients wearing class II graduated compression stockings demonstrate an improvement in skin microcirculation in as little as 1 week, with near normalization of the functional state of microcirculation becoming apparent by day 30.[55] Model experiments with intermittent pneumatic compression were able to demonstrate that there is an increased release of the endothelial relaxing factor (EDRF) nitrogen oxide from the endothelial cells, depending on the amount of shear stress produced by the compression waves.[60] Compression tightens the junctions between the endothelial cells of capillaries[57,61] and reduces proinflammatory cytokines in venous leg ulcers.[62]

ARTERIAL FLOW

A reduction in arterial flow may be expected when the external compression pressure exceeds the intraarterial pressure. This may happen in patients with arterial occlusive disease with a reduced peripheral arterial pressure. To avoid ischemic skin lesions from external compression, it is essential to measure the peripheral arterial pressure using a Doppler probe before strong compression bandages or stockings are applied. It is generally accepted that a Doppler ankle–brachial index (ABPI) of less than 0.5 is a contraindication for sustained compression. However, external compression does not invariably mean reduction of arterial flow.[63] Mayrovitz reported on several experiments concerning arterial blood flow and compression,[64–66] and was able to demonstrate an increase of the pulsatile flow below the knee in healthy volunteers using nuclear magnetic resonance flowmetry.[64] He also demonstrated a reduction in toe blood perfusion, which was greater with increased compression, but not of sub-bandage skin perfusion.

Patients with edematous legs and with an ABPI of between 0.5 and 0.8 may benefit from inelastic or short-stretch bandages applied with a mild resting pressure, because of the edema-removing massage effect that will occur with every ankle movement (see later). Completely inelastic bandages together with walking have a similar effect as intermittent pneumatic compression. The rhythmic pressure peaks of an inelastic bandage during walking can be compared with those exerted by an intermittent pneumatic pressure pump. Several experiments with intermittent pneumatic compression have demonstrated an increase of arterial flow in patients with arterial occlusive disease.[67–72] The decisive mechanisms of action are the reduction of edema, an increase of the arteriovenous pressure gradient, myogenic mechanisms and the release of vasoactive substances from the endothelial cells. Especially during walking with inelastic bandages the increase of the ejection fraction of the venous calf pump may considerably contribute to an increase of arterial blood flow.[73]

BASIC PRINCIPLES OF COMPRESSION

TERMINOLOGY

A confusing variety of partly overlapping terms can be found in the literature.[1,74–84] Only terms of practical importance are listed here:

- **Elasticity:** Capability of a strained body to recover its size and shape after deformation.
- **Extensibility:** Maximum degree, expressed as a percentage of the unloaded size of the compression material to which it can be stretched in the circumferential or longitudinal direction.
- **Hysteresis:** A measure of the energy loss that occurs between loading (stretching) and unloading (relaxing) (see Fig. 6.10). Yarns with minimal hysteresis are best because they have maximum holding power with minimum stretch resistance.
- **Stiffness:** Increase in compression per centimeter increase in the circumference of the leg, expressed in hectopascals per centimeter and/or millimeters of mercury per centimeter.[74] Using in vitro testing, this definition applies also to the 'slope value'.[1]
- **Static stiffness index:** Difference between standing and lying interface pressure measured in vivo at the transition between the muscular and tendinous parts of the medial gastrocnemius muscle ('B1 point').[75,84] Figure 6.5 shows an example.
- **Dynamic stiffness index:** Difference between maximal peak pressure and resting pressure measured in vivo.[85]
- **Resting pressure:** Pressure from the compression device itself with the muscles at rest.

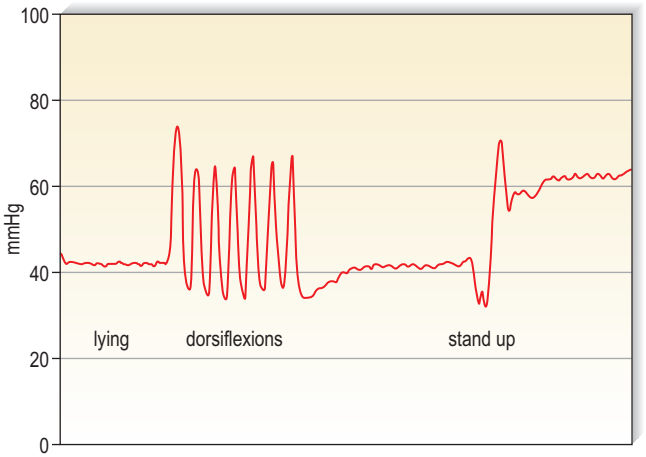

Figure 6.5 Typical pressure curve from the medial lower leg under an inelastic bandage in the supine position *(left),* with dorsiflexions and after standing up. The resting pressure of 40 mmHg rises to 60 mmHg by standing up. The difference between standing and lying pressure has been termed the static stiffness index (SSI).

- **Working pressure:** Pressure coming from inside the device, originating from contracting muscles.
- **Pressure amplitudes:** Difference between maximal and minimal pressure fluctuations during exercise, characterizing the 'massaging effect' of the compression device.
- **Pressure profile, pressure gradient:** Representation of the compression exerted by the device along the leg.
- **Residual pressure:** Compression at a certain point expressed as a percentage of the compression at the ankle.[74]

COMPRESSION PRESSURE AND LAPLACE'S LAW

The compression pressure (Pascal) is defined by the force (Newton) that is exerted to an area of 1 m^2 (Fig. 6.6). The tension in a bandage is determined by the force applied to the fabric during application.

The unit for pressure is 1 Pascal (Pa), which is 1 Newton (N) per square meter. In the medical field, for example measuring blood pressure, the usual unit for pressure is the weight of one cubic millimeter of mercury: 1 mmHg = 133,332 Pa = 1333 hPa

From Figure 6.6, it is clear that the curvature of the leg plays a deciding role for the exerted pressure. If the cylinder in the model was replaced by a cube, the pressure over the flat areas would be zero, whereas it would be very high along the sharp edges of the cube. This is described by Laplace's law stating that the pressure (P) is directly proportional to the tension (T) of the bandage, but inversely proportional to the radius (R) of the curvature to which it is applied (Fig. 6.7):

$$P \sim T/R$$

P decreases as R increases. When R is going to be indefinite such as over the flat areas of a cube, P will become zero.

PRACTICAL CONSEQUENCES OF LAPLACE'S LAW

In general, pressure is calculated for the circumference of the limb at a specific level. Because the leg has an irregular cross section that is not circular, the applied point pressures vary at different locations around the leg. Using Laplace's formula, it is evident that the effective pressure is greatest at the point of minimum radius and least at the point of maximum radius. Thus when a stocking is applied, the anterior aspect of the leg receives the greatest amount of pressure, and the lateral and medial sides of the leg receive the least compression pressure. This is especially important in the malleolar area, where the lowest degree of compression occurs, because the medial and lateral surfaces are flat or concave and the local radius is 'negative' (Fig. 6.8). If there is a venous ulcer situated in the dip behind the malleolus, the only way to bring compression to this region is to put a pad over that area (Fig. 6.9). The reduction of the local radius by pads or rolls in order to increase local pressure has been termed 'positive eccentric compression'.[1]

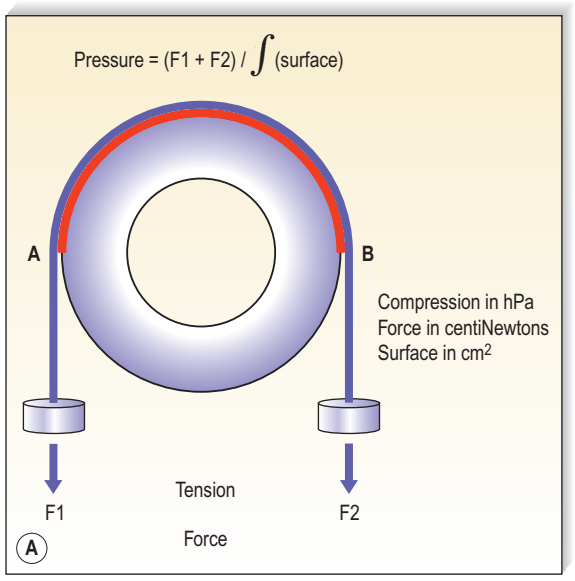

Figure 6.6 The pressure generated by an inelastic bandage is determined by the tension of the fabric. (Courtesy Bernard Lun, Ganzoni, St Just, France.)

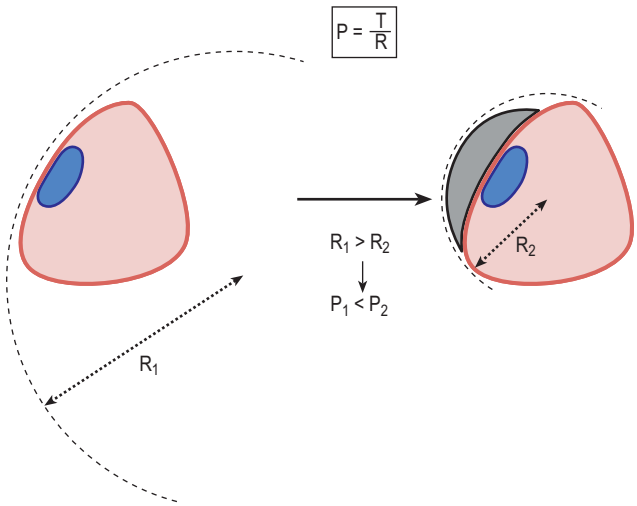

Figure 6.7 According to Laplace's law, the pressure exerted by a bandage is in direct proportional to the radius of the leg. To increase local pressure on flat parts of the lower leg circumference, rubber pads are attached over the area (*black sickle*) to decrease the radius. The *oval* represents a leg ulcer. (From Partsch H. J Dermatol Surg Oncol 1991;17:799.)

On the other hand, tendons and bony prominences are susceptible to a high compression pressure and should therefore be protected under a bandage by decreasing the radius using a cotton wool inlay. The enlargement of the local radius has been termed 'negative eccentric compression'.[1]

It is obvious from Laplace's law that a very thick leg requires more tension to achieve the optimum cutaneous and subcutaneous pressures, whereas a thin leg should be wrapped with a much lower tension.

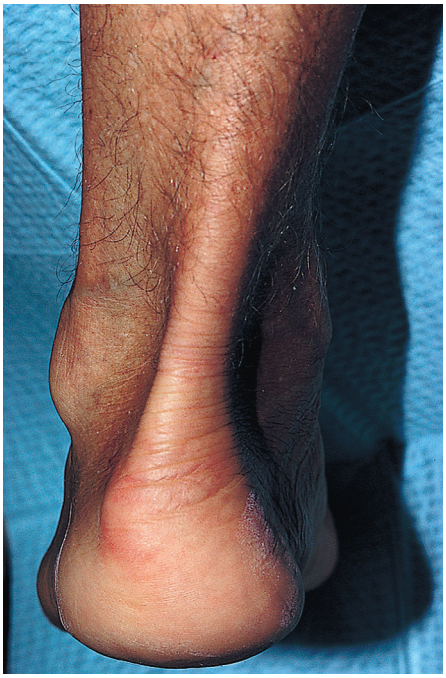

Figure 6.8 Typical appearance of an ankle in posterior orientation. Note the bulging malleoli and the resulting concavity produced on the lateral and medial aspects.

MEASUREMENT OF COMPRESSION PRESSURE

LABORATORY MEASUREMENTS OF COMPRESSION STOCKINGS

The effects of compression depend widely on the exerted pressure, which should be adapted to the underlying condition. Basically the pressure of a stocking is calculated from the force–extension diagram of the elastic fabric on a wooden leg model with defined circular cross sections using Laplace's formula (Fig. 6.10). The range of the compression

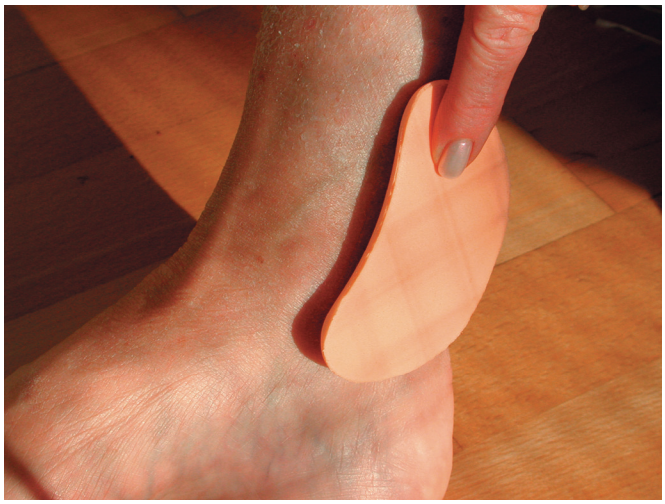

Figure 6.9 A rubber pad put behind the inner ankle increases local pressure. Note that the concave part of the pad is directed towards the skin.

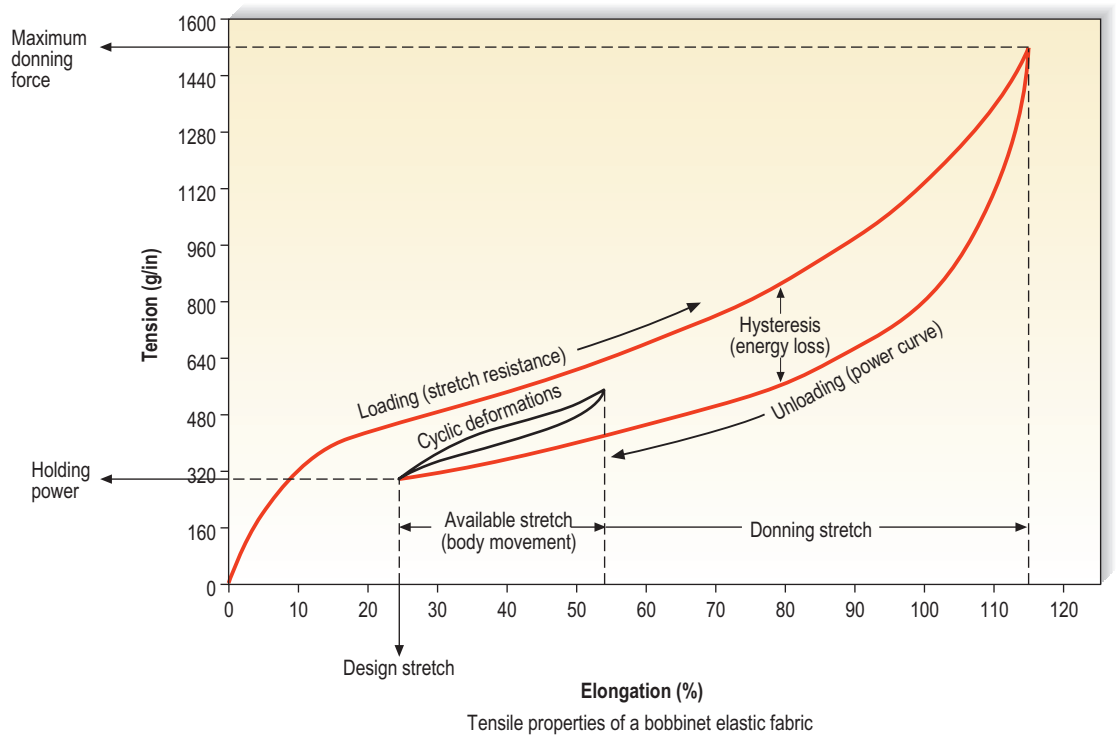

Figure 6.10 Hysteresis curve generated by a bobbinet elastic fabric. (Courtesy Beiersdorf-Jobst, Charlotte, NC.)

pressure indicated by the manufacturers is determined by the measurement of the force necessary to stretch the stocking at certain leg levels (B, B1, C, D, F, G) in a transverse direction. The proportion of stretch and force for each circumference level, which corresponds to the steepness of the so-called slope in the hysteresis curve, reflects the elasticity of the material of the stocking.

Several industrial measuring systems for obtaining hysteresis curves are used, such as the Hosy method, the Hatra tester, the Instron method, the French ITF method and others.

Measuring points, lengths and girths defined by the European standardization proposal (CEN, Centre Européen de Normalisation)[74] are shown in Figure 6.11.

Table 6.1 gives a comparison of compression classes for ready-to-wear and custom stockings used in several countries. The range of compression pressures and also the verbal description of these classes are amazingly variable from one country to another. Additionally, it is important to realize that the given ranges are measured by different methods and so comparisons are problematic. These facts underline the necessity of in vivo pressure measurements on the individual leg in future clinical studies. For a better universal understanding, it is recommended using the pressure range in mmHg rather than compression classes in general.

The pressure values in Table 6.1 refer to level B. The European prestandard[74] defines the ranges of pressure profiles in comparison with the pressure at the smallest leg circumference (position B) as follows: for level B1 70% to 100%, for C and D 50% to 80%, and for F and G 20% to 40% for compression classes III and IV; 20% to 60% for compression classes A and I, and 20% to 50% for compression class II (Fig. 6.12). The producers of compression stockings recommend adjusting the compression class according to the clinical severity.

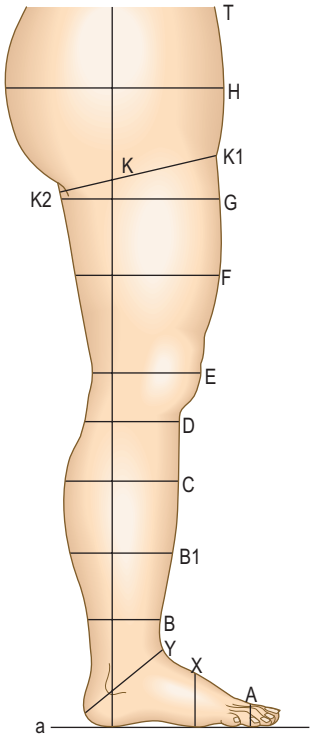

Figure 6.11 Measuring points, lengths and girths on the human leg. Note: measurements should be taken of the patient's leg in a standing position.[74]

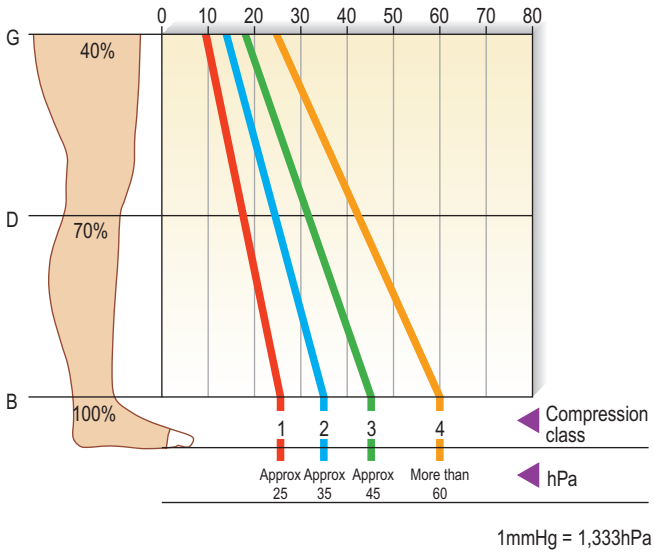

Figure 6.12 Diagram comparing the degree of compression exerted at various locations on the leg with different compression class stockings. *B* is the pressure generated at the ankle; *D* is the pressure generated at the knee; *G* is the pressure generated at the superior thigh. Note that there is a graduation of pressure with all classes of stockings, with the highest pressure exerted at the ankle. Also note that the most significant difference in pressure generated by the different classes of stockings is at the ankle. (Courtesy Juzo, OH.)

Table 6.1 Compression Classes Used in Several Countries*

Compression Class	EU (CEN)[74]	USA	UK (BS 6612)[77]	France	Germany[78]
A	10–14 (light)				
I	15–21 (mild)	15–20 (moderate)	14–17 (light)	10–15	18–21 (light)
II	23–32 (moderate)	20–30 (firm)	18–24 (medium)	15–20	23–32 (medium)
III	34–46 (strong)	30–40 (extra firm)	25–35 (strong)	20–36	34–46 (strong)
IV	>49 (very strong)	40+		>36	>49 (very strong)

*Values are mmHg (1 mmHg = 1333 hPa).
The values indicate the compression exerted by the hosiery at a hypothetical cylindrical ankle.

Table 6.2 Mean Compression Values for an Average Ankle Size

8–15 mmHg	15–20 mmHg	20–30 mmHg	30–40 mmHg	40+ mmHg
Tired, aching legs	Minor varicosities	Moderate to severe varicosities	Severe varicosities	Severe varicosities
Minor ankle, leg and foot swelling	Minor varicosities during pregnancy	Postsurgical	Severe edema	Severe edema
	Tired, aching legs	Moderate edema	Lymphatic edema	Lymphatic edema
	Minor ankle, leg and foot swelling	Postsclerotherapy	Management of active venous ulcerations	Management of active venous ulcerations
	Postsclerotherapy	Helps prevent recurrence of venous ulcerations	Helps prevent recurrence of venous ulcerations	Manage manifestations of PTS
	Helps prevent DVT	Moderate to severe varicosities during pregnancy	Manage manifestations of PTS	Orthostatic hypotension
		Superficial thrombophlebitis	Helps prevent PTS	Postphlebitic syndrome
		Helps prevent DVT	Orthostatic hypotension	CVI
			Postsurgical	
			Postsclerotherapy	
			Helps prevent DVT	
			CVI	

CVI, Chronic venous insufficiency; DVT, deep venous thrombosis; PTS, postthrombotic syndrome.

There is no American standard. Table 6.2 gives an example as recommended by one company (BSN-Jobst, Charlotte, NC).

MEASUREMENTS OF INTERFACE PRESSURE ON THE LEG

Compression therapy is a very effective treatment tool for which the 'dosage', that is the pressure on the individual leg, has been completely underestimated up to now. At least for clinical trials comparing different compression products, we need to measure the interface pressure on the individual leg and not just rely on the specifications of the producers. This is true not only for compression stockings whose pressure range is measured by different laboratory methods, making a comparison in treated patients problematic, but even more so for compression bandages. The pressure exerted by a compression bandage depends completely on the skill and experience of the bandager and only single standards are available that are far away from clinical practice.

Several instruments are available, which should be calibrated on the leg according to a recent consensus recommendation.[86] In this consensus paper, some prerequisites of an 'ideal' pressure sensor are summarized. One location that should always be included in future pressure measurements is B1. This is where the tendinous part of the gastrocnemius muscle changes into the muscular part, showing the most pronounced protrusion of the tendon and the most extensive enlargement of the leg circumference during dorsiflexion or by standing up from the supine position. Whenever in vivo measurements of interface pressure are performed, it is essential to indicate the exact measuring point, the main specifications of the instrument, including the dimensions of the probe, and the body position in which the measurements have been performed. Figure 6.13 shows a pressure measuring instrument that allows continuous pressure registration. The flat probe is inflated only when pressure is measured and can stay on the leg for several days.

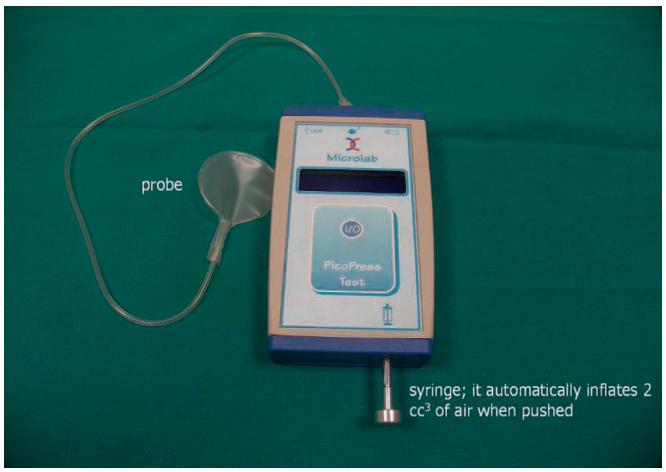

Figure 6.13 Instrument to measure interface pressure continuously. The flat probe is filled with 2 mL air and may be left deflated on the leg for several days. (Picopress, Micolab, Italy.)

Figures 6.4 and 6.5 show pressure curves obtained with this instrument.

RESTING AND WORKING PRESSURE

Some probes allow measurements of interface pressure not only at rest but also continuously during movement. Figure 6.14 shows an example where the interface pressure on the distal leg was measured continuously in different body positions, both for an inelastic and for an elastic bandage. Starting with comparable resting pressure for both bandages, the inelastic bandage has a higher working pressure than the elastic bandage. This difference has a major impact on the efficacy of the compression device concerning edema reduction and improvement of venous pump. Stockings with high stiffness or slope value, even at the same compression level, are better for patients with edema from CVI or other causes.[87] Inelastic bandages are more effective to reduce venous reflux and ambulatory venous hypertension.[40,46]

Measurements of intramuscular pressure have shown higher resting pressure with elastic than with inelastic material, suggesting that elastic compression applied over a long period in the recumbent posture may impede microcirculation and jeopardize tissue viability.[88]

MEASUREMENT OF STIFFNESS

Stiffness is defined as the increase in compression per centimeter increase in the circumference of the leg, expressed in millimeters of mercury per centimeter.[74] This parameter characterizes the distensibility of a textile in addition to the elastic property of a composite bandage, which plays an important role concerning the performance of a compression device during standing and walking. Stiffness may be measured in the laboratory, where it corresponds to the slope of the hysteresis curve. The fact that it can also be assessed by in vivo measurements on the individual leg will certainly achieve increasing practical importance in future trials.[85,86,89]

Measurement of dynamic stiffness during walking requires sophisticated instrumentation and can therefore not be used in routine clinical practice.[85] To obtain valuable information about the elastic property of a compression device, which may be quite complex when several materials are combined, the so-called 'static stiffness index (SSI)' may be a useful alternative.[84] A calibrated pressure sensor is fixed to the medial aspect of the leg at B1. This is the area that will show the most extensive changes in local curvature and leg circumference when the body position is changed between supine and standing. The difference between the interface pressure in the standing and in the lying position, called SSI, is a valuable parameter for the stiffness of the compression system that determines the relationship between resting and working pressure. As is shown in Figure 6.15, inelastic material produces a much higher pressure increase in the upright position than elastic material. It is important to note that different indices may be obtained with different sensors. Therefore reliable comparisons of different compression devices will only be possible by testing using the same sensor on the same site.

It has been shown that different padding materials may change the stiffness of the final bandage.[89]

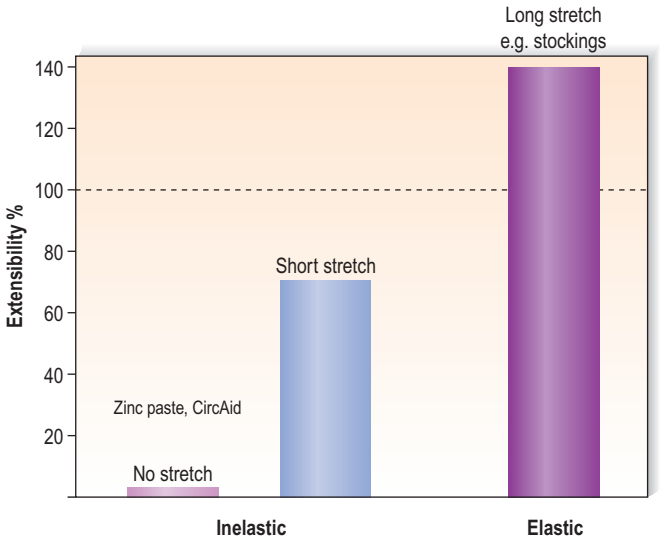

Figure 6.14 Differentiation between inelastic (<100% stretch) and elastic bandage material (>100% stretch) based on measurements in textile laboratories.

COMPRESSION MATERIAL

Different devices/materials are available for compression therapy (Box 6.1). The main categories of compression concerning the elastic properties of the materials are summarized in Table 6.3. Extensibility is the ability of a bandage to increase in length in response to an applied force.

COMPRESSION BANDAGES

There are three basic types of bandages: completely nonelastic bandages, virtually without any stretch, e.g., Unna boot or Velcro-band products; short-stretch bandages (<100% extensibility); and long stretch (>100% extensibility) (see Table 6.3).

No-stretch and short-stretch material is frequently called 'inelastic' and long-stretch material 'elastic' (see Fig. 6.14).

STANDARDS FOR COMPRESSION BANDAGES

There is currently only the British standard (BS) 7505:1995, for compression bandages. It contains four categories

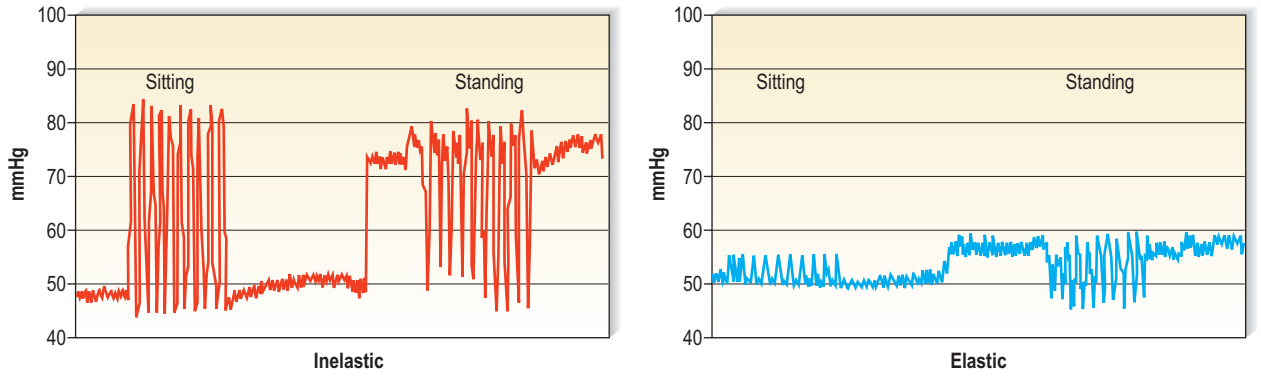

Figure 6.15 Resting and working pressure of an inelastic bandage *(left)* and an elastic bandage *(right),* measured at B1. During movement (dorsiflexions in the sitting position, tip-toes in the standing position) the pressure fluctuations are much higher with the inelastic bandage compared with the elastic bandage. By standing up from the sitting position the pressure rises by 23 mmHg under the inelastic bandage, but by only 8 mmHg under the elastic bandage. This increase of pressure characterizes stiffness.

Table 6.3 Categories of Compression Material

	'Inelastic'		'Elastic'
	No Stretch	**Short Stretch**	**Long Stretch**
Stretch	<10%	<100%	>100%
Application	Trained staff	Trained staff	Every patient
Stays on the leg	Day and night	Day and night	Daytime

Table 6.4 Classification of Compression Bandages by British Standard[77]

Bandage Type BS 7505	Level of Compression	Pressure British Standard (mmHg)
3A	Light	Up to 20
3B	Moderate	21–30
3C	High	31–40
3D	Extra high	41–60

Box 6.1 Types of Compression Device

Graduated Compression Stockings

- Ready-made 'off the shelf' stockings manufactured in fixed sizes
- Made-to-measure stockings, custom-made according to the length and the circumference of the leg
  - Below-knee hosiery
  - Mid-thigh hosiery
  - Thigh hosiery
  - Single-leg panty
  - Panty hosiery

Bandages

- Inelastic
  - No stretch (extensibility close to zero)
  - Short stretch (extensibility <100%)
- Elastic
  - Long stretch (extensibility >100%)
  - 'Nonadhesive', cohesive, adhesive
  - Single component
- Multiple components

Compression Boots

- Water, air
- Velcro-band devices (inelastic)

Intermittent Pneumatic Compression

- Single chamber
- Sequential chambers
  - Foot-pump
  - Lower leg
  - Full leg

of compression bandages,[77] which are summarized in Table 6.4.

By definition, the indicated pressure levels should be achieved on an ankle 23 cm in circumference when applied with a 50% overlap. This classification was constructed based entirely on in vitro measurements and does not correspond to the clinical reality. The resulting pressure of a bandage mainly depends on the stretch during application and far less on the material. Only a few measurements of compression pressure on the human leg have been reported, applying different materials with light, moderate and high strength.[90] It could be demonstrated that the interface pressure of a bandage on the human leg is on average one class higher compared with the values in Table 6.1 for compression stockings. Even with intentionally very loose bandaging in an attempt to achieve 'light compression', the pressure of the 5-m-long bandage, short stretch and long stretch, is always higher than 20 mmHg with one bandage and higher than 30 mmHg with a multilayer technique.

Table 6.5 Interface Pressure of Bandages Measured at B1 in the Supine Position[75]

Pressure (mmHg)	Mild	Moderate	Strong
Consensus proposal	<20	20–40	40–60

Because of these discrepancies, new proposals concerning a bandage classification were made in a consensus conference based on practical measurements in vivo.[75] The eponym 'PLACE' was proposed, containing the main characteristics to be considered when compression bandages are applied: P stands for pressure, LA for layers, C for components and E for the elastic property of the single bandage used. Table 6.5 shows the definition of different pressure ranges. Bandages are always applied with some overlap so that one-layer bandages do not exist. The only one-layer system is a compression stocking. Actually the so-called four-layer bandage is applied with much more than four layers and should correctly be called a 'four-component bandage' because it contains four different bandage materials. Use of the terms 'elastic' and 'inelastic' were proposed only for single bandages based on their elastic properties, but not for a final bandage consisting of different single bandages. In fact the elastic property of the final bandage cannot be predicted based on the elasticity of the single components. Adding several bandages does not only increase the sub-bandage pressure but also enhances the stiffness of the final bandage.

INELASTIC AND SHORT-STRETCH BANDAGES

Bandages with an extensibility close to zero, such as zinc paste (Unna boot) and rigid Velcro-bands like CircAid (CircAid Medical Products, San Diego, CA) or Hydro Boot, (Incappe Inc, Brandon, MS) are examples of completely nonelastic material. Nonelastic bandages must be applied with skill and some knowledge. If light compression is indicated they should be applied without extension of the fabric by molding the material to the leg without tension. When strong compression is indicated completely rigid zinc paste bandages need to be applied with full extension of the material and adjusted to the configuration of the leg. Figure 6.16 shows a bandage applied with zinc paste on the lower leg wrapped over with a short-stretch bandage, and with adhesive bandages over the knee and thigh of a patient with a proximal deep vein thrombosis (DVT).

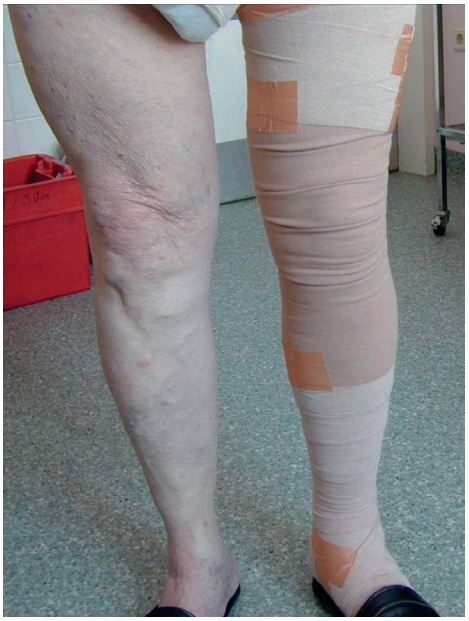

Fig. 6.16 Inelastic compression bandage with high stiffness consisting of a tightly applied zinc paste bandage, wrapped over by a short-stretch cotton wool bandage on the leg and of adhesive bandages over the knee and thigh in a patient with an acute proximal deep vein thrombosis. The initial interface pressure on the lower leg is between 50 and 60 mmHg in the supine position.

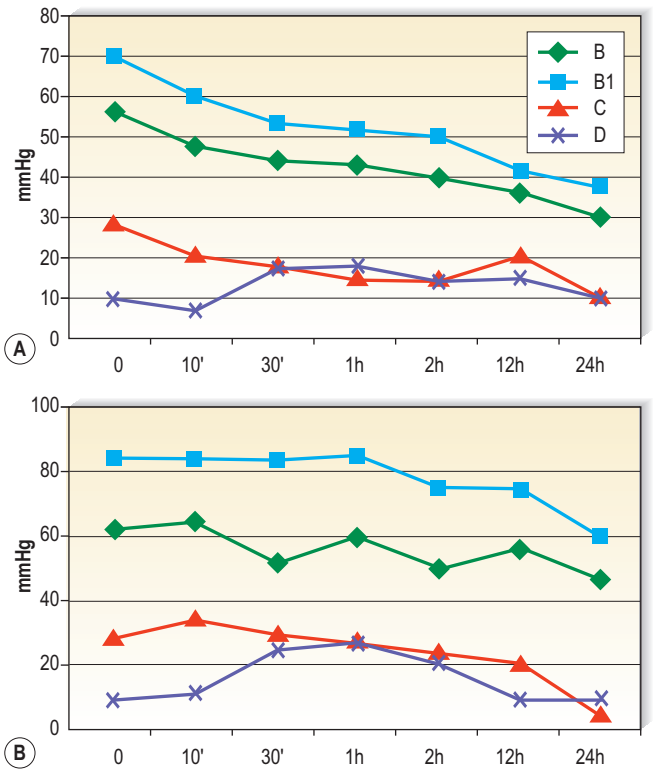

Figure 6.17 Interface pressure exerted by a multilayer short-stretch bandage (Rosidal sys, Lohmann) measured by an MST tester[130] on the medial leg in the supine **(A)** and in the standing position **(B).** Measuring points: B = behind the inner ankle, B1 = 8 cm above, C = 19 cm above, D = 27 cm above the ankle. The pressure drop of this multilayer short-stretch bandage is more pronounced in the supine than in the standing position.

Short-stretch bandages can be extended 30% to 100% and should be applied with a pressure of more than 50 mmHg on the distal leg if strong compression pressure is indicated. As a result of the immediate removal of edema, this pressure will fall to values that are also well tolerated in the supine position. After a few hours there will be a low to slight resting pressure, but still a high and very effective working pressure. Short-stretch bandages exert little pressure when the calf muscles are relaxed, but prevent expansion in calf diameter when the muscles are contracting during standing and walking ('high working pressure'). Therefore they are comfortable when patients are recumbent and they act to decrease venous pressure with ambulation.[40] The main disadvantage is that they may become loose after a few hours of wear, especially when applied too loosely. In immobile patients, correctly applied short-stretch and inelastic bandages are even more effective than long-stretch material. Even minimal toe movement or passive ankle mobilization performed by physiotherapists will produce a much higher massaging effect compared with elastic material.

Nonelastic bandages made of cotton may be washed and reused. Another category of short-stretch material is the cohesive or adhesive bandage. A cohesive bandage sticks only to itself, and not to skin or hair, whereas an adhesive bandage also sticks to the skin. These bandages cannot be reused after removal.

Stiff bandage material is not easy to handle. Most untrained persons apply inelastic bandages with too low a pressure. To obtain a resting pressure on the distal leg of about 40 mmHg, the initial pressure after application should reach about 60 mmHg. As can be seen from the example in Figure 6.17, the resting pressure in the supine position drops from 70 mmHg to 50 mmHg after 2 hours. This pressure exerted by an inelastic bandage is also well tolerated during nighttime. However, there is less pressure loss in the standing position, so an effective range of pressure values is still maintained after 24 hours (see Fig. 6.17). In the first days after bandage application, the reduction of swelling may be so pronounced that the bandages will get loose and have to be renewed. When edema reduction is stabilized, inelastic bandages may stay on the leg for several days.

A study of elastic minimal-stretch and nonelastic orthoses (CircAid) demonstrated that 4 hours after application, elastic bandages had 94% of their initial pressure, compared with 70% for minimal-stretch and 63% for the nonelastic orthose.[91] In the supine position, the decrease at 4 hours was 72% for elastic, 59% for minimal-stretch and 44% for nonelastic compression. One of the advantages of this particular orthosis is the fact that it can be readapted by the patient when it becomes loose (Figs 6.18 and 6.19). Smaller but significant decreases in pressure under short-stretch bandages were also found in studies on changes in pressure with exercising.[92,93] Measurement of compression after walking for 3 hours and then again 7 days later showed a decrease in pressure from 80.5 mmHg to 43.6 mmHg after 3 hours and to 26.3 mmHg after 7 days. In this study, Comprilan (Beiersdorf, Germany) with an extensibility of 70% was used.[92] In the second study, elastic bandages did not demonstrate a similar degree of compression loss after tip-toe exercise.[93] Although the authors speculate that the loss in pressure during exercise may be related to application technique

Figure 6.18 CircAid (San Diego, CA) ready-to-wear compression garment, Flex model.

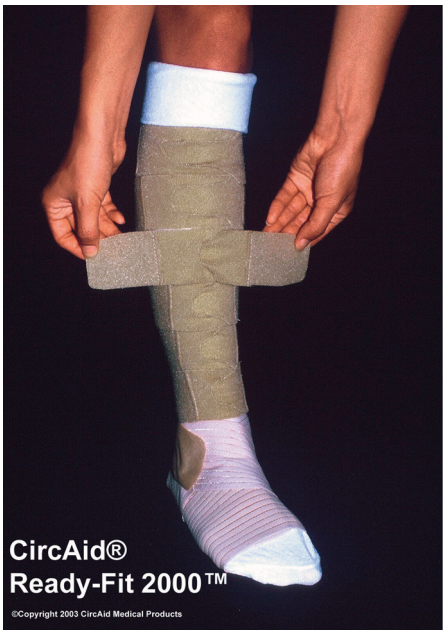

Figure 6.19 CircAid (San Diego, CA) ready-to-wear compression garment, Standard model.

of the short-stretch bandage with a maximum tension of 45% (Compridur; Beiersdorf, Germany), this could also be explained by an immediate volume reduction of the leg as shown in healthy volunteers and in lymphedema patients (Rosidal sys and Rosidal Lymphset; Lohmann & Rauscher, Germany).[94]

When the bandage becomes loose it should be renewed to prevent refilling of the extremity with edema and to avoid tourniquet effects from the down-gliding compression material. In patients with lymphedema, who are best treated with short-stretch bandages in the initial phase, renewal may be necessary once a day.[95]

Main indications for inelastic and short-stretch bandages are venous and mixed arteriovenous leg ulcers, DVT, superficial phlebitis, compression after surgery, sclerotherapy or endovenous therapy of varicose veins and lymphedema.

ELASTIC, LONG-STRETCH BANDAGES

Elastic bandages or compression stockings are usually applied in the morning, preferably before getting up, and are removed before going to bed at night. These highly extensible devices are relatively easy to apply and accommodate changes in leg geometry, expanding and contracting during walking. They sustain applied pressure for extended time periods, but may cause unpleasant feelings in the resting, sitting or lying positions.

Long-stretch bandages can be extended 140% to 200% and thus have a high resting pressure; that is, they exert pressure on the superficial venous system when the limb is at rest with a decreased working pressure as compared with short-stretch bandages (see Fig. 6.15). Because of their intrinsic high resting pressure, they can damage arterial, lymphatic and venous flow if not applied carefully, so they are best used while patients are ambulatory. Their advantage is that they may be molded around the heel and ankle more easily and can sustain their pressure better than inelastic bandages.

Elastic leg compression applied over a long period in the recumbent position may impede microcirculation and jeopardize tissue viability. New materials have been developed that provide effective compression pressures for a wide range of varying stretch. They are applied as multilayer bandages and may stay on the leg for several days and nights (Proguide; Smith & Nephew, UK).

Such bandages can be used to maintain a decongested condition when inelastic bandages are no longer required and may replace elastic stockings if these cannot be put on.

MULTILAYER BANDAGES

In the consensus paper mentioned earlier, it is stated that 'multilayer bandages' are actually multicomponent bandages consisting of different materials for padding, retention and compression.[75]

From these definitions it is quite obvious that many combinations of different materials are possible that will lead not only to an increasing pressure with each layer but also to variable elastic properties of the final bandage. In a comparative trial with different brands of four-layer bandages it was found that a bandage applied as part of a multilayered system achieves only about 70% of the pressure that it exerts when applied alone, thus challenging the commonly held assumption that the final pressure achieved by a multilayer bandaging system is the sum of the pressures exerted by each individual layer.[96] The elastic property of the final bandage will change toward a more inelastic bandage because of the friction of several layers, enabling it to be tolerated in the supine position[97] (Fig. 6.20). One example is the so-called four-layer bandage, which consists of several components of different material (wool, crepe, elastic and self-cohesive), and which may be worn day and night (Profore; Smith & Nephew, Hull, UK).

There were claims that such bandages have not lost pressure at 1-week follow-up.[98] Actually some of our own measurements revealed a pressure loss that started immediately

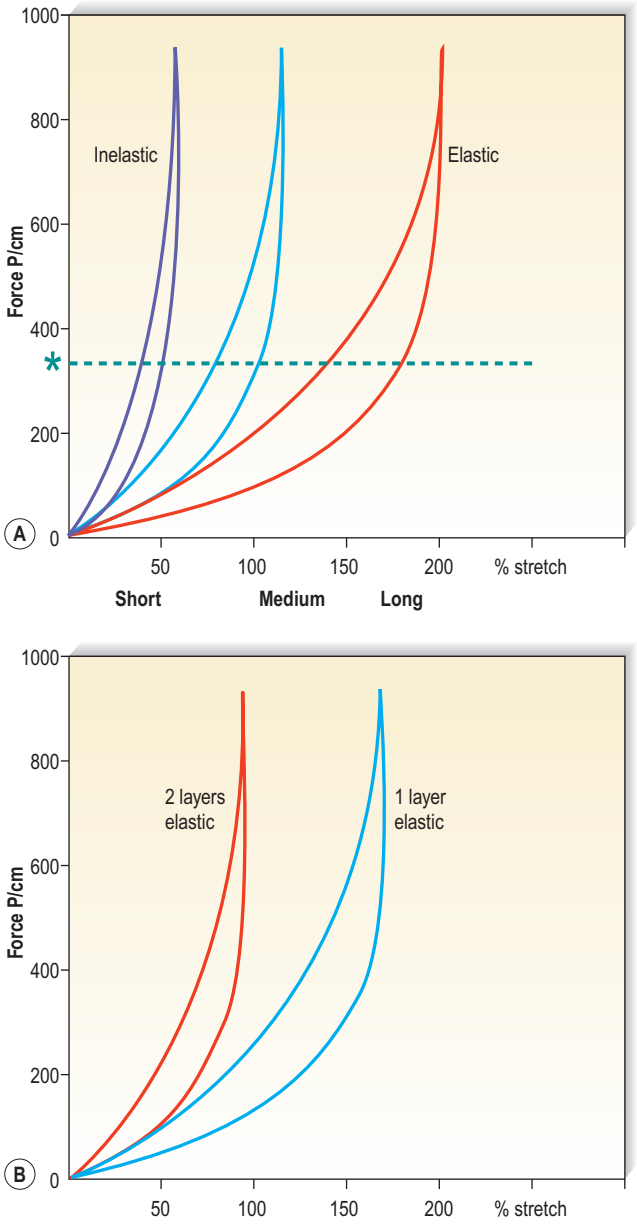

Figure 6.20 Hysteresis curves of different bandage materials. **A,** To achieve the same pressure level on the leg (*blue dashed line*) elastic bandages *(right)* need more stretch than inelastic *(left).* **B,** Compared with one layer of elastic material *(right),* two layers lead to a shift of the hysteresis curve towards the left. The elastic property of the final bandages is similar to a short-stretch bandage *(top).* (Redrawn from Partsch H, Rabe E, Stemmer R. Compression therapy of the extremities. Paris: Editions Phlébologiques Françaises; 1999.)

after application, which is less pronounced compared with short-stretch bandage systems.[99]

One study compared eight different compression bandages under standardized conditions.[97] Multilayer bandage systems composed of short- and medium-stretch bandages exhibit the smallest pressure loss with patient activity and have a significant pressure decrease when the patient is supine. These systems gave better postural and interface pressure changes than all types of single-layer bandages because of an increase in the stiffness of the final multilayer bandage.[84,90]

There are also multilayer systems consisting of short-stretch material, which are equally effective in ulcer healing when applied correctly.[100–103] Examples are the Pütter bandage (Hartmann, Germany), Rosidal sys (Lohmann & Rauscher, Germany), the adhesive Actico bandage (Activa Healthcare, UK), the Coban 2 bandage (3M, Minnesota, USA) and the Fischer bandage, consisting of a tightly applied Unna boot with a short-stretch bandage on top. This latter bandage was recommended by Heinrich Fischer, the pupil of Unna, in 1910 for the treatment of DVT[4] and is still one of the author's favorites in patients with DVT, post-thrombotic syndrome or venous leg ulcers (see Fig. 6.16). The tradition of using multilayer short-stretch bandages is rather restricted to central European countries and to the Netherlands, whereas many bandagers in the UK are more familiar with multilayer systems containing rather long-stretch material.

Several trials have compared multilayer long-stretch bandages with short-stretch, some showing better results with the short-stretch,[100–103] some better with long-stretch multilayer systems.[104,105] Frequently unfair comparisons have been made comparing properly applied versus inadequately applied bandages. In future trials, bandagers should be properly trained for both systems and interface pressure and stiffness should be measured.

One advantage of the multilayer bandages composed of short-stretch material is their reusability, in contrast to the single-use elastic multilayer systems. Short-stretch cotton wool bandages get stiffer with each washing procedure.

The principle of applying several compression layers over each other is also a promising concept for elastic stockings, with regards to an increase in both compression pressure and stiffness.[106,107]

TRAINING IN THE APPLICATION OF BANDAGES

A major drawback of bandages is their nonuniform application. A comparison of the range in pressures measured during application of a long-stretch elastic bandage by skilled nurses versus nursing students demonstrated that the skilled bandager's pressure ranged from 25 to 50 mmHg, and the unskilled bandager's pressure ranged from 15 to 70 mmHg.[108] A recent study checking the sub-bandage pressure showed that nurses with long professional experience tend to apply short-stretch bandages much too loosely (<20 mmHg) and that this can be greatly improved by training.[109]

In another study, similar results were demonstrated, and training programs were suggested that focus on practical bandaging skills.[110]

Several elastic bandages are marked with geometrical figures such as a rectangle that becomes a square when stretched to the proper length (e.g., Setopress; Seton Healthcare Group, Oldham, UK; Proguide; Smith and Nephew, UK; Velpeau; Lohmann & Rauscher, France) (Fig. 6.21). Setopress was studied with five skilled nurses and five unskilled assistants who also applied an Elastocrepe (Smith and Nephew, UK) bandage to the opposite leg. The Setopress bandage applied by experienced nurses most closely approximated target sub-bandage pressures, whereas the unskilled group differed significantly among themselves. As before, both groups differed significantly in applying sub-bandage pressure with the Elastocrepe bandage, with a

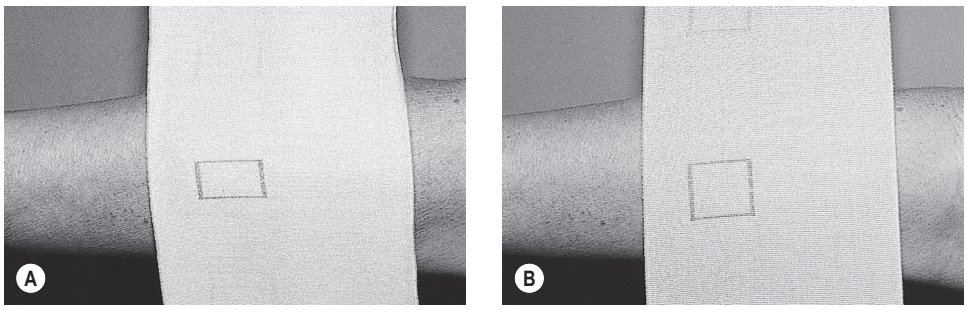

Figure 6.21 Appearance of a 30-mmHg, medium-stretch compression bandage without tension (Setopress, Seton Healthcare Group, Oldham, UK). **A,** Note rectangular boxes. **B,** Same bandage stretched to provide approximately 30 mmHg compression. Note that the rectangular boxes have now assumed a square shape.

significant difference noted between the skilled nurses and unskilled bandagers.[111] An additional study of 18 nurses applying an adhesive compression bandage showed ten nurses producing a tourniquet effect, five producing inadequate ankle pressure, two excessive ankle pressure and one appropriate ankle pressure but with an improper gradient in the calf.[112] Training significantly improved performance. Another study of 48 trained community nurses that compared one inelastic and two elastic bandages showed similar results.[113] The most common problem was production of a calf tourniquet.

In addition, even with physicians who are experts in applying bandages, a true graduation in pressure may not always be obtained. One study of five surgeons showed a range of 21.9 to 52.7 mmHg with application of a short-stretch bandage, with each individual surgeon having a range of 10 to 20 mmHg between bandage applications.[114] The coefficient of variation in each individual ranged from 9.9% to 25.2% with a mean (standard deviation) of 17.0 (4.9%).

Based on the information just presented, it is obvious that training in the application of bandages is very important.[109–116] This is especially true for inelastic bandages, which should be applied with a higher initial pressure compared with elastic material. Instruction of compression application with the use of interface pressure measurement has been shown to improve technique.[116] When teaching 156 persons at a wound healing course, the application of appropriate interface pressures required approximately ten exercises with the use of interface pressure transducers.

Important points to consider when applying a bandage are:

- Elastic bandages are easier to handle than inelastic bandages and may be applied by staff who are not specifically trained, in addition to the patients themselves. This is also true for compression stockings.
- Inelastic material like zinc paste should be applied with much higher resting pressure, pressing the bandage roll toward the leg as if molding clay. To obtain a homogeneous pressure distribution without creating constricting bands or folds, it is advisable to cut the zinc bandage when it does not exactly follow the cone-shaped leg surface during application. A 10-m bandage is recommended for one lower leg. After the lower leg has been covered with several layers, a 5-m-long short-stretch bandage is wrapped over and the patient encouraged to walk around immediately for at least 30 minutes. This short-stretch bandage can be washed and reused with each change of the bandage.
- After some walking the immediate removal of edema causes the pressure to drop to around 40 mmHg. Therefore, in the edematous phase the bandage will become loose after a few days, and it should be renewed or wrapped over with a short-stretch bandage. The same is advisable when exudates from ulceration penetrate the bandage. This may occur especially during the initial treatment phase and the patient should be advised to come back if this happens. Thereafter, the bandage is changed every 7 days on average.
- Bandaging should go up to the capitulum fibulae (Fig. 6.22). The initial turn may be placed around the ankle or between the heel and the dorsal tendon to fix the bandage. Then the bandage is taken down to the foot to the base of the toes. To avoid impeding ankle movement, it is not necessary to cover the whole foot, because slight morning edema developing distal to the bandage will disappear shortly after walking is started. The ankle joint is always bandaged with maximal dorsal flexion of the foot.
- When wrapping the bandage up the leg, overlapping can be done in a spiral fashion or with figures of eight. Circular turns over the conus-shaped part of the leg could lead to a constriction of the skin.
- With a knee-high bandage the proximal end of the bandage should cover the capitulum fibulae.
- Graduated compression is achieved by exerting higher pressure on the distal lower leg than on the proximal calf.
- Graduation in pressure is also ensured by applying even pressure on the bandage, which is stretched to a uniform degree while wrapping in the distal to proximal direction. This occurs according to Laplace's law, which states that smaller diameters have increased pressures as long as tension remains constant and the leg increases in diameter in a distal to proximal direction (see Fig. 6.22).
- Cotton wool padding or a thin polyurethane foam bandage underwrap should be placed on the distal anterior tibial area to protect the protruding tendon with its sharp curvature from pressure that is too high.
- Bandage materials must be nonallergenic to avoid the development of dermatitis.
- The bandage must be applied with no gaps so that each turn overlaps about 50% with the previous turn.

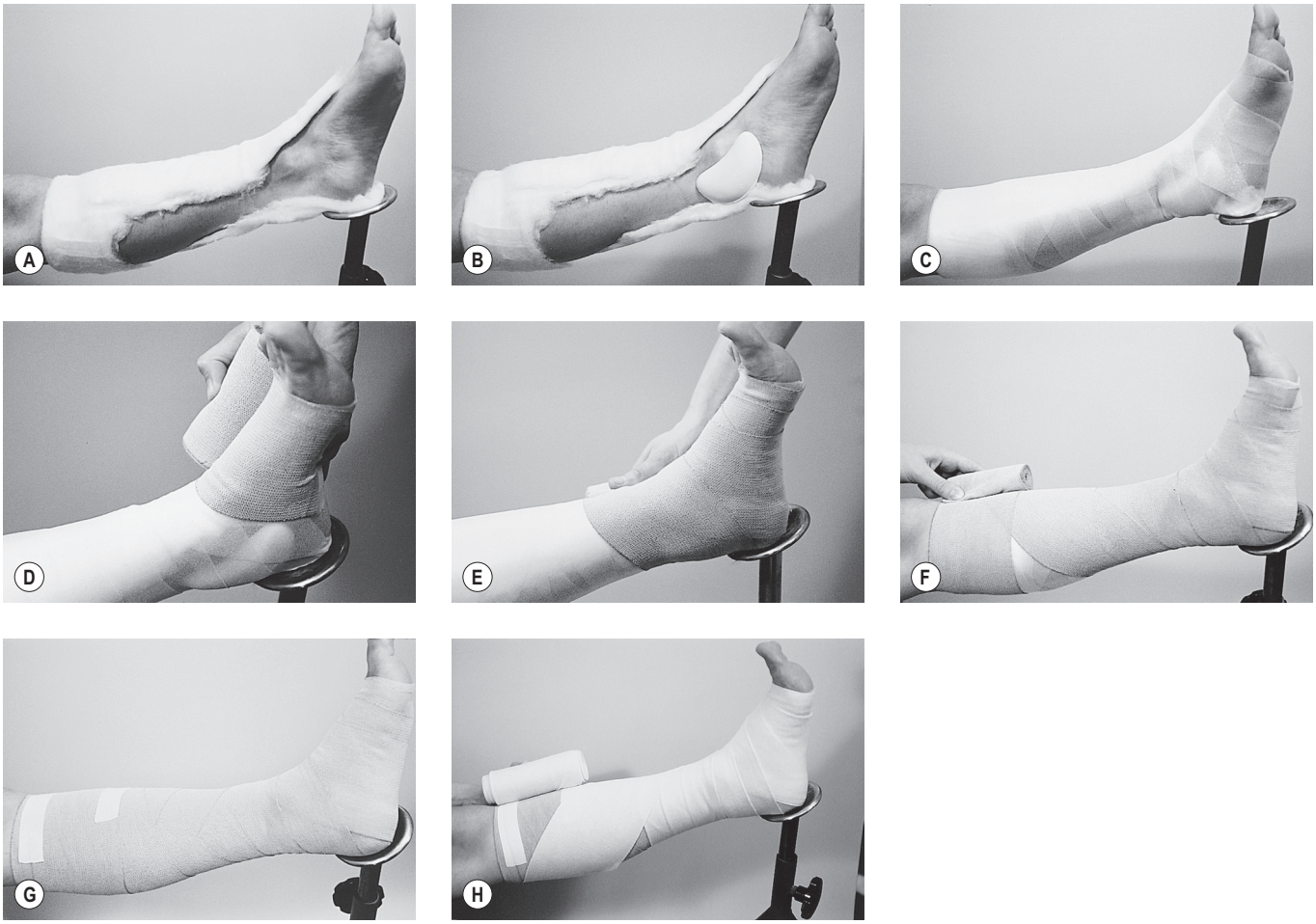

Figure 6.22 Preferred method for applying compression bandages. **A,** All areas with a pronounced curvature, such as ankles, Achilles tendon, instep and sharp edges of the tibia, are leveled and protected with cotton wool. **B,** The retromalleolar space is raised with a foam pad to prevent excess pressure on the medial and lateral malleoli. **C,** Cotton wool and pads are fixed to the leg with a light, absorbent dressing. **D,** Bandaging is begun at the medial dorsal foot with the foot in pronounced dorsiflexion. **E,** With each spiral turn, two thirds of the bandage is covered, except for the turn at the knee (**F**), where there is no circular bandaging, but the bandage turns across the leg and the contour of the leg is followed naturally. Uniform stretch on the bandage is applied at all times. **G,** Appearance of the completed first bandage. **H,** If a second bandage is to be applied, it is begun from the opposite direction from the lateral dorsal superior calf. (From Neumann HAM, Tazelaar DJ. Compression therapy. In Bergan JJ, Goldman MP, editors. Varicose veins and telangiectasia: diagnosis and treatment. St Louis: Quality Medical; 1993.)

- Local compression should be applied over the treated areas to avoid bruising, hematoma, edema and inflammatory reactions. Pads can increase local pressure over ulcers or firm lipodermatosclerotic areas.
- Ask the patient to walk and let them come back when the bandage is too tight. Pain may indicate arterial ischemia.
- Bandaging of the lower leg is sufficient for the majority of patients. Only in cases where there is extensive swelling or phlebitis of the thigh are compression bandages reaching up to the inguinal fold advisable. The flexor tendons in the kneehole should be protected by cotton wool. Adhesive short-stretch material, which does not slip down, is recommended for compressing the thigh. To keep the knee joint mobile, an adhesive two-way stretch bandage is used. To narrow the veins, the sub-bandage pressure at mid-thigh level should be at least 40 mmHg in the standing position.[42]
- Walking exercises are essential to optimize the effect of compression therapy.

COMPRESSION BANDAGES OR COMPRESSION STOCKINGS?

In general, compression bandages are able to achieve higher pressure than compression stockings.[90] Therefore, in severe stages of venous disease, treatment may be initiated with compression bandages.

Bandages are best indicated when temporary compression is required, such as in the acute phase of DVT, superficial phlebitis, in patients with venous ulcers, and in lymphedema and phlebolymphedema. As soon as the inflammatory signs and symptoms and the swelling are improved, compression stockings should be used to maintain the effect. Another benefit of bandages is that they can be reapplied as necessary as the edema in the affected limb is reduced. In this way the optimum compression needed for efficient therapy is obtainable.

Varying the strength of wrapping will alter pressure. The elasticity of bandages, although limited, changes somewhat according to the type used and functions as a fixed support.

Table 6.6 Some Practical Characteristics of Different Compression Products

Feature	CircAid* Legging	Unna Boot	Elastic Stocking	Inelastic Bandage	Elastic Bandage
Easy application	+	0	C	C	C
Unyielding	+	+	0	C	0
Compression maintained	0	0	+	0	+
Compression adjustable	+	0	0	0	(+)
Comfort level	+	+	C	+	C
Overnight removal	+	0	+	0	
Effective life	12 month	1 week	6 month	>6 month	6 month

+, Advantage; 0, disadvantage; C, conditional (depending on compression level and patient's physical conditioning).
*CircAid Medical Products, San Diego, CA.

Stockings, however, with elastic properties and graduated pressures fixed at the time of manufacture, undergo no change until the stocking is worn out and is no longer usable. In fact, stockings must be made of highly elastic materials to enable them to be pulled over the heel of the foot.

Elastic long-stretch bandages and elastic stockings may be handled and reapplied by the patients daily. Usually they are removed overnight. In contrast, Unna boot bandages and short-stretch bandages stay on the leg day and night, and should be changed by the bandager every few days. When they get loose they may be wrapped over by the patient preferably using a washed short-stretch bandage.

Multilayer bandages consisting of several layers of long-stretch material obtain the elastic property of short-stretch bandages (see Fig. 6.20) and may also stay on the leg for several days.

Table 6.6 gives an overview of some practical characteristics of different products.

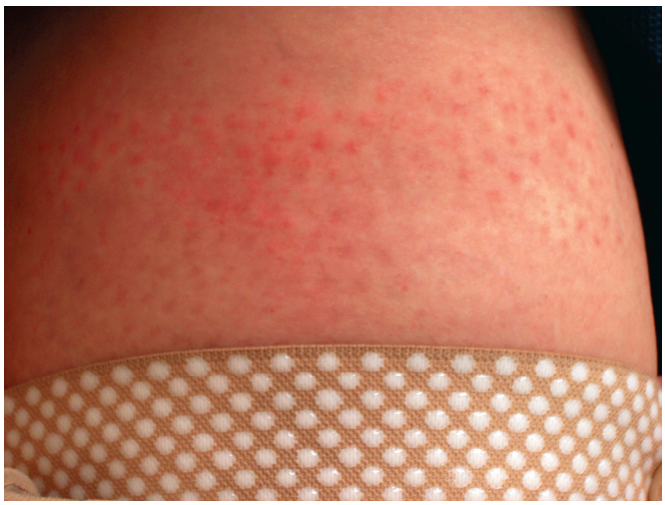

Figure 6.23 Allergic contact dermatitis from the silicone beads on this class II graduated compression stocking. Cutting the silicone band from the stocking and using a garter belt to hold it in place resolved this problem.

COMPRESSION STOCKINGS

Graduated compression stockings are useful both for acute therapy after surgery or sclerotherapy treatment of varicose or telangiectatic leg veins and for long-term therapy in patients with CVI.[80,117] In the supine position, blood is pressed from the superficial to the deep veins. This effect may be used to improve the opacification of the deep veins when performing computed tomography (CT) venography.[118] During standing they achieve only a rather modest reduction of the venous diameters in the leg.[22,119,120] However, they provide an external support to prevent swelling. By virtue of their 'graduation' (see Fig. 6.12), it has been speculated that compression stockings help to propel blood toward the heart during walking.[39–47,121,122] Unlike nonelastic bandages they do not lose compression with time (except after months of continuous use).The importance of a graduated pressure profile for stockings was recently questioned by experimental findings showing a stronger effect of stockings on the venous pump if the stockings used exert a higher pressure over the calf.[123] Such stockings show superiority in reducing clinical symptoms in patients with chronic venous insufficiency.[124]

In general, compression stockings should be used only on legs in which the diameter has stabilized and edema is no longer a factor. When used in this manner, the stocking will correspond to the leg dimensions to prevent a renewed increase in leg circumference. For optimal performance, compression stockings should be fitted early in the day, when edema is reduced. However, even light stockings have been shown to be quite effective in reducing edema.[10]

Although they usually do not have adverse effects when properly fitted, some types of elastic stockings may rarely cause an allergic reaction. This has been reported with elastic stockings composed of 76% nylon and 24% Elastane (Scholl Soft Grip; Scholl, UK) in less than 1% (2 of 126) of patients.[125] More commonly the silicone beads used to help hold the stocking up on the thigh cause an allergic reaction (Fig. 6.23).

CHARACTERISTICS OF MEDICAL GRADUATED COMPRESSION STOCKINGS

Most compression stockings are more or less two-way stretch stockings—elastic in both the longitudinal and transverse directions. This provides the stretch needed to apply a stocking that has the smallest diameter at the ankle and can be drawn over the heel. Two-way stretch stockings also have the characteristics of longitudinal bandages. The longitudinal elasticity of the stocking compensates for differences in limb length, thereby facilitating joint movements. In addition to

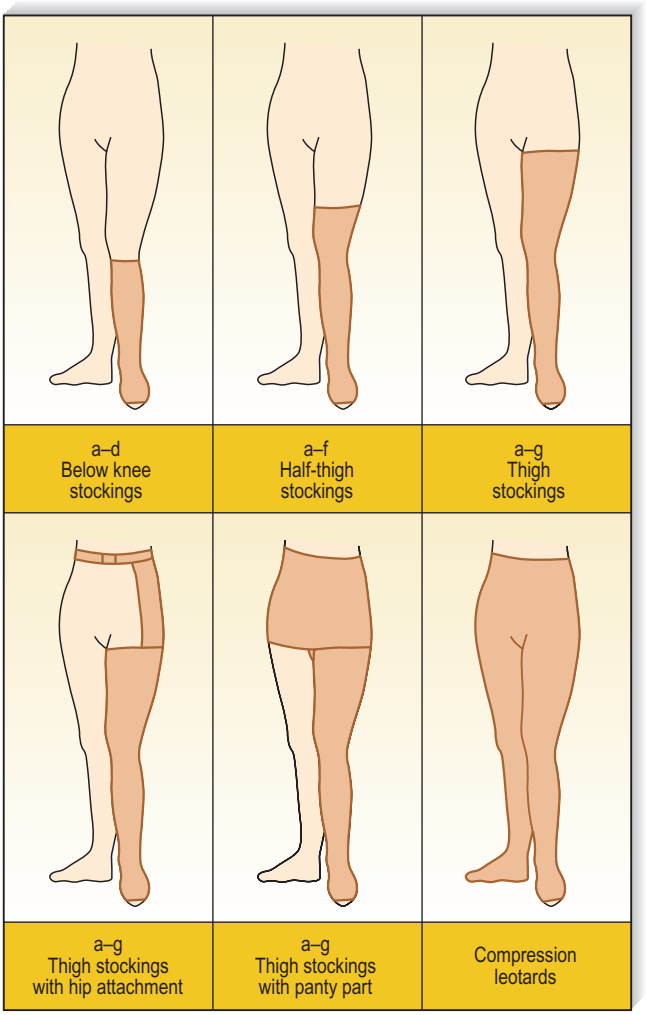

Figure 6.24 Six types of graduated compression stockings widely available. (Courtesy Juzo, OH.)

the compression generated by the stocking, another important parameter is the stiffness, elasticity or slope value of the stocking.

READY-MADE STOCKINGS

Ready-made or off-the-shelf stockings are manufactured in fixed sizes. Most manufacturers have several sizes varying in both length and width at various points on the ankle, calf and thigh (Fig. 6.24). Although the sizes are standardized to some degree by associations of stocking manufacturers, such as the Gütezeichengemeinschaft Medizinischer Kompressionsstrümpfe e.V. (Quality Seal Association for Medical Compression Stockings) in Germany,[78] there may be considerable variation between the sizings of different manufacturers. Therefore it may be prudent for distributors and physicians who dispense stockings to carry multiple brands in the event that some patients experience a poor fit with certain makes. It may be estimated that 80% to 90% of patients seeking treatment for venous disease can be fitted with some form of ready-made stockings.

CUSTOM-MADE STOCKINGS

Made-to-measure stockings are custom-made according to the length and circumference measurements of the patient's leg. Adjustments are made either by hand on flat-knitting machines, in which shaping is achieved by altering the width of the knit, or by machine in a circular-knit manner in which changes in the pressure and width are achieved by varying the tension of the weft and stitch size. Flat-bed knitted hosiery comes with a seam. Round-knitted stockings are seamless and can also be made to measure. For a good fit it is essential to get precise and accurate measurements of the patient. Custom-made garments will fit better than ready-to-wear. Several companies provide garments from woven fabric for patients of all body shapes and required compression levels.

Made-to-measure stockings should be prescribed under the following circumstances:

- For very large or small patients
- When there is a significant difference in the circumference between the right and left leg
- For the maintenance therapy of patients with lymphedema
- For patients with extreme deformities of the leg (e.g., 'champagne-bottle legs')
- When a special pressure gradient is required (e.g., increased pressure over the thigh)
- When the measurements of ready-made stockings do not correspond to the leg length and girth measurements of a patient (i.e., when there is a difference of more than 3 cm between the lower leg length and the standard 39-cm length used for ready-made stockings); this may not be applicable for all brands of stockings
- For patients who have a very large instep-to-heel circumference (i.e., one that is more than 12 cm larger than the smallest ankle circumference)[1]

PRESCRIPTION OF A STOCKING

Individual measurement of a compression stocking should be taken at the beginning of the day, when the leg is less edematous, in the standing position. The most important measurement location is at the ankle, where a graduated stocking exerts the greatest degree of pressure. Therefore, all ready-made stockings include the ankle as one of the measuring points. Measurements taken at various levels of the calf and thigh must also conform to the manufacturer's guidelines. If a calf or thigh diameter does not conform to the manufacturer's guide for that particular stocking size then a made-to-measure stocking should be used.

Recently a biometrical scanner combined with an 'intelligent ordering system' was introduced by the Bauerfeind company. Instead of measuring the leg circumference with a tape, digital photographs of the legs are taken against a structured background, which are then sent to the manufacturer for the production of a stocking to fit that individual.

A common error made by the physician attempting to avoid prescribing a made-to-measure stocking is to prescribe the next larger size of a ready-made stocking. This results in a lower pressure being exerted at the ankle; in addition, the counter-pressures are altered because the wider stocking is designed at all levels for different leg measurements. Proper measurement and fit of a compression stocking becomes increasingly important when higher compression classes are

required. Therefore made-to-measure stockings have particular application for compression classes above 40 mmHg, for example as used in lymphedema.[126]

The physician should note that differences of more than 15 mmHg could occur among different stocking manufacturers, not only by virtue of different types and strengths of elastic materials, but also by different methods of measuring the stocking to fit the leg. Some manufacturers provide only three ankle sizes of stockings, whereas others provide up to six or more ankle sizes. Thus there may be a large variation of applied pressure for different-sized legs among different stocking brands, as dictated by Laplace's law.

All manufacturers of compression stockings use a 'standard' wooden leg (the so-called Hohenstein leg), whose circumferences in each segment are circular.[1] This is also true for the B segment (see Fig. 6.11) representing the ankle area, which is taken as the reference point for indicating the pressure class of the stocking. This B segment is the area in which the crosssection through a human leg shows the most extensive deviations from a circle.[85] Here the radius varies dramatically, being small over the malleoli and the Achilles tendon and even 'negative' between the inner ankle and the tendon. According to the law of Laplace, the compression pressure will therefore also change considerably, which explains the discrepancy between in vitro and in vivo measurements of interface pressure especially in this segment. However, a good correlation could be shown between the pressure ranges declared by the producers of high-quality stockings and the actual interface pressure exerted on the human leg.[127]

STOCKING LENGTHS

Up to six styles of medical compression stockings are available, depending on the manufacturer: knee-length, mid-thigh or high-thigh pantyhose or leotard, one-legged pantyhose, thigh with waist attachment and maternity pantyhose. Some manufacturers have open-toed kinds available for some of the types, especially the single leg, high-thigh variety. Regardless of the style, most stockings are available in three lengths: knee length, mid-thigh and high-thigh. According to the standardized figure, a knee-length stocking is designated as 'AD', a mid-thigh stocking as 'AF' and a (high) thigh-length stocking as 'AG' (see Fig. 6.11).

There are specific indications and contraindications for the various stocking lengths. Knee-length stockings should be prescribed only if the 'C' circumference is approximately 2 cm greater than the 'D' circumference; otherwise it will have no hold on the leg and tend to slide down. In addition, if the 'A to D' length is too great, the excessive length interferes with movement at the knee. The patient usually folds the excess stocking down below the knee; this doubles the counter-pressure at point 'D' and thus may reverse the 'graduated pressure'. Likewise, if the 'A to D' length is too short, the patient will try to stretch the stocking beyond its natural point, thereby decreasing the effective circumferential pressure and thus defeating the purpose of wearing the stocking.

In patients with marked adiposity of the knee region, the upper edge of the stocking may produce skin bulging, which may be particularly bothersome on the inner aspect of the knee. In these cases it may be necessary to fit the patient with a mid-thigh stocking. Alternatively, tumescent liposuction of the bulging knee corrects this deformity and is a simple procedure.

To prevent or treat ankle edema or skin changes caused by CVI the majority of patients can be fitted with below-knee, ready-to-wear stockings.

PRESSURE GRADIENT

Graduation is not only a result of the leg circumference, it can also be added to a circular knit by altering the knitting construction from the ankle to the knee or thigh to reduce the tension from distal to proximal. Some studies have demonstrated that a pressure drop of 26% to 59% from the ankle to the thigh is desirable with graduated medical stockings.[128–130]

As previously explained, the postulated graduated pressure was recently questioned. The measurement of an ideal pressure profile on the human leg depends on several factors, especially on the shape of the measuring point.[131]

It has to be considered that the pressure gradient postulated for compression hosiery is based on pressure readings of the smallest segment of a wooden leg model in the laboratory (B-point) presenting a circular cross section. Owing to the fact that the human leg is flat or even concave at the corresponding medial ankle region, in vivo measurements at this point frequently show lower pressure values than at the B1-point 12 cm above (see Fig. 6.17).

There are many situations for which the dogma of a pressure gradient is unrealistic. Because of the changes of segmental circumferences and local curvatures that happen with every step, the local dynamic pressure fluctuations under a compression device may be very complex and pressure peaks may occur that are higher at a proximal level than distally. In general the necessity for a continuous gradient of pressure maximal at the ankle and diminishing up the limb is founded more on theory than on an evidence base.

New stockings have been introduced that exert a higher pressure over the calf than over the ankle area. These are easier to put on and are advocated not only in sports,[132] but also in venous patients.[133]

PROPER FIT AND POSITION

Because the efficacy of a compression stocking is directly related to a proper fit, its adherence to the leg to prevent vertical movement is important. Pantyhose stockings are the most expensive method to ensure the stocking remains in place by virtue of the attachment at the panty line. The only disadvantages are increased constriction on the lower abdomen and increased temperature and moisture retention in the groin generated by an additional undergarment.

With single-leg, thigh or calf stockings, various inexpensive methods such as adhesive tape, glues, clips or garter belts, serve to ensure proper positioning. Disadvantages of tapes or glues include the pain on removal of tape from hairy legs and the irritation of allergy caused by the adhesive portion of the tape. Various types of clips that secure the stocking to underwear are available. Disadvantages include tearing or stretching of the undergarment and cutaneous pressure and/or irritation by the clip itself.

Garter belts comprise a more elegant, practical and perhaps fashionable method for ensuring correct stocking placement. These belts may be built into the stocking as a

waist attachment or purchased separately in various styles. Disadvantages include the digging in of the belt into an obese thigh if the belt is too narrow and the possibility of the garter itself producing a tourniquet effect.

Finally a new type of silicone top-band on high-thigh- or mid-thigh-length stockings is available from many manufacturers of graduated compression stockings. It keeps the stocking in place without the disadvantages of glues, clips or garter belts.

DONNING MEDICAL COMPRESSION STOCKINGS

Before donning the stocking, the patient should be advised of the following considerations. Hand jewelry should be removed to avoid damaging the stockings. Fingernails should be smooth and relatively short. Rubber gloves are helpful and recommended both to prevent damage to the stockings from long fingernails and to grip the stocking. Talcum powder may be applied to the leg or a light Perlon pantyhose or stocking may be worn under the compression stocking to create a smoother leg over which to slide the stocking. Finally, satin foot 'socks' and foam-rubber foot pads provided by the stocking manufacturer are helpful in getting an open-toe stocking over the ankle (Fig. 6.25).

After preparing the foot and leg, turn the stocking inside out with the foot from the heel to the toe tucked into the stocking (Fig. 6.26A). Stretch the foot opening with the fingers or thumbs of both hands and pull the stocking foot over the foot up to the instep. Draw the stocking upward over the heel until pulling becomes difficult (Fig. 6.26B). Push the fold that forms across the instep and heel of the stocking over the heel. Finally pull the stocking up in sections, always remembering not to pull it over long distances all at once, but to proceed in small steps (Fig. 6.26C). When the stocking is applied without folds over the calf, the thigh

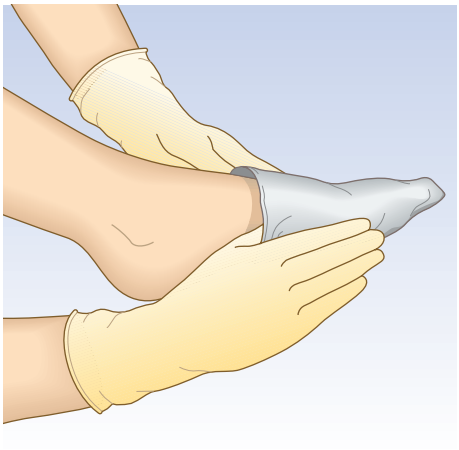

Figure 6.25 Foot sock, which is helpful for getting an open-toed stocking over the ankle.

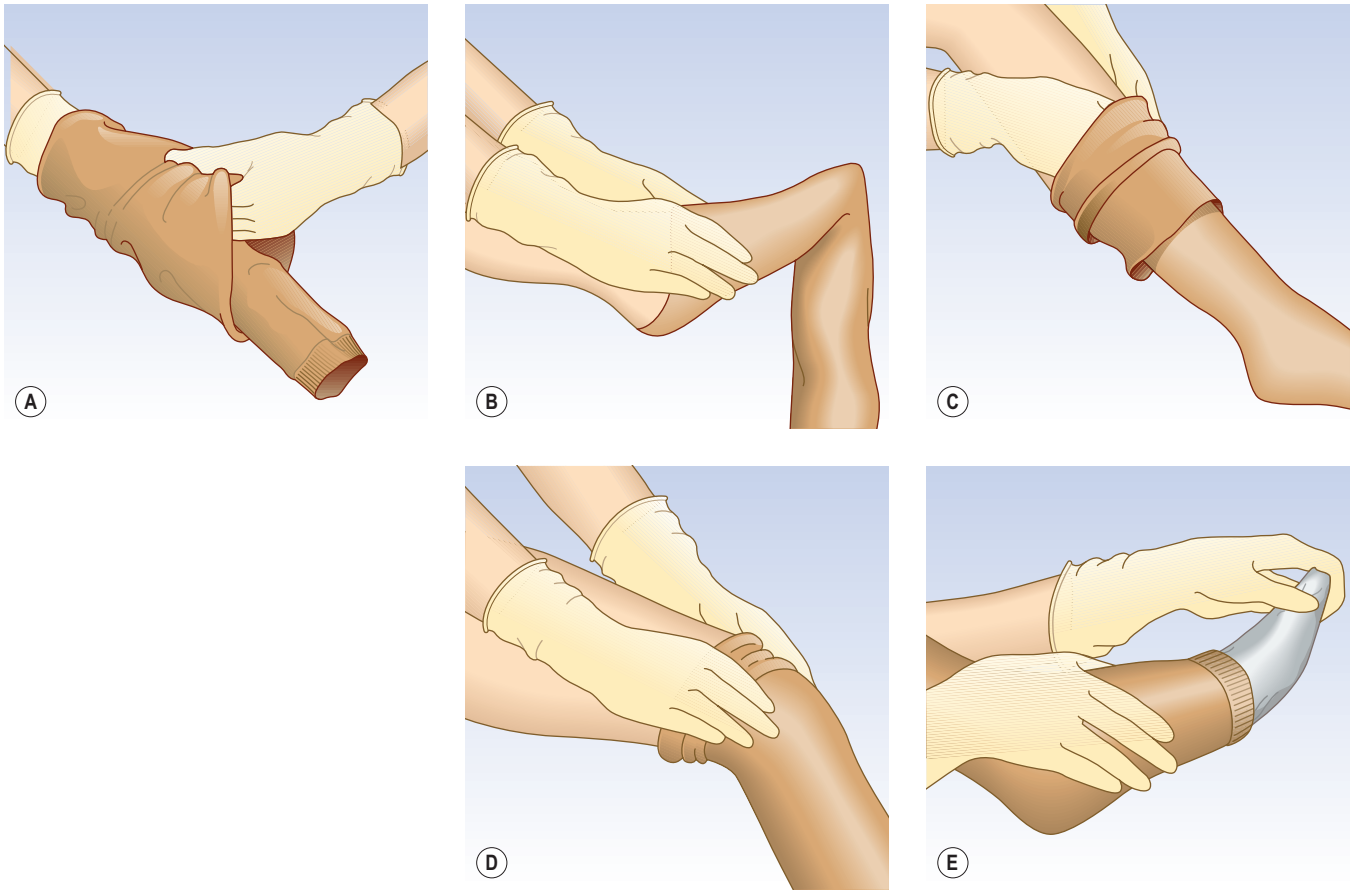

Figure 6.26 Schematic diagram illustrating the proper method for donning the compression stocking. **A,** Turn the stocking inside out. Tuck in the foot from the heel to the toe. **B,** Using both hands, pull the stocking over the foot up to the instep, drawing it upward over the heel. **C,** Continue pulling the stocking up in small sections. **D,** Pull the thigh section over the knee. **E,** Remove the foot sock. (Courtesy Juzo, OH.)

section is then pulled over the knee (Fig. 6.26D). Finally, remove the foot 'sock' (Fig. 6.26E).

It is very important for the physician or nurse to instruct and observe the patient applying the stocking. Compression is effective only when a stocking has been fitted correctly and is applied correctly. If the patient encounters difficulties in applying the stocking because of age, obesity, arthritis, etc., arrangements should be made to have an experienced helper on hand when needed. It is important to note that if patients have difficulty in applying higher-compression class stockings, wearing two layers of lighter stockings, one over the other, should be helpful. As discussed previously, the compressive effects of stockings are additive and stiffness increases exponentially. Zippers in stockings (available on some calf-length stockings) also make donning them easier.

Donning devices significantly improve the ability of elderly patients with CVI to don compression stockings successfully. However, there are differences in user-friendliness among the devices.[134]

An application aid for compression stockings is available from various compression stocking companies. These devices are cleverly-designed simple metal supports that make donning compression stockings easier, even when the stockings must be placed over compression padding (Fig. 6.27). The compression stocking is pulled over the half-circle bracket located on the front (open) side of the device so that the heel portion of the stocking is 2 to 3 inches (about 5–7.5 cm) below the top on the half-circle bracket. The heel portion is positioned facing the user and the toe of the stocking is facing toward the open side of the device. The patient's foot is then placed into the foot of the stocking until the foot is completely on the floor or until the heel is in place. The metal grips on either side are then used to pull the rest of the stocking onto the leg. Once the stocking is above the calf, the device may be pulled away and the remainder of the stocking then can be easily pulled up.

The Doff N' Donner device is an ingenious new donning aid (Sigvaris). Patients may be referred to web pages that also offer demonstrations on YouTube (http://www.supporthosestore.com/Categories/249-Patient-Assistance-Donning-Aids.aspx).

PATIENT COMPLIANCE

Noncompliance is the most important factor limiting the use of compression stockings. The reasons for noncompliance can be grouped into two interdependent major categories: (1) wear-comfort factors and (2) the intangible sense of restriction imposed by the stockings.[135]

In addition to a measurable improvement in multiple parameters of CVI, a study on symptoms of CVI has demonstrated an improvement after 1 and 16 months of wearing graduated compression stockings.[136] In this study 112 patients with CVI and significant CEAP classification [clinical state (C), etiology (E), anatomy (A) and pathophysiology (P)] were treated with a 30- to 40-mmHg graduated compression stocking. Patients rated on a five-point scale the degree of swelling, pain, skin discoloration, cosmetic problems, activity tolerance, depression and sleep problems caused by CVI. There were statistical improvements in all scores at 1 month, with continued improvement at 16 months. Most importantly 70% of patients were still wearing their stockings at 16 months, demonstrating their comfort over the symptoms of CVI. This is in contrast with the impression of poor compliance and indicates improved comfort with modern compression stockings. Similar degrees of improvement were also demonstrated in 31 patients with CVI wearing low- or medium-grade stockings.[137] There was no significant difference in the symptoms of these patients despite the difference in graduated compression. Therefore patients who cannot tolerate high compression classes should be fitted with lower class stockings. Mild compression is better than no compression.

Patients' compliance in wearing their compression stockings is frequently underestimated by the physicians. In a Canadian survey physicians estimated that 50% of patients after DVT would wear compression stockings daily, 30% occasionally and 20% would never wear them.[138] In this

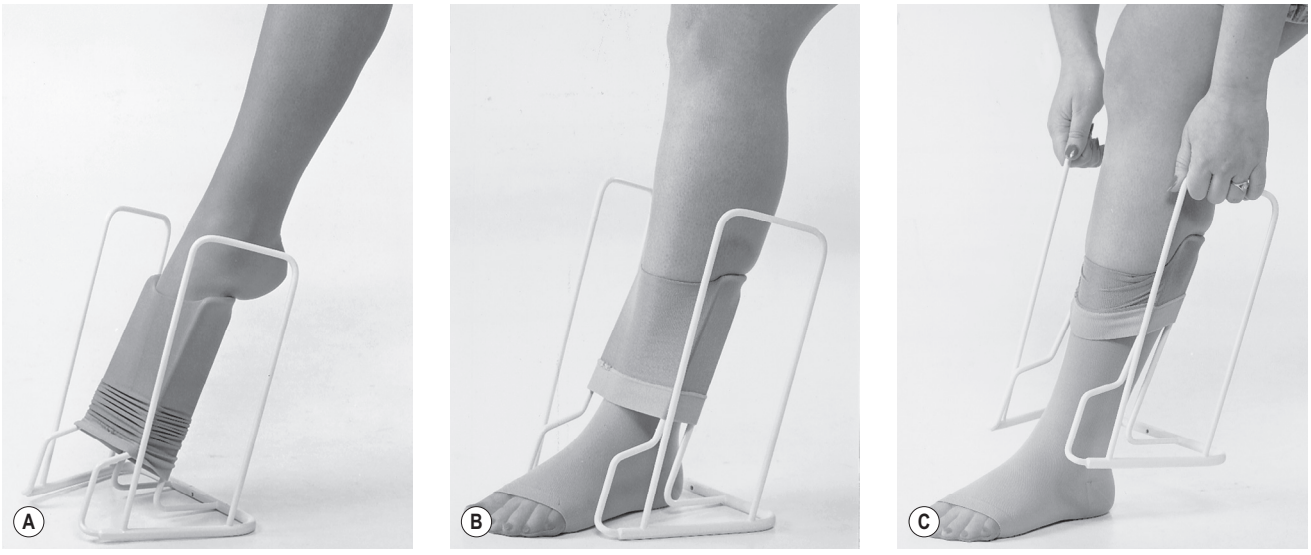

Figure 6.27 Medi Butler. **A,** After putting the compression stocking on the bracket, insert the foot. **B,** Continue until the foot is completely on the floor and the heel is in place. **C,** Pull up on the metal side grips until the Butler is above the calf, then remove it and continue until the stocking is in place. (Courtesy Medi USA, Whitsett, NC.)

study the most important reasons for noncompliance were thought to be discomfort (74%), hard to put on (71%) and high costs (53%). When the patients were asked, daily use was reported by 87%, once or twice weekly by 3%, less than once a week by 6% and never or rarely by 4%. In a European follow-up of patients, it was shown that there is less swelling of the thrombosed leg when the stockings are still being worn 2 years after DVT compared with patients who stop compression therapy before this time, and that most of those patients who still suffer from pronounced residual swelling use them.[139]

CARE OF THE MEDICAL COMPRESSION STOCKING

Because these stockings are worn on a daily basis in extremely close contact with the skin, they are subjected to considerable wear and tear. The chemical stresses from sweat, soaps, creams and body oils, in addition to the physical stresses of the nearly continuous stretch and relaxation with movements of the leg, result in a gradual decline in the compressive effect of the stockings. This decline was measured in class II and class III stockings. Flat-knitted and round-knitted European class II stockings showed a mean pressure decrease from 29.3 to 26.5 mmHg after 3 months of daily wear. Strong stockings had a similar rate of decreasing pressure from 47.5 to 44.2 mmHg.[140] Therefore compression stockings have a limited effective life. To ensure that they last as long as possible, special care is required.

The first lesson in proper stocking care is to avoid excessive trauma. Therefore rubber gloves should be worn when the stocking is put on to avoid tearing the threads with fingernails. Likewise, toenails should be trimmed and hard calluses, verrucas or other rough spots on the feet should be softened or removed. Also the stocking should be eased onto the leg, not pulled.

The stocking should not come into contact with ointments, creams, stain removers or other solvents, especially if it is composed of rubber threads. These substances can damage the fine elastic yarns by causing them to swell, thus reducing the strength and elasticity of the fabric. Some chemical components of topical steroid creams (chlorocresol and glyceryl mono-oleate) may have a negative influence on Lycra yarns, causing a decrease in elasticity and also discoloration.

Regular and careful washing is necessary to maintain the elastic properties of the fabric because of the harmful effects of sweat, skin oils and environmental dirt that accumulate in the fabric while the stocking is worn. These substances will penetrate deeper into the elastic yarns if allowed to remain on the fabric for long intervals between washings. Environmental dust is damaging to the yarn by virtue of its abrasive action when the elastomers are stretched and relaxed.

Ideally compression stockings should be washed every day. In fact, a study of six stocking types machine washed 15 times at 40°C demonstrated no decrease in resting pressure or elasticity.[98] Therefore, if long-term use is required, it is best to provide the patient with two pairs of stockings that can be alternated between washings. Most compression stockings incorporating spandex can be machine washed on a fine-gentle cycle with warm (40°C) water. This gives a better cleansing action than hand washing. (Consult the manufacturer's guidelines for specific instructions.) Gentle detergents without bleach or alkali are best. Gentle spinning after the washing cycle is harmless to compression stockings and quickens the drying process. Rather than being hang-dried from a line, compression stockings should be laid flat on a drying rack or towel. Low heat may be used in the drying process with most brands of compression stockings. With normal wear and proper care, compression stockings should have an effective life of 4 to 6 months.

If compression stockings are worn intermittently (during airplane flights or only after sclerotherapy or surgical treatments), they should be stored in a cool place after washing. Exposure to heat for prolonged periods can degrade the yarn and eliminate compression.

DANGERS, COMPLICATIONS AND CONTRAINDICATIONS

The most important caveat with any kind of compression therapy is the presence of an arterial occlusive disease that may be unrecognized.

Arterial ischemia can occur if the external compression pressure exceeds the intraarterial perfusion pressure. This is of concern particularly in the presence of venous leg ulcers during treatment. Two studies estimated the frequency of unsuspected arterial insufficiency among patients with chronic leg ulcers at 21%[141] and 31%.[142] Callam et al[143] surveyed consultants in general surgery in Scotland regarding their experience with compression therapy in the previous 5 years and found 147 cases of cutaneous ulceration caused by compression. Compression bandages accounted for 74 of 147 cases reported, with elastic and antiembolism stockings accounting for 36 and 38 cases, respectively. Also eight patients were reported who required amputations of the digits or feet as a direct result of arterial ischemia caused by an excessively tight compression bandage or stocking. It has been estimated that up to 50% of patients over 80 years of age with leg ulcerations also have significant arterial disease.[141] In a survey of 1416 venous reflux ulcers, 13.6% had moderate and 2.2% had severe arterial disease.[144]

Consequently the physician should always check arterial pulses before and after applying a compression bandage or fitting a compression stocking, especially in the elderly. Low-stretch bandages offer more safety in patients with arterial disease because these bandages can be applied with a very low resting pressure, achieving still-effective pressure peaks during ambulation. The natural history of such patients presenting with mixed ulceration has been described by Marston et al.[145] It was demonstrated that mixed, arterial–venous ulcers may heal without arterial therapeutic interventions, but healing time is prolonged in comparison with purely venous ulcers. This is in accordance with experimental findings reported by Mosti et al, that showed an increase in arterial inflow in patients with an ankle–brachial pressure index (ABPI; the ratio of ankle blood pressure to brachial blood pressure) between 0.5 and 0.8 as long as the pressure of the nonelastic bandages did not exceed 40 mmHg and at the same time showed an improvement of the ejection fraction of the venous calf pump.[58] Doppler ultrasound allows measurement of arterial pressure, which has to be done in every case before a high-pressure bandage is applied for the first time. An ABPI below 0.5 corresponds to critical

ischemia and is considered to be a contraindication for compression.[1,81,117]

Sensory disturbances should be a warning for reevaluating the degree of compression in the posttreatment period (see Chapter 8). If the patient suffers from diabetic neuropathy, minimal pressure damage to the skin may stay unrecognized and may be the starting point of skin necrosis when the bandage or the stocking is not removed.

When firm compression bandages are applied to both legs, a considerable volume of blood can be shifted toward the heart.[146] This can lead to an increase of the preload of the heart and affect cardiac output. Therefore severe decompensated heart failure should be considered as a contraindication for bilateral firm bandages.

CLINICAL INDICATIONS FOR COMPRESSION THERAPY

A review of all randomized controlled trials (RCTs) assessing the clinical efficacy of compression in venous and lymphatic disorders of the lower extremity has been published.[147]

Compression is the basic treatment modality in patients with chronic venous insufficiency; however, it is still underused.[148]

THE USE OF COMPRESSION ALONE IN PREVENTING VARICOSE AND TELANGIECTATIC LEG VEINS

Although clinical evidence is still lacking that compression is able to reduce a progression of venous disorders, some theoretical considerations support its use.

The cause of varicose veins is unknown. Several data support the assumption that the primary lesions leading to circumscribed dilation of the venous wall are defects at the molecular level in the vessel wall that result in a derangement of the collagen fibers and of the matrix. These anatomic abnormalities cause a disturbance of the hemodynamics, promoting the progression of the disorder.

Varicose and telangiectatic leg veins progress when the volume and subsequent pressure of blood within the vessel lumen exceed the vessel's capacity to enclose that volume. The deep venous system, by virtue of its position within a musculofibrous sheath, can accommodate such changes. Major parts of the superficial venous system are not enclosed in a rigid sheath. Thus to accommodate the increase in flow the vessel lumen increases in diameter. When this increase in diameter is supraphysiologic, the one-way valve cusps no longer meet and they become incompetent. This causes excessive pressure, with blood volume routed into smaller branching vessels, producing an abnormal dilation. This hemodynamic explanation of varicose vein development is best regarded as a vicious cycle (Fig. 6.28).

The primary method of reversing the changes just mentioned is to normalize the quantity of blood within the vessel lumen. This can be accomplished by sealing off incompetent perforator veins or junctions between the deep and superficial systems through surgical ligation, endoluminal radiofrequency closure or sclerotherapy-induced endofibrosis. Compression of the leg provides a sheath around the vessel so that blood flow will be propelled upward toward the heart instead of laterally against the vein wall. Bandages, and to a lesser degree graduated compression stockings, provide the external support needed to produce this effect.

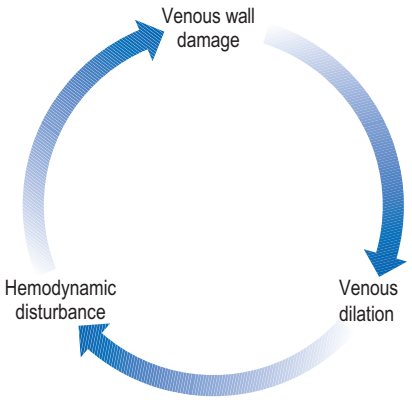

Figure 6.28 Vicious cycle of varicose veins.

Externally supporting untreated varicose veins will narrow their diameter and decrease retrograde blood flow.[149] External pressure may also provide a normalization of cutaneous blood flow. In support of this theory, improvement in cutaneous oxygenation has been demonstrated with the use of compression in patients with venous stasis after only 10 to 15 minutes.[150]

The most important indication for compression in patients with varicose veins is the relief of aching symptoms with all classes of compression stockings.[36,37,121] This has also been shown in an RCT in patients with symptomatic varicose veins of pregnancy.[151] Patients with postphlebitic limbs find that the 30- to 40-mmHg and 40- to 50-mmHg stockings control edema and symptoms better than do 20- to 30-mmHg stockings. Graduated compression stockings of 20 to 30 mmHg are best used for conservative treatment of symptomatic varicose veins and stronger stockings may best be used for conservative treatment of CVI (see previous discussion).[47]

There are no RCTs available showing that compression is able to prevent the progression of venous disease.[147,152]

RATIONALE FOR THE USE OF COMPRESSION IN VARICOSE VEIN SCLEROTHERAPY

The basic concept of Fegan's 'empty vein technique' is to keep the blood clot after injection of the sclerosing agent as small as possible.[153–155] Postsclerotherapy compression primarily eliminates a thrombophlebitic reaction and substitutes a 'sclerophlebitis' with the production of a firm fibrous cord.[156] Compression serves at least six purposes:

1. Compression, if adequate, may result in direct apposition of the treated vein walls to produce a more effective fibrosis (Fig. 6.29).[155,157,158] Therefore weaker sclerosing solutions may be used successfully.
2. Compression of the treated vessel decreases the extent of thrombus formation, which inevitably occurs with the use of all sclerosing agents[158,159]; this may decrease the subsequent risk of recanalization of the treated vessel.[153,154]
3. A decrease in the extent of thrombus formation may also decrease the incidence of postsclerosis pigmentation[158–162] (see Chapter 8).

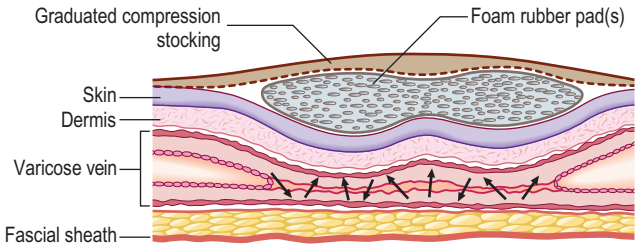

Figure 6.29 Schematic diagram demonstrating idealized compression of a treated varicose vein segment using foam rubber pads under a compression stocking. (Redrawn from Wenner L. Vasa 1986;15:180.)

4. The limitation of thrombosis and phlebitic reactions may prevent the appearance of telangiectatic matting[160] (see Chapter 8).
5. The physiologic effect of compression is to improve the function of the calf muscle pump, which is accompanied by subjective improvement.[163]
6. Compression stockings increase blood flow through the deep venous system.[22] This acts to rapidly clear any sclerosing solution that has inadvertently made its way into the deep venous system and thus prevents damage to valves in the deep venous system.

HOW MUCH PRESSURE IS NECESSARY FOR VARICOSE VEINS?

The optimum interface pressure required to compress the varicose vein after sclerotherapy has yet to be defined.

Initial compression measurements taken during manual wrapping of the leg with Crevic crepe bandages by multiple surgeons using the technique of Fegan[153] show an average between 20 and 100 mmHg with a mean of 54 mmHg at calf level.[128] In addition, experimental varicose vein models have shown this level of compression to cause a reduction of the vessel lumina by 94%.[128] Thus the classic technique for compression sclerotherapy is theoretically sound.

The physician should consider the posture of the patient when prescribing compression stockings. If higher compression pressures are used (e.g., through the use of double stockings), care must be taken to inform patients to remove the outer stocking when not ambulatory. A sustained external pressure above 30 mmHg with elastic material applied to the leg of supine patients is hardly tolerated and may impair peripheral blood circulation and skin temperature.[108] Patients may perceive this as achiness in the ankle area that occurs during sleep and resolves with walking after 30- to 40-mmHg compression stockings have been worn to bed following sclerotherapy.

By having compression of 30 to 40 mmHg at the ankle, the compressive strength at other locations on the leg may be between 10 and 20 mmHg, depending on the site and amount of underlying bone, adipose tissue and muscle.[33] Experimental models have demonstrated that external pressures of 10 to 15 mmHg reduce the capacity of the underlying varicose vein in the upright position only minimally.[22,42,128,164] Therefore with the use of this degree of compression one does not attempt to completely empty intravascular blood from the treated veins.

LOCAL PADS AND ROLLS

To occlude a vein completely, the external pressure should exceed the intravenous pressure. In the standing position, the intravenous pressure is about 70 mmHg at the lower leg and about 30 mmHg at thigh level, depending on the body height. The pressure exerted by a compression stocking at thigh level is about 10 to 15 mmHg, which is too low to occlude the vein.[22,119]

By applying small rolls with different materials over the injected vein, this difficulty may be overcome, as demonstrated in Figure 6.30. When the injected vein is covered by a small rubber roll, a thigh-length compression stocking with a pressure of 15 to 20 mmHg may compress the vein even in the standing position.

The increase of pressure in a localized area by using narrow foam rubber pads under compression stockings has been described by several authors.[165–170] Foam Sorbo pads (STD Pharmaceuticals, Hereford, UK) (Fig. 6.31) are widely used in Great Britain.[156] A new wedge-like rubber foam device (postop device; Medi, Bayreuth, Germany) has been developed specifically for compressing the great saphenous vein on the thigh (Fig. 6.32) and a very satisfying outcome after stripping operation was reported.[48]

Different types of pads do provide different pressures. A study by Hirai et al[168] demonstrated pressure over the anterior tibia with a moderate-pressure stocking to be 20.3 mmHg without pads, 59.1 mmHg with a cotton pad or gauze pad, 73.5 mmHg with a foam rubber pad, and 76.5 mmHg with a hard rubber pad.

In addition to producing an increase in cutaneous pressure, their use, especially in the popliteal region, has decreased the incidence of abrasions from pressure stockings and tape, thereby improving patient comfort. In one physician's practice,[169] foam rubber pads have been noted to produce minor skin irritation (erythema) in up to 28% of patients. Another device for increasing local pressure is Molefoam (Scholl, UK). This product comes in sheets of 7-mm thickness that may easily be cut to size. The adhesive side is covered with paper that is peeled away. Molefoam has a decreased incidence of local irritation (14% versus 28% for Sorbo pads). One study that compared the efficacy of sclerotherapy with Sorbo versus Molefoam showed no difference between the two groups.[169]

Another clever method for increasing local pressure is the use of rolls of cotton wool (Fig. 6.33).[170] The roll is secured with a nonelastic material. This method is advantageous for compressing long lengths of veins. A study of 100 patients (120 legs) with varicose veins treated with sclerotherapy, followed with long cotton wool rolls under compression stockings, found good results in all patients.[170] Compression was given by a combination of European class I (daytime and nighttime) and class II (daytime only) compression hosiery. Only three patients developed intravascular blood clots. The mean pressure under the pads was 84 mmHg (68–122 mmHg). In this study, cotton rolls and class I stockings were removed at 1 week and patients continued to wear class II stockings for an additional 3 weeks.

Local padding of the injected vein may considerably improve the emptying of the vein. A satisfactory compression of the veins by compression stockings may be a problem because of a markedly low pressure especially in the thigh

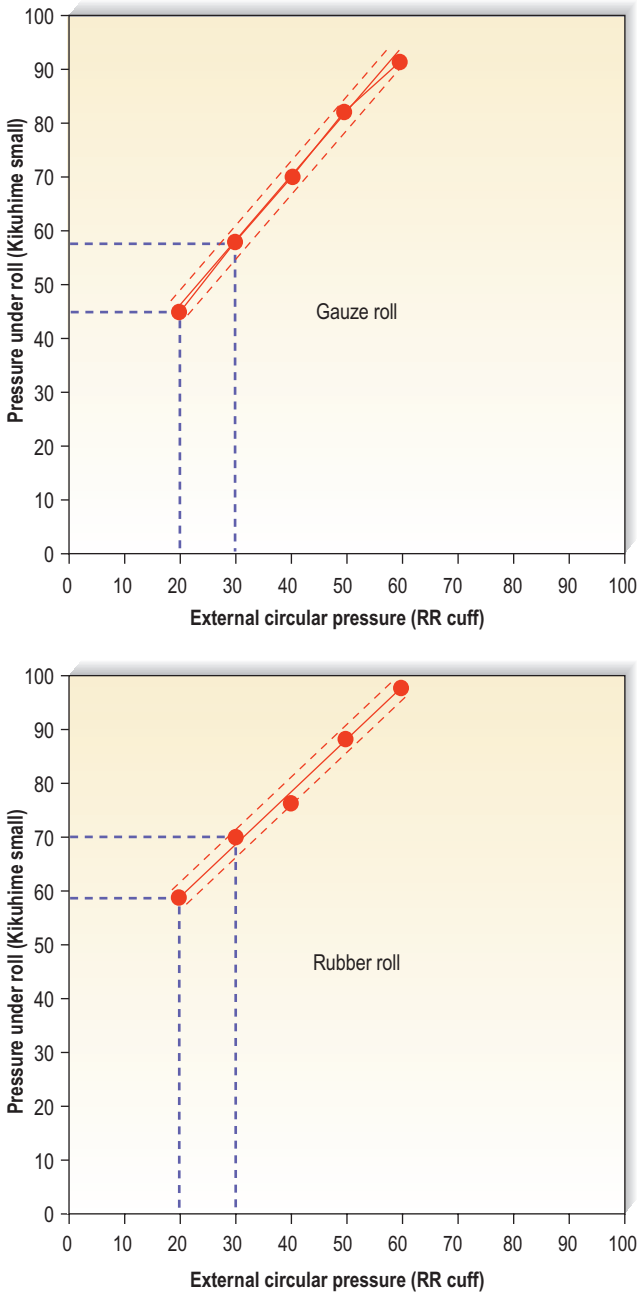

Figure 6.30 A blood pressure cuff ('RR cuff') is applied on the thigh and inflated in a stepwise fashion from 20 to 60 mmHg (*x axis*). The local pressure over the great saphenous vein is measured using a small Kikuhime pressure transducer (MediTrade, Soro, Denmark), which is placed under a 2-cm-thick gauze roll *(top)* and then under a rubber roll with the same dimension *(bottom).* With the soft padding material *(top),* the local pressure over the vein *(y axis)* can be doubled; with the rubber pad *(bottom)*, a cuff pressure of 20 mmHg will increase the local pressure under the pad close to 60 mmHg.

region. In such cases, compression bandages with adhesive material applied over the local pressure rolls may be a good alternative.[48,171]

HOW LONG SHOULD COMPRESSION BE MAINTAINED?

In addition to the degree of compression needed to effect optimal sclerotherapy, the duration needed to maintain

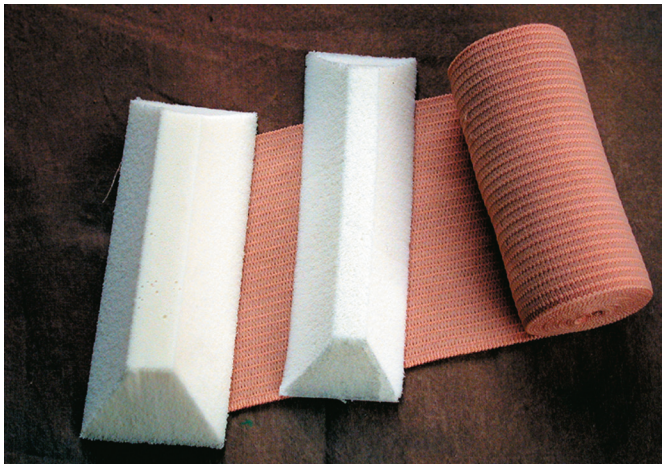

Figure 6.31 Foam Sorbo pads. (STD Pharmaceuticals, Hereford, UK.)

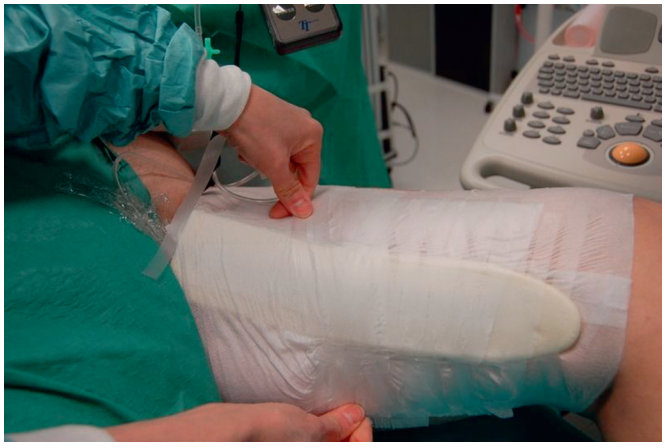

Figure 6.32 A wedge-like foam pad (Postop device, Medi, Germany) is attached to the thigh by crosswise taping after endovenous laser ablation of the great saphenous vein. (Courtesy M. Lugli and O. Maletti, Modena, Italy.)

compression is also open for debate.[172] The classic technique for sclerosis of varicose veins described by Fegan[153,154] and used by Hobbs,[173] Doran and White[174] is to continue compression for 6 weeks. This period was not arrived at randomly but through multiple histologic examinations of sclerotherapy-treated varicose veins at intervals of 30 seconds; 1 and 5 minutes; 12, 24 and 36 hours; 6, 8, 12 and 14 days; 3, 4, 7, 10, 16 and 20 weeks; and 0.5, 1 and 5 years.[175] Fegan concluded that organization of the fibrous occlusion required at least 6 weeks. However, a randomized study found no difference in clinical results at 2 years when compression was maintained for 3 weeks as compared with 6 weeks.[176] Thus many phlebologists recommend a maximum of 3 weeks of compression for varicose veins.

A review on RCTs regarding this question was published in 2006.[145] Studies have shown that compression bandages maintain significant compression for only 6 to 8 hours while patients are ambulatory and lose up to 50% of their initial compression pressure in recumbent patients at 24 hours,[165] thus questioning the rationale for prolonged use. After phlebectomy, bandaging for 1, 3 and 6 weeks did not show a difference in efficacy at 2 months postoperatively.[177]

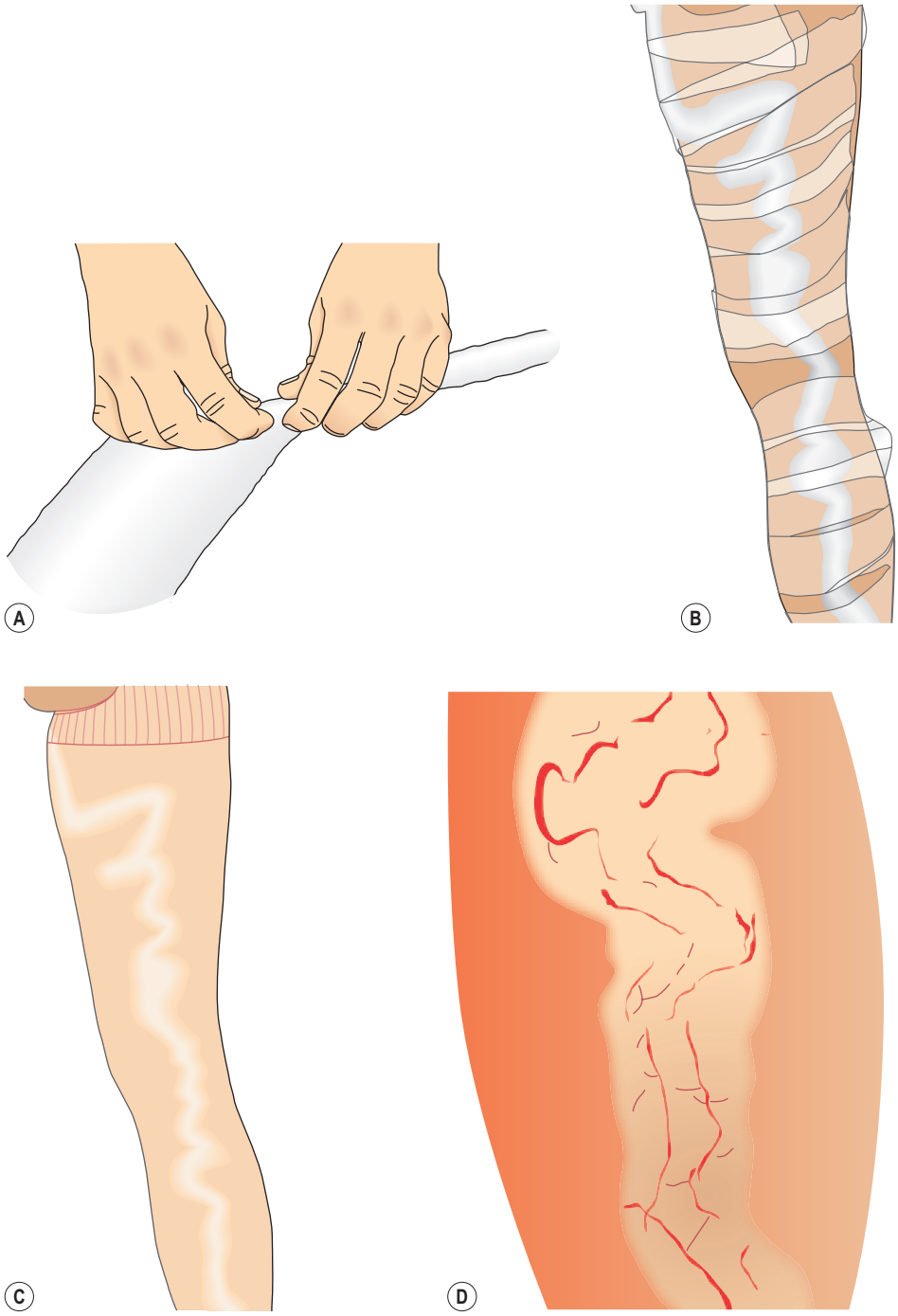

Figure 6.33 **A,** A flat piece of cotton wool is twisted into a firm roll with a diameter of approximately 2 cm. **B,** The cotton wool roll follows the course of the varicose vein and is secured to the skin with 5-cm-wide Leukopore bandage (BSN-Jobst, Charlotte, NC). **C,** Appearance after application of a 30- to 40-mmHg compression stocking. **D,** Appearance after stocking and cotton wool are removed in 2 weeks. Note compression of both the varicose vein and overlying tissues.

However, in this study compression with an elastic bandage was given to all groups for only 1 week, with the variable being a Tubigrip tube gauze (Seton Products, Montgomeryville, PA) applied only during the day, which provided minimal compression. Finally, a randomized study of the use of compressive bandages in the treatment of varicose veins with a 3-month follow-up was reported.[178] The study demonstrated through both subjective and objective findings that 3 days of compression equaled the results at 6 weeks. This study used a Coban bandage dressing that may not maintain effective pressure beyond 8 hours.

A corollary to the amount of time necessary to effect adequate compression is whether it is necessary to continue compression while the patient is lying down or asleep. The authors recommend that some degree of compression be maintained at all times to ensure optimal contraction of

the treated vein. In fact, studies have demonstrated that veins become more distensible during sleep.[179] This has been postulated to occur as a result of respiratory factors or emotional factors during dream states. In addition, thrombogenesis after the sclerotherapy-induced injury to vascular endothelium is maximal 8 hours after treatment, which may be when the patient wishes to lie down (see Chapter 8). Compression here speeds deep venous blood flow to prevent thrombosis in the deep system after treatment. Finally it may be impractical for patients to remove and reapply the stocking at night if they must get out of bed for any reason. Therefore if a high degree of compression is required after treatment, the use of double stockings appears practical, because one of the stockings can be removed while the patient is lying down.

Some anatomic sites necessitate inventive measures to effect compression of the underlying varicose veins. Perhaps the most difficult area to compress on the leg is the vulvar region. The authors have found the 'vulvar pad' described by Nabatoff,[180] and the V2-Supporter (Prenatal Cradle Inc, Hamburg, MI.) described by Ninia,[181] to be useful in this area.

There are colleagues who do not perform any compression after sclerotherapy of large veins, especially in France.[182] Based on a comparative study the general recommendation of using compression after foam-sclerotherapy of the great saphenous vein as a routine has recently been questioned.[183] It has to be emphasized that in this study French compression class II stockings were used corresponding to a pressure range between 15 and 20 mmHg on the leg (around 10 mm Hg at thigh level). This pressure is much too low to narrow veins in the upright position.

SCLEROTHERAPY OF SMALL VEINS

RATIONALE FOR THE USE OF COMPRESSION IN THE TREATMENT OF TELANGIECTASIAS

Although compression sclerotherapy is now standard practice in the treatment of varicose veins, its use in the treatment of smaller abnormal leg veins and telangiectatic 'spider' veins has never been adopted uniformly. Many European colleagues do not use any kind of compression after sclerotherapy of small veins.[182] However, the same justification for the use of compression in larger veins should hold true for its use in smaller veins. Convincing results from a randomized controlled study are favoring the use of compression 23- to 32-mmHg hosiery for 3 weeks after sclerotherapy of small veins.[184]

Duffy[185] has classified unwanted leg veins into six types based on clinical (and possibly functional) appearance (see Box 2.6). Types 1, 1A and 1B are probably dilated venules, possibly with intimate and direct communication to underlying larger veins from which they are direct tributaries.[186] Both Bodian[187] and de Faria and Moraes[188] have found on biopsy examination that such 'telangiectasias' are actually ectatic veins. Therefore because a significant percentage of smaller spider veins occur in direct communication with larger varicose or reticular superficial veins, compression of the 'feeder' vein should decrease, if not eliminate, the blood flow to the smaller connected vessels. Thus in addition to the effects of compression on the treated vessels themselves, compression of the entire leg should lead to a relatively stagnant blood flow in the feeder veins, which should allow for more effective endosclerosis of the treated vessel and a subsequent decreased risk of recanalization. In addition to these hemodynamic reflections the analgesic and antiedema effect of compression, even with low pressures, has to be considered.

HOW MUCH PRESSURE IS NECESSARY TO COMPRESS TELANGIECTASIAS?

The only reported study measuring the pressure necessary to empty superficial 'capillaries' (telangiectasias) on the leg demonstrated that a sudden emptying of superficial cutaneous capillaries occurred between 40 and 60 mmHg at a point 5 cm above the medial malleolus with the patient recumbent.[189] However, 80 mmHg was required to produce a complete emptying of blood with the patient in a standing position. This degree of pressure can be obtained with a bandage wrapped over a local pad but not with graduated compression stockings on areas of the leg above the ankle.

One limitation to the use of compression stockings in treating leg telangiectasias is the lack of complete emptying of the treated telangiectasias when only one stocking is used. Theoretically the incorporation of foam pads directly over the injected vessels and a double layer of compression stockings for daytime use, with one stocking removed on recumbency, should produce a more complete vascular occlusion (Fig. 6.34).

As shown in Figure 6.35 even very high pressure applied by a circular compression device is not able to compress small skin veins.

Based on serial biopsies performed by L. Wenner after sclerotherapy of small veins, Staubesand and Seydewitz were able to demonstrate by electron microscopy less thrombus formation using powerful local compression.[190]

A multicenter, bilateral comparative study through the North American Society of Phlebology (now the American College of Phlebology) examined the necessity for the use of a class II (30- to 40-mmHg) single stocking when treating leg telangiectasias.[191] Thirty-seven women with bilaterally symmetric telangiectatic leg veins of less than 1 mm in diameter were evaluated. One set of vessels was compressed for 3 days with a 30- to 40-mmHg compression stocking (MediUSA, Arlington Heights, IL) over a cotton ball dressing. The alternate set of vessels had a cotton ball dressing applied for 2 hours with paper tape without an overlying compression stocking. With the stocking, a greater clinical resolution occurred after treatment with one sclerotherapy injection on vessels located on the distal leg or when vessels were greater than 0.5 mm in diameter. Vessels located elsewhere or less than 0.5 mm in diameter showed no significant difference when this form of compression was used.

The main benefit of compression treatment was noted in the evaluation of adverse sequelae (Table 6.7).[191] The most significant finding in this study was that 20 to 30 mmHg compression produced a relative decrease in postsclerotherapy hyperpigmentation, which fell from an incidence of 40.5% to 28.5% with the use of compression. In addition, ankle and calf edema were lessened if a graduated compression stocking was worn immediately after sclerotherapy.

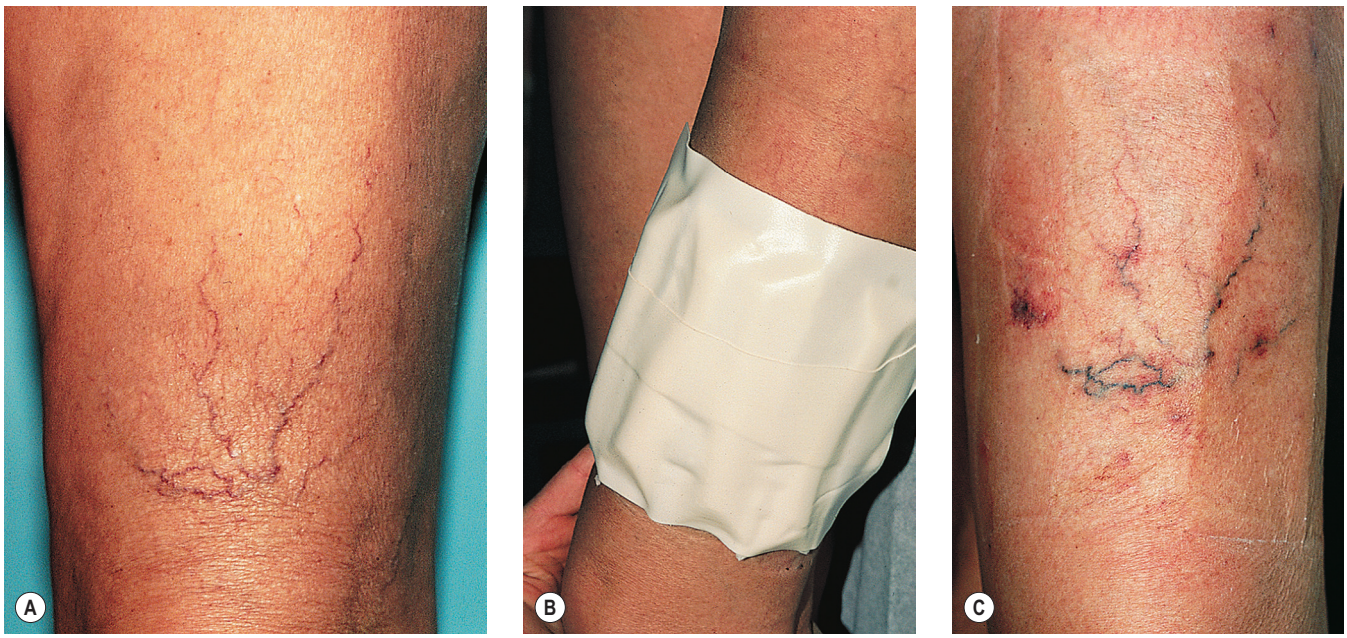

Figure 6.34 **A,** Clinical appearance of venules and telangiectasia on the anterior thigh of a 42-year-old woman, measuring 0.2 to 0.6 mm in diameter, without evidence of an obvious feeding reticular or perforating vein. **B,** Immediately after sclerotherapy with polidocanol 0.5%, STD foam pads were applied over the injected veins and secured with Microfoam tape under a 30- to 40-mmHg graduated compression stocking. **C,** Three days after treatment, immediately after the removal of both the stocking and the pads. There is significant thrombosis of the treated veins even with a high degree of compression, as noted by the indentation of the foam pad on the skin overlying the vessel.

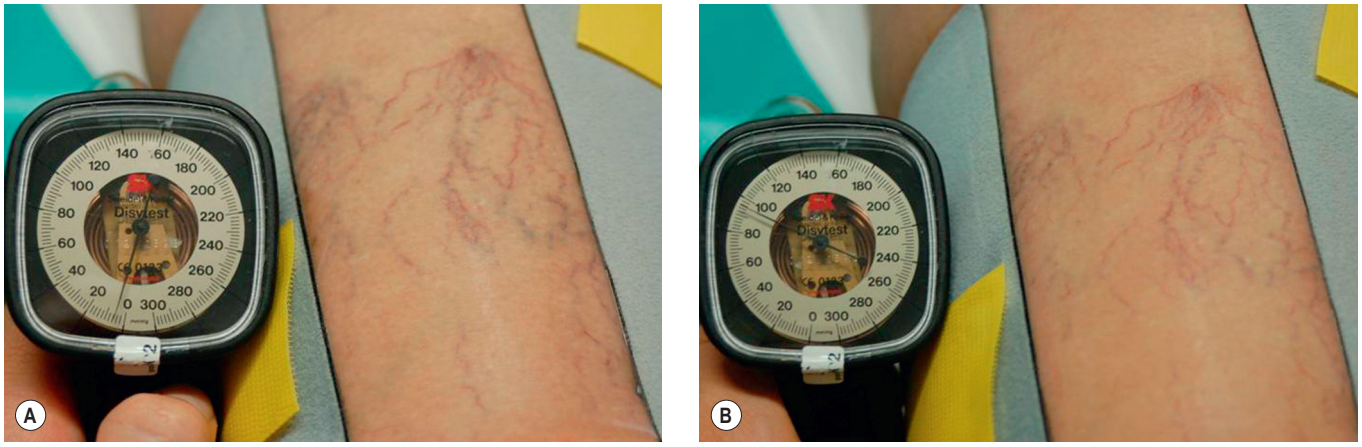

Figure 6.35 Using a blood pressure cuff with an acetate window (Echocuff, VNUS, CA, USA) the effect of compression on the diameter of spider veins on the thigh was investigated. **A,** Loosely applied cuff (6 mmHg); **B,** cuff inflated to 100 mmHg. The experiment shows that small skin veins cannot be compressed by circular compression devices. (Courtesy B. Partsch, Vienna.)

Table 6.7 Adverse Sequelae of Sclerotherapy

	Pigmentation	Ankle edema	Calf edema
Compression	28.5%	33%	–
No compression	40.5%	66%	40%

Modified from Goldman MP et al. J Dermatol Surg Oncol 1990;16:332.

An additional nonrandomized study of 386 patients with leg telangiectasias was conducted without bilateral paired comparison. In this study, 436 legs received graduated elastic stockings (compression class not stated) for 48 to 96 hours, and 182 legs were not compressed. Disappearance of more than 70% of telangiectasias occurred in one treatment in 85.7% of patients who wore compression stockings versus 72.5% of patients without compression ($P < 0.01$). In addition, compression reduced the incidence of pigmentation from 12.2% to 6.7%.

HOW LONG SHOULD COMPRESSION BE MAINTAINED AFTER SCLEROTHERAPY OF SMALL VEINS?

Formal studies on the use of compression in the treatment of leg telangiectasias are rare. A 3-day period for compression of leg telangiectasias is common based on the empirical report of Ouvry and Davy,[160] who advised a minimum of 3 days to limit the development of peripheral inflammation and intravascular thrombosis. Without supporting information, Harridge[192] recommended a 1-week period of compression for spider veins, using a local pressure band of elastic adhesive only. In a methodologically very convincing study showing clear benefits after compression stockings, a wearing time of 3 weeks was recommended.[184]

A review concerning compression and its effects on compression sclerotherapy of reticular and telangiectatic legs veins has been reported.[193] Forty patients were treated with sclerotherapy in three centers, followed by no compression or compression with 20- to 30-mmHg graduated stocking for 3 days, 1 week or 3 weeks. A statistically significant improvement in hyperpigmentation and resolution was seen in patients treated with 3 weeks of compression. Patients treated with compression for 3 days or 1 week also had a greater degree of improvement than patients not treated with compression. Patients treated with compression for 1 or 3 weeks had the least amount of postsclerotherapy hyperpigmentation. The full benefits of compression were seen when patients were examined 6 months after a single treatment. The authors concluded that patients are best treated with either 1 or 3 weeks of compression after sclerotherapy, but that even 3 days of compression offers some improvement over no compression.

In another RCT, the outcome of sclerotherapy with subsequent Elastoplast bandages was compared with the results after 35- to 40-mmHg stockings.[194] After 3 to 6 weeks, the stocking group showed a higher success rate, less thrombosis and less pigmentation.

COMPRESSION THERAPY AFTER VENOUS SURGERY AND ENDOVENOUS CATHETER PROCEDURES

Compression therapy is routinely performed after surgery of large varicose veins.[195,196] According to Perrin, the possible short-term benefits of compression after surgery include prevention of superficial thrombophlebitis and DVT, improvement of wound healing, and reduction of pain, bruising and hematoma. The level of activity, namely ambulation, is improved and return to work can be accelerated.[197]

Prolonged use of compression might provide benefits that include decreased incidence of recurrent varicosities. The progression of chronic venous disease may also be impeded by long-term use of compression. The same applies to the ablation of varicose veins by catheter procedures. However, these ideas are conceptual and supported only by few data that are summarized in a consensus paper on evidence-based compression.[147]

It could be demonstrated that high local compression achieved by using rubber foam pads on the thigh after surgery and after laser abolition of the great saphenous vein, is able to reduce pain and hematoma (see Fig 6.32).[48,198]

RCTs have underlined that after stripping, strong compression, mainly by compression bandages, is advisable especially in the first days after intervention only, whereas prolonged use of stockings would have no benefit.[199,200]

PREGNANCY

Pregnancy is an excellent model for observing the development of varicose veins in a relatively short time period. If the valves are allowed to remain incompetent for prolonged periods, fibrosis of the cusps may occur and cause irreversible damage. This effect is noted commonly in multiparous women who first note the temporary development of varicose veins during their first or second pregnancy. When the factors responsible for dilation of pregnancy-induced varicose veins (excessive blood volume, hormonally-induced relaxation of the vein wall, etc.) resolve, the veins return to normal. However, after repeated pregnancies varicose veins may become permanent. This progression is probably related to recurrent insult on the valves resulting in fibrosis and permanent incompetence. Therefore the use of graduated compression stockings for pregnancy-induced varicose veins could be considered preventive medicine, the goals being to maintain valvular competence and to prevent sustained valvular damage.

One RCT came to the conclusion that compression stockings may be ineffective in preventing the development of small varicose veins and side branches during pregnancy, but they alleviate leg symptoms and reduce the incidence of great saphenous vein reflux at the saphenofemoral junction.[201]

At the first indication of pregnancy, patients should be fitted with a 10- to 30-mmHg graduated pantyhose. In multiparous women or in those with a history of varicose veins, a stronger (30- to 40-mmHg) pantyhose should be worn. In women with large legs or in patients who are too uncomfortable with a 30- to 40-mmHg pantyhose, a calf-length, 20- to 30-mmHg compression stocking can be worn over a 20- to 30-mmHg pantyhose. One study comparing venous emptying between 13- and 25-mmHg ankle compression stockings used during pregnancy found no significant difference between the two compression levels.[202] Patient compliance between the two classes of stockings was the same, with 82% of the 50 women continuing to wear the stockings throughout their pregnancy.[202] Another study showed an improvement in maternal and fetal circulation, with best effects in the range of a 40-mmHg compression.[203]

Even for women in their 35th week of pregnancy, graduated compression stockings are able to increase expelled venous volume, whereas the refilling rate is influenced to a lesser degree, thus minimizing venous congestion in the leg.[204] This has been demonstrated to decrease postural changes in heart rate, preventing the uterovascular syndrome.[203,205] Using these guidelines, compression stockings worn during pregnancy can prevent or lessen the development of venous insufficiency. At the very least, the use of 25-mmHg graduated compression stockings decreased subjective discomfort from 82% to 13% in pregnant women between 30 and 40 weeks gestation and decreased edema from 75% to 14% in these pregnant women.[205]

EDEMA CAUSED BY SITTING AND STANDING; OCCUPATIONAL EDEMA

The rationale described in the previous section also applies to most other forms of venous stasis disease. Compression stockings are helpful to patients in occupations that necessitate standing for long periods. Light-compression stockings may be effective.[206–208] By measuring the physiologic swelling of the legs after a working day using water-displacement volumetry it could be demonstrated that light support stockings were able to significantly reduce evening edema. Compression stockings with an interface pressure of 18 mmHg on the distal leg were able to prevent the swelling after a working day completely.[6]

Light-compression stockings may also improve subjective symptoms of heaviness that occur after long sitting or standing.[7,36,37] A long flight or a car or bus drive for several hours is a typical situation in which leg swelling is a common sign, frequently also connected with subjective symptoms.[209–212] Considerable fluid accumulation in the legs of about 250 mL was measured after long-haul flights. The increase of skin thickness over the shin was even maintained for some days after the flight.[211]

Hagan et al showed that low-ankle-pressure stockings (5 mmHg at ankle, 17–20 mmHg at calf) reduced flight-induced ankle edema and subjectively rated travel symptoms of leg pain, discomfort and swelling, and improved energy levels, ability to concentrate, alertness and postflight sleep.[213]

The clinical benefits of lightweight compression stockings were also shown in flight attendants.[37] A crossover prospective study of 19 flight attendants wearing 8- to 15-mmHg and/or 15- to 20-mmHg graduated stockings demonstrated a statistically significant reduction in leg discomfort, ankle swelling, aching and tiredness in the leg. Interestingly, in this population in which almost all patients had leg telangiectasia (with one person having varicose veins), wearing 15- to 20-mmHg stockings did not significantly improve symptoms over the lighter-strength stockings. Light stockings have been reported to reduce the incidence of flight thrombosis.[214]

Severe stages of edema can be dramatically improved by compression bandages (Fig. 6.36). In chronic edema leading to lipodermatosclerosis on the distal leg, the lymphatics ultimately decompensate. Consequent compression therapy is able to reverse the skin changes and restore normal lymphatic drainage (see Fig. 6.2). For patients who have difficulty donning and doffing compression stockings or compression bandages, the CircAid legging is a viable option and may aid in patient compliance and comfort.[215]

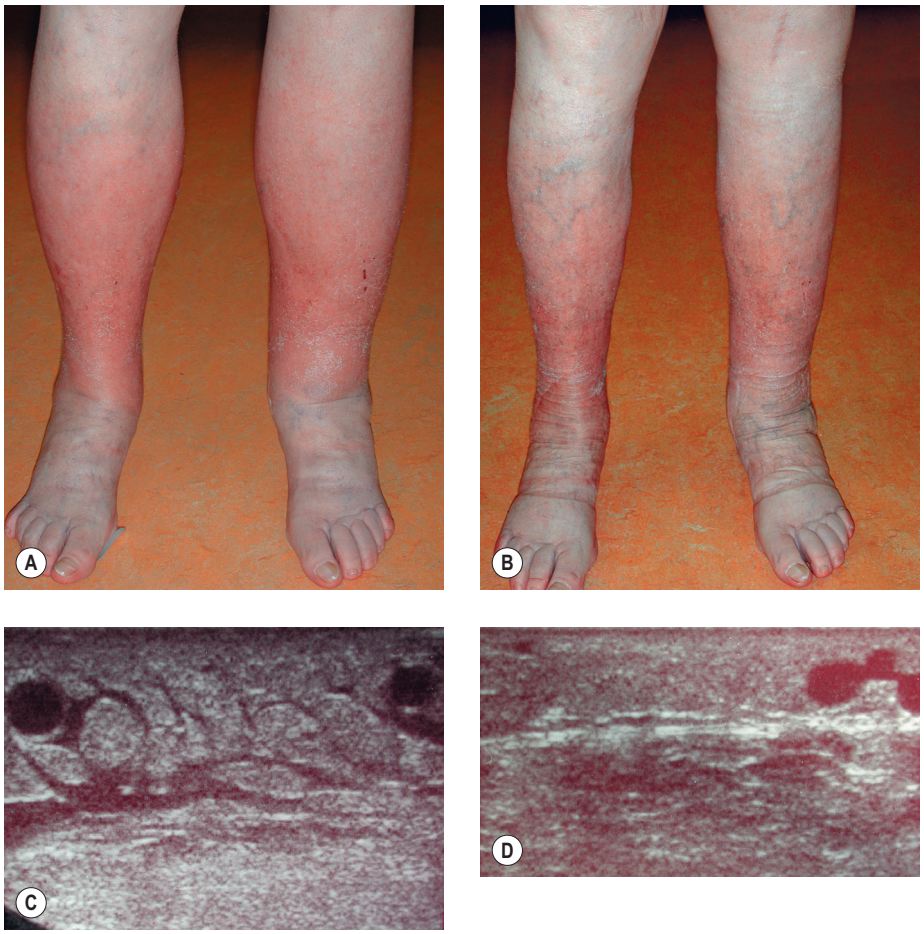

Figure 6.36 **A, B,** Before and after removal of edema in a patient with swollen legs (result of prolonged sitting; 'dependency syndrome') by a multilayer short-stretch compression bandage. After 5 days, the circumference of the calf decreased by 5 cm. **C, D,** Duplex examination before and after treatment shows that the water-filled clefts in the skin have disappeared and that the dermal thickness has halved.

Immobility edema in patients spending most hours of their life in an upright position, e.g., in a wheelchair, is an increasing practical problem. Recommendations that only elastic bandage material can be used on these patients is based on the misconception that inelastic material would work only in active patients who are able to walk. In fact inelastic bandages applied with adequate pressure produce a much higher massaging effect, even with small toe movements or passive mobilization of the ankle, than elastic material.

Additional intermittent pneumatic compression can further help to reduce edema in these patients.[216]

PREVENTION OF DEEP VEIN THROMBOSIS AND POSTTHROMBOTIC SYNDROME

Several RCTs and systematic reviews have shown the beneficial effects of compression in preventing venous thromboembolic diseases in bedridden patients. More convincing studies have been performed with intermittent pneumatic compression than with stockings.[197,217–220] Recent guidelines recommend combined pharmacologic and mechanical prophylaxis, assuming that mechanical methods may increase efficacy and reduce death and morbidity rates without increasing bleeding risk.[221]

Signs and symptoms of a postthrombotic syndrome after proximal DVT may be dramatically reduced if compression stockings are worn in the following years.[222–225] Immediate compression and mobilization in the acute stage of DVT seems to further reduce the incidence and severity of postthrombotic syndrome.[139] However, a large study, which is very much under dispute, was unable to find benefits from wearing compression stockings for preventing postthrombotic syndrome.[226] Delayed start with compression after acute DVT and poor compliance of the patients were the main counter-arguments which were discussed about this study.[227] We recommend wearing the stockings for 2 years and to continue when signs and symptoms of swelling and pain are still present.

TREATMENT OF SUPERFICIAL PHLEBITIS, DEEP VEIN THROMBOSIS AND POSTTHROMBOTIC SYNDROME

Acute superficial phlebitis is an excellent indication for strong compression, preferably by adhesive bandages, especially when thigh veins are also involved. The same is true for phlebitic reactions after sclerotherapy. The patient should be encouraged to walk with a strong bandage as shown in Fig. 6.16. This regimen is completely based on experience. Up to now there is only one RCT available demonstrating modest beneficial effects of compression stockings (20-30 mmHg) in this important indication.[228] Future trials would be desirable using bandages exerting higher pressures.

In acute DVT of mobile outpatients, good compression and immediate ambulation is able to reduce pain and swelling and to prevent thrombus growth.[229,230] This adjunctive treatment always has to be accompanied by exact anticoagulation, preferably with therapeutic doses of low-molecular-weight heparin (LMWH). Firmly applied Fischer bandages in addition to an adhesive thigh bandage exerting a pressure of 40 mmHg showed better results than a thigh-length European class II compression stocking (Sigvaris 503; Ganzoni, Switzerland). Either methods, bandage or stocking, were much better than bed rest.[229,230] However, for those centers that are not familiar with applying appropriately strong short-stretch bandages, good compression stockings may be a valuable alternative. In 1289 consecutive patients with DVT treated by compression bandages, walking exercises and LMWH, the complication rate of symptomatic pulmonary embolism and of fatal events was much lower than in reports from the literature regarding immobilizing the patients.[231] Our recommendation of immediate walking exercises with good compression is in contrast to the clinical routine in many countries. A survey from Canada reported that compression stockings were prescribed in the acute stage of DVT only by 26% of physicians and that 68% prescribed stockings only if venous signs and symptoms were present.[138]

In a subanalysis of the disputed SOX trial[226] no pain relieving effect of compression stockings could be found 2 to 3 weeks after acute DVT.[232] This is very different from our recommendation of immediate mobilization of the patient with acute DVT with good compression, which leads to an instant relief of pain and swelling enabling the patient to walk again.[229,230] This procedure is also able to reduce the incidence of postthrombotic syndrome.[139] Reports on the treatment of patients with a manifest postthrombotic syndrome are scarce.[233]

VENOUS ULCERS

Compression is considered to be the most important conservative treatment modality to heal venous ulcers. However, its importance is still widely underestimated compared with local treatment modalities.

There is no other indication for which the clinical efficacy of compression treatment has been so well established by numerous RCTs.[102,104,105,147] The different compression devices in use require more work in conjunction with measurement of interface pressure and stiffness in the individual patients who are enrolled in comparative trials to achieve reliable comparisons between various products.

Most studies have been undertaken using compression bandages. The following conclusions may be derived from several RCTs and systematic reviews[104,105]:

- Compression increases ulcer healing compared with no compression.
- Multilayered bandages are more effective than single-layered systems.
- High compression is more effective than low compression.
- The conflicting results achieved with different types of compression occur mostly because of inadequate application technique with one product and not because of its inferior elastic property. Four-layer bandages and inelastic multilayer bandages show equal results if both systems are adequately applied.[100,102,103]

Compared with local therapy alone, compression achieves significantly faster healing rates of venous ulcers. The

augmentation of sustained compression with sequential pneumatic compression promotes ulcer healing.[234,235] With adequate compression therapy, 70% of consecutive outpatients with venous ulcers should be healed after 12 weeks. Reports with healing rates lower than 50% raise the suspicion that the technique used was inadequate.[1] This is also true for randomized studies comparing different compression regimens or trying to demonstrate the supplementary effect of drugs. In future studies comparing different materials, it is highly recommended that the sub-bandage pressure be measured, because this parameter is of deciding importance for the healing of venous ulcers.[104,105,236] With optimal compression therapy, baseline ulcer area and ulcer duration are significant predictors of ulcer healing.[237]

If the ulcers are not too large and not too longstanding, favorable results can also be achieved with compression stockings.[107,238–243] Some stockings were developed specifically for treating venous ulcers: 'two-layer stockings' with a basic liner to keep the ulcer dressing in place, and a second outer stocking, thereby enhancing pressure and stiffness, e.g., UlcerCARE which comes with a zip (Beiersdorf-Jobst, Charlotte, NC), Mediven ulcer kit (Medi, Bayreuth, Germany), Venotrain ulcertec (Bauerfeind, Zeulenroda, Germany) with a specifically designed knitting pattern to increase the stiffness in the gaiter area,[241] and Tubulcus (Innothera, Paris, France), which is a ready-made tubular compression device.[244,245]

It can be more difficult to keep a venous ulcer closed than to heal it. Noncompliance of the patient regarding wearing compression stockings is associated with a higher recurrence rate.[246] Recurrence after healing of leg ulcers was shown to be significantly lower if compression stockings with higher pressure were used.[247] For the insurance companies, it would be much cheaper to reimburse for compression stockings after the ulcers are healed than to pay the costs for ulcer recurrences.[248]

LYMPHEDEMA

Conservative management of lymphedema is based on complex decongestive therapy. This treatment modality consists of manual lymph drainage, exercises, skin care, and most importantly, compression.

Multilayer short-stretch bandages are essential to achieve optimal edema reduction.[95,249] Bandaging and subsequent elastic hosiery is more effective than elastic hosiery alone in reducing lymphedema.[249,250] As a result of the fast diminution of limb volume the bandages will loosen rapidly[94] and should be reapplied in the initial phase at least once a day. To maintain the effect and to prevent refilling of the extremity with edema, lifelong wearing of compression hosiery preferably made-to-measure is essential.

OTHER INDICATIONS

Compression is also indicated in many other conditions like posttraumatic hematoma (Fig. 6.37), vasculitis, burns, keloids or after any kind of surgery on the lower extremity. The main reason for the effectiveness of adequate compression on the leg is its action against gravity, preventing swelling and impeding inflammation.

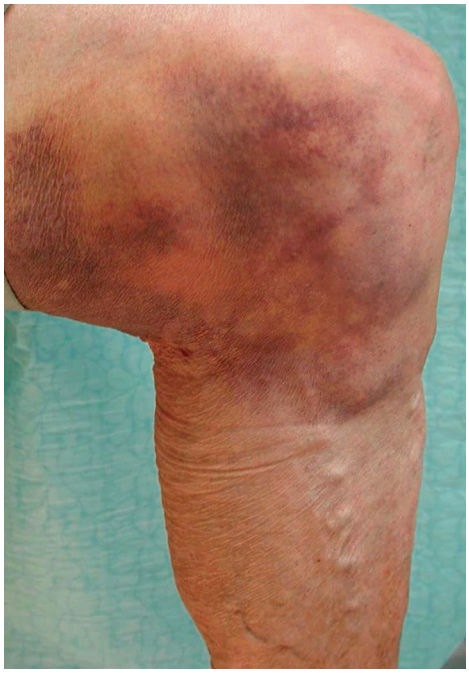

Figure 6.37 Posttraumatic hematoma in a patient who wore compression stockings because of his varicose veins at the time of the trauma. The compressed skin areas are spared from hematoma.

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