CHAPTER 1

Materials for compression therapy

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The PLaCES acronym

Every compression device can be categorized according to the PlaCES acronym, where P stands for pressure, La for layers, C for components, E for elastic properties, and S for surfaces.[1]

Compression pressure is the deciding force of compression therapy targeted to correct the pathological situation. The amount of pressure is known for compression stockings and compression pumps, but not for individually applied bandages, whose application is still an art that needs to be learned and trained. The therapeutic quality of any compression depends on the optimal choice of the material used together with a correct application technique to produce a positive effect with a minimum of negative feelings for the patient.

Our preferred point to measure the compression pressure is the so-called B1 point, where the tendinous part of the gastrocnemius tendon turns into its muscular part, 10-15 cm above the inner malleolus. A cross-section of the leg in that region would reveal a circular appearance, so this is the region where future pressure measurements should be performed. According to an International Compression Club consensus,[1] compression pressure can be classified as mild, medium, strong, and very strong. Different pressure ranges are schematically indicated for different clinical conditions (**Table 1.I**). The pressure range including mild and medium pressure was defined as "lighter" in a recent consensus paper.[2]

Layers: all bandages are applied to the leg with some degree of overlap, which can create some layers of bandage material at specific points along the leg depending on the application technique. As a consequence, "a single layer bandage does not exist because there will always be some overlap so that there are at least two layers of bandage material over each point of the bandaged leg".[1] The only single layer compression device is a medical elastic stocking. The number of layers plays an important role in the stiffness of the compression device and ankle mobility.

Components: in clinical practice, bandages are applied by using different materials to create the final bandage. These materials have different functions like padding, protection, or retention but, most of all, they will have different effects on the sub-bandage pressures of the final bandage. Unfortunately, the terms layers and components are frequently confused in daily use, complicating the understanding of terms like "multilayer", which should in fact be "multicomponent" as all bandages are "multilayer".

Elastic properties: this is a deciding feature that determines the crucial relation between efficacy (pressure) and tolerability of compression ther-

TABLE 1.I. Shows a simplified scheme of compression pressures for some important indications.

Pressure (mmHg)	Indications
<20 mild	maintenance, prevention
20-40 medium	edema, mixed venous-arterial disease
40-60 strong	lymphedema, DVT, phlebitis, after venous procedures
60 very strong	DVT, venous leg ulcers

apy depending on the body position and physical activity of the patient. Elastic, long-stretch materials (maximal extensibility >70%) may be differentiated from inelastic, short-stretch textiles (maximal extensibility <70%).

A compression device with high elasticity may be tolerated as long as the patient is active, but it may cause pain due to strangulation in the sitting or lying position when it is applied with a strong stretch. If this same device is applied too loosely, there is the risk of gliding down, causing friction on the skin, which may even induce ulcerations. On the other hand, inelastic material must be applied at full stretch. Due to the lack of elasticity, it will not cause a strangulation effect. The patient can feel a tightness sensation as soon as the inelastic bandage is applied, and this tightness will disappear in a short time when the bandage loses some pressure. This is one of the reasons why a good compression technique has to be trained in special schooling programs, while ready-made stockings can also be applied by inexperienced people. To get the right pressure during bandage application, some bandages come with geometric shapes printed on the outside of the fabric, like ellipses that should be stretched to circles when the correct pressure is achieved.

Surfaces: the surface of each bandage influences stiffness and pressure after application. Cohesive (sticking on itself) or adhesive (sticking to each material) layers inhibit the expansion of the material and thereby increase stiffness. They may be used as a single component – for example, Porelast© or Acrylastic©, which are stretchable lengthwise only, or Panelast©/Tricoplast©, which can also be stretched obliquely. They may also be used combination with a basic component (Coban 2©, Coban 2 light©). Adhesive bandages (Panelast© and Tricoplast©) or Coban 2 are ideal to apply compression up to the thigh level after an intervention on the great saphenous vein; when correctly applied, they provide a pressure of around 40 mmHg.[3, 4] Silicon pads, which may stay for 1 week,[5] can be placed under the bandage if the intention is to occlude the vein.

Frequently used compression materials

Table 1.II lists some of the frequently used compression materials.

Medical compression stockings

Over the past 30 years, elastic compression has come to dominate the compression area, mainly due to the introduction of medical compression stockings (MCS). Medical compression stockings can be differently named even in this book. They can be named elastic compression stockings (ECS) or medical elastic compression stockings (MECS) because of their elastic properties or also graduated compression stockings (GCS) to highlight that the exerted pressure is graduated: higher at ankle than at calf level. Producers have worked continuously to improve the available products, and doctors and nurses have embraced these products with open arms, especially because they allow delegating a major piece of their work to their customer, the patient. MCS currently dominate the compression scene because they are indicated in many clinical situation of chronic venous disease.[6] The patient bears responsibility for therapeutic success, creating more time for medical staff to concentrate on other problems.

MCS are classified according to the pressure they are able to exert, which is warranted by the manufacturer. The declared pressure values indicate the pressure (mmHg) that should be exerted by the hosiery on a hypothetical cylindrical ankle. Unfortunately, MCS classification differs among countries according to national regulations. Indeed, the same stocking could be categorized class II in one country and class I in another country (**Table 1.III**). For this reason, it has been proposed to indicate the compression range rather than the classification in order to have a clear indication on the nature of the stocking.[7]

Besides calf-length stockings, which are the most frequent prescriptions, thigh-length stockings and pantyhose are also available. Stockings are produced in different colors. They continue to be popular because some compression is effective even in different sports disciplines. This area has become an important field for physiological research concerning the effects of compression.[8]

In an attempt to produce more inelastic stockings, the industry offers flat-knitted models that are measured individually for each patient's leg. Most come with a seam and are bulky. Karin van der Wegen Franken[9] has measured many com-

Table 1.II. Materials for compression therapy.

Type	Example	Application	Advantages	Disadvantages	Stiffness
Elastic stockings (1 component)	variety of products in different compression classes	self-application	patient can remove for hygienic purposes, daily skin care, self- management	low working pressure, difficult donning, must be removed over night	low
Elastic stockings (2 components, elastic kits)	double (multiple) stockings	basal layer stays over night second stocking during day-time	patient can remove for hygienic purposes, daily skin care, self- management	difficult donning, possibly painful during the day, must be removed over night	medium
Long stretch wrap (elastic)	Ace® Perfekta® Dauerbinde K®	easy to apply	self-application, reusable	low working pressure, intolerable when applied with strong stretch, remove over night	low
Short stretch wrap (inelastic)	double Comprilan® double Rosidal K® double Putter binde®	expert personnel required, may stay up to one week	high working pressure, well tolerated during rest; washable and reusable	not easy to apply, loses pressure, slipping	high
Multicomponent short stretch	Coban 2® Rosidal Sys®	expert personnel required, may stay up to one week	high working pressure, well tolerated during rest; less slippage	not reusable (partially or totally)	high
Multicomponent mixed bandages	Profore® (elastic components); Urgo KTwo® (inelastic and elastic components)	expert personnel required, may stay up to one week	high working pressure, well tolerated during rest	not reusable, bulky and warm	high
Inelastic	zinc paste	expert personnel required, may stay up to one week	high working pressure, well tolerated during rest	not easy to apply, loses pressure, not reusable	very high
Adjustable compression wraps (short stretch)	CircAid® ReadyWrap® Compreflex® Compression wrap®	self-application, self-adjustable	patient can remove for hygienic purposes, daily skin care, self- management	not cosmetically appealing	medium/ high
Extremity pumps	variety of products in different versions	self-application, self-adjustable	patient can remove for hygienic purposes, daily skin care, self- management	works when patient is resting for limited time	variable
Hybrid pumps (adaptive compression therapy)	Actitouch® combines sustained with intermittent pressure	self-application, pressure in sustained mode is maintained	patient can remove for hygienic purposes, daily skin care, self- management	not cosmetically appealing	variable

Table 1.III. Elastic stocking.

	British standard	German standard	European standard	USA standard
I	14-17 mmHg	18-21 mmHg	18-21 mmHg	15-20
II	18-24 mmHg	23-32 mmHg	23-32 mmHg	20-30
III	25-35 mmHg	34-46 mmHg	34-46 mmHg	30-40
IV		> 49 mmHg		40-50

pression stockings by the rather sophisticated methodology described by R. Stolk.[10] However, her proposal of declaring a parameter characterizing the stiffness of a compression stocking in the quality description of each brand, based on *in vivo* testing, has yet to be realized. The main advantage of flat-knitted, custom-made stockings is the higher stiffness they provide that make them mainly advocated for maintenance treatment of patients with lymphoedema.

According to international and national rules, MCS should exert a pressure gradient from the distal to proximal direction and have a foot part to prevent distal swelling. However, some studies have shown that a higher pressure over the calf might produce a more efficient result.[11-13] In general, we may state that a stocking exerting pressure <35 mmHg in the upright position is not strong enough to improve a deficient venous pump. It has been shown that the lower leg veins are occluded only with a pressure of about 80 mmHg in an upright position, while lower pressure leads only to some narrowing (**Figure 1.1**).[14, 15] The main problem with MCS is the fact that donning and doffing may be very difficult, especially for immobile and elderly people, a factor that reduces compliance.

Multicomponent stockings

In recent years, double-layer compression stockings have been introduced on the market. The inner stocking, designed to keep local wound dressings in place and stay on the leg overnight, usually has a lower pressure. Median pressure values of about 35.5 mmHg in the supine position and 43.5 mmHg in the standing position at the B1 point have been reported for such double-layer stockings.[16]

Hafner's group in Zurich has developed two special multicomponent compression devices that superimpose MCSs. Both these devices could be donned and doffed easily by 62 probands over the age of 65 years without the need for help.[17, 18] This group has also published a study in which they analyzed several donning devices. They showed that these devices significantly improved the ability of elderly patients with CVI to don compression stockings.[19] Following the instructions of the

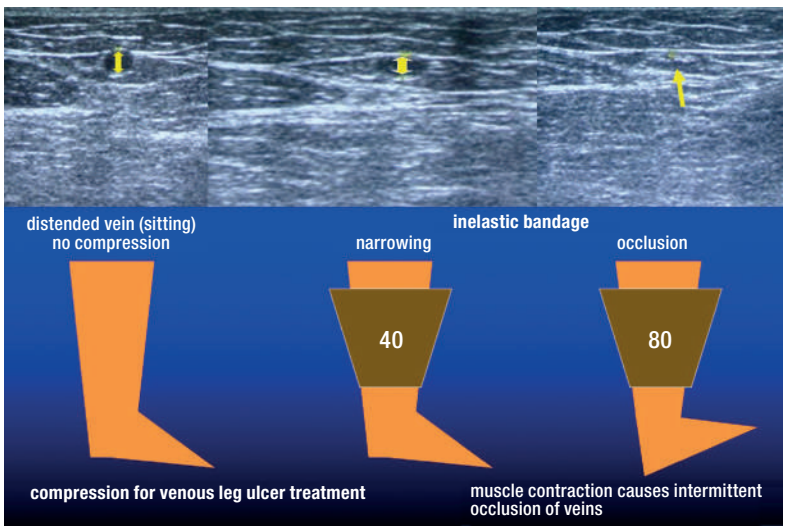

Figure 1.1. An inelastic bandage around the calf exerts 40 mmHg. During muscle contraction due to foot dorsiflexion, the pressure rises to 80 mmHg, and the calf vein closes completely.

producer, a good compression stocking can survive around 6 months of constant wearing before a new pair needs to be prescribed for long-term use.

Single-component elastic bandages

The main feature of an elastic, yielding material is that it is easier to handle and more forgiving compared with an inelastic wrap. This can explain why such bandages are probably still the most frequently used compression materials in non-specialized general practice and emergency departments. They are usually applied by personnel who are not specially trained and who tell the patients to do the same at home.

Single-component bandages such as the elastic ACE© bandage are still popular. Indeed, they are used after varicose vein surgery, although it is difficult to understand how a whole leg can be bandaged adequately by 4- or 6-cm-wide rolls that remain in place for 3-5 days. Numerous studies where compression therapy was not adequately applied were unable to demonstrate positive effects of compression after varicose vein interventions.[20] This is an area showing that good compression, demonstrated by pressure measurements, can make a great difference. It is time to make it clear that without providing the compression pressure, any judgment about a lack of efficacy is in vain.[21, 22]

Multicomponent inelastic bandages

Like all inelastic materials, such bandages should be applied by trained staff to produce a sufficiently high pressure. Coban 2©, Coban 2 Lite©, and Rosidal Sys© are examples of this category. Thin foam layers (*e.g.*, Haftan©) can also be incorporated in several compression products. Their functions are to prevent the bandage from gliding down and to smooth out uneven pressure distribution from the compression layers above. Foam pads are available to increase the local pressure by decreasing the local leg radius following Laplace's law. The combination of a thin foam roll with a short stretch bandage (*e.g.*, Rosidal K©) is an example of a simple form of short stretch therapy.

Mixed (elastic and inelastic) multicomponent bandages

Today, the textile industry provides a variety of products consisting of various fabrics and their combinations that are difficult to manage. Some of these products contain elastic and inelastic components, so classification may be difficult. These bandages usually consist of a basic component covered by a stronger outer component that provides the pressure. Occasionally, these constituents are merged so that the box containing the product has only one or two rolls in it. Such combinations of different compression fabrics have been termed "kits." Many compression kits on the market come with several rolls in a package, although there is a trend to merge several components into one (*e.g.*, Urgo 1©).

The complexity of the discussed items shall be highlighted by discussing two different products that are used frequently worldwide.

- Profore©, the classic "four-layer bandage," is a multi-layer compression bandaging system consisting of five components: a sterile wound contact layer, an absorbing padding bandage, a light conformable bandage, a light compression bandage, and a flexible cohesive bandage. Profore© is still a hallmark of compression bandages, and its efficacy has been demonstrated in several trials.[23-27] In a study concentrating on the effect of compression on leg volume decrease after 1 week, we found initial standing pressures around 60 mmHg and a pressure loss of 16% with Profore© *versus* 96 mmHg and 44% loss of pressure for a strong short-stretch bandage.[28] It has to be noted that every value of the static stiffness index (SSI) exceeded 10 (also in all other studies with Profore©), corresponding to a stiff compression product even though all constituents of the bandage are elastic. We believe that this is due to the friction between the layers and the cohesive function of the outermost component. This is just an example of how the surface of a bandage component also has an influence on its final behavior, underlining the good tolerability of this product when used with high pressures.[29]
- Urgo K2© is another multicomponent bandage. Compression pressure measurements under this bandage have been recorded (**Figure 1.2**): 28 mmHg in the basic layer, and >60 mmHg

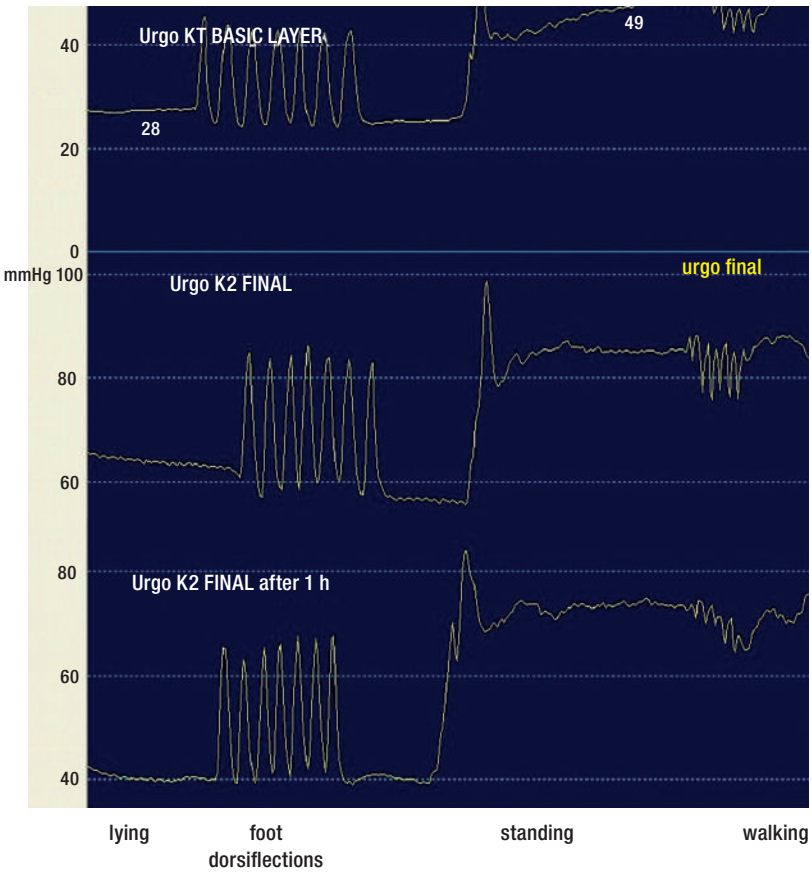

Figure 1.2. Pressure recording under a multicomponent bandage in the lying position, during foot dorsiflexion, in the standing position, and during walking. The upper recording represents the first layer, the middle recording shows a significant pressure increase with the final bandage, the lower recording shows a great pressure reduction after wearing for 1 hour.

with the final bandage (middle), dropping to 40 mmHg after 1 hour. Dorsiflexion in the supine position cause pressure peaks of 45, 86, and 68 mmHg. Standing pressures of 49, 85, and 73 mmHg were well-tolerated. Urgo K2 Lite©, which generates less pressure when correctly applied, was designed for patients with additional arterial occlusive diseases.

Zinc paste bandage

Another example of a very effective compression system is the completely stiff zinc paste bandage. The historic Unna boot should be mentioned here as the prototype of a completely inelastic bandage. The German dermatologist Unna wrapped the leg with some layers of wet gauze rolls and applied freshly prepared warm zinc paste with a brush. Zinc paste contains zinc oxide, linseed oil, wool fats, and calcium carbonate and has a drying, cooling, anti-inflammatory effect.[30] Several companies have introduced ready-to-use zinc paste dressings to the market (*e.g.*, Varicex F©). Some Unna boots also contain calamine lotion and glycerin.

The compression pressure of the zinc paste covered by a tightly applied, inelastic component (Rosidal K©) can be seen in **Figure 1.3**. The initial pressure in the recumbent position is 60 mmHg, dropping to 45 mmHg after dorsiflexion. However, the standing pressure goes up to more than 100 mmHg, revealing an SSI of 60. Subsequently, there is some minor pressure loss, and a bandage change will be necessary after only 1 week. Of note, the outermost bandage of Rosidal K© can be removed and reused after being washed, which is a cost-saving advantage. The main disadvantage is that personnel need to learn and be trained on how to apply such bandages, preferably by experienced teachers. After the bandage has been applied with such a strong compression pressure, the patient should walk for some minutes and come back if pain is intolerable, which is rarely the case. Due to some immediate pressure loss by the bandage to about 40 mmHg, the bandage quickly becomes very

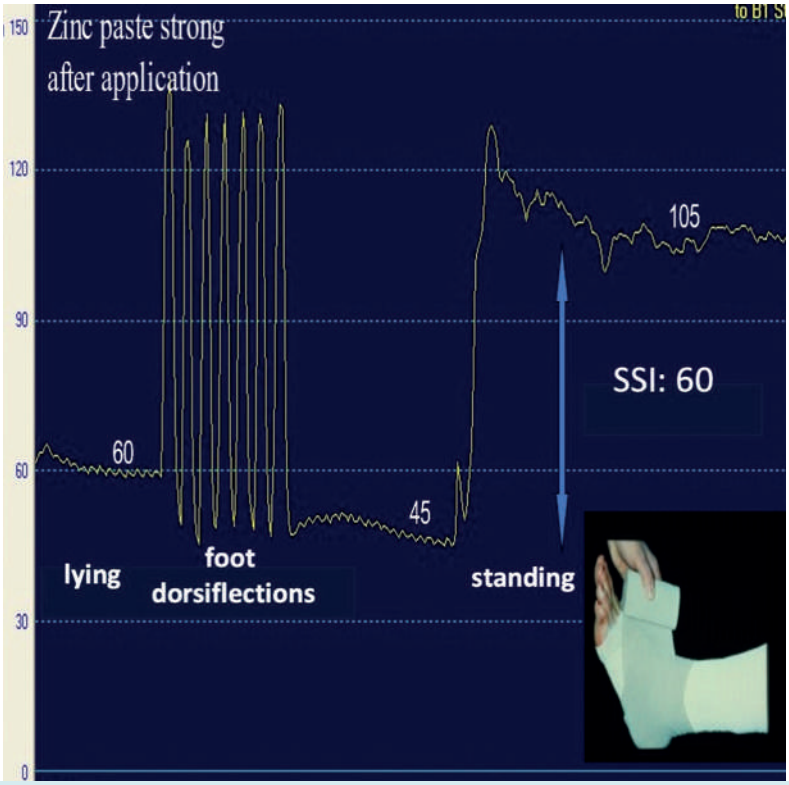

Figure 1.3. Pressure recording with zinc paste.

comfortable and maintains its effectiveness: a standing pressure of about 80 mmHg, an SSI of about 40 mmHg, and wide amplitudes during dorsiflexion and walking (Figure 1.4). Heinrich Fischer, a pupil of Unna, described in his book the surprising fact of dramatic pain-reduction in legs with deep vein thrombosis, which may be painful even under the lightest touch.[30]

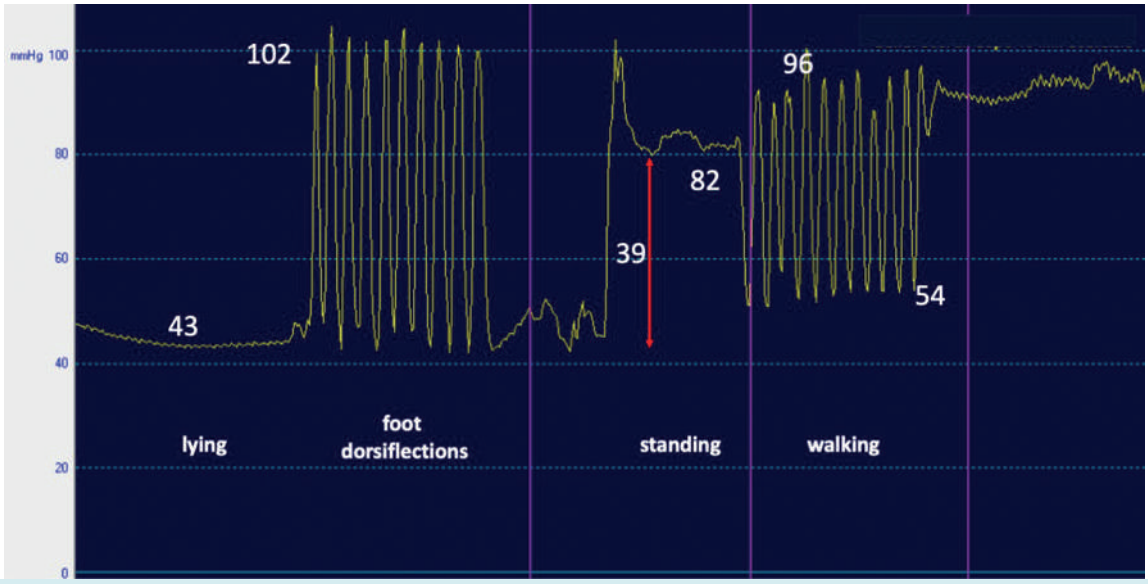

Figure 1.4. Pressure recording with zinc paste after physical exercise.

Adjustable compression wraps

Suffering from lymphedema of her leg, Mrs. Shaw from California got tired of following the advice of her German doctors to wear compression stockings because of the constant feeling of strangulation. Her husband, tired of his wife's complaints, found an ingenious solution: He cut the shaft of a leather boot lengthwise and fixed the free edges with a Velcro© bandage that could be adjusted according to the each person's feelings. Mrs. Shaw was happy, and Mr. Shaw started to develop a new bandage type for which he chose the name Circaid©. Today, several companies produce similar devices for which we propose the name of "adjustable compression wraps" (ACW). The advantages of this device are the ability to exert strong pressure and high stiffness, comfort even when the Velcro® bands are tightly stretched, and pressure maintenance by straps that can be adjusted by the patients themself.

The initial studies showed that this is a very effective modality in the maintenance phase of lymphoedema therapy.[31] These data were later confirmed,[32-35] and researchers demonstrated that ACW are also effective for the treatment of venous edema[36] and venous leg ulcers.[37-40] In a study from Italy,[39] the authors highlighted economic considerations, showing that the material costs for every ulcer healed were lower compared with the bandage group. The economic advantages of ACW are even greater when considering that conventional bandages need to be applied by educated staff, while ACW can be applied by the patients themself. Self-application of ACW has to be learned by the patient, a process that does not take longer than the instructions concerning donning and doffing of a compression stocking. However, Benigni and his group have demonstrated that obesity, gripping difficulties, cognitive impairment, and low social status seem to be factors limiting the daily self-management of ACW in the elderly.[41]

Intermittent pneumatic compression

The primary idea behind intermittent pneumatic compression (IPC) devices is to accelerate venous flow during bedrest and to reduce lymphoedema by using cuffs filled with compressed air.[42-46] These devices have also been used in case of venous leg ulcers and in case of arterial occlusions, that were treated by special pumps. This method has been used in connection with thrombolytic therapy to reduce the dosage of urokinase in case of acute venous thrombosis.[46] However, clear-cut recommendations concerning the "best" IPC machine for a special indication are still lacking. Nevertheless, some arguments favoring a specific pump are based more on theoretical assumptions than on concrete experimental proof. This is especially true for lymphatic problems where the optimal sequence of compression (should treatment start with higher pressure proximally?), the amount and duration of the pressure waves, and the intervals (the duration of a session) have never been stated definitively.

It is also necessary to emphasize that IPC can be used to treat lymphedema as an adjunct to complete decongestive therapy (CDT), particularly in patients with compromised mobility or physical exercise. Although lymphedema is reduced after application, the use of IPC remains controversial due to its adverse effects, including the recurrence of edema due to residual proteins remaining in the interstitial space. Moreover, a revision of the clinical effectiveness on the use of IPC devices for adult patients with lymphedema has been recommended.[47]

Besides the classical indications of thromboprophylaxis[48-52] and treatment of lymphedema, positive results with IPC have also been reported in venous and mixed ulcers[53] as well as in arterial occlusive disease, due to induction of reactive hyperemia.[43] Even critical limb ischemia can be treated effectively by IPC when arterial surgery or endovascular procedures are contraindicated for severely compromised local or general conditions.[54-56] It is encouraging to see enthusiastic reports from physical therapists, although it needs to be underlined that IPC should be seen as a supplement and not as a stand-alone therapy in severe cases.

Absolute and relative contraindications to IPC must be taken into account and risks considered and avoided as much as possible. Adverse events are extremely rare if IPC is used correctly. When the indication and application are correct (also as an add-on therapy), IPC is a safe and effective therapy, especially for the treatment of the described vascular diseases and edema as well as for thrombosis prophylaxis.