Assessing the effectiveness of multilayer inelastic bandaging

Hugo Partsch

Multilayer inelastic lymphoedema bandaging (MLLB) applied with a pressure of >45mmHg is the standard intensive treatment for severe forms of lymphoedema. MLLB consists not only of several layers but also of different single components whose elastic properties may vary. The combination of these layers leads to a change in the elastic property of the final bandage, making it more inelastic. Stiffness, defined by an increase in interface pressure due to an increase in circumference of the bandaged area, is a more adequate term to characterise these elastic properties.

Key words

Lymphoedema
Compression therapy
Bandages
Stiffness

Conservative treatment of lymphoedema is based on decongestive lymphatic therapy (DLT) which consists of compression, manual lymphatic drainage (MLD), skin care and exercise. Some schools use the term complete decongestive physiotherapy (CDP) (Foeldi et al, 2003). The most important single component among these modalities is compression, for which several devices are available, e.g. bandages, compression hosiery, velcro band-wraps and pumps producing intermittent pressure waves.

Bandaging is still the most important treatment modality for the initial therapy phase, especially in moderate to severe forms of lymphoedema, while compression hosiery is mainly used for maintenance therapy after decongestion of the limb. Intermittent pneumatic compression (IPC) can be administered as an additional, supportive tool. In the initial treatment

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phase, good bandages should be applied by well-trained staff for a period of time until no further volume reduction of the treated limb can be obtained. To keep the limb free from oedema, compression therapy needs to be continued, preferably in the form of compression hosiery. If well-fitted compression hosiery is not available, self-bandaging with elastic material may be an alternative .

A recently published international consensus document on the management of lymphoedema has recommended multilayer inelastic lymphoedema bandaging (MLLB) exerting a pressure greater than 45mmHg as 'standard intensive therapy' (Lymphoedema Framework, 2007).

This article will focus mainly on multilayer inelastic lymphoedema bandaging and on new ways of assessing the elastic property of such bandage systems.

Evidence-based compression in lymphoedema

There are only a few randomised controlled trials (RCTs) available which show beneficial effects from the application of compression to reduce the volume of lymphoedematous limbs (Badger et al, 2004). Most of these studies have investigated the additional role of different supplementary modalities to treat lymphoedema, e.g. MLD or electro-stimulation. Only one single RCT has

compared the effects of bandages versus stockings (Badger et al, 2000). The conclusion of this trial was that multilayer bandages followed by hosiery gives a greater and more durable limb volume reduction when compared with hosiery alone.

Characteristics of multilayer inelastic lymphoedema bandaging (MLLB)

The main features characterising a compression device are the interface pressure and the elastic property of the material.

Interface pressure

MLLB are commonly applied with high initial pressure. They usually consist of more than one component and are made up of several layers. The padding layer has the main function of reshaping the limb and avoiding proximal constrictions. After checking the arterial blood supply of the extremity, experienced bandagers will apply short-stretch bandages with considerable tension to achieve an interface pressure of more than 60mmHg on the leg and of about 30–40mmHg on the upper extremity of the arm. These pressures are considerably higher than those achieved with elastic textiles. The common fear that such high pressures would not be tolerated is unjustified, mainly because of the following reasons:

1. There is an immediate pressure drop after the application of a strong inelastic bandage, even without movement. Two hours after bandage

application the pressure values will drop by about 25–50%. This loss of pressure is mainly due to an immediate volume reduction of the lymphoedematous extremity, as can be demonstrated by volumetric measurements. When the bandage becomes loose it should be reapplied to regain its full efficacy. In the initial treatment phase this may be necessary every day, especially in the presence of massive oedema.

2. Inelastic multilayer bandages do not constrict the extremity in the resting position in a similar way as elastic material, due to the property of elastic fibres to regain their unstretched configuration. However, during the volume changes of the limb during muscular contractions, the non-yielding material will create pressure peaks that exert a rhythmic massage. This specific physical property can be characterised by the stiffness of the material.

3. In lymphoedematous limbs the thickness of the skin between the epidermis and the muscle fascia is typically increased as well as the radius of the cross-section area. Even very high pressure exerted during bandage application will be absorbed and dissipated by this natural 'padding layer' of the lymphoedematous skin (*Figure 1*). According to Laplace's Law, sub-bandage pressure is inversely proportional to the radius of the curvature of the limb (Thomas, 2003). This means that those parts of the extremity presenting with a much enlarged contour need to be bandaged with extremely high tension.

A modified intensive therapy using MLLB with reduced pressure is recommended in patients with arterial disease, sensory disturbance, lipoedema, poor mobility/frailty and in people with palliative needs (Lymphoedema Framework, 2007). Bandages exerting high stiffness are also preferred in these situations.

In general, the sub-bandage pressure is mainly modified by the force that the user exerts during application and does not so much depend on the material of the bandage.

Elastic property of the compression material

The differentiation between elastic and inelastic material is based on measuring the stretch of a bandage caused by an increasing force using extensometer devices in the laboratories of the bandage producers. Usually, elastic bandages are characterised by an extensibility of the material by more than 100%, while inelastic bandages are defined by a stretch lower than 100%. These values of stretch cannot be replicated in-daily practice, as they can only be achieved with extreme forces that will never be applied by bandaging a leg.

The experienced bandager will not only adjust the tension during bandage application to the circumference (radius) of each part of the leg, but also to the varying density of the elastic fibres in each compression product. In the experiments shown in *Figure 2* bandages of different materials were applied to 10 legs with such a tension that in each case a pressure of 45mmHg at the medial gaiter area was achieved. The interface pressure was measured using a pressure monitor (a small Kikuhime® probe,

Meditrade, Denmark) and the extension was marked on the bandaged leg and measured by a tape. To obtain the same pressure of 45mmHg, the stretch for a strong elastic bandage (Perfekta® strong, Lohmann & Rauscher, Vienna, Austria) is in the same range of about 40% as for the short-stretch bandage Rosidal K® (Lohmann & Rauscher), while the softer elastic Perfekta® super has to be stretched to 137%. This example clearly shows that declaring the extensibility of a bandage by the manufacturer would only make sense in connection with the intended pressure range on the leg and would therefore be of little help in daily practice.

Another reason why such experimental data are of limited practical value is the increasing use of bandage systems consisting of different components.

When several layers of elastic bandages are applied, the final bandage will become more and more inelastic (Partsch et al, 1999). The four-layer bandage system is an example. Its
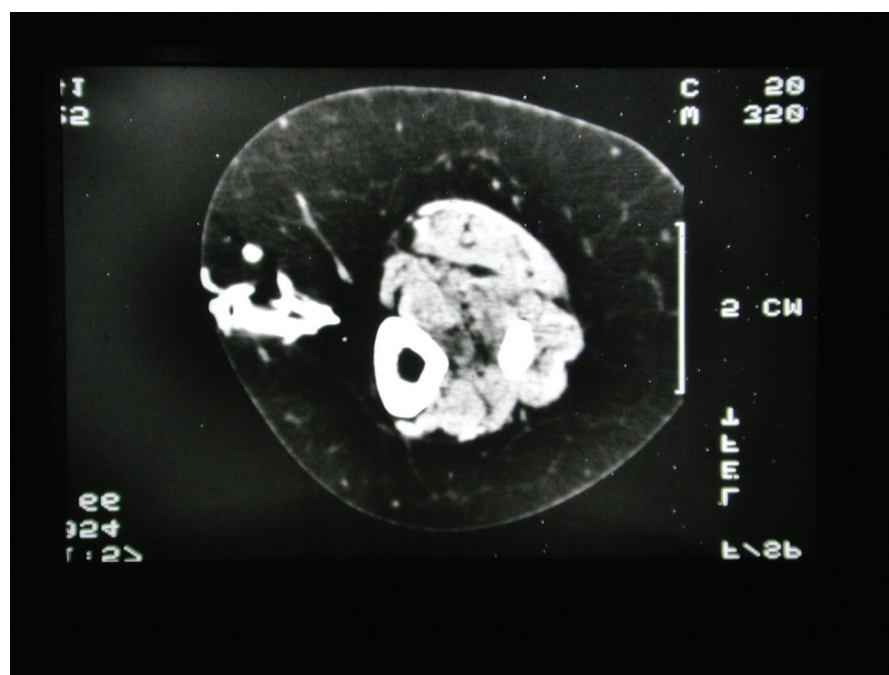

Figure 1. Computer tomography showing the cross-section of a leg in a patient with severe lipo-lymphoedema. The flame-like structure centre-left is the deposit of a contrast medium injected intradermally (indirect lymphography). The white central parts correspond to the intrafascial muscle compartment; the outer black surrounding is the skin with a massively enlarged layer of subcutaneous fat. When the muscle contracts during walking, a non-yielding compression bandage will need to be applied with considerable pressure to squeeze out this layer of fluid.

single components are elastic, but the end-product becomes inelastic. The reason for this change of the elastic property of a compression device is the influence of friction between the different layers. Adhesive and cohesive bandages are characterised by a high degree of friction and will therefore behave like inelastic bandages, even when their fibres allow high extension. Different padding materials result in a final bandage whose elasticity on the leg will be unpredictable.

With the use of the terms multilayer, multicomponent or adhesive and cohesive bandages, it is questionable whether the terms 'elastic' and 'inelastic bandages' still have any meaning.

The terms 'elastic' and 'inelastic' are based on the physical property tested in a laboratory and should only be used in connection with single bandages. When it comes to describing the properties of bandage systems composed of different materials on the leg, it is more reasonable to talk about lower or higher stiffness.

Stiffness

Stiffness is defined by the increase of interface pressure brought about by an increase of the leg circumference by standing or walking (Comité Européen de Normalisation European Prestandard, 2000).

This parameter can be assessed on the individual leg and shows the relationship between resting and working pressure, and is of practical importance because it describes the deciding parameters of good tolerability (low resting pressure) and strong efficacy (high working pressure) of a compression device (Partsch, 2005).

When the muscle contracts, inelastic material will not give way and will produce a higher increase of interface pressure than elastic, yielding material. The pressure increase may exceed 20–50% of the resting pressure, thereby exerting a considerable 'massage effect'.

Figure 3 gives an example comparing the pressure exerted by an inelastic and an elastic bandage, both applied with the same resting pressure. The increase of

sub-bandage pressure when the patient stands as a parameter of stiffness is 22mmHg with the inelastic material and 8mmHg with the elastic one.

A simple method that can easily be performed in practice has been proposed to assess stiffness. A calibrated pressure sensor is fixed to the medial aspect of the leg about 12cm above the inner ankle. This is the area where the muscular part of the gastrocnemius muscle changes into the tendinous part, showing the most extensive changes in local curvature and leg circumference by changing the body position between supine and standing. The difference between the interface pressure in the standing and in the lying position (mmHg), called static stiffness index (SSI), is a valuable parameter for the stiffness of the compression system (Partsch et al, 2006).

Another method showing an excellent correlation with the SSI is to measure the difference between resting pressure and working pressure during dorsiflexion. One important drawback of this method is that it is difficult to reproduce exactly due to the different degrees of dorsiflexions and the restricted ankle mobility in some patients.

The most appropriate way to quantify stiffness would be to measure dynamic stiffness during walking. Unfortunately, this method requires sophisticated instrumentation and therefore cannot be used in routine clinical practice (Stolk et al, 2004).

Several authors have shown that an increase of the sub-bandage pressure of more than 10mmHg describes high stiffness, while a pressure increase of less than 10mmHg characterises bandages and stockings with low stiffness (Hafner et al, 2000; Partsch, 2005). Although this could be shown with several pressure transducers and on different areas of the gaiter area, it has to be stressed that the dimensions of the pressure probes and the curvature of the measuring area on the leg have a considerable influence on the calculated stiffness values. When a leg with a large diameter
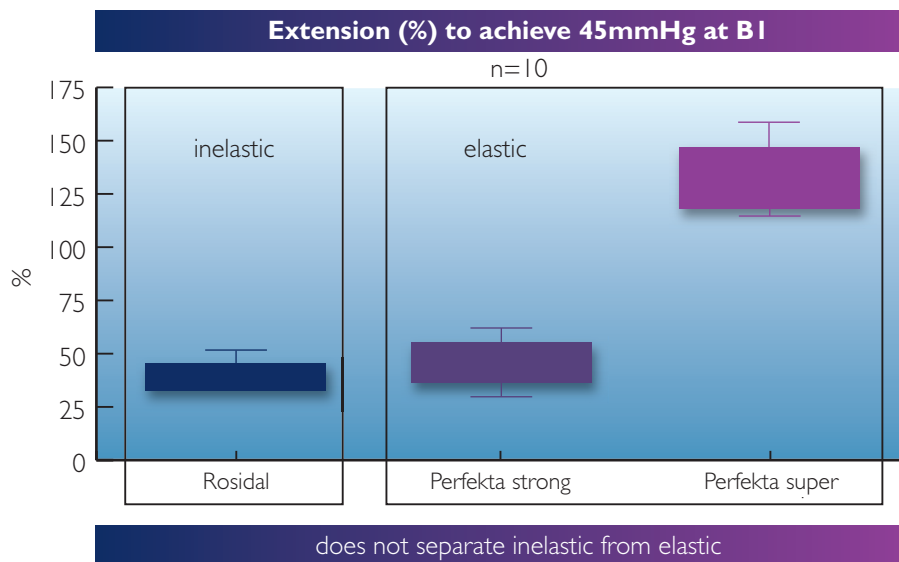

Figure 2. Different compression bandages were applied in 10 volunteers with a tension that resulted in a pressure of 45mmHg above the inner malleolus (measuring point B1, the site where the muscular part of the medial gastrocnemius muscle changes into the tendinous part) and the extension of the materials was measured in relation to the unstretched bandages (%). The median values for the extension were 39% for the short-stretch bandage Rosidal® (Lohmann & Rauscher) and 41.5% for the long-stretch Perfekta® strong (Lohmann & Rauscher). Another elastic long-stretch bandage (Perfekta® super) had to be stretched by 137% (p<0.001) to achieve the same interface pressure. This experiment shows that the declaration of the extension of a bandage by the producer based on in vitro measurements does not give a clinically useful information.
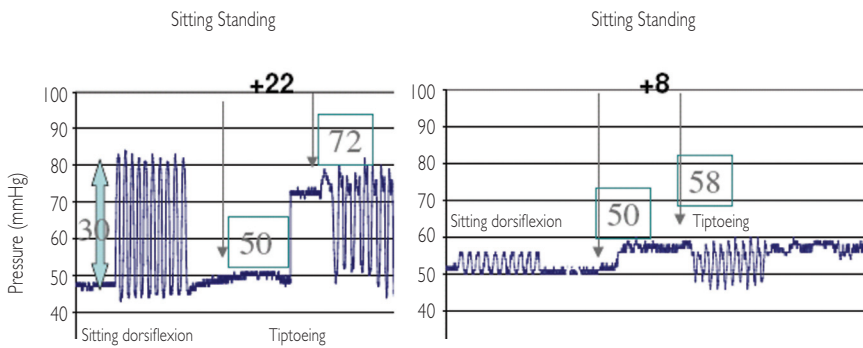
Figure 3. Measurement of the interface pressure exerted by an 'inelastic' short-stretch bandage (left) and by an 'elastic' long-stretch bandage (right) in the supramalleolar region of two legs. The resting pressure in the sitting position was about 50mmHg for both bandages. During dorsiflexions pressure peaks up to more than 80mmHg are achieved by the inelastic, and up to 55mmHg by the elastic material. The pressure increase by standing up was 22mmHg with the inelastic, and 8mmHg with the elastic material. The pressure amplitudes during movement exert a 'massage effect' and are much higher with the inelastic than with the elastic bandage.

is measured with a large pressure probe, the pressure increase by standing up and by walking will be lower than in a patient with a small leg circumference, in whom a small sensor is positioned over the protruding tendon. Particularly in patients with lymphoedema of the lower extremities, the sharp cut-off line of 10mmHg differentiating more or less stiff compression bandages may not be valid in certain cases. Reliable comparisons will only be possible when testing different compression devices by using the same sensor on the same site (Partsch et al, 2006).

Which materials provide high stiffness?

High stiffness defined as tolerable resting pressure and highly effective working pressure can be achieved by short-stretch bandages, multicomponent multilayer bandages and by Velcro-band devices. This is also true for elastic stockings applied over each other (Cornu-Thénard et al, 2007; Partsch et al, 2006). Adhesive and cohesive materials increase stiffness. *Table 1* gives a short overview.

Rationale for using inelastic multilayer bandages in lymphoedema

Most experts experienced in conservative management agree that multilayer short-stretch bandages are preferable for the initial treatment of lymphoedema.

Our knowledge of the mechanisms of action of compression devices is

rather poor. This is especially true in lymphoedema where objective findings are more difficult to prove than in venous pathology. However, some hypothetic arguments favouring material with high stiffness will be outlined.

We need to consider the main features that are different in lymphatic disease compared with venous pathology when choosing a specific form of compression therapy.

Table 2 shows some principal differences concerning compression therapy in venous and lymphatic disease. In fact, venous and lymphatic pathology show considerable overlapping, especially in the area of microcirculation and fluid exchange. The schematic differentiation presented in *Table 2* should mainly serve as a guide for a more detailed discussion.

Lymphoedema patients need continuous compression day and night, at least during the initial phases of treatment. For this purpose, inelastic bandages and compression systems with high stiffness are superior to elastic bandages since they exert a lower resting pressure which will be tolerated also in the supine position.

Oedema reduction seems to be more a question of exerted pressure than of the material used. Higher compression pressure leads to a faster volume reduction of the swollen limb than lower pressure. Again, high pressure produced by inelastic material is better tolerated than the pressure achieved by elastic bandages.

Some authors have experienced a worsening of lymphoedema when using elastic sleeves (Lerner, 2000). A guideline of the German Society of Lymphology strictly recommends against the use of compression garments in the initial treatment phase in order to avoid 'chronification due to an under dosed therapy' (Foeldi et al, 1998).

Compression will always induce some shift of tissue fluids into those areas of the extremity that are not covered by the compression device. This may cause swelling of the toes or fingers and accumulation of fluid in the region of the groin or the axilla. As long as the lymphatic drainage in these areas is intact, such as with pure venous oedema, this increase of fluid

Table 1	
Overview of low and high stiffness compression materials	
Low stiffness	High stiffness
▸▸ Compression stockings (single layer)	▸▸ Rigid bandages (e.g. zinc paste)
	▸▸ Velcro-band devices
	▸▸ Pumps
▸▸ Single component elastic bandages	▸▸ Short-stretch bandages
	▸▸ Adhesive, cohesive bandages
	▸▸ Multilayer bandages

Table 2

Compression in venous and lymphatic oedema

Venous oedema	Lymphatic oedema
▸▸ Mainly induced by gravity ▸▸ Lymphatic load is increased in upright position	▸▸ Induced by lymphatic damage ▸▸ Reduced uptake of lymphatic load day and night
Main effects of compression:	
To reduce capillary filtration (=lymphatic load)	
▸▸ To counteract ambulatory venous hypertension	▸▸ To promote lymphangiomotor function

therapy of lymphoedema is characterised by high peaks of interface pressure during walking (high working pressure) and relatively low and well-tolerated resting pressure. This relationship can be illustrated by stiffness levels, defined by the increase of interface pressure due to an increase in leg circumference. Future studies are needed to evaluate the influence of different pressures and degrees of stiffness on the efficacy of compression bandages in lymphoedema in order to optimise management of this condition. JL

will be compensated by lymphatic drainage. In lymphoedema patients in whom lymphatic drainage is impaired, this swelling should be prevented by bandaging toes and fingers and by giving additional MLD in the region of the proximal parts of the extremities.

Rhythmic forces exerted to lymphangions increase their spontaneous contractions. Such effects have been shown for arterial pulsations, breathing, MLD and compression (Olszewski, 1979). When the patient walks with inelastic bandages, a rhythmic massage of the leg will occur with every step (Olszewski, 1991). The induced improvement of the lymphangiomotoric function may be the basis for the finding that compression therapy, accompanied by MLD, is able to reduce the pathological increase of intralymphatic pressure in lymphoedema patients measured in lymph-capillaries (Franzeck et al, 1997). The stimulation of the spontaneous contractions of lymphatics will, of course, only be possible as long as this physiological function of lymph collectors is still preserved. However, it may be assumed that the high pressure amplitudes produced by walking with inelastic material are also able to compress superficial and deep lymphatics intermittently, in a similar way as demonstrated with superficial and deep veins using ultrasound imaging (Partsch et al, 2007).

Fibrosclerotic tissue is not only a feature of lymphoedema but occurs also in severe chronic venous insufficiency on the distal legs where it is termed

'lipodematosclerosis' (class C4b according to the CEAP; Eklof et al, 2004). Lymphatic abnormalities could be demonstrated in such skin areas using indirect lymphography and it was proposed to call this condition localised lymphoedema (Partsch, 1985). The pathophysiological basis is the exudation of protein-rich fluid into the tissue due to venous hypertension, and the decompensation of the local lymph drainage which becomes unable to cope with the increase of the lymphatic load. The consequent chronic inflammatory process with changes in the tissue metabolism resembles that of primary lymphatic damage and leads to progressive accumulation of fibrotic tissue. Ulceration of the skin may be the ultimate consequence of this chronic inflammation.

Intermittent compression of the fibrotic tissue by inelastic bandages is able to soften the involved skin areas. Several mechanisms of action on the release of vasoactive, anti-inflammatory, anticoagulatory, and fibrinolytic mediators from endothelial cells have been demonstrated by using intermittent pneumatic compression (Dai et al, 2002). It may be assumed that similar effects will occur with intermittent compression exerted by stiff compression and walking. In addition, some data show a down regulation of pro-inflammatory cytokines and receptors by using decongestive lymphatic therapy (Foeldi et al, 2000).

Conclusions

Multilayer inelastic lymphoedema bandaging (MLLB), as used for the initial

Key points

▸▸ Multilayer lymphoedema bandages (MLLB) applied with a pressure of >45mmHg are the basis of complex decongestive therapy in the initial management of lymphoedema.

▸▸ Two main mechanisms of action may be considered: due to the pressure under the bandage the increased tissue pressure will reduce the filtration of fluid from the capillary into the tissue so that the formation of oedema is diminished. This mechanism works day and night. In addition, the sub-bandage pressure rises during walking with each step. This intermittent massage of the leg promotes the spontaneous contractions of the lymhangions.

▸▸ Inelastic, non-yielding compression material leads to high peaks of sub-bandage pressure (massage-effect) when muscles contract during walking.

▸▸ Stiffness is defined by the increase of sub-bandage pressure due to an increase of the leg circumference (standing, walking).

▸▸ Adding several layers of compression bandages over each other increases the stiffness of the final bandage.

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