Classification of Compression Bandages: Practical Aspects

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BACKGROUND Compression bandages appear to be simple medical devices. However, there is a lack of agreement over their classification and confusion over the use of important terms such as elastic, inelastic, and stiffness.

OBJECTIVES The objectives were to propose terms to describe both simple and complex compression bandage systems and to offer classification based on in vivo measurements of subbandage pressure and stiffness.

METHODS A consensus meeting of experts including members from medical professions and from companies producing compression products discussed a proposal that was sent out beforehand and agreed on by the authors after correction.

RESULTS Pressure, layers, components, and elastic properties (P-LA-C-E) are the important characteristics of compression bandages. Based on simple in vivo measurements, pressure ranges and elastic properties of different bandage systems can be described. Descriptions of composite bandages should also report the number of layers of bandage material applied to the leg and the components that have been used to create the final bandage system.

CONCLUSION Future descriptions of compression bandages should include the subbandage pressure range measured in the medial gaiter area, the number of layers, and a specification of the bandage components and of the elastic property (stiffness) of the final bandage.

E. Steinlechner and M. Abel are employees of Lohmann & Rauscher, J. Hutchinson is an employee of ConvaTec, J. Schuren and K. Issberner are 3M employees. Jan Schuren has a patent application on one mentioned product. Travel expenses of the active participants were covered by the Industrial Board.

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ISSN: 1076-0512 • Dermatol Surg 2008;34:600–609 • DOI: 10.1111/j.1524-4725.2007.34116.x

Compression bandaging remains a key intervention in the management of venous and lymphatic disease. This apparently simple intervention depends on the appropriate selection and use of four complex central properties of compression bandages, namely, pressure, layers, components, and elastic properties (P-LA-C-E). Taking each factor in turn, "pressure" relates to the magnitude of the compression applied by the bandage, "layers" refers to the practice of overlapping layers of bandage material when the bandage is applied, "components" relates to the construction of the bandage (single material or composite structure), and "elastic" denotes the likelihood of the bandage applying a high pressure while the wearer is at rest. P-LA-C-E can be used as a help to memorize the deciding characteristics when a bandage is to be described.

Classification of bandage materials is clearly required for a number of purposes including: (1) better patient care; (2) comparison between different devices in future trials; (3) guidance for the health care practitioner regarding the likely effect of the bandage on a patient's leg; (4) support for manufacturers who want to create products with specific compression levels; and (5) product specifications for health authorities and insurance companies concerning reimbursement requirements. Although classification would help meet these goals, there is only one national classification developed in the United Kingdom in 1995 (BS 7505).[1] This classification proposes pressure ranges that may be obtained with different woven or knitted fabrics on the leg entirely based on force-elongation curves from the textile laboratory. Four classes of compression bandages are defined according to their ability to apply a specified subbandage pressure to a known ankle circumference (23 cm) where the bandage is applied with a 50% overlap between successive layers.[1] Today the majority of compression bandages are made with combinations of compression materials of differing texture, which together result in a composite bandage with complexities of both elasticity and the ability to apply compression. The physical properties of such composite bandage systems can only be assessed by measuring subbandage pressure and stiffness in vivo.

This consensus article defines and explains the features of interface pressure, layers, components, and elastic properties of bandage materials themselves, based on measurements on the human leg, to achieve a common language in an area of hitherto confusing terminology. However, the article does neither seek to recommend how bandages should be applied, nor is it the purpose of this consensus document to discuss the mode of action of different compression devices and their clinical outcomes.

The pressure developed beneath a bandage is governed by the tension in the fabric that is exerted when the bandage is applied, the radius of curvature of the limb, and the width and number of layers applied.[2] This simple statement has several practical and important implications. Experienced individual bandagers are likely to apply bandages at differing levels of compression to choose the most appropriate regime for an individual patient.[3,4] The high variability of bandage pressure achieved by inexperienced staff may be reduced by training.[5,6] For example, an experienced bandager will apply a bandage to a small-circumference leg with less tension than he or she would to a leg of larger circumference. Such individual differences must always be considered.

Methods

A draft statement was drawn up by the chairman (H. P.) and sent out to medical experts and representatives from the relevant industrial sector that together constitute the International Compression Club (ICC; http://www.icc-compressionclub.com/) before a consensus meeting held in early October 2006. The draft was mainly based on published data from in vivo measurements from the past years. During the consensus conference, this document, further supplemented by proposals from members of the ICC, was taken as the basis for the discussions. A draft document summarizing the outcome of the meeting was circulated and agreed upon by the majority of the members of the ICC. The following recommendations are the consensus of the ICC members. It should be noted that the consensus conference considered only compression bandages, and these recommendations are not to be considered relevant for compression hosiery.

Recommendations

Subbandage Pressure

If compression bandages are to be used effectively, there must be a balance between the amount of compression (subbandage) pressure that they apply—too low and the bandage will be ineffective but too high and either pressure-induced damage may occur or the wearer will be unable to tolerate the compression. To counteract the increased intravenous pressure in the upright position, the interface pressure of a compression device should exceed 40 mmHg.[7] While in recent years, there have been several reports that have measured subbandage pressures in vivo, comparison between these studies has been compromised by the range of pressure measurement devices used in these studies, one further problem being the variability in sensor positioning upon the leg between studies.[8] Although comparison between studies is limited, one key conclusion can be drawn from the recent in vivo subbandage pressure measurements—that the subbandage pressure ranges reported for bandages that are intended to apply mild, moderate, and strong compression are clearly higher than the ranges given in BS 7505[3,4,9,10] (Table 1). The suggested pressure

TABLE 1. Current Subbandage Pressure Ranges (mmHg) in the British Standard (BS 7505)[1] and Recommended Recalibration to Match In Vivo Pressure Measurements[8]

BS 7505, Compression Bandages	*Recommendation*
<20 (''light'')	<20 (''mild'')
21–30 (''medium'')	20–<40 (''medium'')
31–40 (''high'')	40–<60 (''strong'')
41–60 (''extra high'')	≥60 (''very strong '')

ranges are in complete accordance with the recommendation from a previous international consensus meeting.[11] This discrepancy between the measured subbandage pressures and the pressure ranges used to classify compression bandages has particularly been observed in the case of multilayer bandages. For instance, where bandages that consist of several components are each applied at an intentionally very light tension, the final bandage system may well apply around 30 mmHg, corresponding to the "medium" strength of compression as given in BS 7505.[3]

BS 7505 differentiates between three major groups of compression material:[1]

(1) Conforming stretch bandages;

(2) Light support bandages; and

(3) Compression bandages.

It is a misconception to assign different brands of bandages to one of these three groups, because the pressure exerted by the final bandage will mainly depend on the tension during application rather than the material used. For example, consideration of BS 7505 would call Rosidal, (Lohmann & Rauscher GmbH, Neuwied, Germany) and Comprilan (BSN Jobst, Hamburg, Germany) "light support bandages" (Type 2) and not "compression bandages" (Type 3) while these bandages may exert a resting pressure in vivo of more than 50 mmHg when applied correctly.[3]

The consensus conference agreed that in general the subbandage pressure ranges offered in BS 7505 were lower than the pressures measured in vivo and proposed a recalibration of the subbandage pressure ranges that denote light, medium, and high compression (Table 1). These pressure ranges are considered to be valid where measurements are made while the bandage wearer rests supine and with the subbandage pressure measured at the medial aspect of the lower leg where the tendon changes into the muscular part of the gastrocnemius muscle (measuring point B1).

As implied earlier, it must be stressed that the subbandage pressures during standing and walking will increase, the change depending on the elastic properties of the materials used.

Layers

Every bandage is applied to the leg with some degree of overlap, as the bandage is applied progressively higher up the leg. This overlap can create several layers of bandage material at specific points along the leg with these layers not dependent on the bandage material but upon application technique. The consensus conference agreed that in reality 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. Multilayer bandages could be formed by more than two layers of a single material or, in the case of the so-called four-layer bandage systems, by multiple layers of different bandage materials.

Components

There is a growing trend for the use of both multilayer bandages and bandage kits that consist of several bandaging materials. The combination of different bandage materials will influence subbandage pressure as will the stiffness of the assembled multilayer bandage itself; the influence of these parameters needs to be measured in vivo.

It is not possible to use in vitro data to predict the subbandage pressure and stiffness of the bandage system on the leg. To simplify the discussion on these multilayer systems, it was recommended to adopt the following definitions:

- *Components* of a bandage are the different materials used to create the compression bandage. Besides their intended functions like padding, protection, or retention they will have different effects on the subbandage pressures applied by the assembled bandage.
- *Compression bandaging systems* consist of at least two different bandaging materials applied over each other for the whole length of the bandage.
- They may be provided in one package by the manufacturers and referred to as "kits."
- Examples are the "four-layer" bandage system Profore, (Smith & Nephew UK, Hull, UK) or the short-stretch system Rosidal sys (Lohmann & Rauscher GmbH), which are multilayer, multiple component compression kits.
- A s*ingle compression component* contains one component only. A Pütter-bandage, (Paul Hartmann AG, Heidenheim, Germany) consisting of two short-stretch bandages applied without a padding layer, is an example of a multilayer, single-component compression kit.

Elasticity of Compression Bandages

In Vitro Assessment Hitherto, it has been customary to differentiate between "elastic" ("long-stretch") and "inelastic" ("no-stretch" or "short stretch") compression material on the basis of in vitro measurements made using different extensometer devices to characterize the relationship between exerted power required to distend the bandage and the resulting stretch ("force-elongation" or "hysteresis curve").[12–14] These terms are used in spite of some semantic discussion among the panel members if this terminology is correct from a physical point of view. The main categories of compression bandage elasticity as defined by the percent elongation of the material following application of a force of 10 N/cm bandage width (DIN 61632)[15] are shown in Table 2.

TABLE 2. Definitions of Inelastic and Elastic Bandage Material Based on In Vitro Testing[15]

	Inelastic	*Elastic*	
	Rigid (No-Stretch)	*Short-Stretch*	*Long-Stretch*
Maximal stretch (%) at 10 N/cm bandage width	0–10, e.g., zinc paste	10–100	> 100

TABLE 3. "Practical Stretch" of a Bandage (%) on the Human Leg to Achieve a Subbandage Pressure of 40 mmHg in the Gaiter Area (23-cm Circumference)

	Inelastic		*Elastic*
	Rigid, Nonstretch	*Short-Stretch*	*Long-Stretch*
Practical stretch (%) 1 N/cm width*	0–10	20–50	40–120

*For a bandage with 50% overlap exerting 40 mmHg at the gaiter area (B1).

However, while this classification may be technically adequate, such maximal elongations are unlikely to be reached during bandaging, thereby reducing the value of this classification in practical terms. Treating venous diseases in practice, a bandage is applied with the aim of achieving around 40 mmHg in the gaiter region of the supine subject (measuring point B1). To achieve this level of compression, the typical elongation for a force of 10 N over a 10-cm-wide bandage and an ankle circumference of 23 cm would be between 0 and 120% (Table 3).

The data indicated in Tables 3 and 4 are based on experiments performed on 10 legs of volunteers and on measurements from a total of 26 types of bandages, with different elasticities, generating typical load-extension curves with an extensometer. Figure 1 shows an example (investigations performed by H. P. and E. S.).

In reality this "practical stretch" depends both on the strength and on the density of the elastic fibers in the textile, and it has insufficient power to differentiate between the three categories defined in Table 3. To achieve the same pressure in the gaiter area, a "strong" elastic bandage may be stretched only by 40% while a "weak" bandage may need to be extended over 100%.

A more reliable differentiation is possible by measuring the increase in force obtained by applying additional stretch on the load-elongation curve

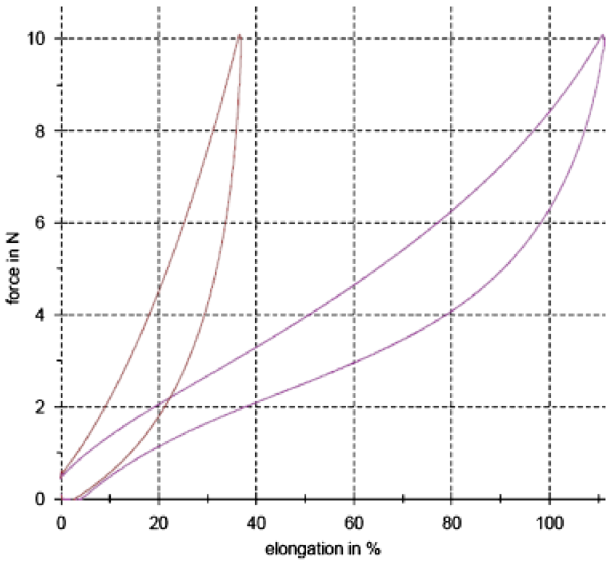


Figure 1. Load-extension curve of an inelastic (short-stretch; left) and an elastic (long-stretch) bandage (right). For a 10-cm-wide bandage, the steepness of the curve at the level of 10 N represents the dynamic module, which is much higher for the short-stretch bandage (0.35 N/%) than for the long-stretch bandage (0.18 N/%; Lohmann & Rauscher Textile Laboratory, Schönau/Tr, Austria). For the practical significance of this, see Figure 2.

according to Table 3. The resulting "dynamic module" corresponds to the steepness of the curve at the force-level of 1 N/cm width (Table 4, Figure 1).

It may be concluded that the extension of a bandage expressed in percent elongation (Tables 2 and 3) or as a dynamic module (Table 4) provides a differentiation of compression bandages based on their elasticity that may best satisfy the textile engineer but not the clinician. The assessment of elasticity is further complicated because the properties of multilayer bandage systems are difficult

TABLE 4. "Dynamic Module" Clearly Separates the Categories of Elastic Properties

	Inelastic		*Elastic*
	Rigid	*Short-Stretch*	*Long-Stretch*
Modulus (N/% stretch)*	>30	>0.3	<0.3

*For a bandage with 50% overlap exerting 40 mmHg at the gaiter area (B1).

to predict. Where the individual component materials may act as elastic bandages, the assembled bandage system may behave as an inelastic bandage.[13,16] Given these challenges to the in vitro classification of bandage elasticity, it is recommended that use of the terms "elastic" or "long-stretch" and "inelastic" or "nonstretch and short-stretch" are restricted to single bandage components and are not used when discussing multilayer compression bandage systems.

In Vivo Assessment Stiffness, which can be defined as the increase in subbandage pressure per centimeter increase in the circumference of the leg,[8] may be a useful parameter if used to define the elasticity of a compression bandage. The segment of the lower leg that will show the most extensive increase in circumference during standing and walking is the gaiter area (measuring point B1).[17,18] In addition, the tendon of the medial gastrocnemius protrudes during standing and on walking, and this will intermittently lead to a reduction of the local radius of the leg and to an increase in subbandage pressure in this region due to Laplace's Law.

Measuring the interface pressure of a bandage in this area the following two features clearly differentiate inelastic from elastic bandage material (Figure 2):[19]

- The amplitudes of the pressure tracing during exercise and
- The pressure increase due to standing up.

Prerequisites to assessing the pressure amplitudes during exercise include the patient's ankle joint mobility and the use of a pressure transducer that allows dynamic measurements to be made. However, neither restriction plays a role when static measurements are done either in the supine or in the standing position.

Several studies have demonstrated that the difference between the subbandage pressure measured in a standing and supine position is indirectly proportional to the stretch length of the bandage.[2–4,8,9,20] This difference measured in the gaiter area has been called the static stiffness index (SSI).[8] The SSI may be taken as a useful parameter to characterize in vivo stiffness for all forms of compression bandages including multicomponent multilayer systems in vivo. In the standing position inelastic bandage systems will produce a higher subbandage pressure than elastic bandages resulting in a higher SSI[3,8,18] (Figure 2). As a practical guide, when the patient moves from the supine to the standing position, a pressure increase of more than 10 mmHg defines inelasticity,

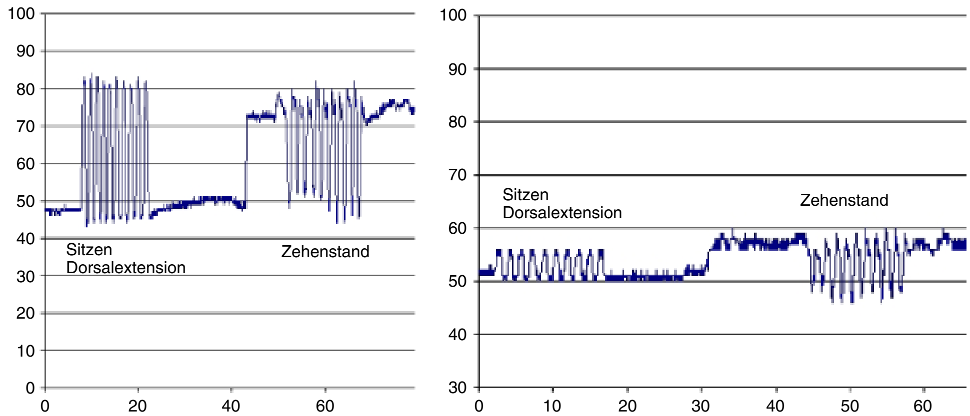


Figure 2. Interface pressure measured at the medial gaiter area at the transition between the muscular and the tendinous part of the gastrocnemius muscle (position B1) by a small probe (Kikuhime, Meditrade, Soro, Denmark): left, under an inelastic bandage; right, under an elastic bandage.[19] The resting pressure in the sitting position is about 50 mmHg for both bandages. Dorsiflexions result in pressure peaks ("working pressure") of more than 80 mmHg under the inelastic bandage, but only of about 55 mmHg under the elastic material. By standing up, the pressure rises to 72 mm (+ 22 mmHg) under the inelastic bandage and to 58 mmHg (+ 8 mmHg) under the elastic bandage.

TABLE 5. SSI (mmHg), the Difference between the Subbandage Pressures Measured in Standing and Supine Position

	Inelastic		*Elastic*
	Rigid	*Short-Stretch*	*Long-Stretch*
SSI*	> 10		< 10

*For a bandage with 50% overlap exerting 40 mmHg at the gaiter area (B1).

whereas an increase of less than 10 mmHg marks elasticity. Based on published pressure measurements, this proposed cutoff value of 10 mmHg is in accordance with several reports using different small measuring devices.[3,9,10,18] This very simple quotient may be taken as a rule of thumb and is measurable in patients without major disfigurations of the legs due to severe obesity or lymphedema (Table 5).

Figure 3 shows SSI values obtained from a wide range of different compression bandages.[18] It can be observed that multicomponent compression bandage systems consisting of mainly elastic components (e.g., Profore, Smith & Nephew UK) have a SSI higher than 10, which puts them in the inelastic domain. This phenomenon where elastic components behave inelastically when assembled can be explained by the friction between the rough surfaces of different layers of bandage that oppose the expansion of the leg. This is in addition to the elastic strain of the fibers themselves.[13] Friction is also high in bandage systems supplied with an *adhesive or cohesive surface*, which results in a higher SSI.

Figure 4 illustrates that the subbandage pressure in the standing position comes very close to the pressure peaks during walking[19] and can therefore be taken as a surrogate parameter for the working pressure seen during locomotion. Given this correlation, it is recommended that the subbandage pressure measured in a standing position better characterizes the performance of a bandage system than subbandage pressures measured in a supine or sitting position.

SSI values are influenced by the dimensions of the pressure measuring device and to some extent also

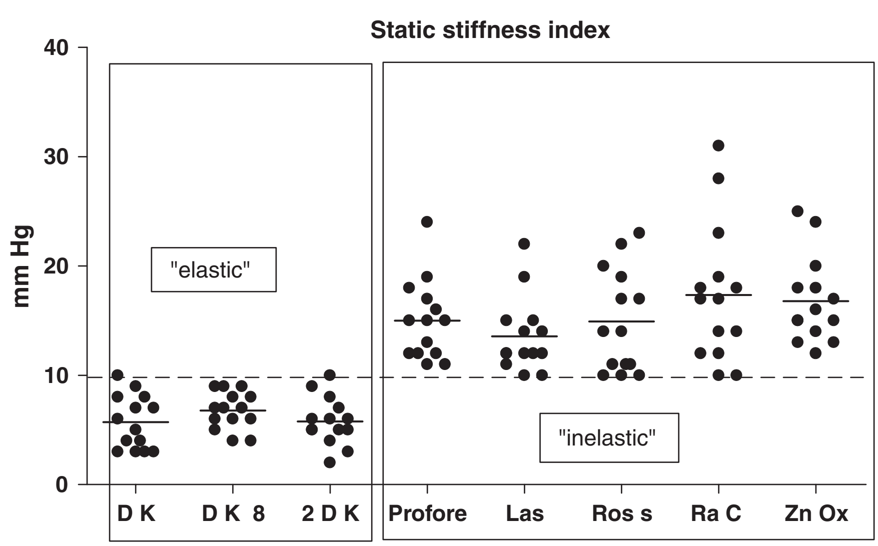
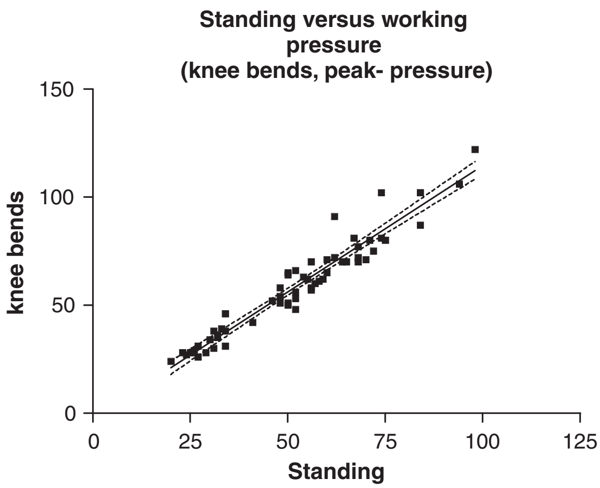


Figure 3. SSI is the pressure difference between the standing and the supine position measured over the tendon in the medial gaiter area. A pressure increase of less than 10 mmHg is observed with elastic bandages (''low stiffness''), while inelastic material produces a pressure increase greater than 10 mmHg (''high stiffness'').[18] DK = DauerbindeC (Lohmann & Rauscher, Germany) 5 m long, spiral application (multilayer, single component); DK 8 = Dauerbinde, figure-of-eight bandaging technique; 2 DK = two 5-m bandages; Profore (Smith & Nephew UK) = multilayer, multicomponent system; Las = Lastoban (Hartmann, Germany) bandage, 5 m long (multilayer, single component); Ros s = Rosidal sys (Lohmann & Rauscher; multilayer, multicomponent system); RaC = Raucodur cohesive (Lohmann & Rauscher; multilayer, single component); ZnOx = zinc paste plus Rosidal K (Lohmann & Rauscher; multilayer, multicomponent).



Pearson r	0.9657
95% confidence interval	0.9430 to 0.9795
P value (two-tailed)	P<0.0001

Figure 4. Using bandages with different elastic properties, there is an excellent correlation between the interface pressure values in the standing position and the peak values during standardized knee bending exercises.[19] The mean pressure values during movement are only slightly higher than those during standing. Interface pressure was measured under compression bandages with different elastic properties using a tester (Sigat, Ganzoni-Sigvaris, St Gallen, Switzerland) in the medial gaiter region ($n = 60$).

by the resting pressure of the bandage.[3] This second factor could be corrected if the SSI is expressed as a percentage of the subbandage pressure measured while standing.[8] A standing pressure being more than 20% higher compared to the supine pressure seems to characterize inelastic or high stiffness bandages. Regardless of this correction it was recommended to use SSI to characterize the performance of a compression bandage because of its simplicity, its ability to predict the likely effect of walking while wearing the bandage, and the likely tolerance of the wearer for the bandage while at rest. For example, a stiff bandage that exerts a subbandage pressure of 60 mmHg while standing may only exert 40 mmHg in a supine position (SSI, standing-supine pressure, 20 mmHg), a level of compression likely to be tolerated by the bandaged person. In contrast, an elastic bandage that applies a subbandage pressure of 60 mmHg while standing may exert a supine pressure of 55 mmHg (SSI, standing-supine pressure, 5 mmHg), which may cause discomfort.

For future research it would be interesting to combine plethysmography with subbandage pressure measurements to allow accurate characterization of the change in pressure as the leg circumference increases and decreases during locomotion. However, such research, while of considerable scientific interest, is unlikely to replace SSI as a simple index for the behavior of compression bandages. In a recent study it was observed that subbandage pressures related to the actual changes in leg circumference may only slightly increase the ability to differentiate between elastic and inelastic bandage systems based upon stiffness measures.[18]

Mode of Application

Different application techniques of bandages will probably also influence their in situ stiffness and subbandage pressures. This problem must be evaluated in future studies because published data are contradictory.[4,20]

Key Recommendations

- **P**ressure, **LA**yers, **C**omponents, and **E**lastic properties (P-LA-C-E) are the main factors that have to be taken into consideration when a compression bandage is applied. The “P-LA-C-E” acronym may assist recall of these four factors.

- **Pressure** measured in vivo in the medial gaiter area in the supine position for training purposes may be classified into the following categories:

- —mild (less than 20 mmHg),
- —moderate (≥ 20–40 mmHg),
- —strong (≥ 40–60 mmHg), or
- —very strong (more than 60 mmHg).

- A double-**layer** bandage is characterized by an overlap of 50%. More layers/overlap result in a multilayer bandage.

- **Components** of a bandage consist of different materials that may have different functions (padding, protection, retention).

- The **elastic properties** of a single bandage may be inelastic (rigid bandages or short-stretch bandages) or elastic (long-stretch bandages).
- Several layers of material (either identical or different materials) have the tendency to make the bandage system stiffer.
- It is recommended that simple, double-layer bandages are characterized by use of the terms "elastic and inelastic." Concerning multilayer bandage systems, it is important to remember that the final bandage system may behave as an inelastic system even though the individual layers act as elastic materials. This is due to the friction generated between bandage layers. Therefore, it is proposed that in the case of multilayer bandage systems and kits, the terms "high or low stiffness" should be used to characterize the behavior of the final bandage.
- Stiffness may be characterized by the increase of interface pressure measured in the gaiter area when standing up from the supine position. A pressure increase of more than 10 mmHg measured in the gaiter area is characteristic of a stiff bandage system.
- Further studies are needed to evaluate the mode of bandage application on subbandage pressure and stiffness.

Summary Statement

The aim of this consensus document is to define the deciding characteristics of a compression bandage: pressure, layers, components, and elastic property. The acronym "PLACE" should remind researchers reporting on compression therapy, but also the producers of compression materials to use the terms proposed in this document to facilitate universal understanding.

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Appendix I

Basic Definitons

Compression implies the deliberate application of pressure to produce a desired clinical effect.[2]

Pressure measured in Pascal or mmHg is the force (Newtons) per area (square centimeters) and depends on the curvature of the compressed limb according to the law of Laplace.

Tension is the force to which the bandage is subjected during application.

Elasticity is the characteristic ability of a material to return to its original shape, size, and condition after it has been stretched thereby applying a force on the tissue on top of the force generated by the application technique

Stretch or "extensibility" determines the change in length that is produced when the bandage is subjected to an extending force.

Stiffness is the increase in compression per centimeter increase in the circumference of the leg.

Appendix II

Some Examples for Single Component Compression Bandages

- *Elastic bandages*:

Ace-bandage (BD, Franklin Lakes, NJ), Perfekta, Dauerbinde (Lohmann & Rauscher GmbH), Surepress, (ConvaTec, Princeton, NJ), Tensopress, (Smith & Nephew UK), Biflex, (Thuasne, Saint-Etienne, France).

- *Inelastic bandages*:

Comprilan, (BSN Jobst), Rosidal K, (Lohmann & Rauscher GmbH), Actiban, (Activa Healthcare Ltd, Burton on Trent, UK), Panelast, (adhesive; Lohmann & Rauscher GmbH).

Examples for Compression Systems (Kits)

When correctly applied, the following examples will deliver strong to very strong compression:

Pütter bandage, (Paul Hartmann AG): multilayer, single component, inelastic bandage with high stiffness.

Profore, (Smith & Nephew UK): four mainly elastic components, bandages with high stiffness.

Rosidal sys, (Lohmann & Rauscher GmbH): two inelastic components, bandages with high stiffness.

Coban 2 Layer compression system, (3M Deutschland GmbH, Neuss, Germany): two cohesive components, bandages with high stiffness.

Unna boot bandage with inelastic bandage: two components; major component is rigid, bandages with high stiffness.