Variability of pressure provided by sustained compression

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Moffatt C. Variability of pressure provided by sustained compression. Int Wound J 2008;5:259–265.

ABSTRACT

Compression therapy is the cornerstone of treatment for patients with venous leg ulcers (VLUs). Although it is generally accepted that the therapeutic outcomes are directly related to the quality of compression therapy, delivering precise and sustained compression therapy is an ongoing challenge for health care professionals. Several factors influence quality of compression therapy: physical structure and elastomeric properties of the compression system, size and shape of the leg, skill and technique of the bandager and physical activity undertaken by the patient. Graduated compression is achieved by applying a bandage at the same tension from ankle to knee, providing the shape of the leg is normal. Many patients with VLUs have distorted legs, challenging the delivery of a desired pressure gradient. Poor bandaging technique can result in little or no benefit or may deliver too high a pressure causing a detrimental effect to the wearer. If the wearer is unable to tolerate the compression, patient concordance and effectiveness are affected. Training has been shown to reduce variability of sub-bandage pressure. Sub-bandage pressure increases during standing and walking. These pressure changes are related to the elastomeric properties of the compression systems. Health care professionals need to understand the properties of the available compression systems and how their application technique must be adjusted.

Key words: Compression stockings ● Compression therapy ● Interface pressure ● Multi-layer bandaging

INTRODUCTION

Compression therapy, whether using high compression, single-layer elastic or inelastic bandages, multi-layer bandages, compression stockings or intermittent pneumatic compression, is widely considered to be the cornerstone for the prevention and conservative treatment of venous leg ulcers (VLUs), varicose veins, deep vein thrombosis and chronic venous insufficiency. Ulcer healing rates of up to 70% at 12 weeks, when combined with a prevention protocol, have been reported with the use of compression therapy, with subsequent improvements in patient pain, mobility and general quality of life(1). However, many studies fail to achieve such impressive results despite the apparent similarities in practice (2,3); the reasons for this remain obscure and cannot be explained by the patient characteristics. Even in studies where less impressive results are achieved, it should be remembered that compression dramatically improves ulcer healing when compared with no compression (4), a situation still often encountered around the world.

Although the exact physiological mechanisms are not entirely understood, compression therapy works by directly affecting venous, arterial and lymphatic function (5). Provided arterial flow is not adversely affected, compression therapy can reverse increased venous hypertension, augment the calf muscle pump, facilitate venous return and improve lymphatic drainage, leading to ulcer healing and less oedema (2,5,6)

While the benefits of compression therapy are clear, controversy remains with regard to pressure recommendations (7). Sustained, graduated external compression indicates that

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Key Points

- compression therapy, whether using high compression, single-layer elastic or inelastic-bandages, multi-layer bandages, compression stockings or intermittent pneumatic compression, is widely considered to be the cornerstone for the prevention and conservative treatment of venous leg ulcers (VLUs), varicose veins, deep vein thrombosis and chronic venous insufficiency
- even in studies where less impressive results are achieved, it should be remembered that compression dramatically improves ulcer healing when compared with no compression, a situation still often encountered around theworld-while the benefits of compression therapy are clear, controversy remains with regard to pressure recommendations

Key Points

- many patients treated in community settings are unlikely to be receiving a correct gradient of pressure because of changes in limb contour; despite this fact, good healing rates have been achieved, and this adds to the complex issues and controversies that surround the use of compression
- if the pressure applied during compressiontherapy is insufficient or not sustained, the efficacy of compression therapy will not be realised
- excessive bandage tension can lead to tissue damage and necrosis
- one of the greatest challenges for the development of compression devices in future is achieving the ability to adapt to different patient characteristics and limb shapes while ensuring effective compression
- a variety of different in vitro and in vivo measurement techniques have been used to measure sub-bandage pressures associated with compression bandages and hosiery
- however, even in controlled settings using a single bandager, consistent leg geometry and with measurements taken immediately after application, a wide range of pressures was observed, indicating significant variability
- the implication is that the prescribed compression therapy pressure is not being delivered and that many compression therapy treatments are providing sub or supratherapeutic pressures

the pressure is highest at the ankle and gradually reduces as it approaches the knee. Although the natural shape of the leg contributes to the gradated pressure, the overall pressure is also dependent on correct technique (8). The extent to which achieving a correct gradient of pressure is important has not yet been determined. Many patients treated in community settings are unlikely to be receiving a correct gradient of pressure because of changes in limb contour. Despite this fact, good healing rates have been achieved, and this adds to the complex issues and controversies that surround the use of compression.

To reverse venous hypertension in an ambulatory patient, an average pressure of 40 mmHg is required at the ankle, with a graduated decrease in compression up the leg to approximately 20 mmHg at the calf (8). This recommended value does not take into account the patient's height or body mass (7) and has not been proven in practice.

If the pressure applied during compression therapy is insufficient or not sustained, the efficacy of compression therapy will not be realised (7). Excessive bandage tension can lead to tissue damage and necrosis (9). In one observational study, Chan *et al.* reported on 12 patients being treated with four-layer compression bandaging for characteristic VLUs who developed de novo toe and cleft ulceration (10). Although the exact cause is unknown, the authors postulated that this may have been a consequence of the poor application of compression with excessive layers applied over the vulnerable area of the forefoot and toes that had not been sufficiently padded to prevent trauma. The application technique for the four-layer bandage is explicit in ensuring that the padding layer extends to the toes and that direct contact with the elastic compression layer is avoided. This is an excellent example of the challenges of correct use of compression in everyday practice: applying sufficient compression to achieve therapeutic benefit while minimising risks associated with excessive localised compression. Much of the emphasis in compression therapy over the past two decades has been on the development of new systems and materials, with less emphasis on how these are translated effectively into practice. While anecdotal evidence suggests that many patients experience problems with high compression, this is based mainly on professional judgements. There has been very little research in which these issues have been explored. Pain with compression is generally recorded as an adverse event within clinical trials; however, the health-related quality of life issues indicate that compression is associated with an improvement in pain principally influenced by achieving ulcer healing. Attempts to understand how well professionals achieve adequate compression are also limited, as studies are rarely undertaken on the types of complex patients with distorted limb shape seen in leg ulcer services. One of the greatest challenges for the development of compression devices in future is achieving the ability to adapt to different patient characteristics and limb shapes while ensuring effective compression.

CHALLENGES ASSOCIATED WITH MEASURING THE SUB-BANDAGE PRESSURE

A variety of different in vitro and in vivo measurement techniques have been used to measure sub-bandage pressures associated with compression bandages and hosiery (11–13). When making in vivo sub-bandage pressure measurements, the placement of sensors is very important. The general consensus is that the B1 position, the area at which the Achilles tendon changes into the calf muscle, should be taken as the reference point for sub-bandage pressure measurements (14,15). Furthermore, they recommend measuring pressure with the patient in both supine and standing positions, when activating the calf muscle and ankle joint pumps, when walking on a treadmill, standing on tiptoe or flexing the knee and with passive ankle movement (15).

However, even in controlled settings using a single bandager, consistent leg geometry and with measurements taken immediately after application, a wide range of pressures was observed, indicating significant variability (16). The implication is that the prescribed compression therapy pressure is not being delivered and that many compression therapy treatments are providing sub- or supratherapeutic pressures.

THE SCIENCE OF COMPRESSION THERAPY

Given the practical difficulties associated with measuring sub-bandage pressure, the Laplace's equation can be used to predict the average pressure exerted by a compression therapy material for a given level of applied tension (17). The degree of compression produced by any bandage system over time is governed by the laws of physics and, specifically, by Laplace's law, which describes the relationship between the internal and the external pressures of a vessel, in this case a patient's leg. The use of a modified and simplified version of the Laplace's equation, given below, to estimate the average sub-bandage pressure (3) that will be exerted by a bandage on a limb of known circumference has been advocated (18).

$$\text{Pressure (mmHg)} = \frac{\text{Tension (Kgf)} \times \text{number of bandage layers} \times 4620 \ \text{(constant)}}{\text{Circumference of limb (cm)} \times \text{bandage width (cm)}}.$$

The terms used in this equation are defined in Table 1 (3). It is important to note that the sub-bandage pressure calculated using this equation applies only at the time of application (17). The principles of Laplace have not been translated into effective application of compression in clinical practice. Practitioners frequently struggle to understand these principles, especially, the relationship between small circumference and increased pressure. Conversely, many patients have larger circumference limbs and an inadequate level of pressure is applied. Many compression systems have not been designed to address these issues. The ankle circumference range for the majority of elastic bandages is 18–26 cm; however, a proportion of patients fall outside of this and the correct level of compression will not be achieved unless there is an adaptation to the method of application or a change in product use. Some systems, such as the four-layer bandage system, have been modified for small and large limbs to try to ensure correct pressure on different limb sizes (19). There is little evidence that practitioners are able to modify the compression level for the different patient groups.

FACTORS CONTRIBUTING TO THE VARIABILITY OF PRESSURE DURING COMPRESSION THERAPY

Several factors contribute to the variability in interface pressure values observed during compression therapy, and they are discussed in the context of their effects on key variables in the Laplace's equation. These include the physical and elastomeric properties of the bandage as they relate to tension, the number of bandage layers as it relates to application technique, the size and shape of the limb during rest and exercise, bandage width and the skill and consistency of the practitioner.

Physical and elastomeric properties of the bandage as they relate to tension

Using the Laplace's equation, the pressure applied is directly proportional to the tension but inversely proportional to the size of the limb. In other words, bandages applied more tightly or with greater tension result in higher sub-bandage pressures. Assuming that a bandage is applied at the same tension from ankle to knee, the natural shape of the leg leads to gradual reductions in pressure. However, in the clinical setting, tension is determined by the bandager during application and by the extension of the bandage. Furthermore, even if tension is initially uniformly applied, the ability to sustain that degree of tension, and therefore pressure, over a period of time is dependent upon the bandage's extensibility, which is a function of its inherent elastomeric properties (18). Practitioners often find difficulty in ensuring that there is no change in the tension of the bandage. Common problems are found when bandages are too short. If the practitioner feels the bandage will not extend to the knee, he or she will extend the bandage, thus increasing the tension. Patients with heavy limbs that cannot be lifted by the practitioner are another challenge. An increase in tension is often seen around the ankle because of the difficulties of holding the limb while bandaging. Some manufacturers include bandage symbols to guide the correct extension of bandage. These can be helpful but are not always used appropriately. Much of the guidance given on ensuring correct tension is based on the testing of compression materials in a laboratory setting and not on the realities of the care setting and differences of patient groups.

Key Points

- the degree of compression produced by any bandage system over time is governed by the laws of physics and, specifically, by Laplace's law, which describes the relationship between the internal and the external pressures of a vessel, in this case a patient's leg
- the principles of Laplace have not been translated into effective application of compression in clinical practice
- much of the guidance given on ensuring correct tension is based on the testing of compression materials in a laboratory setting and not on the realities of the care setting and differences of patient groups

Key Points

- the potential consequence of increasing application bandage pressure is unknown
- the more layers of bandages that are applied, the higher the sub-bandage pressure exerted will be
- with regard to variability, one study showed relatively small differences between sub-bandage pressures when an elastic bandage was applied using the spiral or figure-eight technique

Table 1 Explanation of the components of Laplace's Law (3)

P = Pressure	The amount of pressure exerted by the bandage on the limb, expressed in mmHg.
T = Tension	Tension relates to the amount of force required or used to apply the bandage. Tension is directly proportional to the bandage pressure. The bandage's ability to retain that tension depends on the elastomeric properties of the bandage.
N = Number of layers	The more bandages (of a similar type) applied, the higher the pressure will be. The number of layers not only relates to the number of bandages used but also to the application of the bandage using either the spiral or the figure-of-eight technique and the degree of overlap.
C = Circumference of the limb	Sub-bandage pressure is inversely proportional to limb circumference, that is the smaller the limb, the higher the pressure. It is imperative to measure the ankle circumference (at the thinnest point, just above the malleolus) as this measurement will help to determine the appropriate bandage choice.
W = Width of the bandage	The narrower the bandage, the greater the pressure and vice versa. For a 'normal' adult-sized leg, a 10-cm bandage is usually the most appropriate.

Tension tends to decrease over time for all bandage materials, but this is especially true for short-stretch (<70% stretch) materials with less elastomeric property compared with medium-stretch (70–140%) and long-stretch (>140%) materials (2,20,21). Larson and Futtrup observed that the working pressure at ankle level after 7–8 hours of wear dropped by 25% and 5% for short-stretch and long-stretch bandages, respectively (20). In the clinical setting where compression therapy is routinely applied to a leg with oedema, a greater decline in pressure will be observed as the reduction of oedema changes the circumference of the leg. Sub-optimal pressures can occur and bandages will need to be reapplied. Following surgery for varicose veins, Raj et al. reported that to achieve sustained clinically effective pressure levels, cotton bandages had to be reapplied every 6–8 hours (22). Although elastic bandages provide the most sustained compression, they also have the lowest margin of safety because pressure remains high even when the patient is lying down and compression therapy is not needed (21).

Because pressure applied during compression therapy diminishes over time, maintaining the recommended 40 mmHg resting ankle level pressure would require proportionately increasing initial application pressures; however, the potential consequence of increasing application bandage pressure is unknown.

Number of bandage layers and application technique

The more layers of bandages that are applied, the higher the sub-bandage pressure exerted will be. Note, however, the number of bandage layers in the Laplace's equation relates only to a single turn of bandage that is applied to the limb at right angles (17). In the clinical setting, bandages are typically applied using either the spiral or the figure-of-eight technique, which necessitates a certain degree of overlap. Using the modified Laplace's equation, an overlap of 50% effectively equates to two layers of bandage when the spiral technique is used or to four layers when using the figure-of-eight technique (3,17,18). The degree of overlap must be applied consistently to ensure even pressure along the leg (3). A significantly greater (>50%) degree of overlap can result in localised areas of very high tension and should be avoided (17). The relationship between the number of bandage layers and the sub-bandage pressure is also important when considering that bandages can slip or become displaced, leading to multiple layers of overlap and localised areas of high pressure (18). With regard to variability, one study showed relatively small differences between sub-bandage pressures when an elastic bandage was applied using the spiral or figure-eight technique, with a maximum 6 mmHg difference reported for a given bandage applied at a known tension (11).

The advantage of multicomponent bandaging is that it can be used to deliver incrementally increased pressure (8). However, with multilayered bandages, the final pressure does not equal the sum of each individual layer. Instead, the multiple layers exert approximately 70% of the pressure of the total layers used alone (23). A four-layer method is commonly used for compression therapy for VLUs but can vary depending on which of two traditional bandaging techniques is used, the spiral method or the figure-eight method (8,11). In one study (8), both techniques produced graduated compression and were safe and comfortable. However, using the figure-eight method, pressure was particularly high overlying the Achilles tendon, an area that is difficult to heal if damaged.

Recommendations for the layering of compression bandages are based on technical testing methods (7). Consistent application of compression layers is a major problem in practice. Patients with large, exudating wounds frequently have many layers of dressings and padding that influence the potential of the compression layers to achieve the correct pressure. The correct overlapping of bandages is also a problem. Tall patients or those with large limbs will require more than one bandage to achieve compression from toe to knee. If a second bandage is required, extra layers of bandage are often applied to anchor the bandage, thus influencing the compression profile. If a whole bandage is not needed, excessive layers are often wrapped around the top of the calf, thus creating a tourniquet effect.

Size and shape of the limb at rest and during exercise

The size and shape of the limb is important. Using the modified Laplace's equation, sub-bandage pressure is inversely proportional to limb circumference. In practical terms, this means that the smaller the limb, the higher the pressure. It also means that pressure is highest at the smallest part of the leg, which for most patients is the ankle just above the malleolus, and this is where the circumference measurement should be taken. Because legs are not uniformly circular, bandage pressure will vary considerably with the highest pressure at the malleolus (ankle bone) and tibial crest (shin) (18). Owing to the increased pressure at these areas, padding is generally applied to protect the leg at these points (18).

There are several important practical considerations with regard to the effect of size and shape of limb on pressure variability. For example, the limbs may be disproportional in size. Common shape deformities seen in patients with VLUs include loss of natural gradient and inverse champagne limb (3). Loss of limb shape can cause a reverse pressure gradient to be applied by the compression with the associated problems of oedema formation in the foot and pressure damage over the tibial crest. In champagne-bottle-shaped limbs, the pressure at the ankle may be sufficient but the calf pressure may be too low. Slippage and trauma are a common issue in these circumstances. Limb size and shape may also change with oedema, so much so that with a large, oedematous leg, the pressure gradient may in fact be insufficient to produce a significant clinical effect (3). Different body positions (lying, sitting and standing) and actions (resting and walking) produce considerable changes in limb dimensions, changes that affect interface pressures (24).

Bandage width

Bandage width also plays a role in pressure variability, with narrower bandages exerting greater sub-bandage pressure than wider bandages. Because pressure is force per unit area, a 10-cm-wide bandage will produce only half the pressure of a 5-cm-wide bandage, provided that they are applied with the same force (17). Here, the width of the bandage is the measured width once the bandage has been applied, not the width of the unstretched fabric (17); this is important, as some bandages decrease in width as they are stretched (17).

The skill of the operator

Up to this point, the discussion has been somewhat theoretical and based on Laplace's law; however, the real-world clinical setting can be very different. Although the previously discussed factors are important, in the clinic, much of the variability in pressure associated with compression therapy is because of the skill of the operator. Consistency of technique is important to limiting variability of interface pressure. Unfortunately, bandage application technique may be inconsistent even among experienced nurses, with sizeable pressure variations observed with different practitioners. In one study, designed to compare the differences

Key Points

- the size and shape of the limb is important
- using the modified Laplace's equation, sub bandage pressure is inversely proportional to limb circumference; in practical terms, this means that the smaller the limb, the higher the pressure
- different body positions (lying, sitting and standing) and actions (resting and walking) produce considerable changes in limb dimensions, changes that affect interface pressures
- bandage width also plays a role in pressure variability, with narrower bandages exerting greater sub-bandage pressure than wider bandages
- in the clinic, much of the variability in pressure associated with compression therapy is because of the skill of the operator
- bandage application technique may be inconsistent even among experienced nurses, with sizeable pressure variations observed with different practitioners

Key Points

- training can be used to reduce the variability of interface pressure as well as to avoid potentially dangerous interface pressures
- with regular practice, this high degree of competence can be retained, and experienced practitioners will be able to achieve consistent resting pressure in a normal shaped limb
- compression therapy is both an art and a science and, as such, there will continue to be variability of pressure
- nurses continue to play an increasing role in delivering effective compression therapy, often measuring limbs, fitting compression stockings or bandaging, aiding in the selection of compression therapy and determining the required level of compression
- nurses also play a vital role in improving patient adherence with compression therapy both during and after ulcer healing
- a better utilisation of nurses' skills, combined with the development of new compression systems that provide precise and sustained pressure, will continue to advance the treatment of venous disease

in pressure between two bandaging techniques, ten trained and experienced nurses were excluded because of inconsistent bandaging technique(8). This group represented 38% of the recruited nurses who were selected based on training or were instructor on leg ulcer management. Intuitively, less experienced nurses would be expected to bring an even higher degree of inconsistency to their bandaging technique. Fortunately, training can be used to reduce the variability of interface pressure as well as to avoid potentially dangerous interface pressures. Hafner et al. showed that even beginners were able to achieve target pressures in four consecutive bandage applications after only ten individual exercises and to avoid interface pressure greater than 60 mmHg after only four training sessions (25). With regular practice, this high degree of competence can be retained, and experienced practitioners will be able to achieve consistent resting pressure in a normal shaped limb.

DISCUSSION AND CONCLUSION

Compression therapy is both an art and a science and, as such, there will continue to be variability of pressure. Nurses continue to play an increasing role in delivering effective compression therapy, often measuring limbs, fitting compression stockings or bandaging, aiding in the selection of compression therapy and determining the required level of compression.

Nurses also play a vital role in improving patient adherence with compression therapy both during and after ulcer healing. In one study that included patients' compression bandages or stockings, full adherence to compression therapy was reported in only 39% of patients (26). In another study with patients with healed ulcers, 52% of patients wore their stockings daily for the first 6 months after their VLU had healed, 16% wore them most days, 5% wore them occasionally and 22% did not wear them at all after their ulcer had healed (27). Interestingly, a patient's age and sex, the degree of difficulty in applying stockings and cosmetic appearance did not influence this decision (27). Instead, the two most important factors affecting increased use of stockings were the patient's belief that wearing stockings was worthwhile and the opinion that they would prevent a recurrence of an ulcer(27). This is where nursing staff can really have an impact by educating patients regarding the chronic nature of leg ulcers and the long-term benefits of regular compression therapy. Selection of the compression modality that best suits the patient's lifestyle will help ensure concordance with treatment (28,29). Correct application of compression bandages is also crucial as painful treatment is less likely to be adhered to.

When pressure is viewed as a prescribed 'dosage', it is clear that the degree of interface pressure variability associated with currently available compression therapy systems is not optimal (24). In fact, some have proposed that the variability of healing rates may be related to variability of pressure (2, 6, 30). While manufacturers have improved compression systems to reduce pressure variability, the goal of delivering precise, sustained compression remains a challenge. A better utilisation of nurses' skills, combined with the development of new compression systems that provide precise and sustained pressure, will continue to advance the treatment of venous disease.

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