Chapter 6

Nonwoven Padding for Compression Management

Bipin Kumar

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/61309

Abstract

Nonwovens play an important and crucial role in the designing of appropriate structures for healthcare and hygiene products. One such application is the use of nonwoven padding in a multi-layer compression system recommended for the treatment of chronic venous disorders. Padding helps in ensuring uniform pressure distribution underneath the bandaging layer wrapped around the circumference of the limb. Apart from the pressure management, padding also facilitates body fluids' absorption and removal, and provides thermal and tactile comfort to ensure better compliance of the multi-layer compression system. This chapter analyses the different roles of padding in compression management. The importance of different nonwovens and their structure on the padding performance are also reviewed, using both experimental and theoretical analyses. Finally, some useful recommendations are provided for design considerations to develop optimized products.

Keywords: Padding, Nonwoven, Venous Ulcers, Pressure, Wadding, Multi-layer bandaging

1. Introduction

Today, nonwoven fabrics are the fastest growing area of the textile industry [1, 2]. As nonwoven fabrics are made directly from fibres, bypassing the large number of operations involved in assembling fibres first into yarn and then preparing the yarns suitably for the fabric formation process, tremendously decreases the labour cost, allows easier cutting and sewing for unskilled labour and reduces the lag time during production process [3]. Furthermore, nonwoven allows modifying its properties by selecting different fibres or binders and controlling the arrangement of the fibres in the web. Hence, they are successful in many industrial and medical applications including geotextiles, diapers, wipes, draperies, furniture, mattress, mattress pads, apparel, etc. [4]. Each of these applications has different demands due to which the specific properties and characteristics of the nonwoven must be addressed carefully in order to design optimised fabric structure with maximum benefits. This chapter focuses on a particular end application for the nonwoven as a padding bandage used in multi-layer compression system recommended for chronic venous ulcers.

Nonwoven padding is an essential component in a multi-layer compression system [5, 6]. Padding lies underneath compression bandage or stocking through which substantial amount of pressure is exerted on the limb of patient. Padding plays two major functions: first it helps to maintain uniform pressure around the circumference of limb, and, second, it helps in proper exchange of moisture or air for improved comfort to the patient. This chapter addresses several issues related to padding: it begins by mentioning the medical problem, identifying the product requirements, describing the role of fibre and construction, attempting theoretical modelling to understand padding behaviour, examining the structure–property relationship and finally recommending the optimised product.

2. Chronic venous disorders

Chronic venous disorder occurs due to improper functioning of venous system, especially in the lower extremity, which makes it difficult for the venous reflux to return to the heart from the legs [7, 8]. Patients suffering from such disorders have poor quality of life due to consistent pain, limited mobility, physical function, depression, social isolation and high treatment cost [9]. It has been estimated that 1% of the general population (age group: 18–64) is suffering from chronic venous disorders [10]. This rate is further increased to 4% in people over the age of 65 [11]. Furthermore, it has been anticipated that the rate will increase significantly in future due to changing lifestyle and the growing aging population.

Chronic venous disorders such as varicose veins, deep vein thrombosis, oedema, ulcers, lymphoedema, etc., happen primarily in lower limbs when the veins are not able to pump enough blood back to the heart. This improper functioning is the result of venous hypertension [12]. In most cases, venous hypertension is caused by reflux through incompetent valves, but other causes include venous outflow obstruction and failure of the calf-muscle pump owing to obesity or leg immobility. Deep vein thrombosis is the condition where the blood clots (thrombus) inside the veins, which obstructs the smooth flow of blood toward the heart [13]. The blood trying to pass through these blocked veins can increase the blood pressure in the vein, which, in turn, will overload the valves. This can lead to damage to the valves, which can further worsen the problem as these incompetent values will not be able to prevent backflow of blood. This may result in pooling of blood in the surrounding tissues, which will cause swelling (also termed as oedema). Over time, this can worsen the condition and result in venous ulceration (Figure 1).

http://dx.doi.org/10.5772/61309

(a) (b) (c)

Figure 1. Different forms of chronic venous symptoms in lower leg (varicose veins, venous oedema and venous leg ulcers; from left to right)

2.1. Compression Therapy – Importance of External Pressure

Compression therapy is the cornerstone of treatment for phlebological and lymphatic conditions [7, 14-17]. The prime objective of compression therapy is to reduce the venous pressure in the affected limb region [13, 17, 18]. This finally serves several functions:

It reduces the venous diameter and increases the interstitial pressure in the surrounding, which increases the blood flow in the deep veins.

It restores the valve function by bringing the walls of the veins closer together.

It reduces blood pressure in the superficial venous system.

It reduces the pressure differences between the capillaries and the tissue to prevent backflow.

It increases the cutaneous microcirculation, favours white cell detachment from the endothelium and prevents further adhesion.

It reintegrates the interstitial liquids into the vessels.

The main parameter responsible for clinical efficiency is the interface pressure [19-26]. Interface pressure is defined as the pressure exerted by the compression system over the surface of skin. The Laplace's Law is used to predict the interface pressure (P), which is a function of the tension in the fabric, and the circumference of the limb [16, 21, 27]. This can be expressed as:

$$P = \frac{F}{r} \tag{1}$$

where F is the tension in the fabric per unit length, and r is the limb radius. The efficacy of the treatment is undoubtedly dependent on this interface pressure as this has to be quite accurate within certain limits and should not be below or above the prescribed level, otherwise it can lead to certain complications during treatment [25, 28]. Low pressure will not have the benefit of external compression, and very high pressure impedes the arterial flow, which can cause discomfort. The optimal pressure necessary to overcome venous hypertension is not well known, but an external pressure of 35–40 mmHg at the ankle is necessary to prevent capillary exudation in legs affected by chronic venous insufficiency [11, 26].

2.2. Treatment Modalities – Need for Different Textile Materials

Several important factors must be present for a health practitioner to use compression systems, like knowing how to use different products, knowing the best available compression modalities available for the treatment, being able to identify the aetiology of the ulcer, and the willingness of the patient to agree to the commencement of compression treatment and for this to be sustained. Today, there exist several modes of compression devices. Table 1 lists some of the most common devices used for providing pressure. The basic constructions are woven or knitted. Woven construction consists of two sets of perpendicular yarns (also known as warp and weft yarns) that are interlaced together with the help of weaving process. Knitted construction consists of intersecting loops that are produced by a knitting process.

Medical Device	Advantages	Disadvantages
Bandage	√ Maintained compression √ Pressure can be adjusted √ Recommended for high level of compression (35–80 mmHg)	√ Need to be applied by well-trained physicians and nurses √ Pressure variation and no measurement
Stocking	√ No trained physicians required √ Suitable for low pressure (20–40 mmHg)	√ Difficult to put in √ Different stocking for different legs
Extremity pump	√ Augment venous return √ Effective for immobile patients	√ Expensive, noisy, bulky √ Requires immobility for a few hours/day

Table 1. Pressure devices

Nonwoven is not used for generating compression. But it does play a very important role in compression and comfort management, which is discussed in the next section. Nonwoven is commonly used for the preparation of padding material for the multi-layer compression bandaging system. In a multi-layer compression system, there exist several layers of fabrics in addition to compression layer:

- *Wound contact layer:* It directly touches with wound portion of the skin and provides antimicrobial benefits.
- *Absorbent padding bandage:* It is applied from ankle to knee using a simple spiral technique and 50% overlap. This chapter primarily focus on this layer.
- *Compression bandage:* This is used over the padding layer. Its main function is to provide compression. It is applied from the ankle to the knee, using a figure of eight technique at 50% extension.

- *Flexible cohesive bandage:* This is the last layer which is used to secure all the innermost layers in place.

The roles of each of these layers are critical in the successful treatment of venous diseases.

3. Padding bandage

3.1. Role and function

In addition to compression layer, the role of padding is also critical in the successful treatment of chronic venous disorders. A suitable thickness of padding (~1–2.5 cm) is used between the bandage and skin layer for uniform pressure distribution [5, 29]. Padding is wrapped underneath the compression bandage and left over the wounded area for long period of time. In order to distribute pressure evenly around the limb, it is essential that high pressures created at the tibia and fibula regions are absorbed by the padding material. The normal pressure applied by the compression bandage gets absorbed and distributed within the structure of padding bandage. Some amount of pressure is dissipated in the structure, and the rest is transmitted through the thickness of the padding bandage to exert final absolute pressure on the patient's leg. Padding can also be used to reshape legs which are not narrower at the ankle than the calf. It helps to reshape the limb more like a cone-shape so that the pressure gradient can be achieved with more pressure at the ankle and less at the calf.

In addition to pressure management by padding, the other concern is to maintain good thermo-physiological comfort and to ensure better compliance for the patient during the course of compression treatment [30]. The thermo-physiological comfort concerns the heat and moisture transmission characteristics through clothing, that is, transmission of heat, air and moisture (liquid and vapour) [31, 32]. Multi-layer compression systems, such as 4-layer bandaging, are used for extended periods of time with minimum dressing change. This may cause overheating of the underlying tissues and, perhaps, excessive sweat production due to poor air or moisture exchange between the body and the surrounding [33]. Clearly, the removal of excess fluid or exudates is extremely important to avoid irritation and ensure comfort to the patients. Over-hydration or even maceration of the underlying tissues is likely to happen if the body fluids are not continuously removed from the affected region. Improper management of excessive wound exudates or other body fluids may delay healing and lead to other complications. The padding is used underneath the bandage and therefore is in direct contact with the skin. The interaction of fluids with the padding is therefore critical, as this determines the ability of padding to spread the liquid to a wider area and therefore helps in faster evaporation and prevention of excess moisture build-up. This will also provide better comfort to the patient. Furthermore, the surplus heat produced due to muscular activity should be discharged into the surrounding to facilitate wound healing. Several properties of padding including air permeability, moisture and thermal transmission, wicking, etc., are important here to finally ensure better thermo-physiological comfort of the compression product.

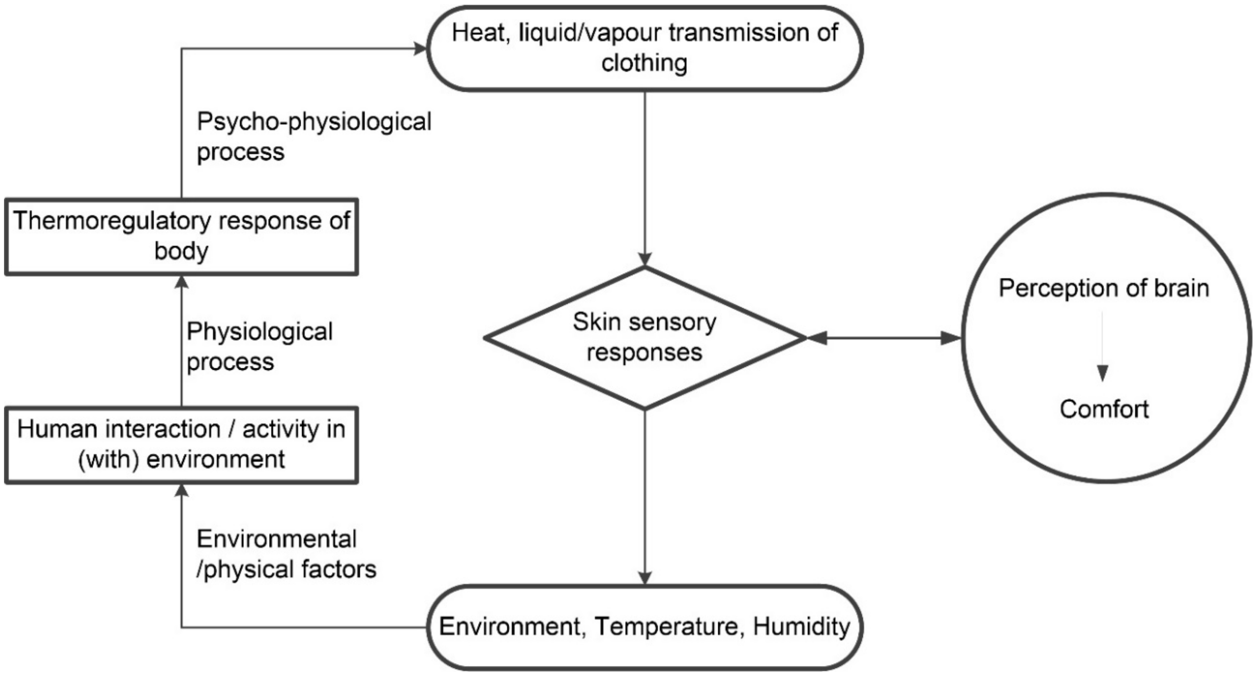

Figure 2. Important physical and physiological factors affecting padding comfort

Other comfort for padding includes the sensorial or tactile comfort which is related to the mechanical contact of the fabric with skin, that is, how a fabric or garment feels when it is worn next to the skin [31]. These are fabric handle or feel, softness, fullness, warm–cool touch, static charge generation, flexing, pricking, itching, etc. The physiological comfort, such as fitting, which is related to aesthetic properties of the fabric, that is, drape, lustre, colour, crease, pilling, staining, etc., are not our concern for the padding application. Figure 2 lists the important physical and physiological factors affecting padding comfort. Among all comfort characteristics, the most important factor is the movement of heat and moisture (liquid and vapour) through padding to maintain the thermal equilibrium between human body and the environment.

3.2. Material and structure

Nonwoven used for padding is developed either via needle-punching or thermal-bonding process. Needle-punched technology is where the entanglement of fibres is achieved via mechanical punching using needle beds. In thermal-bonding process, heat is used for the bonding of fibrous web. The fibres used for nonwoven padding is either single-component fibres (polyester, polypropylene, viscose, or cotton) or blend of fibres (polyester/viscose, polyolefin/viscose or polyester/cotton) in the structure [29]. In addition to nonwoven structure, the foam materials are also used as padding. The material used for foam padding is polyurethane and the common structure is open cell foam. Polyurethane foam materials have the advantage of not adhering to the wound or surrounding skin, which makes them attractive when treating fragile skin often found in the elderly [34]. Also these polyurethane materials absorb wound drainage four times more than hydrocolloid dressings of similar sizes. Foam

http://dx.doi.org/10.5772/61309

dressings are usually supplied as square pads of different sizes with steep edges. Hybrid structure can also be used as padding [30]. Laminating foams on the woven or knitted structure are being commercially used. Also, the combination of nonwoven and open cell elastic foam is also found where the foam is laminated on the filament-reinforced nonwoven.

3.3. Ideal padding

Several requirements must be met before considering a nonwoven as an ideal padding bandage. Some of critical needs are [6]:

- It should be light weight and easy to handle. Since multi-layer compression system has multiple layers, the overall system seems bulky and heavy to the patient. A light padding will not add too much weight and therefore is recommended for the therapy.
- It should be soft and impart cushioning effect to the limb. As the padding is in direct contact with the skin, so a soft padding will provide better sensorial or tactile comfort.
- It should be capable of distributing pressure at critical regions especially over bony prominence. This is important to prevent tissue damage.
- It should have good fluid absorptions and wicking properties. To tackle excess sweating or exudates, the padding should be able to transport these fluids to wider areas for faster evaporation.
- It should not produce irritation or any allergic reaction to the skin on prolonged contact.
- It should be cheap and easily available.
- It should tear easily by hand. The limb shape or size for different patients is different and therefore there are different requirements for the lengths and thicknesses of padding. Padding with high tearing strength will add more difficulties to nurses or health practitioners during wrapping.
- It should not be very stiff and should be easily conformable with the contour of the limb.

4. Measurement techniques

4.1. Pressure sensor/compression-recovery test

The measurement of interface pressure exerted by a compression device is of importance, for both efficacy and tolerability. Several instruments are available that can be used for pressure measurement directly on the leg. Most of them are air-filled devices such as Kikuhime® (Meditrade, Soro, Denmark; Figure 3a), SlGaT-tester® (Ganzoni-Sigvaris, St. Gallen, Switzerland), and Picopress® (Microlab, Padua, Italy) [35]. They are inexpensive, thin, flexible, adjustable and optimised for different applications and different measuring regimes. Picopress® and SlGaT-tester® allow continuous recording during dynamic tests and over longer time periods. Although direct pressure measurement on the limb is more relevant, there exist several limitations of using *in vivo* measurement techniques. Especially, when comparing different padding performance on a leg, there exist unavoidable variation in application techniques and varying limb movement. Moreover, the location of pressure sensor at the critical sites especially over bony prominence is highly unstable, which may cause unnecessary noise or experimental error. The above facts indicate the need for a simple or alternative method to obtain pressure absorption ability of padding.

Compression load-recovery test is common to obtain the energy absorption ability of a nonwoven material. An Essediel thickness tester was used for measuring compression characteristics of textile materials (Figure 3b). The specimen was placed on a flat surface, and the transverse weight was applied using a pressure foot (20 mm diameter). The compressive pressure was increased from 20 to 200 kPa by applying additional dead weights during the compression cycle, and similarly in recovery the pressure was decreased in steps. The thicknesses were measured at different compressive loads during compression and recovery cycles. The initial thickness T_0 was taken for the initial pressure P_0 (~2 kPa), which was due to weight of the pressure foot without any applied external load. The works done during compression and recovery process can be obtained from the plot of thickness versus compressive pressure (Figure 6). These calculated energies can be further used to characterise padding performance as discussed in detail in the next section.

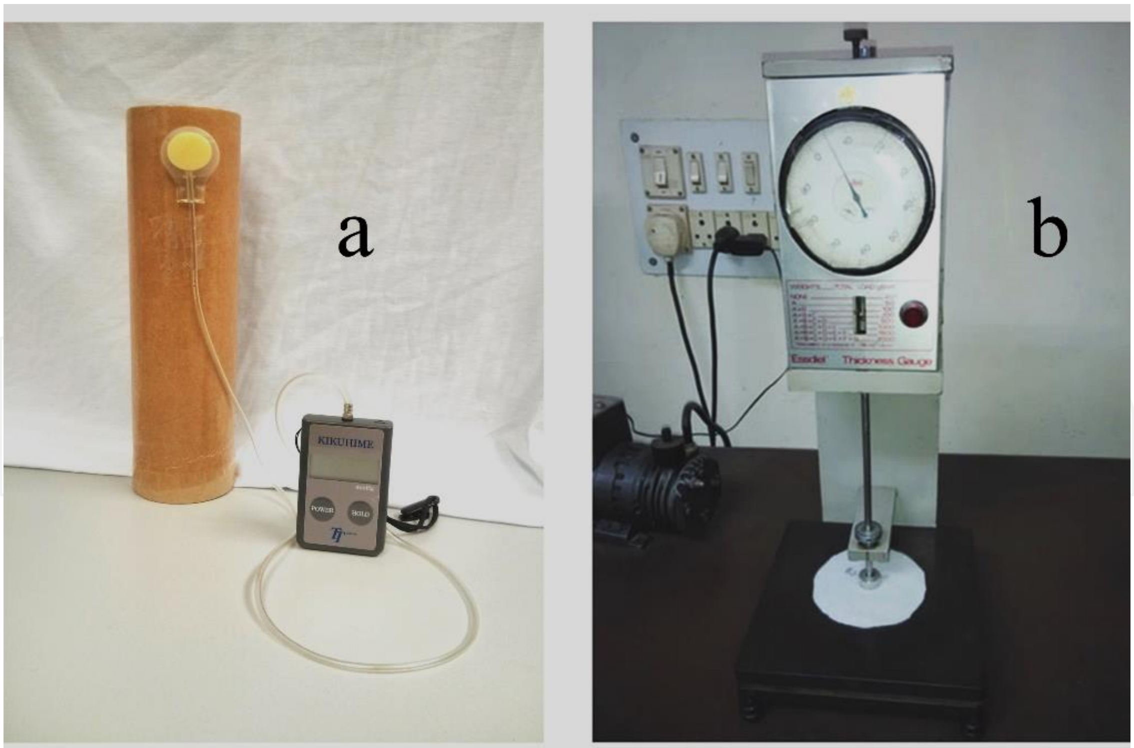

Figure 3. a) A simple prototype for the pressure measurement using Kikuhime® pressure sensor; b) An Essediel thickness tester for compression-recovery test

http://dx.doi.org/10.5772/61309

4.2. Comfort characterizations

Thermo-physiological wear comfort and skin sensational wear comfort are two main aspects of wear comfort of any clothing [31]. The first one concerns the heat and moisture transport properties of the fabric, while the latter one deals with the mechanical contact of the fabric with the skin, its softness and pliability in movement and its lack of prickle, irritation and cling when damp. The main properties of the fabric that influences the thermal comfort are: air permeability, water or moisture vapour permeability/transportation and heat transmission [36]. Air permeability is a measure of how well a fabric allows the passage of air through it. It is expressed as the volume of air (in cc) that passes in 1 s through 1 cm^2 of fabric under a pressure head of 1 cm of water. Figure 4a shows the photograph of a TEXTEST Air Permeability Tester (FX3300) to measure the air permeability at a standard atmosphere of 98 Pa. Similar to air permeability, the moisture vapour transmission indicates the breathability of the textile to allow water vapour to pass out from the skin surface through the textile. This is expressed as the steady water vapour flow in unit time through unit area of body, normal to specific parallel surfaces, under specific conditions of temperature and humidity at each surface. Figure 4b shows a Moisture Vapour Transmission Tester (Model CS-141), which offers an easy and fast method to obtain the moisture vapour transmission rate. Thermal comfort is related to the fabric's ability to maintain skin temperature and allow transfer of perspiration produced from the body. For the evaluation of thermal comfort, a very simple instrument Alambeta (Sensora) is available, which can measure thermal characteristics of textile such as thermal resistance, thermal conductivity and thermal absorptivity (Figure 4c).

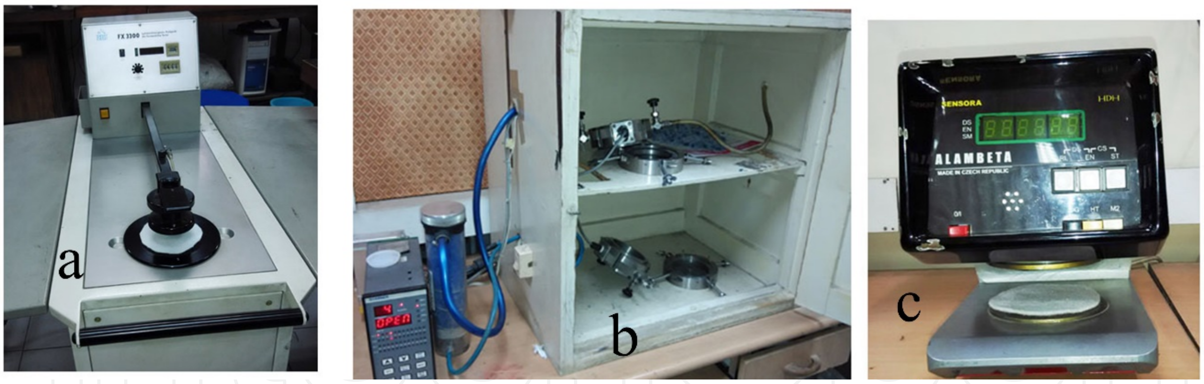

Figure 4. (a) TEXTEST air permeability tester; b) moisture vapour transmission tester (Model CS-141); c) Alambeta (Sensora) for heat transmission

Apart from the above-mentioned comfort properties, liquid transport behaviour of padding is also critical. This helps in removing body fluids or exudates from the wounded portion to prevent excess moisture build-up that causes irritation or discomfort to the wearer. The measurement of fluid transport is essential to understand how padding behaves on interaction with the fluids and what should be ideal structure for the nonwoven to obtain more spreading of body fluids to promote faster evaporation or removal. Several vertical and in-plane wicking tester are available that can be used for easy assessment [37-41]. Vertical wicking is determined by measuring the wicking height against gravity for a hanging fabric. An in-plane wicking deals with the transport behaviour in the horizontal plane of the fabric and describes several useful parameters such as the liquid flow anisotropy, the rate of movement, and the area of wet surface with time. Figure 5 shows the photograph of the computerized wicking tester for in-plane transport measurement [41].

Figure 5. Photograph of the instrumental set-up for measuring in-plane wicking

5. Theoretical insights into padding behaviour

5.1. Modelling of pressure loss

The magnitude of final pressure that appears on the surface of skin is more relevant in the compression treatment. Compression bandage applies a total pressure on the surface of padding which causes a pressure loss. This pressure loss is attributed to the significant changes in structure of the padding during compression, which results in its permanent thickness reduction, and significant energy loss. The absorbed energy by the padding during compressive load could be a good indicator of the pressure loss or absorption during the use of padding beneath compression bandage. The thickness change during compression-load-recovery test is used to obtain this energy loss or absorption in the nonwoven structure. The thickness changes in loading can be expressed as [42, 43]:

$$\frac{T}{T_o} = 1 - \alpha \ln\left(\frac{P}{P_o}\right) \tag{2}$$

where T is the thickness at arbitrary pressure P, T_o is the initial thickness at pressure P_o and α is the compressibility parameter. After loading to final pressure P_f, the thickness of the sample reduces to a lowest thickness T_f. During recovery case, the thickness T at arbitrary lower pressure P ($<P_f$) can be expressed as:

$$\frac{T}{T_f} = \left(\frac{P}{P_f}\right)^{-\beta} \tag{3}$$

whereβ is the recovery parameter. Both α and β are dimensionless constants that could be easily obtained by a simple load-recovery test. Using these parameters, it is possible to characterise the compressional and recovery behaviour of different types of nonwoven fabrics. Figure 6 shows a typical thickness-pressure curve for a nonwoven fabric during loading and unloading. The shaded area under load and recovery curve represents the energy loss during a cycle. The work done during compression (E_c) can be obtained using Eq. (2) as:

$$E_c = \int_{T_o}^{T_f} PAdT = P_o A \int_{T_o}^{T_f} e^{\frac{1}{\alpha\left(1-\frac{T}{T_o}\right)}} dT \tag{4}$$

where A is the area of specimen; T_o and T_f are initial and final thicknesses, respectively; and P_o is the initial pressure. The potential energy recovered during release of load (E_r) taking into account Eq. (3), is given by:

$$E_r = \int_{T_f}^{T_r} PAdT = P_o A \int_{T_f}^{T_r} \left(\frac{T}{T_o}\right)^{\frac{-1}{\beta}} dT \tag{5}$$

where T_r is the recovered thickness after load removal. Using these potential energies (E_r and E_c), it is possible to calculate the energy loss (EL) of the fabric during the compression recovery cycle:

$$EL = \frac{E_c - E_r}{E_c} \tag{6}$$

The lower the value of EL (energy loss), the poorer is the performance of padding in energy absorbance. Padding bandage lies underneath the compression bandage that applies signifi-

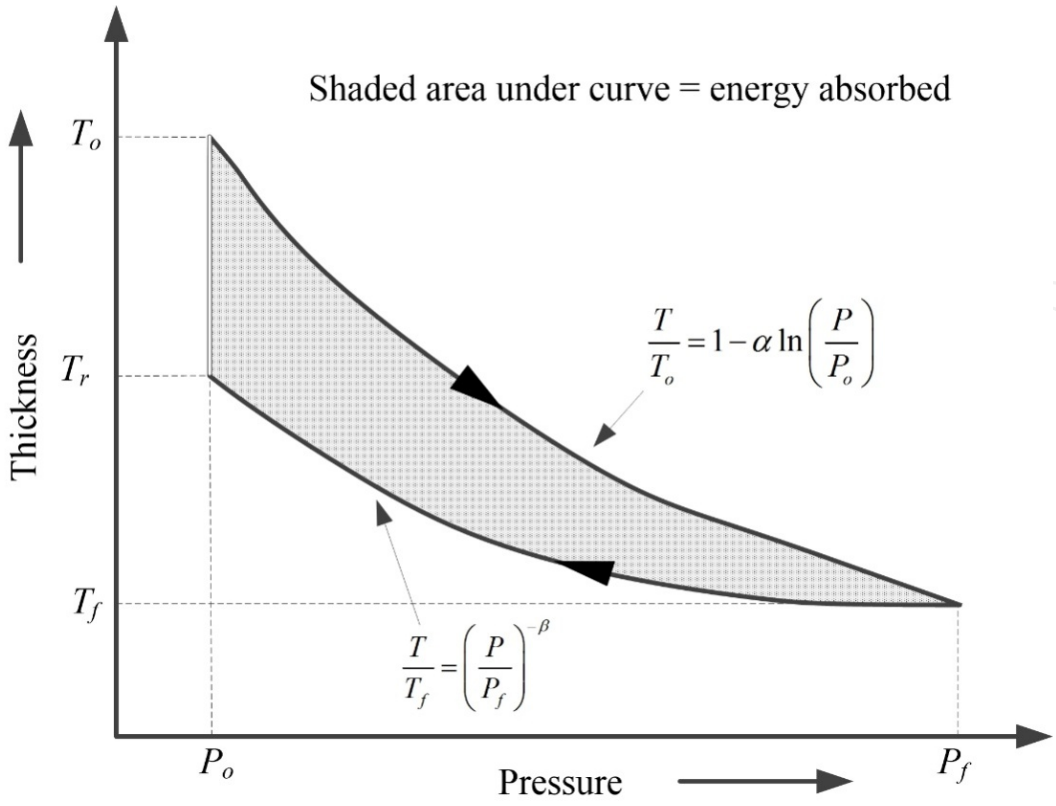

Figure 6. A typical curve of pressure-thickness data for a nonwoven

cant amount of interface pressure in the range from 10 to 50 mmHg, depending on severity of venous disease. The applied pressure by the compression bandage on the padding has two components: first, the pressure that is transferred through padding and finally appears on the skin; second, the pressure loss in the padding structure. This pressure loss can be related to the energy loss *EL* as described in Eq. (6). So, the pressure results can be expressed as:

$$P_f = P_T - P_l = P_T - f\left(EL\right) \times P_T = \frac{F}{r}\left(1 - f\left(EL\right)\right) \tag{7}$$

where, P_f is the final pressure on the surface of skin, F is the applied force to the compression bandage which generates total pressure P_T on the padding, r is the radius of the limb and P_l is the pressure loss that can be related to *EL*. Using a set of experimental results, one can easily obtain the function relating pressure loss and energy loss for a given padding sample. Once expressed, it would be easy to obtain the final pressure at any given applied force (F). The measurement of applied force is difficult to judge during wrapping but the applied extension ε is easy to measure. The applied force F is related to the extension applied in the compression bandage during wrapping:

$$F = \tau \times \varepsilon \tag{8}$$

where τ is the tensile modulus of the compression bandage. So, using the experimental results of tensile test for the compression bandage and the load-recovery tests for padding bandage, it is possible to predict the pressure results of the multi-layer compression system. Both these experiments can be done in the laboratory and therefore provide a simple method to access multi-layer bandaging performance.

5.2. Understanding Liquid Transport

Liquid transport, that is, wicking, happens due to capillary action that occurs when the fibrous network is completely or partially immersed in a liquid or in contact with a limited amount of liquid from an infinite (unlimited) or limited (finite) reservoir [39]. During transport, the liquid in a nonwoven structure can transmit through the thickness of the sample, that is, transverse wicking, or it can move along the plane of the fabric, that is, longitudinal or in-plane wicking [39, 44-46]. The thickness of padding is small as compared to other dimensions; and therefore, the liquid transmission in the plane of padding is more relevant for the present case. The basic theory in the field of non-homogeneous flows was proposed by Young and Laplace, which is related to the equation of capillarity as [44, 47]:

$$\Delta P = -\gamma \nabla \hat{n} \tag{9}$$

where ΔP is the pressure difference across the fluid interface, γ is the surface tension (or wall tension) and $\hat{n}$ is the unit normal pointing out of the surface. This describes the capillary pressure difference sustained across a curved interface between two immiscible fluids, such as water and air, due to the phenomenon of surface or wall tension. Lucas and Washburn further extended their work on capillary-driven non-homogeneous flows, which has been frequently used in textile areas [45, 47-49]. The Lucas–Washburn theory relates the rate of fluid flow into a circular tube via capillary action. This theory is a special form of a laminar viscous flow of a Newtonian liquid in a cylindrical type as expressed by Hagen–Poiseuille law [50]:

$$\frac{dV}{dt} = \frac{\pi r^4 \left(p_a - p_b\right)}{8 l \mu} \tag{10}$$

$\frac{dV}{dt}$ is the volume flow rate of the Newtonian fluid, $p_a - p_b$ is the pressure difference between the tube ends, r and L are the radius and length of the tube, respectively, and μ is the viscosity of the fluid. The structure of a nonwoven resulted in complex network of pores in a three-dimensional (3D) network. For simplification, a capillary or pore in the network is assumed as a cylindrical tube (radius r) in which the distance travelled by the liquid along the capillary axis is l (Figure 7a). The capillary pressure (P_a) and the hydrostatic pressure (P_b) can be expressed as:

$$p_a = \frac{2\gamma \cos\theta}{r} \tag{11}$$

$$p_b = l\sigma g \cos\beta \tag{12}$$

where θ is the contact angle between the liquid surface and the capillary wall and β denotes the angle between the tube and the vertical axis (Figure 7a).

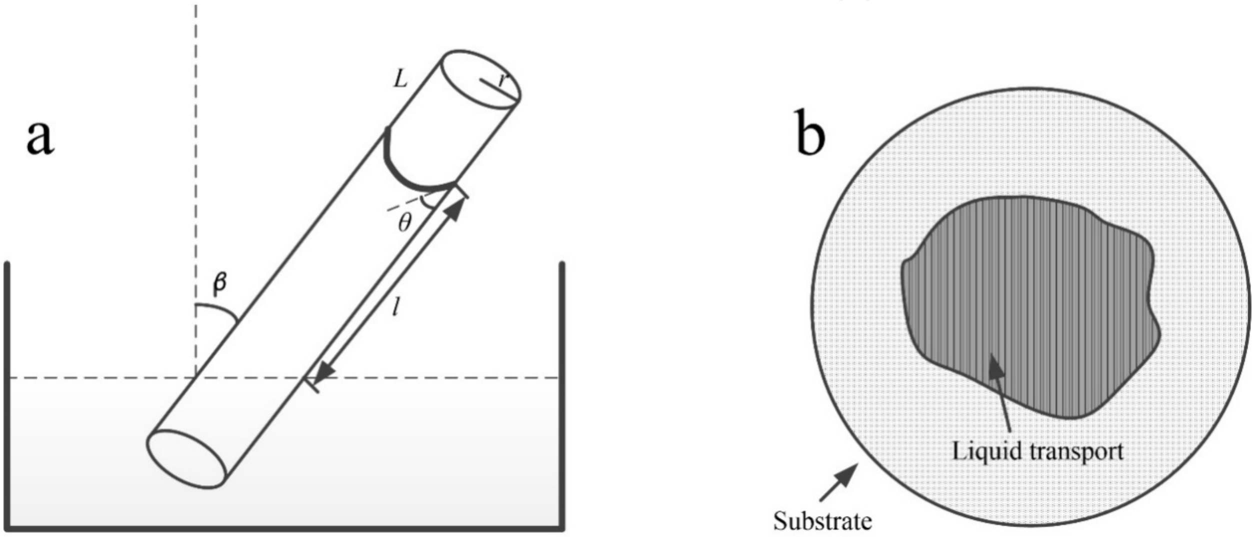

Figure 7. a) A tube (L) of a radius r is suspended in a liquid source. The distance travelled by the liquid along the capillary axis is l. (b) Liquid transport on the surface of a textile substrate

Substituting, Eqs. (11) and (12) in Eq. (10) and expressing the volume V as $\pi r^2 l$, we can obtain the Lucas–Washburn equation to express the flow rate as:

$$\frac{dl}{dt} = \frac{r\gamma \cos\theta}{4\mu l} - \frac{r^2 \sigma g \cos\beta}{8\mu} \tag{13}$$

The parameters, r, γ, θ, μ, σ, g *and* β remain constant for a given system, so Eq. (5) can be simplified to:

$$\frac{dl}{dt} = \frac{a}{l} - b$$

where a and b are constants. When the penetration of liquid is horizontal ($\beta = 90°$), the effects of the gravitation field are negligible and the acceleration g vanishes and therefore the second term (b) can be neglected. Finally, the wicking length (l) can be solved as [47, 48]:

$$l = \left(2at\right)^{1/2} \tag{14}$$

The above equation can be used for our case where the liquid from a point source is poured at the centre of a textile substrate and the spreading occurs radially outward in horizontal plane (Figure 7b).

6. Structure–property relationship

Although different nonwoven materials such as needle-punch, melt spun, thermal bonded, etc. are used as padding, this chapter focuses more on the needle-punch structures. A needle-punch structure is obtained from the entanglement of fibres which is achieved via mechanical punching using needle beds [3, 4]. The structure is decided by the fibres and the processing parameters, for example, fibre size and distribution, depth of needle penetration, amount of feed, layering factor, and needle punching frequency. As an example, the results of a set of nonwoven samples made from 100% polypropylene fibres are described. The varying parameters are the fibre linear density (expressed as denier ⊚ weight of 9000 m length of fibre), mass per square meter (g/m^2) and needling density (punches/m^2) of the nonwoven. Three levels of fibre denier (2.5, 6 and 15) are taken for comparison. The gram per unit area and needling density (punches/m^2) of the nonwoven samples can be obtained by changing the machine parameters. The effect of different levels for the mass per square meter (100, 200, 300 and 400 g/m^2) and needling density (50E4, 130E4 and 210E4 punches/m^2) is explained on the pressure and comfort performance of padding product.

6.1. Energy or pressure absorption

Energy or pressure absorbed (%) by padding decreases with increase in mass per unit area of padding (Figure 8a). This is due to the fact that the increase in mass per unit area leads to availability of more number of fibres for sharing the compressive load. Availability of more fibres increases entanglement during preparatory methods, and this causes more frictional resistance to prevent fibre-to-fibre slippage during compression load-recovery test. Reduction of fibre slippages minimizes the permanent deformation in compression-load recovery test. Therefore, lower energy absorption is obtained for higher mass per unit area of padding. Furthermore, the amount of energy loss decreases with increasing needling density (Figure 8b). Increase in needling density also stimulates more entanglement of fibres, which causes the compact and stiff structure of padding [42, 43]. This avoids fibre-to-fibre slippages during compression; hence, there will be low energy or pressure absorption for a stiff padding compared to soft padding. In real scenario, the use of a heavy and stiff padding should be avoided as it would not be able to absorb the excess pressure at critical regions. If comparing different fibres, it can be concluded that the energy absorbed is less for padding composed of thinner fibre than coarser fibre (Figure 8c). Thick or coarse fibre has less specific area compared to thin fibre, due to which the frictional resistance within the porous network of padding will be lesser for thick fibre compared to thin fibre. Moreover, padding made from coarser fibre has more porous structure. This all results in more energy absorption and therefore more pressure reduction for the padding made from higher fibre linear density compared to lower fibre linear density.

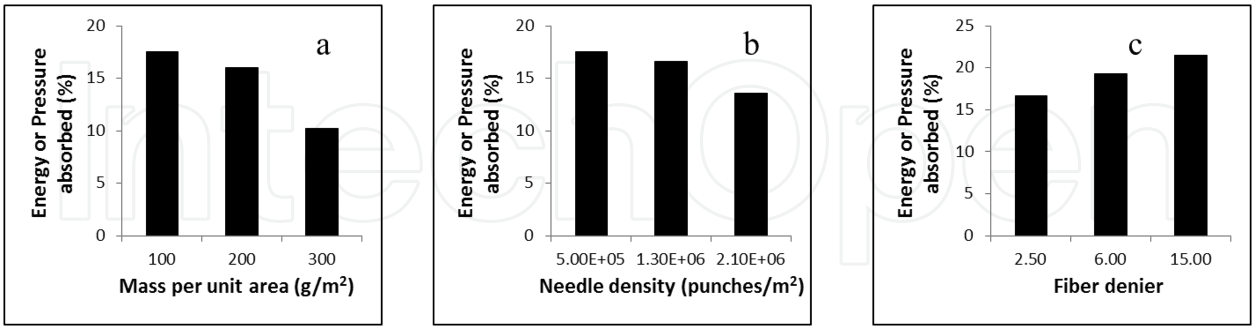

Figure 8. Effect of structural parameters of nonwoven on pressure absorbency: (a) effect of mass per unit area (50E4 punches/m^2; 2.5 denier); (b) effect of needling density (100 g/m^2; 2.5 denier); (c) effect of fibre denier (100g/m^2; 130E4 punches/m^2)

6.2. Thermo-physiological comfort

The effect of structural parameters is same on the air permeability and moisture vapour transmission rate (MVTR). Air permeability and MVTR decreases with increasing the level of both mass per unit area and needle density (Figures 9a, 9b, 10a & 10b). This is due to decrease in size of the air-conducting channels during more punching process and also due to availability of more fibres for the entanglement, which decreases the permeability of the air or moisture to the padding. The effect is opposite for the fibre denier where both increase with increase in the fibre denier (Figure 9c & 10c). The density of the padding bandages decreases with increase in fibre denier due to which there is increase in the size of the air channels which provide easy air or moisture flow.

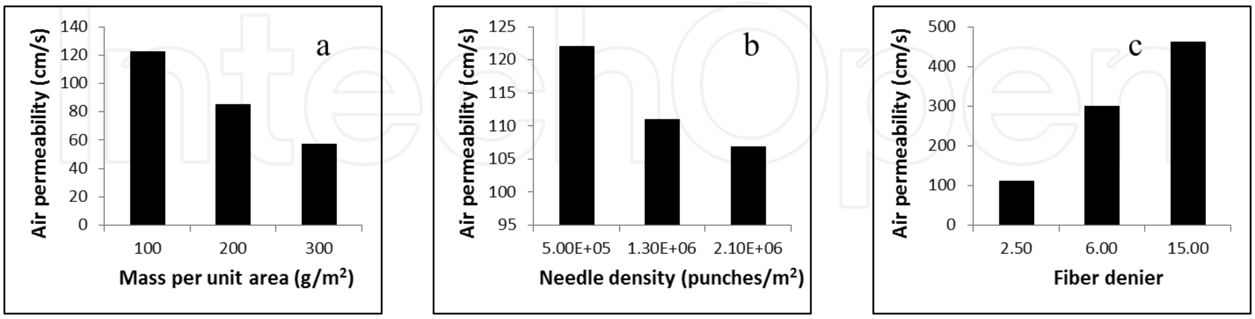

Figure 9. Effect of structural parameters of nonwoven on air permeability: (a) effect of mass per unit area (50E4 punches/m^2; 2.5 denier); (b) effect of needling density (100 g/m^2; 2.5 denier); (c) effect of fibre denier (100g/m^2; 130E4 punches/m^2)

For thermal results, the thermal resistance increases with increase in mass per unit area for same level of needling density (Figure 11a). This is because thickness of samples increases with

http://dx.doi.org/10.5772/61309

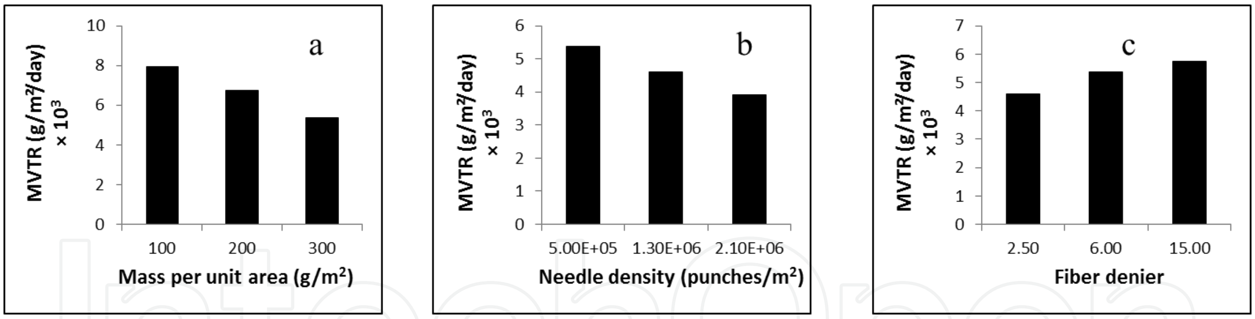

Figure 10. Effect of structural parameters of nonwoven on moisture vapour transmission rate (MVTR): (a) effect of mass per unit area (130E4 punches/m^2; 6 denier); (b) effect of needling density (300 g/m^2; 2.5 denier); (c) effect of fibre denier (300g/m^2; 130E4 punches/m^2)

increase in mass per unit area. Also the thermal resistance of padding decreases with increase in needling density (Figure 11b). For the liquid transport (Figure 7b), the spreading time is lower for the samples having more free spaces in the capillary network. Increasing mass per unit area and needling density reduces the porosity, and stimulates lower rate for fluid transport and takes more time (Figure 12a & 12b). Nonwoven made from coarser fibres results in larger capillaries and shows faster spreading rate and takes lower time (Figure 12c).

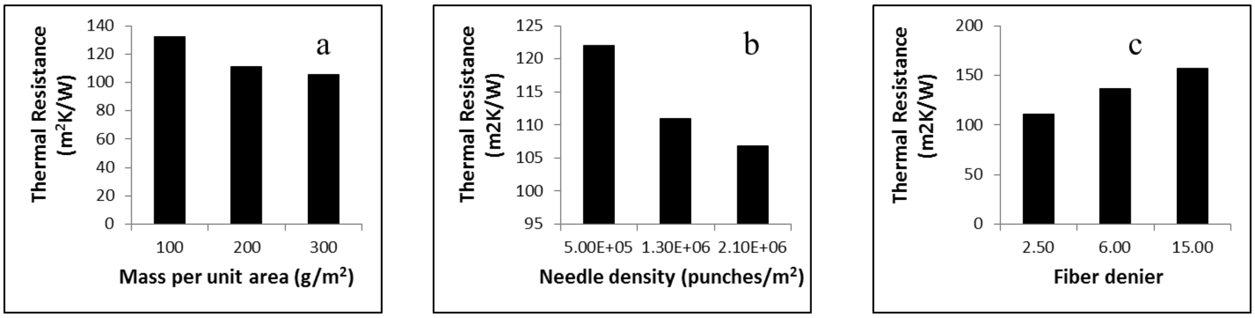

Figure 11. Effect of structural parameters of nonwoven on thermal resistance: (a) effect of mass per unit area (50E4 punches/m^2; 2.5 denier); (b) effect of needling density (100 g/m^2; 2.5 denier); (c) effect of fibre denier (100g/m^2; 130E4 punches/m^2)

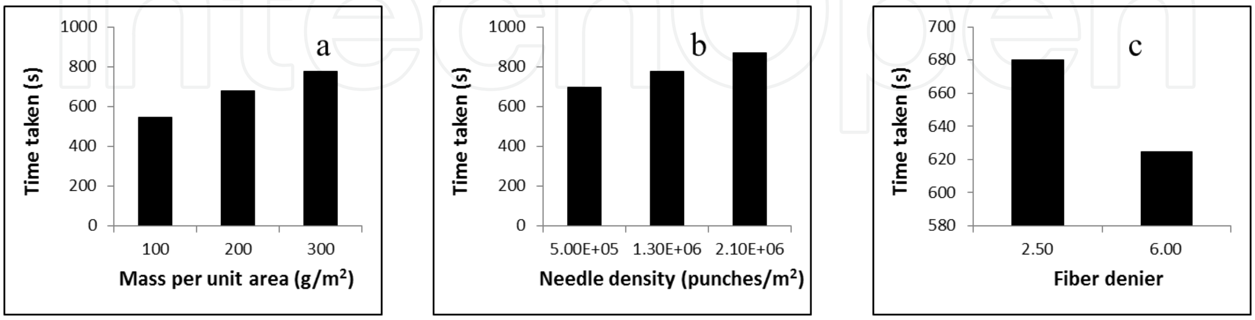

Figure 12. Effect of structural parameters of nonwoven on liquid transport (time taken represents the total period taken by liquid to cover an area 380 cm^2 of a circular specimen as shown in Figure 7b): (a) effect of mass per unit area (1300E4 punches/m^2; 2.5 denier); (b) effect of needling density (300 g/m^2; 2.5 denier); (c) effect of fibre denier (200g/m^2; 130E4 punches/m^2)

6.3. Design consideration

Several inferences can be drawn based on the above results of needle-punched padding:

- Padding materials should be made as isotropic as possible, for any anisotropy will lead to behaviour variations at different directions, thus causing non-uniform pressure performance and less effective fluid absorption or transmission properties in certain directions.
- It is recommended that padding with more porosity and larger pore size could help in better management of liquid exudates, air or moisture exchange. To achieve that the mass per unit area and needling density of the nonwoven has to be decreased which results in more porosity. This will accelerate the evaporation and thereby prevent excess moisture build-up. Moreover, fibres with higher linear density should be selected for the preparation of padding to get bigger pore size that is more suitable for faster spreading.
- In general practice, a heavier or thicker padding is recommended in order to obtain maximum pressure reduction especially at critical regions over bony prominences such as tibia or fibula. However, a heavier padding will be more obstructive in liquid flow. So, a balance should be made to get optimum pressure performance with good transport/transmission characteristics.

All the above points should be taken into consideration to design or develop suitable padding structure for maximum performance.

7. Future study

Padding is critical in compression management; it serves several functions including pressure or comfort management. Padding can have different fibrous materials or structure due to which it can have different mechanical responses while it is being used. Understanding of all these parameters is essential to have improved understanding of the role of textile material or structure for the designing or engineering of optimised products. This chapter introduces the structure–property relationship of nonwoven padding. However, there exist several gaps in the literature which should be systematically examined for further improvement. Some future outlooks could be as follows:

1. All the above description is based on the single padding layer. However, the padding is just one of the parts of the multi-layer compression system. The system has multiple layers of different fabrics once wrapped over the limb. These include cohesive, padding, compression and wound layers. Each of these layers performs a different role or function. The performance of overall assemblies should also be assessed for better judgement.
2. Padding bandage lies underneath the bandage that applies significant amount of interface pressure in the range from 10 to 50 mmHg to the leg. Under external compression, the porosity or indeed the wicking performance of the padding will change significantly; so it is expected that the liquid transport or other transmission behaviour of the same padding material will vary when exposed to different levels of normal compression.

Clearly, the effect of the external pressure has to be accounted for in future analysis. Also the model for fluid transport should be modified accordingly to account for porosity change due to external pressure.

3. This chapter focuses more on the performance of only needle-punched samples. Study should be conducted for other nonwovens such as thermal-bonded and melt-spun. The performance of other fibres such as PET, cotton, wool and viscose should also be examined.

4. The patients using compression treatment can have dynamic or static nature. Especially old patients prefer to sit for longer period of time, and the limb is therefore under static state. On the other hand, there may be some group of patients who are still active or working even under compression treatment. Under such circumstances, the limbs can undergo active movement. The assessment of padding should be done for both static and dynamic cases.

5. Although the present study is based on lab-based measurement, it may be possible to have different results once used on the real leg. More sophisticated approaches are needed to do an *in vivo* study to compare it with *in vitro* results.

6. Textiles give us a lot of flexibility in choosing an appropriate structure or weave for a particular application. Although the nonwoven is primarily used in the padding for so long, but there is still possibility to look for other textile structure. The spacer fabric (3D warp knitted structure) could have more potential in compression and comfort outcomes. The comparisons of the nonwoven with other textile structures should also be examined.

7. Compression system is usually worn for an extended period of time. This chapter only reveals the immediate response of the padding. Further study should be conducted on evaluating the time dependence performance.

8. Summary

This chapter introduces the basics of a medical problem related to venous disorders and related compression modalities. The need and role of different fibrous materials in compression management are presented. More focus is given in describing the critical functions of the padding. Padding is used for the pressure redistribution on the limb. Furthermore, it helps to ensure proper comfort to the wearer due to proper management of heat, moisture, air, liquid, etc. Herein, the nonwoven paddings have been evaluated for the compression and different comfort properties including air permeability, moisture transmission, heat flow and liquid transport. The importance of different nonwovens and their structures are reviewed, which could affect padding performance. Based on the observed results, it has been recommended that padding with more porosity and larger pore size results in more pressure absorption and good transmission (air/moisture/liquid). Padding with low mass per unit area and needling density results in more porosity and therefore can help in faster transport of fluids, air or moisture to a larger area. Moreover, fibres with higher linear density should be selected for the preparation of padding to get bigger pore size, which is more suitable for faster transmission and more pressure absorption. This can further help in deciding the optimum structure or material for an ideal product. Some useful theoretical insights are also provided to relate the structure–property relationship to access different padding performance using model parameters. In conclusion, this chapter could serve as a complete package to readers regarding nonwoven product development and optimization. Some future goals are also listed, demanding more innovative solutions or approaches to overcome the limitations of the existing problems, and exploiting the existing features and capacity of nonwoven padding.

Author details

Bipin Kumar*

Address all correspondence to: bipiniitd18@gmail.com

Division of Textiles, Biological & Agricultural Engineering, The University of California at Davis, USA

References

[1] Rupp, J., Nonwovens: Challenges & trends, environmental factors. *Textile World*, 2009. 159(6): p. 34-6.

[2] Russell, S., *Handbook of nonwovens*. 2006, Cambridge, England: Woodhead Publishing Ltd., p. 1-15

[3] Banerjee, P.K., *Principles of Fabric Formation*. 2015, Boca Raton, FL 33487-2742: CRC press, p. 9-19

[4] Batra, S.K. and B. Pourdeyhimi, *Introduction to Nonwovens Technology*. 2012, Lancaster, Pennsylvania 17602 USA: DEStech Publications, Inc., p. 3-11

[5] Rajendran, S. and S. Anand, Developments in medical textiles. *Textile Progress*, 2002. 32(4): p. 1-42.

[6] Anand, S.C., et al., *Medical and Healthcare Textiles*. 2010: Elsevier, p. 257-262

[7] Partsch, H., Compression therapy in leg ulcers. *Rev Vasc Med*, 2013. 1(1): p. 9-14.

[8] Kumar, B., A. Das, and R. Alagirusamy, Effect of material and structure of compression bandage on interface pressure variation over time. *Phlebology*, 2013. 29(6): p. 376-385.

[9] Reich-Schupke, S., et al., Quality of life and patients' view of compression therapy. *Int Angiol*, 2009. 28(5): p. 385-93.

[10] Evans, C.J., et al., Prevalence of varicose veins and chronic venous insufficiency in men and women in the general population: Edinburgh Vein Study. *J Epidemiol Comm Health*, 1999. 53(3): p. 149-153.

[11] Patel, N.P., N. Labropoulos, and P.J. Pappas, Current management of venous ulceration. *Plast Reconstruct Surg*, 2006. 117(7): p. 254s-260s.

[12] Bergan, J.J., et al., Mechanisms of disease: Chronic venous disease. *N Eng J Med*, 2006. 355(5): p. 488-498.

[13] Partsch, H., Compression therapy for deep vein thrombosis. *Vasa-Eur J Vasc Med*, 2014. 43(5): p. 305-307.

[14] Dennis, M., et al., Effectiveness of thigh-length graduated compression stockings to reduce the risk of deep vein thrombosis after stroke (CLOTS trial 1): a multicentre, randomised controlled trial. *Lancet*, 2009. 373(9679): p. 1958-65.

[15] Kumar, B., A. Das, and R. Alagirusamy, An approach to determine pressure profile generated by compression bandage using quasi-linear viscoelastic model. *J Biomech Engin-Trans Asme*, 2012. 134(9).

[16] Kumar, B., A. Das, and R. Alagirusamy, Prediction of internal pressure profile of compression bandages using stress relaxation parameters. *Biorheology*, 2012. 49(1): p. 1-13.

[17] Kumar, B., A. Das, and R. Alagirusamy, Study on interface pressure generated by a bandage using in vitro pressure measurement system. *J Textile Instit*, 2013. 104(12): p. 1374-1383.

[18] Kumar, B., A. Das, and R. Alagirusamy, *Science of Compression Bandages*. 2014: WPI India, p. 41-55

[19] Hafner, J., et al., Instruction of compression therapy by means of interface pressure measurement. *Dermatol Surg*, 2000. 26(5): p. 481-486.

[20] Partsch, H., Compression for the management of venous leg ulcers: which material do we have? *Phlebology*, 2014. 29: p. 140-145.

[21] Thomas, S., The production and measurement of sub-bandage pressure: Laplace's Law revisited. *J Wound Care*, 2014. 23(5): p. 234-246.

[22] Zarchi, K. and G.B.E. Jemec, Delivery of compression therapy for venous leg ulcers. *Jama Dermatol*, 2014. 150(7): p. 730-736.

[23] Kumar, B., A. Das, and R. Alagirusamy, *An approach to examine dynamic behavior of medical compression bandage. J Textile Instit*, 2013. 104(5): p. 521-529.

[24] Kumar, B., A. Das, and R. Alagirusamy, Analysis of factors governing dynamic stiffness index of medical compression bandages. *Biorheology*, 2012. 49(5-6): p. 375-384.

[25] Kumar, B., A. Das, and R. Alagirusamy, *Analysis of sub-bandage pressure of compression bandages during exercise. J Tissue Viability*, 2012. 21(4): p. 115-124.

[26] Das, A., et al., Pressure profiling of compression bandages by a computerized instrument. *Ind J Fibre Textile Res*, 2012. 37(2): p. 114-119.

[27] Basford, J.R., The Law of Laplace and its relevance to contemporary medicine and rehabilitation. *Arch Phys Med Rehabil*, 2002. 83(8): p. 1165-70.

[28] Mosti, G. and H. Partsch, High compression pressure over the calf is more effective than graduated compression in enhancing venous pump function. *Eur J Vasc Endovasc Surg*, 2012. 44(3): p. 332-336.

[29] Rajendran, S. and S.C. Anand, Contribution of textiles to medical and healthcare products and developing innovative medical devices. *Ind J Fibre Textile Res*, 2006. 31(1): p. 215-229.

[30] Fauland, G., et al., Assessment of moisture management performance of multilayer compression bandages. *Textile Res J*, 2012. 83(8): p. 871-880.

[31] Das, A. and R. Alagirusamy, *Science in Clothing Comfort*. 2010: Woodhead Publishing India Pvt Ltd, p 17-39

[32] Kumar, B., A. Das, and P.A. Singh, Studies on elastane-cotton core-spun stretch yarns and fabrics: Part III-Comfort characteristics. *Ind J Fibre Textile Res*, 2014. 39(3): p. 282-288.

[33] Cutting, K.F. and R.J. White, Avoidance and management of peri-wound maceration of the skin. *Prof Nurse*, 2002. 18(1): p. 33, 35-36.

[34] Al-Muhairi, A. and T. Phillips, Surgical pearl: A wound dressing tip for venous ulcers. *Wounds Compend Clin Res Pract*, 2006. 18(6): p. 158-161.

[35] Partsch, H. and G. Mosti, Comparison of three portable instruments to measure compression pressure. *Int Angiol: J Int Union Angiol*, 2010. 29(5): p. 426-430.

[36] Das, A., V.K. Kothari, and A. Sadachar, Comfort characteristics of fabrics made of compact yarns. *Fibers Polym*, 2007. 8(1): p. 116-122.

[37] Kumar, B. and A. Das, Vertical wicking behavior of knitted fabrics. *Fibers Polym*, 2014.

[38] Raja, D., et al., Comparison of different methods to measure the transverse wicking behaviour of fabrics. *J Indus Textiles*, 2014. 43(3): p. 366-382.

[39] Kumar, B., et al., Characterization of liquid transport in needle-punched nonwovens. I. Wicking under infinite liquid reservoir. *Fibers Polym*, 2014. 15(12): p. 2665-2670.

[40] Kumar, B. and A. Das, Vertical wicking behavior of knitted fabrics. *Fibers Polym*, 2014. 15(3): p. 625-631.

http://dx.doi.org/10.5772/61309

[41] Kumar, B. and A. Das, Design and development of a Computerized Wicking Tester for longitudinal wicking in fibrous assemblies. *J Textile Instit*, 2014. 105(8): p. 850-859.

[42] Kothari, V.K. and A. Das, Compressional behavior of layered needle-punched nonwoven geotextiles. *Geotext Geomemb*, 1993. 12(2): p. 179-191.

[43] Kothari, V.K. and A. Das, Compressional behavior of nonwoven geotextiles. *Geotext Geomemb*, 1992. 11(3): p. 235-253.

[44] Kissa, E., Wetting and wicking. *Textile Res J*, 1996. 66(10): p. 660-668.

[45] Pan, N. and W. Zhong, Fluid Transport Phenomena in Fibrous Materials. *Textile Progress*, 2006. 38(2): p. 1-93.

[46] Patnaik, A., et al., Wetting and Wicking in Fibrous Materials. *Textile Progress*, 2006. 38(1): p. 1-105.

[47] Mhetre, S. and R. Parachuru, The effect of fabric structure and yarn-to-yarn liquid migration on liquid transport in fabrics. *J Textile Instit*, 2010. 101(7): p. 621-626.

[48] Lukas, D., et al., Computer simulation of 3-D liquid transport in fibrous materials. *Simulat-Transact Soc Modeling Simulat Int*, 2004. 80(11): p. 547-557.

[49] Zhu, L., et al., Static and dynamic aspects of liquid capillary flow in thermally bonded polyester nonwoven fabrics. *J Adhesion Sci Technol*, 2008. 22(7): p. 745-760.

[50] Landau, L.D. and E.M. Lifshitz, *Fluid Mechanic*s, Second Edition: Volume 6 (Course of Theoretical Physics S). 1987, Moscow: Nauka, p. 47-98.

IntechOpen