Material, structure, and design of textile-based compression devices for managing chronic edema

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Abstract

Background: Compression bandages, stockings, and pneumatic compression devices are common classifications of compression products, used alone or in combination. The structure of these compression products is complex: they are typically multi-layered, overlapped, stretched and applied to a three-dimensional curved surface part of the body. This research aims to review the materials, designs, and fabrication processes/technologies of a variety of compression devices used in management of chronic edema by considering contributions of materials/textiles, as well as prototyping technologies. Method: Relevant papers/patents for review were identified using keywords associated with materials, designs, and fabrication processes of textile-based compression devices/products for treatments of the edematous lower limb. Results: Modern Compression therapies employ textile materials with a variety of fiber types, yarns and fabric structures, and wide range of elasticity and extensibility (i.e. inelastic to elastic, short stretch to long stretch) to provide the required pressure to the lower leg. Compression fabrics are fabricated using a variety of production technologies and machineries, and they have a wide range of physical and performance attributes. Conclusions: Appropriate selection of materials and fabrication technologies for use in compression therapy is essential to enhance the success in the management of chronic edema. This review might aid in the development and
implementation of textiles/materials, and improvement in design of the textile-based compression devices to increase the efficacy of compression therapies in the management of chronic edema, allowing patients to improve their long-term health.

**Keywords**
compression textiles, pneumatic compression devices, materials and designs, chronic edema, bandages and stockings

**Introduction**
Textile-based compression therapy is considered as an effective treatment for a range of venous diseases i.e. varicose veins, chronic edema, venous eczema, deep vein thrombosis, and ulcers, and is used for other applications (e.g. athletic and sports recovery, improve extravehicular activity, enhanced proprioception).\(^1\)–\(^4\) Chronic edema is noticeable swelling caused by aberrant fluid accumulation in the interstitial spaces of the body, and is mainly caused by the effects of gravity followed by imbalance of the hydrostatic and osmotic pressures.\(^5\),\(^6\) In the initial stage of the swelling, the lymphatic system compensates for the increased volume of fluid in the tissue spaces by increasing lymph flow activity. However, if the lymphatic system is pushed beyond its maximum working capacity it may be overwhelmed by the additional fluid and be unable to drain the excess fluid accumulated in the interstitial spaces. Over time and/or in the case of inadequate treatment, the over extension of the system may lead to damage of lymphatic valves. Consequently, fluid accumulation increases along with initiation and progression of protein deposition in the tissue. Skin in this stage of edema is smooth. Without treatment, the swelling progresses further where there is large volume of protein content present in the tissue, and oxygenation and nutrition of the tissue may reduce resulting in the skin hardening.\(^5\),\(^7\),\(^8\) Further complexity is added due to edema increasing the risk of greater severity of this chronic condition. Edema, by preventing fresh oxygenated blood flow into the limb can also contribute to worsening of ulcerations.\(^9\)–\(^12\) The prevalence of diverse populations for chronic edema is summarized in Kankariya et al.\(^13\), although the results of these prevalence investigation were published in the early 2000s (2002–2013), and no further data has been identified.

**Search strategy**
Materials, designs, and fabrication processes of textile-based compression devices/products for treatments of the edematous lower limb were identified from the English language restricted refereed, published literature (the period ranges from 1996 to 2022). Sources examined included patents (AusPat (Australia’s patent) search system, EPO (European patent office who is responsible for setting up search reports for national patent applications on behalf of the patent offices of European nations) search system, USPTO (United States patent and trademark office) search system (100+ patents)), Google Scholar, PubMed Central® library, material-based, and textile-based journals (500+ papers),
and webpages for compression products (50+ webpages). Synonymous keywords (i.e. chronic or venous edema in lower extremities or lower limb or lower leg; compression therapy or textile or mode or wrap or modality; compression treatment or intervention; compression bandage or compression stocking or pneumatic compression device; material or textile fiber or yarn or fabric; knit or woven or nonwoven; compression product design or structure; fabrication or manufacturing or development of compression devices or products; sealing or joining or bonding the edges of inflatable bladder or sleeve or pressure chamber) were used to ensure all relevant references were included. Titles, abstracts, conclusions, and full texts of patents /articles were screened to identify all the relevant papers/patents.

**Background**

Textile-based compression treatment is still the gold standard for managing chronic disease, including edema in the lower extremities. Textile-based compression products apply ongoing pressure against the user’s skin surface while in a supine posture. Due to the increased venous pressure in resting upright postures, higher external pressure is required than in the supine posture. When ‘working’, the underlying muscles contract and expand, applying pressure on the compression fabric, causing the vein width to narrow and the pressure in the veins of the limb is increased. The increased pressure in the veins stimulates pumping of the lymphatic system and encourages re-absorption of lymphatic fluid and reduces fluid leakage out of the capillaries into interstitial space. These combine actions (more reabsorption and less leaking of fluid) helps to manage and/or reduce the edema.14,15

Compression bandages, stockings, and pneumatic compression devices (PCDs) are common classifications of compression products, used alone or in combination, for the management of all kinds of swollen extremities i.e. edema.16 The characteristics of these compression modalities reflecting the different materials, designs, and fabrication processes used (Figure 1)17

Conventional products used for compression include bandages and stockings. These compression devices are classified based on the pressure exerted (pressure range) on the lower extremity (Table 1).18–23 They can be further grouped by number of layers, components of materials, and elasticity. For example, a compression bandage can be multi-layer (given that single-layer bandage does not exist for such application/s because every bandage is wrapped with some overlap, resulting in at least two-layers of bandage materials at any given position on the lower leg), elastic or inelastic, single component or multiple components. In multi-component compression bandage single component items may be elastic or inelastic; however, the elasticity of multiple component systems comprised of combinations of elastic and/or inelastic components will differ from that of the components. Applying multiple components of elastic bandage materials resulting in an inelastic bandage system as the friction between the surfaces of the bandage layers opposes the elastic expansion of the textile materials.18,25,26 As a result, the pressure applied by multi-component assemblies made up of elastic and/or inelastic components will be different than the pressure applied by the constituent single component. Compression products are sold in different sizes and with thigh-length or knee-length form.27

Pneumatic compression is a concept used to treat the venous disease in lower limb for over 170 years.28 A pneumatic compression system is an assembly of inflatable bladders,
a source of pressurized gas, and connecting tubes (materials, and designs of connecting tube and source of pressurized gas are however beyond the scope of this study). The design of PCDs varies according to these assembled components i.e. construction processes and material properties of bladders, segmentation, compression mode (way of connecting of the bladders to tubes), size of air pump and connecting tubes.\textsuperscript{29,30} In a clinical context the bladder/s inflates and deflates to generate the desired pressure on the lower limb.\textsuperscript{2} Bladders may be inflated by one of three compression modes: (a) a uniform compression mode (the single value of pressure is applied over the whole limb by inflating all air chambers simultaneously), (b) a graduated compression mode (non-uniform pressure is applied over the limb by inflating all air chambers simultaneously but with higher pressure at the ankle and lower pressure at the thigh), (c) sequential compression mode (a uniform pressure is applied to the limb by sequentially inflating the air chambers beginning at the distal leg chamber and progressing to the most proximal leg chamber).\textsuperscript{30–32} The

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**Figure 1.** Variations in compression bandages and stockings: Characteristics, materials, and fabrication methods.
Table 1. Pressure range classification of compression bandages, and stockings.

(a) Compression bandages

| Compression class | 3A [mmHg] | 3B [mmHg] | 3C [mmHg] | 3D [mmHg] | Reference |
|-------------------|-----------|-----------|-----------|-----------|-----------|
| Compression level | Light     | Medium    | High      | Extra high| Reference |
| British standard (BS 7505: 1995) | <20 | 21–30 | 31–40 | 41–60 | 18,24 |
| German standard (RAL-GZ 387) | 18.4–21.2 | 25.1–32.1 | 36.4–46.5 | >59 | 182,183 |
| International compression club (ICC) recommendation | <20 | 20–39 | 40–59 | >59 | 18 |

(b) Compression stockings

| Compression class | I [mmHg] | II [mmHg] | III [mmHg] | IV [mmHg] | Reference |
|-------------------|----------|----------|-----------|----------|-----------|
| Europe (ENV 12718: 2001) | 15–21 | 23–32 | 34–46 | >49 | 184 |
| France (ASQUAL) | 10–15 | 15–20 | 20–36 | >36 | 185 |
| Germany (RAL-GZ 387/1, 2008) | 18–21 | 23–32 | 34–46 | >49 | 186 |
| UK (BS 6612: 1985) | 14–17 | 18–24 | 25–35 | NA | 187 |
| USA | 15–20 | 20–30 | 30–40 | NA | 188,189 |
| International compression club (ICC) recommendation | 10–19 | 20–29 | 30–39 | >39 | 19 |

Note: Values reported are the measure of the pressure (mmHg) at the ankle only. Pressure exerted at calf can range from 50 to 80% of ankle pressure, whereas pressure applied at thigh can range from 20 to 60% of ankle pressure.184,186

Pressure exerted cyclically also varies among pneumatic devices.30–33 Pneumatic compression devices, unlike conventional compression devices, which generate a static force on the lower extremities and rely on the changes in muscle tone caused by the physical movement of the patients, simulate the muscle tone irrespective of the physical movement of the patients. As a result, these pneumatic devices are helpful for use by people with mobility issues such as elderly, obesity, and/or overweight patients, who spend considerable time in bed or on a wheelchair, and for whom other options may be limited.29,34,35

PCDs can be classified as circumferential and non-circumferential based on inflatable bladders encircled around the lower leg. Circumferential pneumatic devices encircle and compress the whole leg, and are often configured either with a zipper, or as loose garments in which the size adjustment system is not available or with Velcro® or another adhesive which enables size to be adjusted.31,36 Non-circumferential bladders encircle only part of the leg circumference, resulting in a smaller air volume being needed. The device is applied on the posterior part of the leg as deep veins, which are responsible for flowing 90% of the blood back to the heart with the help of muscle pump, are located there.37 The non-circumferential devices are the wrap-around type and require the material over the part of the leg without the bladder not to stretch. Pressure is thus applied as a result of inflation of the posterior bladder. If
the garment is free to slide over the skin surface, then the pressure profile obtained by the non-circumferential designs should match with that of circumferential devices.\textsuperscript{30}

Researchers have investigated and reported the effectiveness of a variety of different compression devices for venous disorders, not limited to edema [e.g. \textsuperscript{38–48}]. In general, these studies concluded that in the treatment of venous disorder applying some compression, using any type of existing compression modalities, is better than no compression. However, no conclusive evidence currently exists to suggest which compression modality is most effective for managing chronic edema. Amount of applied pressure required at different positions on the lower leg (pressure gradient across the lower leg) for efficient chronic edema management is also a point of contention. Less or negligible consideration has been paid in these studies to the examining the effects of properties and performance of the compression products, with respect to textile/material variables, structural designs (e.g. accommodating three dimensional shapes of the lower leg), and the interactions between patient body and textiles/materials (e.g. managing sensible and insensible water vapor loss from the skin).\textsuperscript{49–53} Kankariya et al.\textsuperscript{13} concluded that adopting the interdisciplinary approach i.e. by considering the physiological-based, textile-based, and human-based factors along with level of tolerance of pressure by the patient can enhance the success in the management of chronic edema. Professional guidelines for selection of compression product/s are presented by Bjork et al.\textsuperscript{54} and evaluation methodologies and effectiveness of diverse range of compression products in managing lower limb edema both at home and clinically are summarized by Kankariya et al.\textsuperscript{13} Various textile-based compression devices have been discussed in terms of their advantages and disadvantages by Nair.\textsuperscript{55}

Rapid technological advancements in the textile and prototyping industries, and development activities in material processing/sealing have enhanced the possibilities for improving compression products. Developments in compression textile structures, and impact of physical and mechanical properties of textile structures on pressure performance, limited to conventional compression products, were reviewed more than 14 years ago by Milosavljevic et al.\textsuperscript{56} and again 5 years ago by Liu et al.\textsuperscript{17} Performance characteristics, i.e. pressure (6–124 mmHg) and inflation time (∼1 mm–9 mm), of eight types of PCD were analysed and evaluated by Rithalia et al.\textsuperscript{33} Developments in components of PCDs (i.e. bladder, pump), and their characteristics (i.e. pressure range, inflation-deflation time cycle) were reviewed in 2008.\textsuperscript{30} However, missing from these reviews were consideration of materials/textiles, structures/designs, fabrication processes, and thermophysiological performance properties of PCDs. Partsch\textsuperscript{29,34} concluded that using pneumatic device as a compression modality is under used. This paper aims to review materials/textiles used in variety of compression devices, structural design, and fabrication processes to develop the compression products to manage the edema of the lower leg.

**Materials, and structural design of compression bandages and stockings**

**Fabric structure**

Fabrics used in compression devices can be fabricated using a variety of manufacturing methods i.e. weaving, knitting, and non-woven production (Table 2).\textsuperscript{57–60} Each method
can produce a variety of structures depending on the raw materials, machineries and the manufacturer processes/technologies (Figure 2). The fabric structure affects the physical and performance properties of the fabric. For example, a dense (or heavier) fabric is reported to generate more pressure than that of lower density (or lighter) fabric. Also for the same applied tension during bandaging, the reduction in pressure over time for a high density fabric was less than that of a lower density fabric made from the same material. By increasing or decreasing the number of threads per unit length in fabric as well as by altering the density of feed yarn, the density of the fabric or tightness factor of the fabric structure can be altered. Tensile strain, shear stiffness and bending rigidity of compression fabric are other parameters influencing the level of pressure that a fabric can apply over the leg. For example, in graduated compression stockings, the fabric with lower resistances to bending, shearing and extension forces were shown to exert less pressure than the fabrics which have higher resistances. The fabric structure also affects

Table 2. Manufacturing methods to fabricate the fabrics used in compression devices: Advantages and disadvantages.

| Manufacturing methods | Advantages                                                                 | Disadvantage                                                                 |
|-----------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Circular knitting     | Light weight, thinner, seamless, and highly elastic                       | Not suitable for the wearer with extreme differences in limb circumference or a highly unusual limb shape |
|                       | Usually use for class I to class III of compression class                 | Tendency to form constriction marks in skin folds                             |
|                       | Apply pressure across a larger area of leg                               | Tendency to curl down the leg                                                |
| Flat knitting         | Fit to the wearer                                                         | Thicker, less elastic                                                       |
|                       | High stiffness, and can exert pressure range from compression class I to class IV | One seam on the back of compression device                                  |
|                       | Less of a tendency to form constriction marks in skin folds               | Apply pressure in between seam/stitches                                       |
| Weaving               | Suitable for inelastic bandage                                           | Less extensibility and recovery properties                                  |
|                       | High stiffness                                                            | Less thermo-physiological and sensory comfort                                |
|                       |                                                                           | Proper application is not easy                                              |
| Non-woven             | Enhance uniformity of applying pressure around the limb                   | Not washable                                                                |
|                       | Enhance comfort behavior of the multi-layer compression device            | Not reusable                                                                |

References: 54,71,72,74,99–101.

Note: There is considerable variation within each category of compression, e.g. (1) Twill and Satin weave fabrics have more potential for achieving higher elasticity than plain weaves, (2) Some flat knit fabrics (e.g. fabrics produced on V-bed flat knit machines) are seamless, soft, and are less rigid than traditional or seamed equivalents, (3) Single jersey circular knit fabrics exhibit lower resistance to thermal than rib and interlock circular knits. It is important to note that no single textile type is superior to another; rather, each fabric has its own set of advantages and disadvantages that are specific to that individual’s edema presentation.
Figure 2. Compression fabric construction platform and hierarchy.
the thermophysiological and sensory acceptability properties of the fabric such as transportation properties of sensible and insensible moisture is modified by changing the ways water, water-vapor and air will pass through the fabric. Different fabric structures have interstitial spaces of different sizes and geometries resulting in different water absorption, water permeability, water and air resistance, and wetting properties. These in turn will also affect thermal resistance. Researchers concluded that thinner fabrics and fabrics with higher interstitial spaces are less resistance to both water-vapor and heat and more permeable to air than thicker fabrics and fabrics with fewer and/or smaller interstitial spaces. Fabric conditions of use i.e. whether they are relaxed or extended also have an effect on the physical and performance properties of fabrics, given that extended fabric exhibit thinner and more open up the fabric structure resulting in less resistance to thermal and water-vapor transfer, more permeable to water-vapor, more permeable to air compared to relaxed fabrics.

For compression products, knitted fabric is the most prevalent fabric structure. Knitted fabric is a two-dimensional structure made up of natural yarn and/or synthetic filament. Knitting process allows the yarn to be manipulated to form multiple intersecting loops (stitches), with directionality termed wale and course. Number of courses and wales per unit length, size and gauge of needles are the knitting structure variables affecting the physical properties of the knit fabrics i.e. fabric thickness, mass per unit area, and porosity which in turn affect the pressure generated by knit fabric on the lower leg (i.e. increase in stitch length or decrease in gauge of needles generates a decrease in interface pressure), and properties such as water absorption, thermal resistance, and permeability to water and air. Circular and flat knitting technologies are the most often used methods for producing elastic compression textiles. A circular knitting machine fabricates a seamless tube of fabric by using yarn with a 360° cartridge of needles. Whereas, a flat knitting machine, in which the needles are arranged in horizontal bars, produces a sheet of fabric that needs to be cut and sewed using a pattern in order to create the finished compression product. Advantages and disadvantages of circular knit and flat-knit compression textiles to manage the lymphedema of the lower leg have been reported by Reich et al. (However, there have been no clinical studies comparing the safety and efficacy of circular-knit compression stockings versus flat-knit compression stockings in edema patients to date.) Structures with potential for use in the compression device, are single jersey, rib, interlock, and derivative of single jersey but with combinations of float stitches, tuck stitches, and loops in the knit structure. Unlike single jersey knitted fabric, which is made with a single set of needles, double jersey textiles, such as rib or interlock, are made with two sets of needles resulting in their construction reduce the natural extensibility of the structure. Each knitted structure offers advantages in terms of efficiently manage the thermal and water, knitting flexibility, and wearing comfort. For example, single jersey fabrics exhibit higher permeability to water-vapor than rib and interlock fabrics, whereas knit structures with float (miss) stitches provide higher rate of water absorption, water transport ability, and spreading speed of the water on the surface compared to single jersey and tuck stitch knit fabrics.

Knitted fabrics possess greater extensibility and recovery properties than woven fabrics, and thus provide the wearer with greater freedom of movement. Extensibility of knit fabrics is the most important mechanical requirement for the fabrication of
compression devices as stretch allows the device to conform to the complex shape of the human leg. Knitted fabrics also have a smaller number of fabric contact points with the skin which makes them feel more comfortable, in comparison to woven fabrics which have smooth surfaces with resulting in generation of a larger number of contact points on the skin.  

Knitted fabrics are preferred for next to skin use due to specific characteristics such as thermal conductivity, water-vapor permeability, and moisture absorption and transmission properties. Moreover, knitted fabrics exhibit other desirable characteristics such as being warm, lightweight, and more wrinkle resistant.

Woven technique is generally used to create inelastic bandages, which are generally made up of 100% cotton or cotton and viscose blend with nylon. A woven fabric consists of two set of yarns interlaced at perpendicular direction known as warp (longitudinal direction) and weft (lateral direction). The warp yarns follow the length of the loom and are remained taut, whereas the weft yarns are made to introduce the shed across the width created by the parallel sets of warp threads. Variations in three critical factors, namely warp/weft density, types of weave, and yarn count, can affect the features of woven bandages, and all of these three factors are interrelated to each other. All other woven fabric parameters i.e. cover factor, thickness, mass, porosity are dependent on the primary variables, and influence the interface pressure (and/or reduction in interface pressure over time), and comfort properties of the fabric. Plain weave fabric and/or fabric with higher warp/weft density, for example, produces a fabric with compact structure (higher cover factor) as compared to other weave structures and fabrics with lower density, resulting in lower reduction of interface pressure over time. The compact structure of the plain weave fabric does not allow more air space into the fabric, and therefore exhibit higher thermal resistance compared to other weaves. Twill weave produces higher extensibility and smoothness than plain weave fabrics. Furthermore, the bending and shear rigidity of twill fabric is lower than that of plain weave due to less interference between the warp and weft threads which in turn influence the interface pressure. Aboalasaad et al. concluded that tension in the bandage fabric is directly proportional to bandage extension and its porosity, and bandage porosity increases with bandage extension and weave angle. Fabric with more interstitial space shows less resistant to thermal and water-vapor, and more permeable to air, due to trapping more air in the fabric. The effects of woven fabric parameters on thermal and moisture behavior of fabrics, in details, are reported in the related studies.

The performance of pressure garments is associated with the dimensions of the garment, the dimensions of the body, and ease between the fabric and the body. Based on the ease present, negative fit fabric designs (where the fabric size is smaller than the body size (ease <0)) produce pressure on the body. The degree of pressure is influenced by the extensibility (i.e. spandex or Lycra® content) and other characteristics of the fabrics. Compression fabrics/products are either customized by cut and sew methods according to the patient’s body measurement or available as a whole garment (seamless garment) in standard sizes with no (or minimal) cutting and sewing processes. Stockings which fit too loose or tightly can influence the efficiency of compression.

The fabric structures used in compression products are homogeneous in nature, although the yarns, layers, and components used in them may be heterogeneous, and
structural densities may vary along the length. Whereas, the underlying tissue’s characteristics (i.e. hard tissue of bony parts – anterior region, soft tissue of muscle sections – posterior region), and radius of curvature at any given cross section of lower leg is irregular. As a result, some locations on the lower leg are more vulnerable to pressure damage due to excessive pressure applied during therapy than others. The irregular cross-sectional shape of the tibia may necessitate the modification of a compression product, possibly by the addition of padding materials between the compression device and the body surface.95–98 Nonwovens are generally used as a padding component in multi-layer compression kit, which offers protection to the sensitive skin without risk of allergic reaction, aid to maintain uniform pressure around the circumference of the limb, and help in proper exchange of moisture or air for improved comfort to the patient.99–101 As per ISO 9092,102 nonwoven is a manufactured sheet, batt or web of randomly or directionally oriented fibers which are bonded by friction, adhesion or cohesion. In addition, the conical form of the lower leg may require the use of adhesive (adhere to surfaces i.e. skin, textiles) and/or cohesive (self-adhering) compression bandages.103–105 In adhesive/cohesive bandages, the textile fabrics are coated with an adherent substance i.e. zinc oxide, polyacryl that gives the bandages the ability to adhere to different surfaces i.e. textiles, skin surfaces.106 Liu et al.107 attempted to develop a heterogeneous compression design to distribute the even pressure on the lower leg. Heterogeneous compression stockings with different elasticity in the same cross-sectional fabric tube was developed by three-dimensional knitting machine. The result from this study shows that these heterogeneous compression stockings have capability of reshaping the pressure distribution i.e. the lower elastic segment positioned at the anterior tibial area and high elastic segment at the posterior muscular region improved the distribution of the pressure, although, the study was done on the wooden manikin lower leg model. Changes in the radius of curvature of the lower leg while performing activities i.e. running, jogging or walking were not considered in this study.

Many other special structures have also been developed and studied.108–113 Spacer fabrics also known as three dimensional fabrics, consists of two separate textile sheets (which are kept connected vertically with spacer yarn), have positive qualities for their potential use in edema treatment.108,109 These spacer fabrics can be manufactured with different methods i.e. weaving, weft or warp knitting.114–117 A tri-laminated flame bonded structure for compression garments was developed by Yildiz et al.110 In this structure the back face of the fabric was a single jersey, giving the fabric a greater stretch and recovery than normal capacity of the fabric, whereas the face side of the fabric was plush knitted using terry knitting, making it more absorbent and smoother. Poly-chloroprene rubber was sandwiched in between back and face layer of the knit structure. The fabric was soft, flexible and had good extensibility and recovery properties. However, the weight (684 g/m²) and thickness (3.81 mm) of this fabric were high and thus it was unsuitable for the use in compression devices.
Yarns and fibers

The compression fabrics can have different yarn structures such as staple spun, core spun, filament yarns and different fiber compositions such as nylon, wool, cotton, Lycra®, rubber and non-latex materials. The elastic bandage fabric is often fabricated with arrangement of two types of yarn i.e. ground yarn and inlay yarn. The ground yarns are responsible for stiffness, thickness, while inlay yarns are responsible for tension. Heterogeneous yarn materials, combination of the core with covered sheath materials, are used to produce inlay yarn. The core materials might be high stretchable elastomeric yarn i.e. rubber, polyurethane or spandex, or less stretchable yarns i.e. polyamide or polyester. Staple fibers i.e. cotton, wool in the covering permits the comfort and appearance. The wrapping can control to obtain yarns with different strength and stretch-ability. There are various covering methods to manufacture the covered yarns i.e. single covering, double covering, core twisting, core spinning, and air-jet covering. These inlay yarns can be inserted with each course /weft or in according to selected pattern. The inlay yarns under different tension can be introduced in the pressure fabric by manipulating the tension regulator of the machine. Increasing the thickness of the elastic core of the inlay yarn results in more tension in the inlay yarn and, as a result, in the fabric, which generates more pressure. The mechanical properties of the inlay threads i.e. elasticity, tenacity, durability are depends on the draw ratio, types of covering, twist per meter, linear density. By picking the suitable yarns, it is possible to manufacture an extensible bandage which execute in a predetermined fashion resulting to meet a particular clinical need and also the strength or power of a bandage may be controlled.

Synthetic materials i.e. nylon, polyester, or polypropylene in compression devices have been used and described in many studies, and appear to have been selected by considering how best to ensure loss of sensible moisture. However, the thermal balance of the compression device is related to dynamic interactions between the compression device and the lower leg. The lower leg does not remain in a thermal steady state, but is continuously exposed to the environmental conditions and affected by interactions among skin, general metabolism, and the compression device. Both the sensible and insensible moisture transmission, and heat transmission characteristics of a material play a crucial role in maintaining the thermal balance of the lower leg. Nylon/spandex blend yarns are used in compression textiles, owing to their higher extensibility and tenacity, and better thermal stability. Lycra®/spandex is used with different types of fibers i.e. cotton, nylon, viscose, with different blend ratios to construct the bandages, which can produce the various level of pressure. As Lycra /spandex doesn’t contain the latex element, therefore people with latex allergies is often recommended to use the Lycra® based fabric.

Due to the chemical composition and physical structure of wool fiber, many advantages may arise as a result of using wool fibers in the engineering of compression devices. The chemical blocks, amino acids, of wool fiber form hydrogen bonds with water molecules, incorporating the water into the fiber. A small amount of heat is released as a by-product of this hydrogen bonding reaction. Therefore, although water content
increases the wool fabric feels warmer making wool a good choice for use in damp and cold conditions.\textsuperscript{137–139} Fiber/material compositions in different components of selected commercially available compression products, properties i.e. pressure range, elasticity of existing compression kits, and advantages - disadvantages are given in Table 3.

Despite the variety of fiber types used and available for fabrication of compression devices, Bera et al.\textsuperscript{140} claimed that fiber has little or no effect on the compression generated. Thermal properties and air permeability of the device is also not affected. However, water-vapor permeability properties differed significantly as illustrated by differences in moisture regain capacity.\textsuperscript{140} Stoffberg et al.\textsuperscript{65} concluded that thermophysical behavior of fabric is more influenced by the physical properties of the fabric, i.e. thickness, mass per unit area, than by fiber types. This is well accepted in the scientific literature.

**Pneumatic compression device – Bladder design and fabrication process**

Bladders in pneumatic compression systems are designed to wrap around the lower limb.\textsuperscript{29,30} Different design options are used to achieve leg compression; foot compression, calf compression, thigh compression, and combinations of calf, thigh, and foot compression.\textsuperscript{32,141} Bladders are fabricated by seaming two sheets of air impervious materials, e.g. silicone, polyethylene, polyvinyl chloride (PVC), or polyurethane, together, then attached to a source of pressurized gas (Table 4).\textsuperscript{142–145} As part of an inflated bladder, these two sheets are structured so they maintain a required pressure and maintain this over time. The wall of the bladder may be any thickness i.e. that needed to contain the air at its predetermined/specified level. The thickness of the sheet depends on the material from which the bladder is fabricated. For example, to exert the same level of pressure, elastic materials can be comparatively thinner than inelastic materials.\textsuperscript{146} The bladder sheets may be coated or laminated to protect from puncture and enhance durability,\textsuperscript{147} and attached with fastening strips, complementary fastening strips, and/or hook-and-loop attachments (e.g. Velcro®). The loop fastening and hook fastening strips may be secured to the inner and outer sheet of the bladder respectively.\textsuperscript{148}

Examination of patents reveal that bladders were generally fabricated using impervious sheets without consideration to manage the sensible and insensible water produced by the body during normal metabolism. Nicholson et al.\textsuperscript{149} attempted to address the issue of moisture accumulation on the skin by sealing the outer inelastic plastic sheet to an inner soft sheet to provide an air space between the sheets while also applying uniform pressure to the leg. Perforations were placed in the inner sheet to facilitate the passage of moisture from the skin of the participant to the environment thus facilitating evaporation of the moisture. The aim of such perforations is to enhance comfort of the participants. However, rigid or hard structure outer shells may restrict the free movement of the participant and also require careful consideration.

One such device was developed by Tordella et al.\textsuperscript{143} who constructed a bladder with outer and inner sheets which were seamed at the perimeter. While the structure was airtight and was thick enough to sustain the applied pressure over a number of treatment cycles without bursting, the sheets were fabricated from polyvinyl chloride or
| Extensibility - elasticity: stiffness | Product name (Company name); pressure [mmHg] | Components and materials | Advantages | Disadvantages | Reference |
|------------------------------------|---------------------------------------------|--------------------------|------------|--------------|-----------|
| No stretch bandage - inelastic bandage; Very high stiffness | Viscopaste® - unna boot (smith & nephew) 20–30 | Zinc oxide paste impregnated in woven cotton gauze | High working pressure, low or tolerable resting pressure | Needs to be applied by trained staff, messy, not suitable for a user sensitive or allergic to zinc, not reusable, fast pressure loss | 206,208 |
| Short stretch bandage - inelastic bandage; high stiffness | Comprilan® (BSN medical) 40 | Component 1: Compression (cotton) | High working pressure, low or tolerable resting pressure, washable and reusable, light and conformable | Difficulty of achieving the desired pressure, needs to be applied at full stretch, more slippage, fast pressure loss | 207,208 |
| Actico® (Activa healthcare – Since 2008 known as Lohmann & Rauscher) 30–40 | Flexi-Ban (polyester wadding) or Cellona® undercast padding (polyester or cotton wadding) | Component 1: Compression (cotton/polyamide/elastane) inelastic cohesive bandage | High working pressure, low or tolerable resting pressure, washable and reusable, light and conformable | | 191 |
| Long stretch bandage - elastic bandage; low stiffness | Setopress® (Molnlycke) 30–40 | Component 1: Compression (cotton/viscose/polyamide/Lycra®) | Sustained pressure, washable and reusable | Low working pressure, less slippage | 192,193,208 |
| Surepress® (ConvaTec) 30–40 | Component 1: Compression (cotton/polyamide/elastomeric yarn) elastic bandage | | | | 192,194 |
| Comperm® LF (Hartmann USA) 15–50 | Component 1: Compression (cotton/polyester/latex free elastomer) circular knitted elastic bandage | | | | 213 |

(continued)
| Extensibility - elasticity; stiffness | Product name (Company name); pressure [mmHg] | Components and materials | Advantages | Disadvantages | Reference |
|-------------------------------------|-----------------------------------------------|--------------------------|-------------|---------------|-----------|
| Multilayer, two components - inelastic system; high stiffness | Actico® 2C (Activa healthcare) 30–40 | Component 1: Foam padding plus a comfort layer (cotton) Component 2: Compression (cotton/polyamide/elastane) inelastic cohesive bandage | High working pressure, low or tolerable resting pressure, less slippage, self-adherent but not to skin | Not reusable, needs to be applied by trained staff | 196,208 |
|                                      | Coban® 2 (3M) 35–40 | Component 1: Foam (polyurethane foam with cohesive nonwoven backing) Component 2: Compression (polyester/spandex) inelastic cohesive bandage (Spandex filament/100 mm: Coban® 2 – ~55; Coban® 2 Lite – 28) |                                     |                                                       | 105,197-199 |
|                                      | Coban® 2 Lite (3M) 25–30 | Component 1: K-Tech™ (visco and polyester wadding with a polyester and elastane knitted layer) inelastic bandage Component 2: K-Press™ (acrylic/polyamide/elastane with or without latex; latex in cohesive material) elastic knitted cohesive bandage |                                      |                                                          | 200 |
|                                      | Urgo K Two™ (urgo medical) 30–40 | Component 1: K-Soft™ (visco and polyester wadding) nonwoven inelastic wadding Component 2: K-Lite™ (visco/nylon/elastomeric yarn) elastic knitted cohesive bandage Component 3: K-Plus™ (visco/nylon/elastomeric yarn) elastic knitted bandage Component 4: Ko-Flex™ or K-ThreeC™ (cotton/acrylic/elastomeric yarn – coated with latex) elastic knitted cohesive bandage | High working pressure, low resting pressure | Needs to be applied by trained staff, bulkiness or four layers can adversely effect on thermo-physiological comfort | 201,208 |
| Multilayer - four components - inelastic system; high stiffness | Urgo K Four™ (urgo medical) 30–40 | Component 1: K-Soft™ (visco and polyester wadding) nonwoven inelastic wadding Component 2: K-Lite™ (visco/nylon/elastomeric yarn) elastic knitted cohesive bandage Component 3: K-Plus™ (visco/nylon/elastomeric yarn) elastic knitted bandage Component 4: Ko-Flex™ or K-ThreeC™ (cotton/acrylic/elastomeric yarn – coated with latex) elastic knitted cohesive bandage | High working pressure, low resting pressure | Needs to be applied by trained staff, bulkiness or four layers can adversely effect on thermo-physiological comfort | 201,208 |

(continued)
| Product name (Company name); pressure [mmHg] | Components and materials | Advantages | Disadvantages | Reference |
|---------------------------------------------|--------------------------|------------|---------------|-----------|
| Profore™, Profore™ Lite (smith & nephew) 17–40 | Component 1: Softban™ natural padding (polyester) - inelastic, nonwoven padding | — | — | 202 |
| | Component 2: Crepe (cotton) inelastic, knitted/woven bandage | | | |
| | Component 3: Litepress™ compression (wool/cotton/rubber) elastic, knitted/woven bandage (this component is not included in Profore™ Lite) | | | |
| | Component 4: Coplus™ (nylon/elastane web, coated with latex) elastic, nonwoven cohesive bandage | | | |
| Robinson® ultra four (Robinson healthcare) 30–40 | Component 1: Ultra soft™ (viscose/polyester) inelastic nonwoven padding | — | — | 203 |
| | Component 2: Ultra Lite™ (viscose/elastic yarn) elastic knitted cohesive bandage | | | |
| | Component 3: Ultra Plus™ (viscose/nylon/elastic yarn) elastic knitted bandage | | | |
| | Component 4: Ultra-Fast™ (cotton/acrylic/elastic yarn – free from latex) elastic knitted cohesive bandage | | | |
| Rosidal sys® (Lohmann & Rauscher) 60–90 | Component 1: Tg® tubular (cotton/viscose) circular knitted seamless structure | — | — | 204 |
| | Component 2: Rosidal® soft foam padding (polyurethane) | | | |
| | Component 3: Rosidal® K (cotton) - inelastic cohesive bandage + Porofix® (viscose) synthetic rubber adhesive tape | | | |
| | Component 4: Mallelast® haft (cotton/viscose woven/knitted structure coated with rubber) elastic cohesive bandage | | | |
| Extensibility - elasticity; stiffness | Product name (Company name); pressure [mmHg] | Components and materials | Advantages | Disadvantages | Reference |
|-------------------------------------|-----------------------------------------------|--------------------------|------------|--------------|-----------|
| Long stretch - elastic stocking; low stiffness (note: circular knit fabric is seamless and not as stiff and dense as flat knit) | Juzo<sup>®</sup> compression stocking (Juzo) 15–40 | Component 1: Stocking (cotton) flat knit structure | Self-management | Low working pressure, difficult to put on | 205,208 |
|                                       | Mediven<sup>®</sup> forte compression stocking (Medi GmbH) 23–46 | Component 1: Stocking (polyamide/elastane) circular knit structure | | | 209 |
| Long stretch - elastic system; Medium stiffness | Jobst ulcer CARE<sup>®</sup> (BSN medical GmbH) 40 | Component 1: Liner Component 2: Stocking (nylon/spandex/silk) circular knit structure | Self-application, self-management, liner layer can stay overnight and keep the dressing in place, stocking layer can apply daytime | Low working pressure, difficult to put on | 190,208 |
|                                       | Mediven<sup>®</sup> ulcer kit (Medi GmbH) 40 | Component 1: Liner Component 2: Mediven<sup>®</sup> plus stocking (polyamide/elastane) circular knit structure | | | 211 |

Note: (1) Elastic knee length stocking (Mediven Forte<sup>®</sup>) with a pressure of 30 mmHg is equally effective as multilayer - multicomponent inelastic bandage system (Cellona<sup>®</sup> + Rosidal K<sup>®</sup> + Mollalast<sup>®</sup>), when applied with full stretch, exerting initial pressure over 60 mmHg in reducing lower leg edema (volume reductions were: 9.6% vs. 11.5% after two days, 13.2% vs 15.6% after 7 days).<sup>210</sup>

(2) Group A (inelastic bandage system (Cellona<sup>®</sup> + Mollalast<sup>®</sup> + Rosidal K<sup>®</sup>) applied for 2 weeks at weekly intervals followed by Mediven Forte<sup>®</sup> elastic stocking applied for the following 2 weeks) and Group B (knee length “liner” from the Mediven<sup>®</sup> Ulcer Kit for 1 week followed by superimposition of Mediven<sup>®</sup> Plus stocking for the next 3 weeks) showed the same reductions in edema volume (Volume reductions were 12.8% vs 13.0% after one week, 17.8% vs 16.2% after two weeks, and 17.3% vs 17.0% after 4 weeks.).<sup>212</sup>

(3) Short stretch bandages may stretch up to 70% of their original length, whereas long stretch bandages can stretch more than 140%.

(4) Wadding is a loose mass of fibers in a roll or sheet usually used as padding.<sup>75</sup>
Table 4. Material components and structure in pneumatic compression device (review of patents).

| Number of layers | Bladder material                  | Extra layer | Sealing** | Advantages                                           | Disadvantages                                                                                   | Patent number reference |
|-----------------|-----------------------------------|-------------|-----------|-----------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------|
| 2               | Nylon coated with polyethylene    | -           | Heat sealing; adhesive bonding; RF welding          | Light weight                                                                                   | Moisture is trapped between the air impermeable sheets and the wearer’s skin surface, making it uncomfortable for the wearer | US 6846295 B1 152       |
| 2               | Polyethylene, polyurethane        | -           | -         | Sensorial comfort, move the moisture from the skin surface and collected at the openings          | Limited thermo-physiological comfort                                                            | US 0187503 A1 143       |
| 3               | Polyurethane or PVC               | Nylon       | Laminate  | Limited thermo-physiological comfort                                                            |                                                                                                  | US 8636679 B2 153       |
| 3               | PVC; 0.1–0.3 mm thickness          | Polyester (non-woven) | RF welding |                                                                                                  |                                                                                                  | US 7442175 B2, US 8079970 B2, US 8029451 B2 154–156 |
| 3               | PVC                               | Nylon (woven) | -         | Heat sealing; adhesive bonding; RF welding                                                      |                                                                                                  | US 7044924 B1 148       |
| 3               | PVC; 0.1–0.3 mm thickness          | Polyester (non-woven) | -         |                                                                                                  |                                                                                                  | US 5795312, US 5435009 157,158 |

(continued)
### Table 4. (continued)

| Number of layers* | Bladder material | Extra layer | Sealing** | Advantages | Disadvantages | Patent number reference |
|-------------------|------------------|-------------|-----------|------------|---------------|-------------------------|
| 4                 | PVC; 0.2 mm thickness | Polyester; 0.2 mm thickness | RF welding; any chemical or mechanical bonding | Enhanced thermo-physiological and sensorial comfort | May feel heavy to the patient over an extended period of use | US 0338552 A1 159 |
| 4                 | Polyethylene; 0.1 - 0.2 mm thickness | Polyester or polypropylene, (non-woven) | RF welding | | | US 0079692 A1 160 |
| 4                 | Reinforced nylon in between two polyethylene layers | Polyester or polypropylene, (non-woven) | Molten polyethylene | | | US 8313450 B2 161 |
| 4                 | PVC | Polyester filament or microfiber (woven, knit) | RF welding | | | US 8029450 B2 162 |
| 4                 | PVC | Outer layer - loop pile fabric, skin layer - polyester foam | RF welding | | | WO 2003007855 A1, US 2005/0070828 A1 163,164 |
| 4                 | Polyurethane | Woven nylon | RF welding | | | US 4722332 A 165 |
| 4                 | PVC | Outer layer - warp knit polyester with raised loops of nylon or polyester, skin layer - nonwoven | RF welding | | | US 4198961 A 166 |

*Bladder with four layers, two intermediate air impervious layers cover with skin layer and outer layer.

*Bladder with three layers, two air impervious layers cover from one side only with inner skin layer.

*Bladder with two layers, two air impervious layers with no outer covering.

**Heat sealing, and radio frequency (RF) welding melt and join sealant layers without the need of adhesives or solvents, reducing contamination and enhancing welded component recyclability. The main drawback of RF welding is that it can only be used on materials with polar groups in their chemical structure (i.e. RF is suitable for PVC, polyurethane; not suitable for silicone). Adhesive or chemical bonding seal the edges of the layers of bladder on the application of solvents for cleaning or primer, and adhesive to the inner surface of the sealant layers. The adhesive must be chosen carefully to suit the type of materials being bonded. Because adhesives and solvents are chemical compounds, they require appropriate handling precautions.
polyethylene, and thus impervious to moisture. Consequently, the bladder was perforated completely through bottom and top sheets, to provide cooling to an adjacent portion of the leg. However, the arrangement of perforations did not provide sufficient passage to remove the fluid trapped under the sheets away from the vent apertures. The evaporation was thus restricted to the vent opening and the areas adjacent to the vent opening under the impervious sheets. To enhance the moisture management efficiency of the bladder, nylon-coated polyurethane sheets have also been used to fabricate bladder layers. Again, perforations were punched through the top and bottom sheets, and between adjacent seams to facilitate evaporation of moisture. Of concern is potential for perforations to lower pressure near the seam or adjacent to the bladders, and that this may result in plasma pooling.

In order to facilitate sensible water loss, three-layer bladder assemblies have also been developed using different material components including an additional next to skin layer (e.g. US 7044924 B1, US 8636679 B2, US 7442175 B2, US 8079970 B2, US 8029451 B2, US 5795312, US 7044924 B1). For example Roth et al. used a woven material made of nylon which was applied to the technical face of the bladder. Note that, the mode of attachment of the nylon layer to the inner surface was not disclosed in the patent. Understanding the mode of attachment is critical, as laminating the woven material to the sheet may interrupt the arrangement of the fibers e.g. making them discontinuous and deteriorating moisture transportation capacity of the material. In another example a polyester nonwoven structure welded with a PVC impervious layer, 0.1–0.3 mm thick, was used as an additional next to skin layer.

Further advancements, such as securing together inner two impervious layers covered by outer two layers to make a compression sleeve have been described (e.g. US 2013/0338552 A1, US 2013/0079692 A1, US 8313450 B2, US 8029450 B2, WO 2003007855 A1, US 2005/0070828 A1, US 4722332 A, US 4198961) (Table 4). The inner layer was adjacent to the leg and in contact with the wearer’s leg during use. The inner intermediate layer was overlaid on inner most layer. The outer most cover layer, which was furthest from the leg, was secured to the outer intermediate layer. The intermediate layers were secured together by welding, adhesive, mechanical or chemical process. All layers had the same geometric shape and size and were superposed on each other with their edges coinciding. The intermediate layers were the film of polyurethane, nylon-reinforced polyurethane, or a PVC material, all impervious to air. The inner and outer layers were knit or nonwoven structures composed of polyester filament, polyester microfiber, or polypropylene material. The outer cover layers were joined with the outer perimeter of the intermediate layers. Perforations were made through the intermediate layers to provide a passage for moisture. The inner layer pulled the moisture from the skin to dissipate through the perforations and finally from the outer layer. However, the perforations in the layers may create a low-pressure zone reducing the efficiency of the device.

The proper size and fit of compression sleeves over the lower leg, given that the radius of curvature at any cross-section of the lower limb (i.e. anterior edge of the tibia bone, calf) is irregular, was not considered either in above mentioned PCD patents, nor in the studies carried out to validate the theoretical models to predict the pressure generated by
PCDs to the lower leg. The patterns for inner and outer layers of pneumatic compression sleeves for three different positions of irregularly-shaped lower limb manikin i.e. ankle, below calf, and calf were created using a combination of drape and flat pattern techniques. The inner sleeve layer was shaped to fit the leg manikin at specific position. The circumference of the outer layer of the pneumatic compression sleeve was greater than the circumference of the inner layer. Equal fullness was optimized and added to the inner layer of the basic pattern to create a larger pattern for the outer layer of the compression sleeve. The difference in size of the two layers affected the size of the bladder and inflation pressure. Compression sleeves were fabricated by bonding the edges of inner and outer silicone layers followed by sealing this bond using the tape. The effect of multi-layer assemblies composed of a wool-based next-to-skin knit layer (in extended conditions to simulate the end-use or application), and outer two silicone layers with and without vents across the silicone layers on thermal and moisture behavior of a potential PCD was investigated. Water vapor resistance of the multi-layered assembly dropped significantly by forming ventilation of ~2% of total surface area, allowing it to create an acceptable microenvironment for the user. Although, this study was the limit examination of the thermophysiological properties of single layer material/s, and multi-layer assemblies using a sweating guarded hot plate. The study can be extended to measure performance properties of assemblies using thermal manikin approach, and human trials to better understand the thermophysiological, and sensorial properties of the silicone based pneumatic compression device.

**Application of smart materials in compression devices**

Recently, the research focus in smart materials/polymers has been intensified in their applications in healthcare areas including compression products. Smart materials are stimuli-responsive materials that react to changes in external condition or stimuli such as temperature, pressure, voltage. Many researchers have developed and studied stimuli-responsive compression product, with the capability of producing controlled compression on the lower leg, using shape memory alloys or polymers. Porurazadi et al. and Calabrese et al. used Electro Active Polymers (EAP) to design and produce an active compression bandage that is activated by external electric stimuli. Moein and Menon designed and fabricated an active compression bandage using a sheet of thermoplastic polycarbonate, and shape memory alloy wires (low temperature Flexinol actuator wire). Holschuh et al. claims to be the first to describe a technology that incorporates integrated shape-changing materials to generate pressure-controlled compression textile garments. They designed a compression garment with at least one passive flexible member and one active actuator with shape memory alloy that can apply or remove compression depending on whether or not an applied stimulus is present. Bipin et al. designed and investigated a compression stocking comprising shape-memory polymer that allowed externally controlling the pressure level in the wrapped position on the lower leg. These various studies, however, have not taken into consideration the factor of irregularity exist in the limb circumference in their designs. Clinical research evidence for
the use of compression products with smart materials for managing chronic edema has not been identified.

Ideal materials, and designs of compression devices

Properties critical to selection of materials and their performance are that they are light in weight, puncture resistant (in case of PCDs), sufficiently flexible to allow conformation to the body shape, air and water-vapor permeable, and that they exhibit low thermal and water-vapor resistance.13,58,69 Other factors include presence of frictional properties and response to repeated cycle without wrinkles occurring. A further requirement is that compression devices must not abrade the affected or adjacent skin. The surface of the device which comes in contact with skin should be flexible enough to accommodate any sensory limitations /requirements of the tissue body parts i.e. foot and lower leg on which it is applied.176,177

A compression device should accommodate the 3-dimensional shape of the leg.13 Wearing a compression device that does not fit the patient’s leg characteristics may enhance the severity of edema. A compression device that is too tight may cause tissue damage and discomfort for patients. On the other hand, a device that is too loose will not apply the predetermined pressure to the leg and will not accomplish its purpose.13 Designing a compression device using lower leg shape and size information will ensure the best fit of the device on the patient’s leg and will enhance overall comfort of the wearer.178

The newly designed compression device should be easy to put on and take off. Elderly, overweight, patients with mobility issues, and the bed or wheelchair bound patient should be able to apply the compression device independently and accurately. Easy donning and doffing, by patients would facilitate regular use of the device which in turn would help reduce the swelling and hence edema.29,176

For successful edema therapy, sustained pressure is necessary during the time the compression device is wrapped around the lower leg. However because most textiles (i.e. fabrics used in compression bandage, stocking) are viscoelastic, the applied contact pressure decays with time.63,179 During treatment for PCDs, there should be no air leakage.145

The existing compression products do not encourage regular use of these devices. Participants have been shown to stop compression treatments due to discomfort and low sensory acceptability.45,180 The compression devices are recommended to apply to the body for prolonged periods of time (for 3 months to years).110,181 The newly-designed compression device should maintain high sensory acceptability to attract the wearer to use in a regular fashion. It should efficiently manage the sensible and insensible water loss, and should maintain an acceptable physiological comfort i.e. heat and sweating.69,176

Conclusions

Compression textiles in the form of bandages, stockings, and PCDs, are used in managing the edema by applying pressure on the lower limb. The diverse materials, structural
designs, and fabrication technologies/processes employed in these compression modalities are reflected in the characteristics of compression products. Selecting proper materials, and designing the compression device based on shape, size, and properties of the tissue of the lower leg might provide the greatest results for pressure therapy. As compression devices are normally come into direct contact with human skin, effectively management of sensible and insensible water, thermal and moisture, and sensorial comfort are critical.

In summarily, despite for providing the required amount of pressure, a compression device should be designed which:

- Can be easily and independently applied
- Exerts and maintains the required level of pressure
- Accommodates the 3-dimensional shape of the leg
- Exerts a pressure gradient appropriately along the length of the leg
- Maintains high sensory acceptability (including sensory perception of materials/device i.e. smoothness, roughness, stickiness, prickliness, and itchiness; thermophysiological behavior of materials/device)

Further advancements in heterogeneous compression designs and stimuli responsive compression products, while taking into account the factor of irregularity in the limb circumference and the comfort (thermophysiological and sensorial) properties of the compression device, have the potential to be a breakthrough in the near future.

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Notes

1. Patients who do not have severe leg swelling or who are in the early stages of edema should use a Class 1 compression stocking. Compression of Class II can be used to treat lymphatic chronic edema. In severe lymphedema or venous leg ulcers, compression classes III and IV are
commonly employed. However, as different national pressure classification systems of compression devices are discrepant, patient may receive class I compression stockings with a pressure between 10-15 mmHg from manufacturer in country X and between 15-20 mmHg from manufacturer in country Y. The patient’s level of pressure tolerance should be considered in addition to the pressure prescription for the lower leg.

2. Given that pressures beyond 40 mmHg did not substantially reduce edema, the optimal configuration for lowering edema was determined to be 30–40 mmHg of interface pressure, 10 s deflation time, and 15 s inflating time. Taradaj, on the other hand, found that IPC with a pressure of 120 mmHg considerably reduces edema whereas therapies with a pressure of 60 mmHg are ineffective.

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