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Full Length Research Paper

Influence of pressure from compression textile bands: Their uses in the treatment of venous human leg ulcers

Bachir Chemani* and Rachid Halfaoui

Laboratory of Processing and Shaping of Fibrous Materials and Polymers, Department of Engineering Process, Faculty of Engineering Sciences, University M'Hamed BOUGARRA, Boumerdes 35000, Algeria.

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The aim of study was to evaluate pressure distribution characteristics of the elastic textile bandages using two instrumental techniques: a prototype instrument and a load transference. The prototype instrument which simulates shape of real leg has pressure sensors which measure bandage pressure. Using this instrument, the results show that elastic textile bandages presents different pressure distribution characteristics and none produces a uniform distribution around lower limb. The load transference test procedure is used to determine whether a relationship exists between elastic textile bandage structure and pressure distribution characteristics. The test procedure assesses degree of load, directly transferred through a textile when loads series are applied to bandaging surface. A range of weave fabrics was produced using needle weaving machine and a sewing technique. A textile bandage was developed with optimal characteristics far superior pressure distribution than other bandages. From results, we find that theoretical pressure is not consistent exactly with practical pressure. It is important in this study to make a practical application for specialized nurses in order to verify the results and draw useful conclusions for predicting the use of this type of elastic band.

Key words: Textile, cotton, pressure, venous ulcers, elastic.

INTRODUCTION

The immobility for prolonged periods, the paralysis and other venous disorders contribute to the formation of leg ulcers. Compression bandaging is the most important single element in the conservative treatment of venous leg ulcers. The application of external compression by means of elasticity bandages serves to increase the velocity of blood flow within the veins by providing support to the calf muscles. The level of pressure exerted on the leg is a function of the tension induced into the compression bandage during application, the layers number used and the limb circumference (Van Der Molen and Kuiper, 2001).

Since the pressure produced is inversely proportional to the circumference of the limb then a pressure gradient is formed where higher pressures are exerted on the ankle than on the calf if the bandage is applied at constant tension (Moffatt, 2002, 2007). However, mis-use of compression bandages have in some instances led to further venous system complications, notably bandage induced ulcers (Zhang et al., 2002). Such ulcers may occur at the foot, fibula, and tibia regions of the leg where high compression bandage pressures are exerted over a

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*Corresponding author. E-mail: chemani_ba@yahoo.fr, Tel/Fax: 213 24 81 91 53.

relatively small radius of curvature. In addition, because there is little subcutaneous tissue in this region, the likelihood of further complications is extended. The need to distribute the pressure equally on all points of the lower limb, whilst offering protection to the tibia and fibula regions is extremely important (Stacey et al., 2002). A variety of bandages are used beneath compression bandages as padding layers in order to evenly distribute pressure and give protection (Khokar, 2001). These include polyurethane foam bandages and nonwoven orthopedic waddings but there is little published material which defines their use for this particular problem or whether they have the performance criteria necessary to provide adequate pressure distribution (Onofrei et al., 2010). In order to distribute compression bandage pressure evenly around the limb it is essential that high pressures created at the tibia and fibula regions are absorbed by the padding bandage material (Radu et al., 2008). The load transference test procedure was developed so that a quick assessment of the pressure distribution characteristics of padding bandages can be made. We will also use the Laplace law to theoretically (Thomas, 2003), calculate the pressures applied, and then compare the results. This law is applied in many sectors of science, including medicine, to calculate the forces exercised on blood vessels and alveoli filled with fluid. It is necessary to use the conversion of the measuring units of measurement, that is to say, using the units pertaining to each other. According to Laplace's law, the sub-bandage pressure is directly proportional to the voltage of the latter, but inversely proportional to the radius of curvature of the body on which it is applied. In order to use Laplace's law to estimate the pressure under the bandage, it is also necessary to consider two other factors: the width *B* and number of layer applied *N*.

The calculated value of the sub-bandage pressure is the average pressure to be exerted by a bandage on one leg whose circumference is known. Calculated pressure values are significantly lower than the measured values, as shown in Figure 4, and so these results are very useful because it tells us about the behavior of the pressure applied and calculated. This leads us to say that it is therefore very important to pose elastic bands on the patient's limb in an efficient manner, hence the need to train the person responsible for this task. In second place, it has been reported that knowledge about bandages is poor and that sub-bandage pressures are largely inappropriate.

Community nurses care for the majority of patients with leg ulcers and hence it was decided to study the way in which community nurses apply bandages, and the extent to which their technique improves after training. It was also intended to test whether the bandage characteristics were a significant factor in aiding bandage application.

The main objective of this research was to produce a bandage material with far superior pressure distribution characteristics.

MATERIALS AND METHODS

The final properties of textiles depend more or less on many different technical and technological parameters, which should already be adjusted during the design phase of a textile. The fabric composed to warp yarns and weft, which mechanical properties and physical (count, strength and breaking elongation, fineness, the number of towers, the composition of raw materials, post-processing, etc.), have a significant influence (Kumar et al., 2013b, c).

To predict interfacial pressure induced by different textile structure on a curved surface of the human body, the relationship between the tensile properties of an elastic fabric, the curvature of the shaped surface, and the pressure of the skin and textile interfacial may be formulated into a mathematical expression. Pressure bandage are made from strong elastic fabric containing Lycra. Lycra several types can be used. The different degrees of elasticity and strength of materials with different degrees of tissue tension can induce different degrees of pressure on patients.

The five bandages were given identification codes (MT1, MT2, MT3, MT4 and MT5) prior to pressure distribution testing; a description of the bandages is given in Table 1. Throughout this investigation a standard high compression bandage was used in order to exert the required level of pressure 38 mmHg. A constant bandage tension of 450 cN was introduced into the compression bandage during application.

An elastic textile fabrics number were produced using weaving needle looms and sewing techniques. These fabrics were subsequently tested on load transference. It was found that the load transference performances of a fabric are reduced as a result of sewing technique. Therefore, a variety of samples were adopted until an optimum bandage will produce. The optimum bandage MT4 composed of Polyester 30%, Lycra 20%, cotton 50%, distributes pressure throughout its unique structure due to the weaving technique used. Textile fabric and padding is assembled using seam.

The theoretical method pressure calculation

Using the Laplace law to estimate the pressure under the bandage, it is also necessary to take into account two other factors: the bandage width *B* and the number of layers applied *N*. The calculated value of sub-bandage pressure is the average pressure to be exerted by a bandage on one leg whose circumference is known. To reduce the pressure variations in a given area under the bandage, padding can be used under compression bandages. Many types of tissues are composed of woven yarn, each thread composed of a plurality of fibers or yarn twisted together. Other, more advanced, the yarn cross sections may be elliptical, lenticular or racetrack.

However, in order to maintain a reasonable degree of simplicity, the banding pressure can be formulated by mathematical expression:

$$\mathrm{Pi} - \mathrm{Pe} = \frac{\mathrm{T1}}{\mathrm{R}} + \frac{\mathrm{T2}}{\mathrm{R}} \quad (1)$$

$$\mathrm{P} = \mathrm{Pi} - \mathrm{Pe} = \frac{2\mathrm{T}}{\mathrm{R}} \quad (2)$$

Where: Pi - The internal pressure, Pe -The external pressure, T1 - The positive tension of textile, T2 - The negative tension of textile, R - The curvature radius, T- Tension of bandage.

Equation (2) shows that pressure inside of a spherical surface is always greater than external pressure, but the difference tends

Table 1. Sample of elastic textile bandages used in study.

Sample	Composition		Elongation (%)	Relaxed linear density, yarns/10 cm		Weave	Pending bandage material
	Warp yarns (%)	Weft yarns (%)		Weft	Warp		
MT1	Polyester 42 Lycra 8 Coton 50	Coton 100%	70	75	120	Weave plain	Polyurethane 2
MT2	Polyester 38 Lycra 12 Coton 50	Coton 100%	90	90	120	Weave plain	Polyurethane 2
MT3	Polyester 34 lycra 16 Coton 50	Coton 100%	110	110	120	Weave plain	Polyurethane 2
MT4	Polyester 30 lycra 20 Coton 50	Coton 100%	160	120	120	Weave plain	Polyurethane 2
MT5	Polyester 34 lycra 24 Coton 50	Coton 100%	190	135	120	Weave plain	Polyurethane 2

towards zero when the radius tends to infinity (when the surface becomes flat). However, pressure difference increases if the radius becomes smaller and tends to infinity as R tends to zero. When the wall is perfectly cylindrical, simply use the following Equation (3).

$$P = \frac{T}{R} \qquad (3)$$

This law is applied in many sectors of science, including medicine, to calculate the forces exercised on blood vessels and alveoli filled with fluid. It is necessary to use the measuring unit's conversion of measurement, that is to say, using units pertaining to each other. The most common unit used is Pascal for measuring the pressure and Newton unit as measure of force, but in medical field often used following units. To reduce errors due to measurement units, it is important to consider a constant coefficient of conversion of measurement units *K* and Equation (3) takes following form:

$$P = \frac{T\,K}{R} \qquad (4)$$

$$P = \frac{F}{2\pi RB} \qquad (5)$$

In case of a single bandage layer applied to a member, the pressure is exerted on surface covered by the textile. This pressure will be determined by total force applied to fabric and the width the bandage in relation to the definition of pressure. Pressure applied is proportional to force on the textile and inversely proportional to application surface. Total tension developed by an elastic band is equal to sum of warp yarn tensions. The result is that number of layers, applied with a constant tension, is proportional to number of warp yarn in a point of application on surface of leg. Thus it is essential to consider number of layers in the calculations. The original formula to calculating pressure is expressed as Equation (5).

$$P = \frac{T\,.\,N}{L\,.\,B} \qquad (6)$$

To move from one measurement unit to another and to avoid significant errors due to conversion of measurement units, it is useful to consider a constant K in final equation, the equation gives a *K* value of 4620. So we get the following expression (Thomas, 2003):

$$P(\mathrm{mmHg}) = \frac{T(\mathrm{Kgf}).N.4620}{L(\mathrm{cm}).B(\mathrm{cm})} \qquad (7)$$

Where: P - Pressure (mmHg), T - Tension (Kgf), L - The circumference (cm), B - Width (cm),
N - Number of layers applied.

The experimental study techniques pressure's measuring

Method of load transference

The load transference instrumental technique is based on the same type of strain gauge measurement system adopted for the prototype instrument. The load transference test-rig is used in conjunction with a Fabric Thickness Tester (Figure 1). Different loads of increasing magnitude 0 to 900 cN are applied on to surface of padding bandage single layer material and the degree of load transferred through padding bandage structure is measured by the instrument. To calibrate load transference instrument, a range of known loads 0 to 900 cN with 100 cN intervals were applied via the large contact area diameter 10 cm directly on to smaller contact area diameter 1 cm and the corresponding measured loads were recorded. The relationship between known and measured loads provides the calibration line by which load transference of padding bandages is assessed. When a load is applied onto the surface of a padding bandage material the load proportion which is transferred

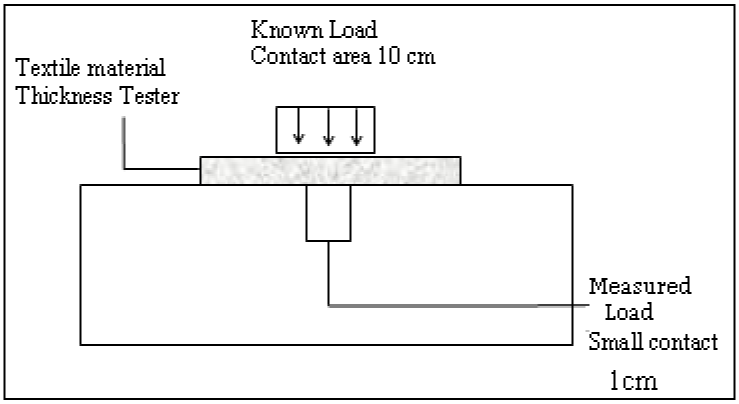

Figure 1. Load transference instrument.

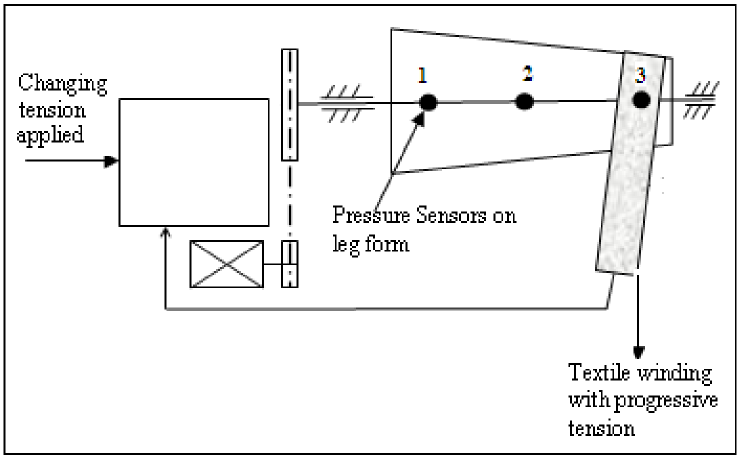

Figure 2. Prototype instrument.

through material is governed by bandage structure. Constant load transference for each increase in applied load signifies that the padding bandage material has ability to absorb high loads throughout its structure.

Using prototype instrument

The prototype instrument (Figure 2) developed in this work consists of using a mannequin leg which has eight strain gauges located inside the leg so that pressure measurements can be made at ankle, calf and positions below knee. The strain gauges are strategically positioned so that pressure measurements can be made at tibia, front and back of leg. Bandage pressure is detected by means of pressure pins which are connected to each strain gauge and protrude from inside of the leg to outer surface. To determine the pressure distribution characteristics of the bandages on the prototype instrument, one end of the bandage was attached to instrument. The prototype instrument was then rotated so that two layers of the bandage were applied. A double layer of the compression bandage, applied at a constant tension of 450 cN was placed over the padding layers and the pressure was recorded by the pressure sensors.

Each bandage was tested five times at each pressure sensor location and the recordings averaged in order to map the pressure around the instrument. Pressure measurements were taken from the application of the compression bandage to the prototype instrument without any padding layers. These pressure measurements serve to assess the pressure distribution characteristics of the padding bandages. Figure 2 illustrated a line diagram of the prototype instrument showing location of the pressure sensors numbered from smallest to largest diameter.

Practical application

Five district and practice nurses attended study days on the management of leg ulcers and were recruited as a convenience sample. The pressure produced by the nurses using each of the three selected bandages on the investigator's leg was measured using sensors and an oscillograph recording. Measurement sites were the lateral aspect of the leg, 40 mm above the center of the lateral malleolus and at the widest point of the leg, along a line joining the lateral malleolus and the tibia tuberoses. Training in compression bandaging was provided using feedback from pressure at the first study day. Nurses were also provided with

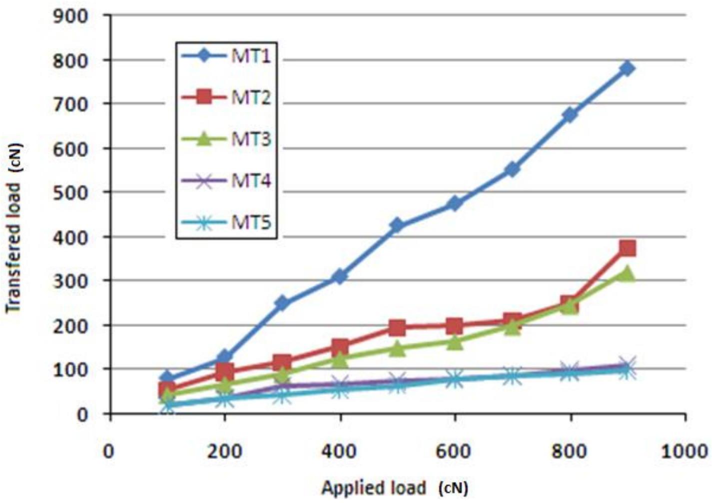

Figure 3. Transmitted load depending the applied load.

Table 2. Measured load depending the applied load.

Applied load (cN) applied	MT1	MT2	Measured load (cN) MT3	MT4	MT5
0	0	0	0	0	0
100	80	54	43	20	20
200	128	95	67	36	34
300	250	115	90	65	42
400	310	150	125	67	56
500	426	195	150	75	64
600	475	200	165	80	78
700	552	210	198	87	86
800	675	250	245	98	92
900	780	375	320	110	98

bandages to practice at home. Post-training bandaging technique was reassessed after two weeks. Immediately after their returning for a second study day, the nurses reapplies all three bandages and the result of sub-bandage pressures were recorded. The same leg, sensor sites and pressure monitor were used as at initial assessment and results are shown in Table 5.

RESULTS AND DISCUSSION

The load transference of all the bandages is shown in Figure 3. The results demonstrate that bandages exhibit different load transference properties and effectiveness of each bandage is determined by its relative position to calibration line. With textile sample MT1, the load transference line is positioned close to calibration line which indicates that the high degree of known load is directly transferred through bandage structure.

Therefore, the composite bandage is unable to dissipate loads throughout its structure and offers little support to application of known load. The MT2 and MT3 bandages sample exhibit similar load transference performances. The initial load transference, in the known load range 0 to 500 cN, is relatively low (Table 2). Throughout this range, both bandages have demonstrated their ability to support and distribute load since the degree of load transferred through the structure is minimal. At load range 500 to 900 cN, it can be seen that load transference bandage changes. The degree of load which is transferred through the bandage structure increases indicating that ability to support and distribute load rapidly, diminishes as the known load is increased. With the MT4 and MT5 bandages, the load transferred through the bandage structure remains constant throughout the load range 0 to 900 cN. Therefore, both bandages are able to absorb high loads and dissipate the load through their entire structure while load transferred through is minimal. The pressure distribution characteristics of the bandages obtained using the

Table 3. Pressure Distribution using prototype instrument.

Textile pressure using pressure sensor (mmHg)	**Ankle**	**Leg area**	**Below knee**
		Calf	
Theoretical	52.4	30.2	32.6
Compression MT1	60.9	24.6	49.2
Compression MT2	49.0	33.6	42.6
Compression MT3	62.3	33.2	42.8
Compression MT4	53.2	32.4	34.6
Compression MT5	48.1	25.2	37.8

Table 4. Calculation results on five different humans subjects using MT5.

Human subject (S)	**1**			**2**			**3**			**4**			**5**		
Z	Z1	Z2	Z3	Z1	Z2	Z3	Z1	Z2	Z3	Z1	Z2	Z3	Z1	Z2	Z3
Cm (cm)	31.7	29.3	26.5	33.5	31.1	27.6	31.4	26.1	23.2	31.0	27.1	24.1	33.0	31.8	28.2
Pm (mm Hg)	21.4	21.3	20.5	21.2	20.5	18.6	19.6	23.2	19.4	18.9	20.2	21.3	20.8	21.5	19.5

Cm - Circumference of each measuring location on the low limb (cm), Pm - pressure calculated (mm Hg), S - Human subject: Z1 (Ankle), Z2 (Calf), Z3 (Below knee).

prototype instrument is shown in Table 3. The theoretical pressures calculated from the leg circumference at ankle, calf, and below knee positions are lower than pressures exerted by the compression bandage when no padding layer was used. High compression bandage pressures are exerted on the tibia. We note importance of prototype instrument, sensors 1 and 3 which results in an uneven pressure distribution at the ankle and below knee positions. However, around circumference of the calf an even pressure distribution maintained since the tibia at this position, is less pronounced and therefore, pressure exerted by the compression bandage is low. The bandages do not produce uniform pressure distributions around circumferences of the ankle, calf, and below knee positions of the prototype instrument.

The results show that the MT5 bandage performs better and its application both is reducing the tibia pressures and provides even pressure distributions around circumferences of the ankle, calf, and knee. From Table 4, we observed the results of calculations to five real pressures on the MT5 elastic band.

If we compare these results with the experiment results on the prototype, we observe that there is some difference, amounting to approximately 60% at the ankle, 5% at the calf and 38% above the knee. The main problem with bandaging technique is production of a reverse pressure gradient and ankle pressures are being too high or too low in 20% of bandages. Thus pressure gradient and ankle pressure will be the dependent variables in the impact analysis of training on bandaging. Pressures obtained according to the bandages applied by nurses are shown in Table 5.

The pressures generated by compression bandage must be equal any points in the leg around a given circumference. The application of padding bandages should provide an even pressure distribution by reducing high pressures exerted on tibia and fibula prominences. The results obtained demonstrate that excessive pressures are not significantly reduced by the bandages investigated in this study. The relationships which exist between large and small curvatures radius of leg are directly responsible for these non-uniform pressure distributions. High pressures are generated over a relatively small radius of curvature.

The instrumental test procedures used in study confirm that bandages have different pressure distribution characteristics. The results show that MT5 bandage is the most performance and this can be attributed to its ability to absorb as well as dissipate high compression bandage pressures. This ability is largely determined by the bandage structure governed by arrangement and interaction of the constituent fibers. The MT5 bandage has a better load transference due to its complex structure which consists of a large number of fibers which are formed during weaving. The fibers are positioned perpendicular to the bandage plane within the structure and support loads which are applied onto the bandage surface.

Resistance and support to the applied load is provided by a combination of both number of fiber contained within structure and relative stiffness of each fiber. The overall fiber system of the MT5 bandage is able to provide support to any load within the range to 0-900 cN. A small proportion of applied load is directly transferred through while the remainder is dissipated throughout the bandage structure. This unique property contributes to superior pressure distribution characteristic of this bandage. The MT4 bandage has a similar load transference performance to the MT5 bandage but has inferior pressure distribution characteristic. This can be attributed

Table 5. Practical Pressures obtained.

Bandage	**Ankle *Theoretical pressure* (mmHg)**	**Ankle *Practical pressure* (mmHg)**	**Below knee *Theoretical pressure* (mmHg)**	**Below knee *Practical pressure* (mmHg)**
MT1	60.9	24.02	49.2	25.19
MT2	49.0	29.04	42.6	25.02
MT3	62.3	29.02	42.8	24.95

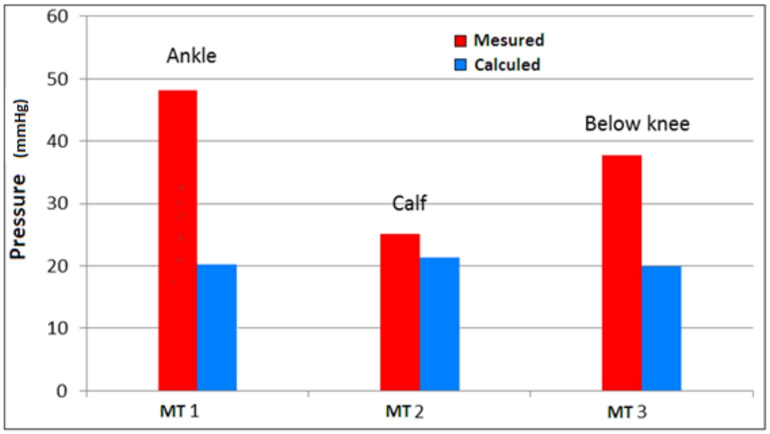

Figure 4. Pressure measured and calculated.

to its high flexural rigidity which makes it less conformable than fiber-based bandages and is more likely to crease when applied around the limb. Following the result, high compression bandage pressures are generated over areas that have become large. The MT2 and MT3 bandages are able to dissipate low loads throughout their structures.

However, this ability decreases quickly when applied load is increased 500 to 900 cN. A greater proportion load is transferred through the padding bandage. Therefore, the high compression bandage pressures which are generated over a small radius of curvature are not absorbed by the bandages. The band structure MT1 is a little less complex and consists of loose fibers found primarily on horizontal plane of bandage. The application of loads to padding bandage surface culminates in the displacement of the fibers relative to one another. The increase in the load resulting from the large number of fibers displaced which reducing the degree support and a higher proportion of applied load is transferred through while the load dissipated is minimal. The fibers contained within the MT1 bandage form a segregated structure in which individual fibers are not combined to enhance the bandage properties. Resistance and support to applied loads is not provided by this segregated structure since the fibers have no direct inter relationship relative to one another and leads to poor pressure distribution characteristic.

The load transference bandage can be used to determine its pressure distribution characteristics. The bandages having high load transference, as the MT1 bandage, are unable to absorb high compression bandage pressures and produce uniform pressure distributions. In practical the pressures of ankle were lower than calf pressures ($p<0.05$) for three bandages, the gradient is greater than 1.0 (Figure 4). The change in the pressure gradient was achieved by decreasing the calf pressure rather than increasing the ankle pressure. The ankle pressure remained marginally low throughout the study to around 25 to 30 mmHg compared to recommended value 40 mmHg.

Conclusions

None of bandages investigated in this work provides uniform pressure distributions around the limb. The structure of bandage is regarded as important factor to producing uniform pressure distribution. The load transference test procedure has shown that each bandage has completely different load transference. The results confirm that bandage structure has greatly influences overall pressure distribution characteristics. Bandages having good load transference performance are able to absorb and dissipate loads throughout their structure.

The optimum bandage MT5 developed in this study has better performance of load transference than the fiber bandage. These results give a superior pressure distribution characteristic. A limited number of field trials have also been carried out for comparative performance of newly developed bandage MT5 and a commercially available product. Trials have confirmed that the MT5 bandage possesses superior pressure distribution characteristics when applied around lower limb. The results also indicate that this new bandage structure enables reduction of pressure experienced by the patient on certain parts of the leg and also assists to achieving more uniform pressure distributions. The nurses perform extremely poorly initially and their technique improved after training. There is no statistically significant difference between numbers of nurses applying the strips correctly.

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Conflict of Interests

The author(s) have not declared any conflict of interests.

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