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Title: Impact of moisture on the pressure delivering potential of pressure garments

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Impact of moisture on the pressure delivering potential of pressure garments

Abstract

- (1) Objective: To measure the impact of moisture content on fabric tension and thus pressure delivering potential of pressure garments.
- (2) Methods: Four different fabrics currently used in the construction of pressure garments were evaluated in 7 different states of 'wetness' from completely dry to completely saturated in water or artificial perspiration. Standard laboratory methods were used to measure the initial tension in fabrics and the tension after 11 cycles of extension. Pressures that would be exerted by these fabrics were calculated using the Laplace Law.
- (3) Results: Our results showed that the tension, and therefore pressure delivering ability, of fabrics used in pressure garments was significantly reduced when they were wet but that the amount or type of 'wetness' did not have a significant impact on pressure delivering ability.
- (4) Conclusions: The pressure exerted by pressure garments is believed to be critical to treatment success and can be predicted based on laboratory measurement of the fabric's tension profile. All previous measurement of pressure garments/fabrics has been undertaken using dry fabrics in either laboratory or clinical conditions. However, many patients have complained of increased perspiration when wearing pressure garments and many burn victims live and work in hot conditions where high levels of perspiration may be expected. This study showed that the pressure delivering potential of fabrics is significantly reduced when wet. Thus pressure garments that are expected to be wet when worn should be constructed based on tension measurements taken from the testing of wet fabrics.

Key words: Pressure garment; perspiration; tension; pressure; wet.

Introduction

In 2004 almost 11 million people required medical attention for their burn injury and each year an estimated 265 000 people die as the result of severe burn injury [1]. Between 32 and 67% of the surviving millions of burn injured people will develop hypertrophic scars following severe burn injury and some will develop contractures leading to loss of function [2]. Burns are significantly more prevalent in low- and middle-income countries (1.3 per 100,000 of population) than they are in high-income countries (0.14 per 100,000 of population) [1,3], with the highest incidence of burns in southeast Asia and Africa [4]. In Bangladesh alone, some 31,000 children are left with a permanent disability following burn injury each year and in rural Nepal burns account for 5% of all disabilities [1].

Pressure garments have been the main method of treating hypertrophic burn scars since the early 1970s [5-15]. There is a general consensus that pressure garments should be used to prevent and treat hypertrophic scars but very few clinical trials of pressure garments have been undertaken and the evidence for their effectiveness is limited [15-17]. The limited evidence for the effectiveness of pressure garments may be related to the variation in pressures currently exerted by pressure garments and the difficulties in measuring pressure quickly and accurately in a clinical environment. Pressure garments are believed by many to hasten scar maturation [2,8,15,18-19], improve the appearance of scars [6,15,18,20-23] and control the itchiness and pain associated with scars [23-29]. In addition to this, wearing pressure garments until the hypertrophic scar has matured, and stopped being active and contractile in nature, provides an effective prophylactic treatment for contractures [15,18,19,24,26,27,29-35] maintaining joint mobility [6,25,33,36] and helping to prevent disability.

There are many types of pressure garment [37,38] but all follow similar principles of construction, in that they are all made from elastic fabrics and are designed to exert pressure on the underlying tissues by virtue of the fact that they are made smaller than the body they are designed to fit [37, 38]. It is widely acknowledged that made to measure pressure garments are the most effective form

of therapy [18] for many reasons [37], not least of which is the ability to ensure good 'fit' [28,38,39] and deliver a specific pressure or range of pressures to the scars [40,41]. Although, the ideal pressure for scar treatment has never been scientifically established [5,13,16,42-45] most clinicians agree that the pressure delivered has a significant impact on treatment success and side effects [5,15,28,37,44,46]. There remains much debate on the ideal pressure for scar treatment but the 2 main theories are:

- a) That pressure should exceed capillary pressure (25mmHg) for effective treatment [5,7,8,19,24,29,30,47-49]
- b) Pressures between about 15 and 24mmHg [5,8,12,15,24,42,50] are effective.

Most commercial suppliers of pressure garments produce garments that deliver a particular target pressure or pressure gradient on delivery [15,18,36,37,51,52]. They often target 25mmHg at the scar site in established scars and use lower pressures for children or any patient's first set of pressure garments, when their scars are most fragile. Some commercial suppliers have long used CAD systems, or paper based equivalents, based on test data from their fabrics and the application of the Laplace Law, to calculate the size of pressure garment that will exert particular pressures on their patients. This method of pressure garment design and construction has previously been published in Burns [40,41] and a method for delivering graduated compression is also now available [53]. It has previously been established that the pressure exerted by pressure garments reduces over time and use [5,15,54] and that washing pressure garments helps the garment to regain its pressure delivering potential [54]. It is also known that if the pressure garment makes contact with moisturisers or oils, used in scar management, the pressure that the garment exerts is further reduced [54].

It has been previously acknowledged that there are several issues with pressure garments, some of which affect treatment efficacy directly and others affect patient compliance with treatment [2,16,37]. Among these, discomfort from heat and perspiration has been noted [2,14,26,39,48,55]

particularly in hot and humid conditions [16,39]. In one German study 80% of patients complained of increased 'sweating' when wearing pressure garments [2]. However, the impact of perspiration on the pressure delivered by pressure garments has never been measured. Since the incidence of serious burn injury is highest in Southeast Asia and Africa [4] with over 1 million people seeking medical attention annually for moderate or severe burns in India alone [1], one would expect wearers of pressure garments in these countries to be hot and perspiring much of the time. Therefore, we sought to establish whether the pressure exerted by pressure garments is affected by moisture content.

Method

Four fabrics commonly used for pressure garment construction were selected for evaluation: a warp knitted sleeknit made from nylon and elastane, a weft knitted tubigrip made from cotton with nylon covered elastodiene and 2 different powernet fabrics both made from nylon and elastane, which will be referred to as powernet 1 and powernet 2.

Each fabric was tested under 7 sets of conditions:

1. Oven dry
2. Standard atmospheric conditions (20 ± 2 °C and $65 \pm 5\%$ Relative Humidity)
3. Partially saturated (approximately 33%) with water
4. Partially saturated (approximately 67%) with water
5. Fully saturated with water
6. Fully saturated with acidic artificial perspiration
7. Fully saturated with alkaline artificial perspiration

7 sets of 5 test specimens were cut from each fabric in the main direction of stretch, which would be the circumferential direction of the fabric when constructed into pressure garments. All specimens were cut from fabrics that had been conditioned in a laboratory maintained at 20 ± 2 °C and $65 \pm 5\%$ Relative Humidity. Specimens had a gauge length of 100mm and were 50mm wide, cut parallel to the elastic yarns in the fabric, ensuring that none of the elastic yarns in the structure were damaged. Therefore, the 3 warp knitted fabrics (sleeknit and both powernets) were longer in the warp direction than weft, while the weft knitted (tubigrip) fabric was longer in the weft direction. Specimens were then prepared for testing:

- All the specimens for testing in oven-dry or saturated states were weighed accurately under standard atmospheric conditions. They were subsequently placed in soapy water (23.39g of synperonic BD100 surfactant per litre of water) for 10 seconds and then thoroughly rinsed in cold water. This process was repeated and then the excess water was removed using a padding mangle.
- Oven-dry specimens were dried in a laboratory oven at 60°C until a constant weight was obtained (3 consecutive identical weights to the nearest milligram). Oven-dry specimens were transported to the conditioned laboratory in a desiccator and were tested immediately on removal from the desiccator.
- ‘Standard atmospheric conditions’ specimens were tested following cutting. All standard laboratory measurements of textiles should be made under these conditions, so these specimens could be considered ‘normal’.
- ‘Partially saturated’ specimens were taken to the conditioned laboratory and allowed to dry to their target weight*. Once they reached their target weight they were stored in plastic bags until they could be tested.
- ‘Fully saturated’ test specimens were sealed in plastic bags immediately after they had been mangled to retain their full moisture content. Each specimen was individually removed from its plastic bag in the laboratory, weighed and then immediately tested.

- ‘Fully perspiration saturated’ specimens were soaked in artificial perspiration solution (acid perspiration solution 2 or alkali perspiration solution, freshly prepared in accordance with ISO 105-E104) for 30 minutes to allow the solution to fully penetrate the specimens. Excess solution was removed using the padding mangle and specimens were immediately placed in plastic bags to prevent drying. Each specimen was individually removed from its plastic bag in the laboratory, weighed and then immediately tested.

* The target weight of each ‘partially saturated’ test specimen was calculated by: first calculating the weight of liquid water in each ‘fully saturated’ test specimen (weight after fully saturating minus the conditioned weight of the same specimen) as a percentage of the specimen’s conditioned weight. The target weight of the first set of ‘partially saturated’ test specimens was set as the conditioned weight of the specimen plus 1/3rd of the increase in weight attributed to the wetting of the ‘fully saturated’ test specimens. The target weight of the second set of ‘partially saturated’ test specimens was set as the conditioned weight of the specimen plus 2/3rd of the increase in weight attributed to the wetting of the ‘fully saturated’ test specimens.

Specimens were tested on an Instron 3345 tensile testing machine. Each specimen was extended 11 times at a rate of 180 mm/min from 0 to 100% extension, specimen extension and load in Newtons were recorded. The fabric tension (T) was calculated in Nm^{-1} at 24% extension, on each of the 11 extension cycles, and from this the pressure that would be exerted on a small limb circumference of 14cm was calculated using the modified version of the Laplace Law: Pressure in mmHg = $(4.713 \times T) \div \text{circumference in cm}$ [38].

Test rationale:

- 24% fabric extension was selected as fabrics are commonly extended by this amount in pressure garment construction (relationships between moisture content and fabric tension were similar at all extensions used to make pressure garments for patients).

- The limb circumference of 14cm was selected to demonstrate the impact of moisture content on pressure. According to the Laplace Law, pressures are most dramatically affected by changes in fabric tension at small circumferences [36,38]. However, although the numerical difference in pressure varies with limb circumference, the statistical significance of the trends discussed would be the same on all body circumferences. This is because the statistical significance was derived from the measured tension in the fabrics (which would be consistent regardless of body circumference).
- 11 'cycles' of extension from 0 to 100% were used in order to artificially accelerate the loss of tension that would normally occur in pressure garments over a period of wear whilst maintaining the stated moisture content as closely as possible.
- It is not particularly useful to know the pressure delivering potential of an oven-dry fabric since fabrics and garments are rarely, if ever, used in this state but the measurement was made in order to better understand the difference between the standard samples, tested under normal atmospheric conditions and containing atmospheric moisture, and those tested when wet. The oven-dry samples quickly absorbed moisture from the atmosphere and thus quickly reduced their pressure delivering potential during testing.

Fabric tension and moisture content, by weight, were correlated using Minitab 17 software to establish whether moisture content had a significant impact on fabric tension. Correlations were calculated for fabric tension and moisture content broken down into the following data sets: all 7 data sets and the 5 data sets where specimens contained no moisture (oven dry), water vapour or liquid water only (i.e. artificial perspiration samples excluded). The 95% confidence intervals (mean \pm 2 standard errors) of each set of fabric tension data were calculated so that it could be determined whether individual fabric tensions were significantly affected by moisture content.

Results and discussion

Part 1 – impact of moisture content on initial pressure

Figure 1 shows the mean pressure that would be exerted on a 14cm circumference limb by pressure garments that were oven dry (0% moisture), containing atmospheric moisture after conditioning in standard atmospheric conditions (between 2 and 6.5% moisture vapour) and 3 levels of saturation in water (between 21.2 and 153.9% water). Note that the data points in Figure 1 are not aligned due to each fabric having a different level of absorption. Figure 1, and the statistical calculations undertaken, shows that:

- Each elastic fabric exerted its highest pressures when completely dry.
- Each fabric exerted, between 9.6 and 15.2%, less pressure when it contained atmospheric moisture and this difference was statistically significant at 95% confidence level.
- The pressure exerted by fabrics containing liquid water was significantly lower (at 95% confidence level) than those containing only atmospheric moisture. The average difference in pressure between wet samples (containing any amount of liquid water) and those tested under standard atmospheric conditions ranged from 12.6% less pressure in wet sleeknit samples to 42.8% less pressure in wet samples of powernet 2.
- However, there was no significant difference in the pressures that could be delivered by fabrics that contained different amounts of liquid water. Therefore, although fabric saturation (or wetness) decreased the pressure delivering potential of pressure garment fabrics it did not appear to be a progressive condition.
- Powernets 1 and 2 absorbed significantly less water than either sleeknit or tubigrip fabrics but powernet 2, particularly, was significantly more affected by the liquid it had absorbed.

- As with previous studies [36,38], Figure 1 shows that, different fabrics used in the construction of pressure garments have different tensions and pressure delivering abilities.

Figure 1 shows that each fabric has different pressure delivering potential when dry and that the pressure delivering potential of different fabrics is reduced by different amounts when wet. So if the same reduction factors were used in pressure garment construction different pressures would be exerted by different fabrics [36,39]. Therefore, it is important to test each fabric and design pressure garments based on the tension profile of the fabric [38,39]. The biggest differences in pressure exerted will be noticed on smaller limbs as previously discussed [36,38,39].

This series of experiments clearly demonstrated that sample, or pressure garment, wetting would reduce the pressure it was capable of exerting. However, in practice the source of wetting would typically be human perspiration. Therefore, the experiment was repeated by wetting a set of samples in artificial perspiration (1 set of samples was saturated in acidic 'perspiration' and a second set was saturated in alkali 'perspiration'). Figure 2 shows that the tensions measured, and thus the pressures that would be exerted, in samples saturated in artificial perspiration were similar (not

Table 1 shows that powernet 1, sleeknit and Tubigrip specimens delivered broadly similar %reduction in Tension across different states of 'wetness' and therefore the higher the fabric's tension (when measured normally, under standard atmospheric conditions) the greater the tension lost tended to be. However, powernet 2 lost more than twice as much of its tension in percentage terms than any other fabric. This is further evidence, if any was needed, that one cannot tell how a fabric will perform based on its appearance or even basic test data.

This finding should be explored further and could be taken into account in certain conditions. If the pressure garment is expected to be wet during the majority of the wearing time the fabric

measurements, upon which garment dimensions were based, could be made on wet samples. As Figures 1 and 2 show, the difference between pressures exerted by wet and dry samples varied from fabric to fabric and therefore it would be necessary to know the behaviour of each fabric before designing and constructing pressure garments from it. Therefore, to ensure consistent pressures are delivered to all patients, it would be possible to build pressure garment design tools [39,51] based on the measurement of wet fabrics for hospitals or companies supplying pressure garments to patients living and/or working in hot/humid conditions.

Part 2 – impact of moisture content on fabric's ability to maintain pressure

Figures 3 to 6 show that none of the samples were able to maintain the initial tension at 24% extension for 11 cycles. As previously reported the tension normally declines most rapidly between the first and second extension cycle and thereafter a more gradual decline in tension/pressure is observed [52]. In this case the tension at the first extension in all warp knitted samples (powernets and sleeknit) was significantly higher (at 24% extension) than the tension at the second extension, as Figures 3, 4 and 5 indicate. The decline in tension between cycles 2 and 11 of these fabrics was only statistically significant in 7 out of the 21 sets of warp knitted test specimens and was not consistent in terms of the amount or source of moisture content.

All tubigrip specimens had significantly less tension after 11 extension cycles compared to their first, but the loss of tension between the first and second extension was only statistically significant for the specimens tested under standard atmospheric conditions. Further, the decline in tension between the 2nd and 11th extension was only statistically significant in 3 of the 7 sets of tubigrip specimens (including the set tested under standard atmospheric conditions). As Figure 6 shows the tubigrip specimens behaved less consistently than the warp knitted specimens. This difference

might be expected since they have very different construction in terms of knit, fibre content and resultant 'power'.

Although there was a statistically significant relationship between increased moisture content of fabrics and their (decreased) tension at the first extension, this was not always the case for the tension at either 2nd or 11th extension. There were no consistent or statistically significant relationships between the moisture content of the fabrics and the % tension lost between the 1st and 11th extension (or indeed between the tensions at any other pair of extensions). It is thought possible that the slight drying of the wet specimens during the test may have resulted in a slight increase in tension compared to what might have been measured had they maintained identical moisture content throughout the duration of test. Also, the oven-dry specimens began absorbing moisture from the atmosphere as soon as they were exposed to it and this may have decreased their tension further as the test progressed. The impact of moisture content on pressure garments' ability to maintain tension, and thus pressure, should be investigated further.

Conclusions

- Elastic fabrics for pressure garment construction will deliver significantly higher pressures when they are dry than when they are wet.
- If fabrics are likely to be wet during wear then this should be taken into account during the design of the pressure garment.
- Water and (artificial) perspiration affect fabric tension in similar ways and the amount of fabric wetting does not appear to be important.
- The impact of moisture content affects different fabrics, for pressure garment use, to different extents. Therefore, before making pressure garments that may be wet during use,

each fabric should be tested in both wet and dry states to enable clinicians to determine the most appropriate pressure for treatment.

- The impact of perspiration on long term pressure delivery is not known, but given the significant impact of 'wetness' on the tension/extension property of elastic fabrics measured here, it seems worthy of further investigation.

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Figure legends:

Figure 1 – Impact of moisture content (atmospheric/water) on pressure delivering capacity of pressure garment fabrics

Figure 2 – impact of water and artificial perspiration on mean initial pressure that would be exerted on a 14cm circumference limb

Figure 3 – Tension at 24% extension in wet and dry specimens of powernet 1 during cyclic testing

Figures 4, 5 and 6 - tension at 24% extension in wet and dry specimens of powernet 2 (left), sleeknit (middle) and tubigrip (right) specimens during cyclic testing

Table 1 – Tension difference between ‘dry’ specimens (containing atmospheric moisture) and ‘wet’ specimens on first extension

fabric	Tension N/m (standard atmospheric conditions)	reduction in fabric Tension when specimens were wet:									
		33% water		67% water		100% water		acid persp.		alkali persp.	
		N/m	%	N/m	%	N/m	%	N/m	%	N/m	%
powernet 1	163.7	26.2		24.5		28.0		24.0		17.4	
			16.0		15.0		17.1		14.7		10.6
powernet 2	102.4	45.1		43.7		40.2		44.2		45.8	
			44.0		42.7		39.3		43.1		44.7
sleeknit	63.0	9.1		6.6		8.4		8.2		7.3	
			14.4		10.5		13.3		13.0		11.6
tubigrip	25.8	3.8		4.2		3.3		3.7		2.3	
			14.6		16.2		12.5		14.5		8.9