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Factors influencing the effectiveness of compression garments used in sports

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Abstract

This research seeks to investigate the effects of physical attributes of suitable knitted fabrics on the amount of pressure generated on the underlying body. We aim to predict the magnitude of pressure applied to a cylindrical body of known radius by generating specific amounts of tension to an external fabric cover. The paper first addresses the tensile properties of knitted fabric samples with different orientations to stretch, predictive pressure generated by compression garments and then discusses a method of validating the reliability of Laplace law for calculating applied pressures that are generated by compression garments.

Keywords: Compression garments; Knitted fabrics; Laplace law; Pressure mapping; Directional orientation of fabrics to stretch;

Introduction

Athletes have experimented for years with compression garments in sports both as an ergogenic, performance enhancement and recovery aid. The majority of commercial branded garments currently available for sport applications are claimed to provide the wearer with enhanced blood flow, better muscle oxygenation, reduced fatigue, faster recovery, reduced muscle oscillation and reduced muscle injury. Some research has been undertaken to identify performance effects and the related physiological mechanisms [1,2,3] relevant to these types of garments, however there is no available research we are aware of that quantifies pressure produced by these garments and the interactions between the garment and the underlying body of an athlete. Lawrence and Kakkar [4] concluded that an optimal pressure gradient of 18mmHg at the ankle, 14 mmHg at the calf, 8 mmHg at the knee, 10 mmHg at the lower thigh and 8 mmHg at the upper thigh would generate the fastest venous flow. The graduated pressures generated by commercial branded sport garments ranges from19.0-30.0 mmHg at the ankle to 17.6-25.0 mmHg at the calf and to 9.1-18.0 mmHg at the thigh [5,6], but these claims are not substantiated by any research.

The degree of pressure produced by a compression garment is determined by a complex interrelation between the following principle factors: the construction and fit of the garment; structure and physical properties of its

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materials; the size and shape of the part of the body to which it is applied; and the nature of the sporting activity undertaken. Existing research in the area of the use of compression garments for treatment of the hypertrophic scars indicates that application of the Laplace law formula is a suitable method to predict the magnitude of the pressure that can be applied to a cylindrical body of known radius by applying specific amounts of tension to an external fabric covering [7].

1. Use of the Laplace equation for compression prediction

The Laplace equation used to predict the fabric pressure is derived from the formula that defines the relationship between the pressure gradient across a closed elastic membrane or liquid film sphere and the tension in the membrane or film [8,9,10]:

$$P_\alpha - P_\beta = 2\gamma/r \,, \qquad (1)$$

where P_α and P_β are respectively the internal and external pressures at the surface, r the radius of curvature and γ is the tension in the film. The equation indicates that the pressure inside a spherical surface is always greater than the pressure outside, but that the difference decreases to zero as the radius becomes infinite (when the surface is flat). When calculating the pressure in the wall of a cylinder, a modified formula is required:

$$P = T/r \,, \qquad (2)$$

where P *(Pa)* is the pressure, T *(N/m)* is the tension in the cylinder wall, r*(m)* is the radius of the cylinder .

Thus the interface pressure induced by a compression garment is directly proportional to the fabric tension per unit width, and inversely proportional to the radius of curvature at the point under investigation. It is obvious that a normal athlete's limb has a surface of complex curvature. If the stretch fabric was considered to be a homogeneous material, when it is applied around a circumference of varying radius of curvature, varying degrees of pressure would be achieved. If a required pressure profile has to be achieved over the athlete's leg, for example, it is clear that the properties and behavior of the stretch fabrics in the garment generating the pressure has to be understood.

In this research the following assumptions were made: the relationship between the pressure P generated by the compression garment, circumferential tension force in the fabric T and the limb circumference C *(m)* is described by the Laplace formula *(2)*; the circumferences of the limb C are accepted as circles; the longitudinal stretch of the fabrics in the garment is not considered; and value of predictive pressure only applies at the time of application.

Taking into consideration that in physiological and medical practices the pressure is measured in *mmHg* The Laplace formula was modified further:

$$P' = 2\pi T * 133.3/C \,, \text{ where } P' \text{ is the predictive pressure in } mmHg. \qquad (3)$$

The ratio of the tensile force T to circumference C for a given fabric represents a quantitative measure of the relevant structural properties of that particular fabric. A high T/C ratio represents a tight fitting fabric, and a low ratio represents a looser fitting fabric. By the modified Laplace law, we would expect fabrics with a higher T/C ratio to produce greater pressure. This single quantitative measure may provide an approximation of many fabric properties that are relevant in the design of compression and general sport garments, and may provide insight for the development of a predictive model for the behavior of garments under tension. It is important to note however, that due to the nonlinear dynamics of stretching and deformation in fabrics and garments, the ratio T/C may not be constant over a whole garment over time. However, in any particular region of interest, measurement of T/C may provide a useful tool for garment design.

2. Experimental

Three commercial knitted fabrics suitable for sport compression garments applications were chosen.

Furthermore, two commercially available branded lower body compression garments (*SK* and *XS)* were selected for the research. Construction, physical parameters, performance attributes and tensile characteristics of the commercial fabrics and fabrics comprising the compression garments were analysed and compared. Two human models (*C* - fit and *V* – athletic) with different body measurements were selected according to their weight and height to suit the medium size of the commercial garments as recommended by the manufacturer. Using the modified Laplace formula *(3)*, the predictive pressure generated by the garments and sample fabrics in different points of the lower limbs were calculated and compared for different body types.

2.1. Materials

Six knitted fabrics were used for the study: 3 warp- and 3 weft-knitted constructions with the following parameters (Table 1):

Table 1. Physical parameters of fabric samples

Fabric	Fabric Construction	Course Density per cm	Wale Density per cm	Fabric thickness (mm)	Mass per unit area (g/m^2)	Fiber Composition (%)
A	Warp knit - Tricot	47	35	0.7	195	Elastane 15/Nylon 85
B	Weft knit- Single Jersey	29	22	0.6	221	Elastane 6/Polyester 94
C	Warp knit - Tricot	32	23	0.6	233	Elastane 20/Nylon 80
D	Weft knit – Single Jersey (garment *XS*)	52	23	0.5	244	Elastane 20/Nylon 80
E	Weft knit – Single Jersey (garment *XS*)	48	25	0.5	260	Elastane 27/ Nylon 73
F	Warp knit – Tricot (garment *SK*)	48	29	0.6	201	Elastane 22/Nylon microfiber 78

2.2. Methods

The models were measured to the developed protocol (Fig.1 a, Table 2).

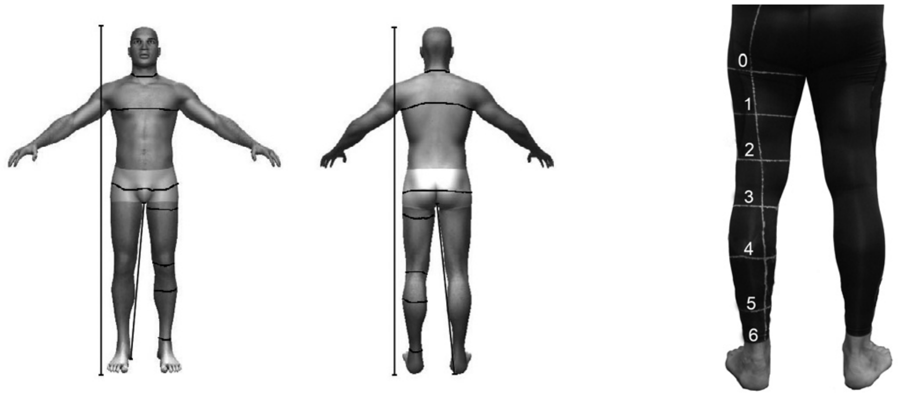
Each garment was divided into six horizontal sections and each section was measured at their circumference while garments were worn by models (Fig.1 b) and also when not worn. The measurements were then converted into percentage extension from relaxed to the worn garment. Fabric samples were tested for the extension at specified force according to British Standard 4952:1992, both in warp (length-wise) and weft (width-wise) directions with 5 specimens in each direction and the mean values were calculated (Fig.2 a). During the first cycle (Fig.2 a) the fabric specimen was extended with the load increasing from 2N preload (point 1), to up to 20N. The extension stopped at point 2, the load was released and the sample returned to 0% extension (point 2 to 3), then immediately the specimen was extended in the second cycle (point 3 to 4), where extension at specified force was recorded (point 4).

As clearly seen from the Fig.1 b, orientation of the fabric comprising the garment deviates when it is worn: warp from strictly vertical and weft from horizontal; thus the extension at the specified force will be different to that measured in the same fabric in warp and weft direction.

The fabric samples were also tested for the extension at specified force in the 10 degrees intervals between warp and weft direction (Fig.2 b) with the test results used to calculate the predictive pressure generated by the garment with the different fabric orientation.

3. Results

Based on calculated extension of the garment *XS* when worn by models *C* and *V* at its different sections (Fig. 3 a) and on the force under which the fabric was extended when garment is worn, the predictive pressure *P'* was calculated (Fig.3 b; 4 a, b).

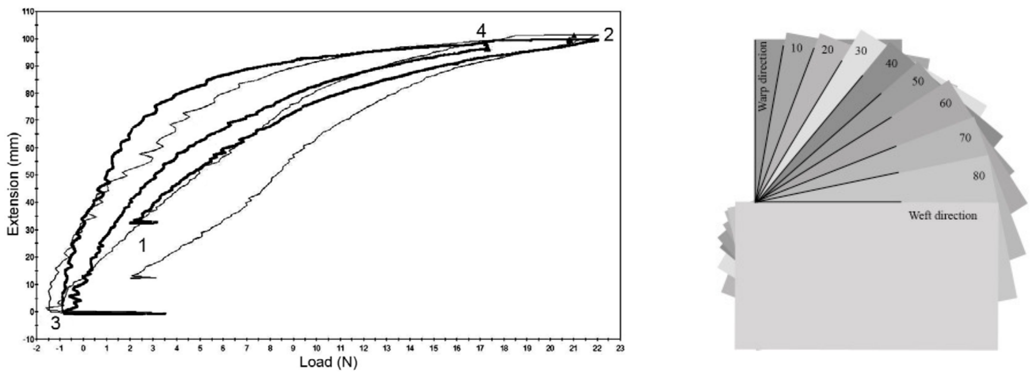


(a) (b)

Fig.1. (a) Points of model body measurements, front and back; (b) Compression garment *XS* worn by model C with garment sections 0-6

Table 2. Lower body measurements for models *V* and *C*.

Model	Waist (cm)	Hips (cm)	Outside leg (cm)	Inseam (cm)	Thigh (cm)	Knee (cm)	Calf (cm)	Ankle (cm)	Height (cm)	Weight (kg)
V	90	95	104	81	64.5	38	41	23	175	87
C	100	109	112	80	58	39	41	25.5	178	89



(a) (b)

Fig.2. (a) Determination of extension at specified force, sample *C*: grey – weft direction, black – warp direction; (b) specimen from sample *C* in 10 degrees intervals between weft and warp direction

3.1. Predictive pressure generated by garments and different fabrics.

Taking into consideration the differences in body measurements of the models used (Table 2) it is clear from Fig.3a that the garment extension when worn and fabric strain at different sections differ from each other, the biggest differences being at the ankle and thigh. The highest garment extension and thus fabric strain is at the calf section and is up to about 100% more that those at other sections. This is due to the construction and fit of the garment.

From Fig.3b we observe that the greatest variation in predictive pressure *P'* due to angle occurs at section 6, corresponding to the ankle. This suggests that orientation and hence garment construction as well as fabric structure is a determinant in the pressure being applied by a garment at the section with small circumference. We also observe that for most samples, the greatest pressure occurs where the direction of tension is at 60 degrees to the warp of the fabric. This property is a function of garment construction and fit, but as a garment moves and shifts while it is worn, the angle of applied fabric tension at various sections may also change. Therefore the dynamics of a sport compression garment as it is being worn are also important in the investigation of its performance with respect to the generated pressure.

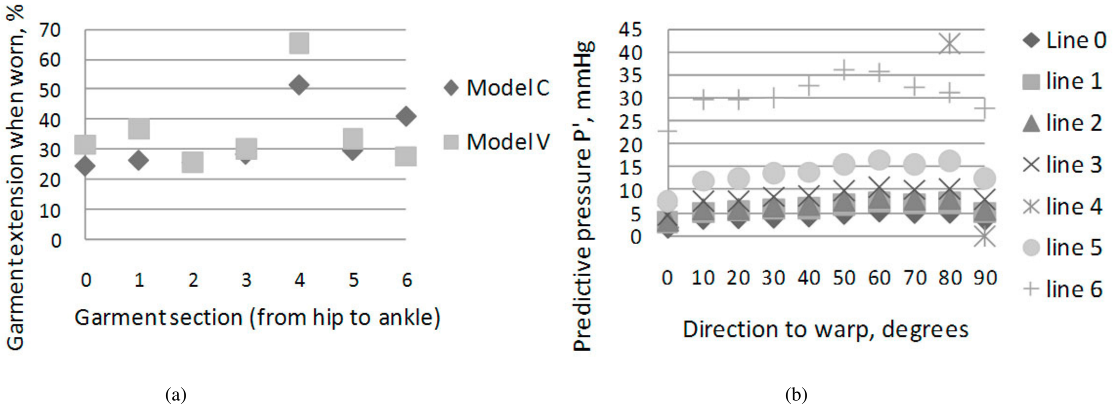


Fig.3. (a) *XS* garment extension when worn by models *C* and *V*; (b) Predictive Pressure *P'* generated by sample *C* under its different orientation at sections 0-6 of the garment *XS* worn by model *C*

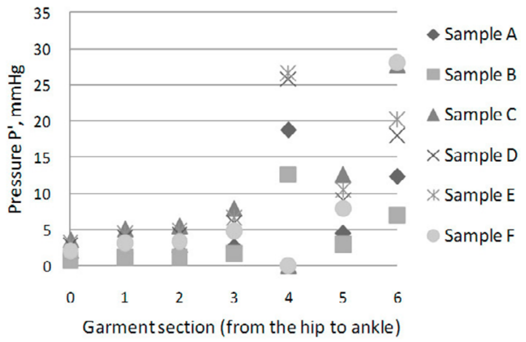
From Fig.4a and b it is clear that increasing graduated compression from thigh to the ankle of the athlete is generally achieved by the sample garment if made of different fabrics and worn by models with different lower body measurements except the calf section. It is important to note that predictive pressure generated at the calf section by all fabrics (excluding only sample F) is substantially higher than at the other sections except for the ankle in both models, and that is substantially higher than necessary to achieve the graduated compression. It is also clear that, in addition, the pressure will rise further as the knee joint will flex during the dynamic movement. Both models commented on the garment being uncomfortable and “too tight at the knee, especially during movement and prolonged wear”. In addition, it is evident from Fig.4 that predictive pressure generated by the garment of the same construction will depend on the tensile properties of the fabric(s) it is made of and could vary within 400%.

3.2. Proposed method of validating the reliability of Laplace law for calculating applied pressures that are generated by compression garments.

The proposed method will utilize the engineered testing rig that should consist of a fixed rigid cylinder (limb) capable of circumference change. The cylinder will be covered with soft material to simulate the human skin with pressure sensors installed on the surface. A fabric covering sleeve whose circumferential diameter is smaller than that of a cylinder would be subjected to tension when stretched over it and, as a result, pressure would be applied to the underlying surface. Thus in using this approach to create tension in the covering sleeve, both tension and the amount of resultant pressure would be dependant upon the elasticity and the orientation of the fabric. Furthermore, the rig may be able to rotate and pivot about its base for use in the wind tunnel enabling the change to the wind-facing profile for the testing of compression garments suitable for high-speed sports.

4. Conclusions and Discussions

The principle of the benefits of the graduated pressure generated by sport compression garments that decreases from the ankle section to the thigh section is relatively well researched and physiologically robust. The ratio of the tensile force T to circumference C in modified Laplace’s formula for a given fabric represents a quantitative measure of the relevant structural properties of that particular fabric. A high *T/C* ratio represents a tight fitting fabric, and a low ratio represents a looser fitting fabric.



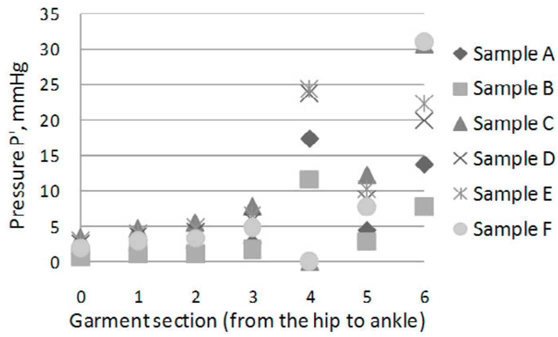


Fig.4. (a) Predictive Pressure *P'* generated by different fabrics in different sections if used in the same garment construction worn by model C; (b) worn by model *V*.

Experimental fabrics with a higher *T/C* ratio produced greater predictive pressure on the underlying athlete's limbs. This single quantitative measure may provide an approximation of many fabric properties that are relevant in the design of compression and general sport garments, and may provide insight for the development of a predictive model for the behavior of garments under tension. It is important to note however, that due to the nonlinear dynamics of stretching and deformation in fabrics and garments, the ratio *T/C* may not be constant over a whole garment over time. However, in any particular region of interest, measurement of *T/C* may provide a useful tool for garment design. The value of predictive pressure only applies at the time of application, as most fabrics will lose a significant amount of their initial tension overtime due to fabric fatigue which will result in a reduction in applied pressure. Garment construction, fabrics used, garment fit and positioning on an athlete's body play a significant role in the amount of predictive pressure generated by the compression garment. An athlete's limb will exhibit a marked difference in radius at various points around its circumference thus the actual pressure values will differ from the calculated predictive values and will not be uniformly distributed.

Further developed methodology for predicting and measuring the pressure generated by compression garments is required. Currently, a comprehensive methodology based on 'state-of-the-art' pressure sensors and pressure mats with associated electronics, data acquisition, and processing software is being jointly developed in the School of Aerospace, Mechanical and Manufacturing Engineering, and the School of Textiles and Fashion, RMIT University. Using this experimental pressure measurement methodology, a complete mapping of pressure due to compression over the full body shape will be achieved.

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