Fibers and Polymers 2005, Vol.6, No.4, 322-331

Effects of Material Properties and Fabric Structure Characteristics of Graduated Compression Stockings (GCS) on the Skin Pressure Distributions

Rong Liu*, Yi-Lin Kwok, Yi Li, Terence-T Lao[1], and Xin Zhang[2]

Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
[1]Department of Obstetrics and Gynaecology, Faculty of Medicine, The University of Hong Kong,
Queen Mary Hospital, Pokfulam Road, Hong Kong
[2]Department of Clothing Art and Design, Xi'an University of Engineering Science and Technology, Xi'an, China

(Received July 26, 2005; Revised October 6, 2005; Accepted October 13, 2005)

Abstract: Graduated compression stockings (GCS) have been widely used for the prophylaxis and treatment of venous diseases. Their gradient pressure function largely related to their fabric structure and material properties. By combing fabric physical testing and wear trials, this study investigated the GCSs fabric structure and material properties at different locations along the stocking hoses, and quantitatively analyzed the effects of fabrics on skin pressure longitudinal and transverse distributions. We concluded that, Structural characteristics and material properties of stocking fabrics were not uniform along the hoses, but a gradual variation from ankle to thigh regions, which significantly influenced the corresponding skin pressure gradient distributions; Tensile (WT, EM) and shearing properties (G) generated most significant differences among ankle, knee and thigh regions along the stocking hose, which significantly influenced the skin pressure lognitudinal gradient distribution. More material indices generating significant gradual changes occurred in the fabric wale direction along stocking hose, meaning that materials properties in wale direction would exert more important impact on the skin pressure gradient performances. And, the greater tensibility and smoother surface of fabric in wale direction would contribute to put stocking on and off, and facilitate wearers' leg extension-flexion movements. The indices of WT and EM of stocking fabrics in series A have strong linear correlations with skin pressure lognitudinal distribution, which largely related to their better performances in gradual changes of material properties. Skin pressure applied by fabric with same material properties produced pronounced differences among four different directions around certain cross-sections of human leg, especially at the ankle region; and, the skin pressure magnitudes at ankle region were more easily influenced by the materials properties, which were considered to be largely related to the anatomic structure of human leg.

Keywords: Material property, Fabric structure, Compression stockings, Skin pressure, Distribution

Introduction

Graduated compression stockings (GCS) have been widely used for the prophylaxis and treatment of varicose veins, deep-vein thrombosis, recurrence of leg ulceration, and the control of lymphoedema. The amount of pressure (i.e., levels) applied depends on severity; while, an appropriate pressure gradient distribution delivered is the most important guarantee to achieve GCS therapeutic effectiveness.

Substantial medical researches [1-4] have demonstrated that graduated compression, which gives maximum compression at the ankle, decreasing as it extends up the legs, produced a significant greater increase in vein blood flow than compression distributed uniformly. Meanwhile, the physical presence of the stocking can help to control the diameter of superficial veins not to excessively expand by their limited ability of the hosiery to stretch, thus preventing blood congestion and accelerating venous return of the lower limb. However, GCS therapy has not been always effective in clinical practical as it has been in research studies. Some researchers found that some of GCSs tested failed to produce the ideal pressure gradient and a significant number produced a tourniquet effect [4].

Actually, skin pressure distribution is closely related to the materials properties and structural characteristics of GCS fabrics. Some physiologists [5,6] have found that GCS fabrics with different elasticity (stretch) produced different skin pressure gradient (slopes) distribution, which significantly influenced the patients' venous haemodynamics (e.g., capillary filtration rate).

Nowadays, different synthetic elastomers and weaving methods have been adopted in compression stocking production. However, a complete understanding of the influence of materials properties and structures of GCSs fabrics on their pressure distributions and how to achieve satisfactory compression distribution through improving stocking materials has not been developed. Therefore, basic and sufficient researches still need to be conducted.

The objective of the present study was to investigate the fabric properties and structural characteristics of different GCSs, and to quantitatively analyze the effects of material properties on the corresponding skin pressure distributions, by conducting a series of materials physical testing and wear trials. This research work was hoped to provide correlative designers and manufacturers with a useful reference for improving the therapeutic function of GCS production.

---

*Corresponding author: 02902390r@polyu.edu.hk

Table 1. Basic description of tested stocking fabrics

Pressure level	Sample code	Specified ankle pressure (mmHg)	Fiber content	Thickness mean (mm)	Weight mean (g/m^2)
Light	A1	10-14	Polyamide : 80 % Elastomeric : 20 %	0.41	106.7
	B1	12-16	Polyamide : 83 % Elastomeric : 17 %	0.28	63.3
Mild	A2	18.4-21.2	Polyamide : 64 % Elastomeric : 36 %	0.74	246.7
	B2	18-25	Polyamide : 75 % Elastomeric : 25 %	0.36	89.0
Moderate	A3	25.1-32.1	Polyamide : 73 % Elastomeric : 27 %	0.75	250.16
	B3	20-30	Polyamide : 74 % Elastomeric : 18 % Gommures : 8 %	0.97	251.3
Strong	A4	36.4-46.5	Polyamide : 73 % Elastomeric : 27 %	1.18	376.3
	B4	30-40	Polyamide : 50 % Elastomeric : 15 % Gommures : 35 %	1.45	435.7

Experimental

Materials Physical Testing

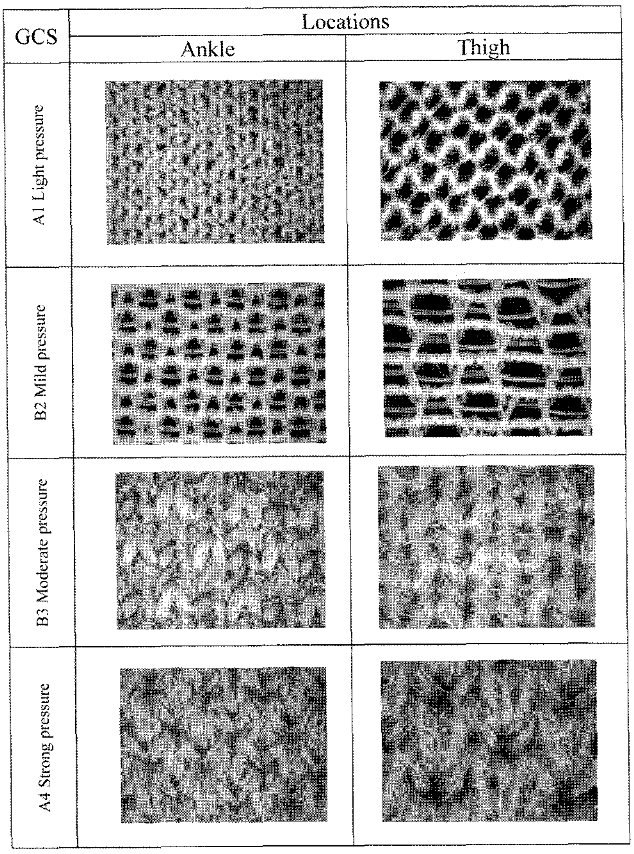
In this study, two series of eight different kinds of GCSs with different pressure levels were selected. The basic features of them are listed in Table 1.

To investigate the effects of material properties on skin pressure gradient distribution from the ankle to the thigh, three swatches with standard size of 20 cm × 20 cm were obtained along the tested stocking hose, and named as ankle, knee and thigh, respectively. Figure 1 shows the photomicrographs of the segmental swatches of different stocking samples, and their fabric knitted structures were diagrammatized in Figures 2 and 3.

The tested stocking fabrics all belong to plain weft knitted structure (Figure 2). Three fundamental stitches were utilized in the knitted stocking fabrics (Figure 3). They were plain stitch (e.g., B3, A4), tuck stitch (e.g., A1), and miss-stitch (e.g., B2). The yarns of stockings with higher pressure (i.e., A3 and A4) were thicker than that with lower pressure levels (i.e., A1 and B2). And, the number of loops per inch at ankle region seemed to be greater than that at thigh region (Figure 1).

The material mechanical and surface properties of these samples were measured by using KESF standard evaluation system in an environment controlled laboratory (Temperature: 20 °C ± 2 °C, Relative Humidity: 65 ± 3 %). Table 2 shows the testing indices and corresponding instrument settings.

For biaxial deformations or bidirectional tests, such as tensile, bending, shearing and surface properties, each sample was measured repeatedly three times for each direction (i.e., wale



(Amplified scale: 1:200)

Figure 1. Photomicrographs of segmental swatches of different tested stocking hoses.

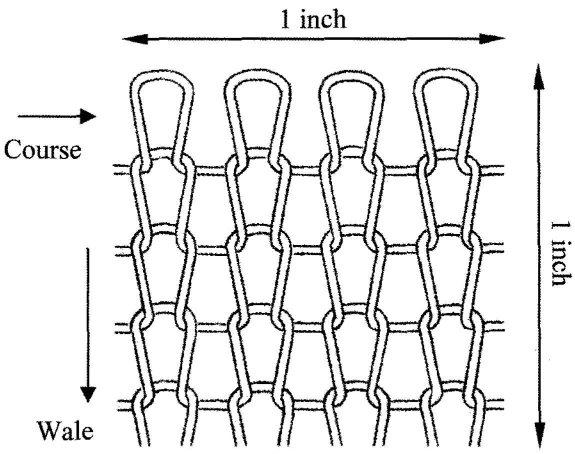
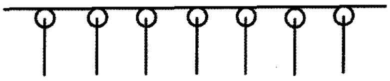
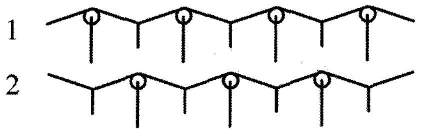


Figure 2. Plain weft knitted structure.

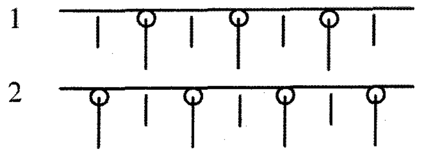
and course); while for compression property which has no requirements for direction, each sample was tested five times at different locations. In order to minimize the shape instability of knitted fabric, all samples are conditioned in a standard atmosphere for 24 hours prior to the formal testing.



(a) Plain stitch



(b) Tuck stitch



(c) Miss stitch

Figure 3. Yarn path diagram.

Skin Pressure Objective Evaluation

To investigate the skin pressure gradient distribution applied by testing stocking samples, wear trials were carried out in a climate chamber with temperature at 23 ± 0.5 ° and relative humidity at 65 ± 3 %). Six healthy female (mean age 33.33 ± 6.37 years, height 159.67 ± 4.71 cm, weight 52.58 ± 5.04 kg, body mass index 20.48 ± 1.90 kg/m^2) volunteered to participate in this investigation. The main anthropometric parameters comprised circumferences, and heights between

Table 2. The testing indices and corresponding instrument settings

Properties	Test nature	Indices	Symbol	Unit	Instrument settings
Mechanical	Tensile	Tensile energy	WT	gf · cm/cm^2	KES-FB1 Velocity: 0.2 mm/s Elongation: 50 mm/10 v Processing rate: 2.5 s, 0.5 s (only for GCS_A4 & B4) Maximum load: 50 gf/cm
		Linearity	LT	–	
		Tensile resilience	RT	%	
		Tensile strain	EM	%	
	Bending	Bending rigidity	B	gf · cm^2/cm	KES-FB2 Rate of bending: 2.5/cm K = 0,5 to 1.5 cm^{-1} K = 1.0 cm^{-1}
		Hysteresis of bending moment	2HB	gf · cm/cm	
	Shearing	Shear stiffness	G	gf/cm. degree	KES-FB1 Shear tension: 10 gf/cm Maximum shear angle: +8.0 to –8.0 2HG = 0.5, 2HG5 = 5.0, G = 0.5 to 2.5
		Hysteresis at 0 = 0.5 °	2HG	gf/cm	
		Hysteresis at 0 = 5.0 °	2HG5	gf/cm	
	Compression	Linearity	LC	–	KES-FB3 Velocity: 50 s/mm Compression area: 2 cm^2 Processing rate: 0.1 s Maximum load: 50 g/m^2
		Compressional energy	WC	gf · cm/cm^2	
		Resilience	RC	%	
Surface	Surface	Coefficient of friction	MIU	–	KES-FB4 Velocity: 1.0 mm/s Roughness contactor comp.: 10 gf
		Mean deviation of MIU	MMD	–	
		Geometrical roughness	SMD	μm	
Construction	Weight	Weight	W	mg/cm^2	Weight per unit area
	Thickness	Thickness	T	mm	Thickness at 0.5 gf/cm^2

Table 3. The anthropometric parameters of subjects' lower limb (n = 6)

Items	Minimum ankle girth (cm)	Maximum calf girth (cm)	Knee girth (cm)	Mid-thigh girth (cm)	The height of ankle	The height of calf	The height of knee	The height of thigh
Mean	26.08	32.12	39.05	52.75	6.20	28.75	42.75	58.3
S.D	2.67	2.29	3.37	5.30	0.66	2.08	2.10	3.92

each circumference and the floor. The testing results were listed in Table 3.

Each of them was required to wear all stocking samples with fitting sizes in standing position.

Skin pressures at 16 different locations distributed in four height levels (the smallest ankle, widest calf, knee over patella, and mid-thigh) and at four directions (anterior, medial, posterior and lateral) along the lower limb were measured by using calibrated FlexiForce interface pressure sensors (Tekscan, Inc., U.S.A) and a multichannel pressure measuring system. The wear trials procedures have been approved by the Human Ethics Committee of Hong Kong PolyU. More detained information about skin pressure testing can refer to [7].

Results and Discussion

Basic Structural Characteristics of Stocking Fabrics

To understand the effects of fabric properties on skin pressure gradient distribution, the basic structural characteristics of fabrics located in different positions along the stocking hoses were investigated first.

Figure 4 showed that, for all tested GCSs, their fabric weights located in the ankle region were the greatest, and then the knee and the thigh.

The stitch density of weft-knitted fabrics are normally expressed as the number of wales per unit length times the number of courses per unit length. Figure 5 showed the stitch densities per inch at three locations of tested stocking fabrics. We can see that the greatest stitch densities were all located in the

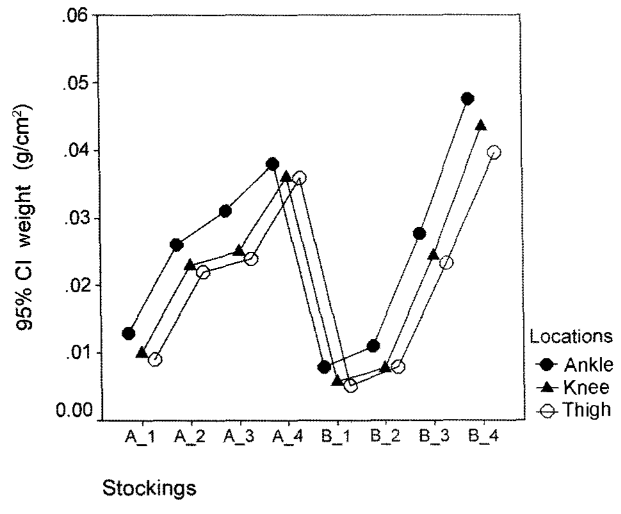


Figure 4. Weight of fabrics at different locations of tested stockings.

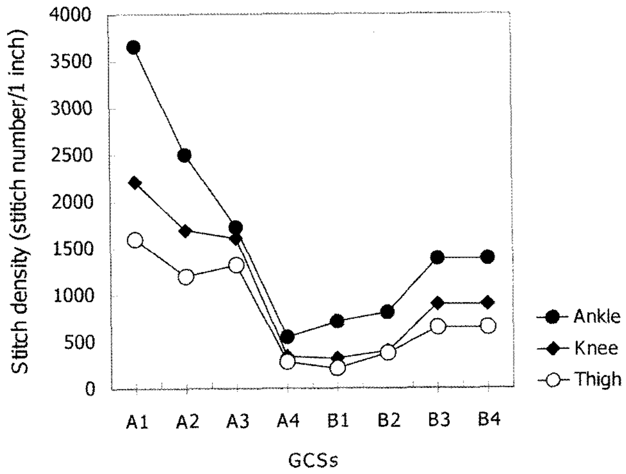
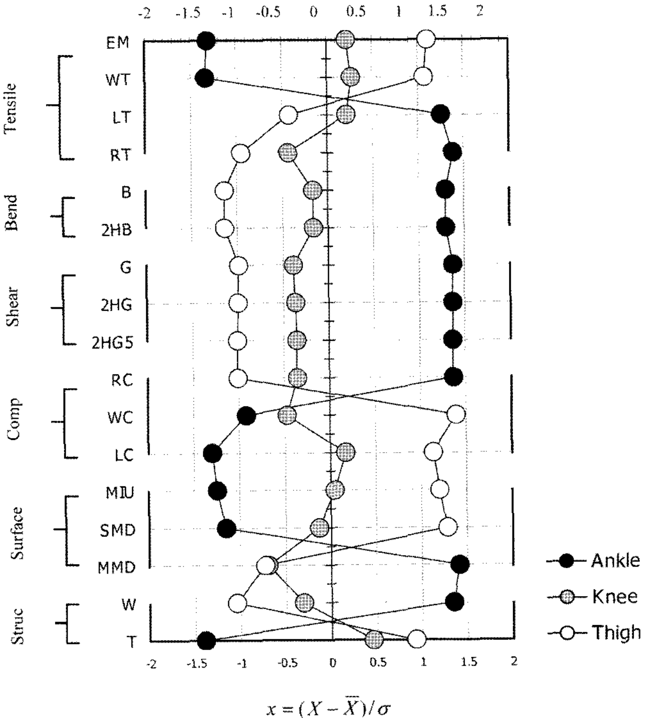


Figure 5. Stitch densities at different locations along stocking fabrics.



x = normalised value, X = measured value of typical index, $\bar{x}$ = mean value of all tested GCS fabrics for one typical index, σ = standard deviation of all tested GCS fabrics for one typical index.

Figure 6. Material properties of GCS(s) fabric at three different locations along the stocking hose.

fabrics at ankle region, and decreased to the fabric at the thigh. These structural features would influence their fabric mechanical behavior.

General Analysis of Material Properties of Fabrics at Different Locations along Stocking Hose

By using normalization analysis, Figure 6 showed the fabric mechanical and surface properties at three different locations (ankle, knee and thigh) along the stocking hoses.

It can be seen that almost all indices of materials properties produced gradient changing tendency from ankle to thigh regions along the stocking hose. For mechanical properties, the stocking fabrics at ankle region has the lowest values in tensile strain (EM), tensile energy (WT), compressional energy (WC), and compression linearity (LC), and has the highest values in indices of bending and shearing properties, meaning that the fabrics at the ankle region had the least tensibility and the greatest resistances to deformations. Meanwhile, from the ankle to the thigh region, the values of MIU and SMD were increased.

We considered that such gradual changes in materials properties along hoses would influence the corresponding contacting conditions between skin and stocking, thus producing gradient distribution in skin pressure from the ankle to the thigh of human leg.

Indices Significantly Changing among Different Locations along Stocking Hose

Table 4 respectively shows the indices whose values significantly changed along the stocking hoses in series A and series B.

Table 4. Summary of variances analysis of material indices whose values significantly changed among different locations along stockings hose in series A and series B

Table 4-1	Series A (ankle, knee, thigh)			
Properties	Indices	F	P (sig.)	Asterisk
Tensile	EM	11.224	0.001	***
	WT	10.268	0.002	***
	LT	4.186	0.045	**
Shearing	G	11.331	0.001	***
	2HG	5.889	0.018	**
	2HG5	6.759	0.011	**
Surface	MIU	19.259	0.000	***
	SMD	12.290	0.001	***
Table 4-2	Series B (ankle, knee, thigh)			
Properties	Indices	F	P (sig.)	Asterisk
Tensile	EM	26.792	0.000	***
	WT	24.361	0.000	***
Shearing	G	12.233	0.001	***
	2HG	8.759	0.004	***
	2HG5	9.482	0.003	***

***: $P < 0.01$, **: $P < 0.05$.

We found that shearing and tensile properties produced significant differences ($P < 0.05$) along the three different locations (ankle, knee, and thigh) for the two series GCSs. In which, the indices of EM, WT and G possessed higher F values ($F > 10.0$, $P < 0.01$), meaning that these indices would possibly exert more influences on skin pressure gradient distributions.

Meanwhile, we found that significant differences on surface properties (MIU and SMD) ($P < 0.01$) also existed among three locations of stockings in series A.

Figure 7 further compared the gradual changes in material properties between the two series stockings. We can see that, along the locations of stocking hose, the values of EM, WT and MIU were all raised for the two series stockings. And, compared with series B, stockings in series A produced more linear increase in tensile and shearing properties (Figure 7a, b, d). In Figure 7(c), we can see that from ankle to thigh region, the shear stiffness values of the two series stockings were all decreased, but series A performed higher values in G than that of series B.

Comparisons on Gradual Changes in Material Properties in Both Wale and Course Directions

By using ANOVA analysis, Table 5 summarized the material properties producing significant gradual changes along stocking hose in both wale and course directions.

Table 5. Summary of variances analysis of significant differences on material properties along different location of stocking hose in wale and course directions

Table 5-1		Series A (ankle, knee, and thigh)			
Properties	Indices	Wale direction*		Course direction	
		F	P (sig.)	F	P (sig.)
Tensile	EM	23.170	0.000	1.775	–
	WT	24.267	0.000	1.242	–
Shearing	G	5.888	0.021	5.128	0.030
	2HG	4.317	0.045	1.775	–
	2HG5	4.626	0.039	2.489	–
Surface	MIU	15.222	0.000	6.150	0.018
	SMD	8.363	0.007	1.937	–
	MMD	9.154	0.005	9.577	0.004
Table 5-2		Series B (ankle, knee, and thigh)			
Properties	Indices	Wale direction		Course direction	
		F	P (sig.)	F	P (sig.)
Tensile	EM	45.513	0.000	4.486	0.042
	WT	34.323	0.000	5.016	0.032
Shearing	G	6.723	0.014	5.194	0.029
	2HG	4.522	0.041	3.997	–
	2HG5	5.802	0.022	3.641	–
Surface	MIU	0.00	–	4.488	0.042

*The wale direction accords with the lognitudinal direction of stocking hose.

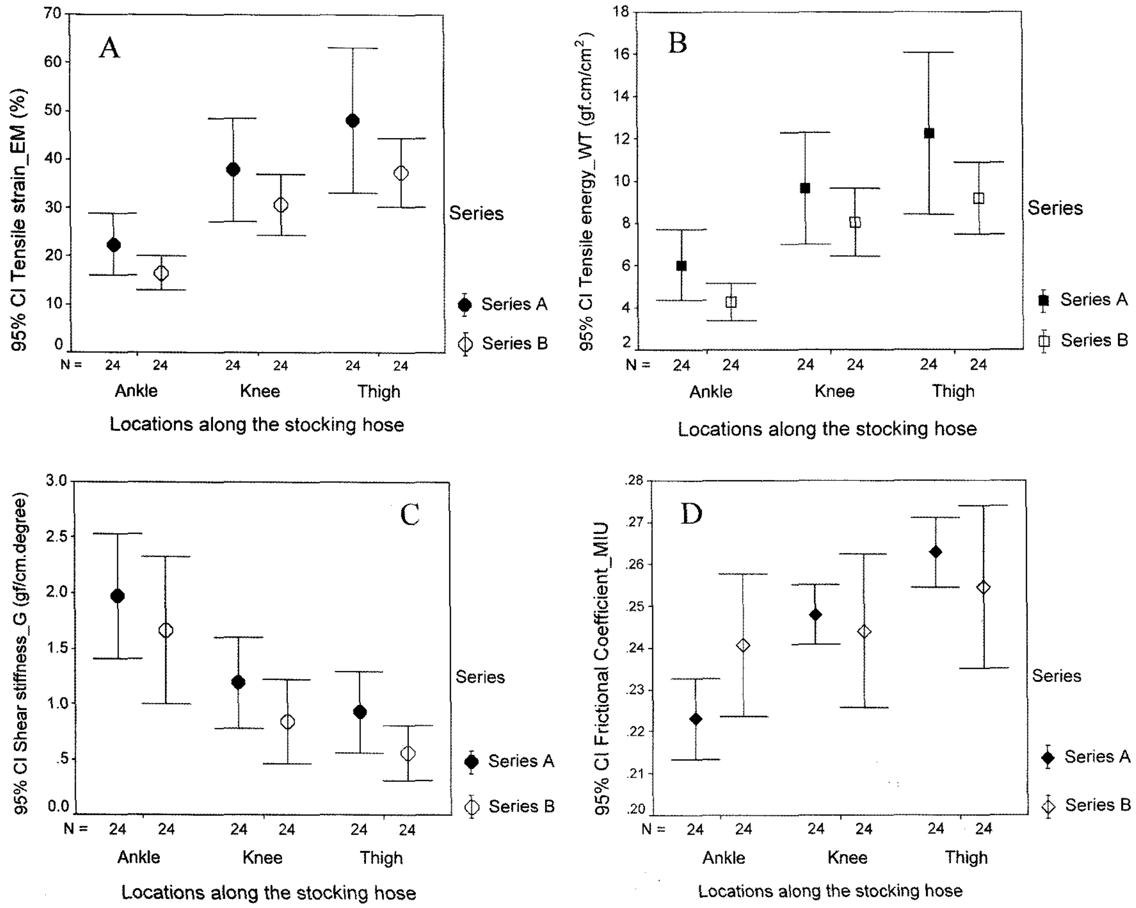


Figure 7. Comparisons between series A and B on the material indices whose values strong significantly changed along the different locations of stocking hoses.

Compared with course direction, more indices values produced significant differences (longwise) along stocking hose in wale direction, such as tensile ($P < 0.001$) and shearing properties ($P < 0.05$). In addition, surface property also significant differs ($P < 0.01$) in wale direction among different locations along stocking hoses in series A.

Figure 8 further presented the gradual changes of the material indices with higher F values in both wale and course directions along the stocking hoses.

From Figure 8A, B, we found that from ankle to thigh region, the values of WT and EM indices were all gradually raised in wale and course directions along stocking hose. However, more significant linear increase slope from the ankle to the thigh occurred in the fabric wale direction. And, their WT and EM values in wale direction were significantly higher than that in course direction ($P < 0.05$, by using ANOVA analysis), meaning that the fabric in wale direction has better extensibility and linear elasticity.

Figure 8C showed that with the elevation of locations along the stocking hose, the value of shear stiffness (G) in both wale and course directions were all significantly decreased, and no significant differences in G values existed between the two directions of stocking fabrics ($P > 0.05$). In Figure 8D, it can be seen that the MIU values showed a gradual increase from the ankle to the thigh in both directions, whereas, the fabric surface in wale direction were significantly smoother than that in course direction.

From the above analysis, we considered that materials properties in wale direction would possibly exert greater influences on their skin pressure gradient distribution. The significant gradual changes of tensile properties in wale direction would also bring important positive action on skin pressure gradient performance. Meanwhile, the greater tensibility and smoother surface of fabric in wale direction would contribute to putting-on and off of stocking hose, and facilitate wearers' leg movements, such as knee-bend and knee-extension.

The Effects of Materials Properties of GCS Fabrics on the Skin Pressure Distributions

In wear trials, the skin pressure distributing at ankle, calf, knee and thigh locations exerted by different GCSs were

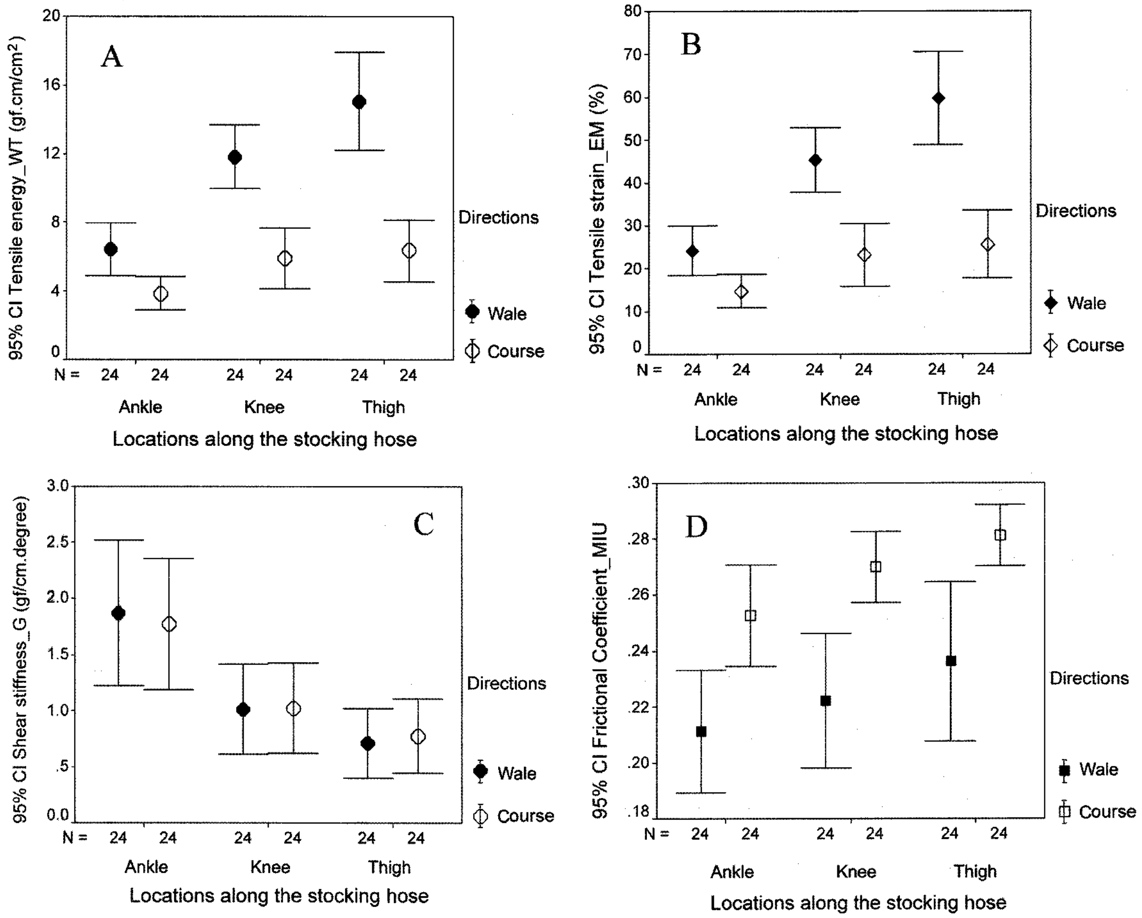


Figure 8. Comparative analyses on gradual changes in material properties along stocking hose between wale and course directions.

Table 6. Effects of different GCSs on the skin pressure gradient distribution

Dependent variable: skin pressure (Pa)					
Source	Type III sum of squares	df	Mean square	F	P (sig.)
Corrected model	2799656.981[a]	2	1399828.491	16.758	.000
Intercept	25112716.380	1	25112716.380	300.644	. 000
Locations along the stocking hose	2799656.981	2	1399828.491	16.758	.000
Error	1754124.167	21	83529.722		
Total	29666497.528	24			
Corrected total	4553781.148	23			

[a] R squared = 0.615 (adjusted R squared = 0.578).

examined. Table 6 quantified the effects of GCSs on skin pressure gradient distribution along the subjects' legs by using univariate analysis of variance.

We can see that strong significant differences ($P < 0.001$) on skin pressure existed among different locations along human leg, meaning that the gradual changes in material properties along stocking hose indeed exerted great influences on the corresponding skin pressure distributions.

Effects of Materials Properties on Skin Pressure Lognitudinal Distributions

In above material analysis, the changes of fabric properties appeared to be linear along the stocking hose; consequently, linear regression and ANOVA analysis were conducted to examine the effects of different materials properties on skin pressure lognitudinal distribution. The result was listed in Table 7.

Table 7. Summary of material properties significantly influencing skin pressure gradient distribution Dependent variable: skin pressure gradient distribution

Properties	Indices	R*	F	P (sig.)
	Series A			
Tensile	EM	0.816	19.915	0.001
	WT	0.855	27.258	0.000
Shearing	G	0.744	12.368	0.006
	2HG5	0.701	9.643	0.011
Bending	B	0.679	8.025	0.017
Weight	W	0.650	7.307	0.022
	Series B			
Tensile	EM	0.717	10.550	0.009
	WT	0.726	11.137	0.008
Shearing	G	0.721	10.799	0.008

*Correlation coefficient: a measure of linear relationship.

It can be seen that for two series stockings, tensile and shearing properties all significantly influenced the skin pressure gradient distribution, especially the indices WT ($P < 0.01$), EM ($P < 0.01$), and G ($P < 0.01$). Meanwhile, we noted that, the indices of WT and EM of stocking fabrics in series A have strong linear correlations with skin pressure lognitudinal distribution ($0.8 < |R| < 1$). This result largely related to their better performances in gradual changes of material property (Figure 7). The indices of G, B and W also significantly influenced skin pressure distribution, but their correlation were in medium level ($0.5 < |R| < 0.8$).

The above analysis indicated that the gradual changes in tensile (WT, EM) and shearing properties (G) of stocking fabrics would play more pronounced roles in skin pressure gradient distribution. Their effects were further visualized in Figure 9.

We can see that, with the increase of EM and WT values, skin pressure was gradually decreased. Among them, higher skin pressures were focused on the ankle region, where their corresponding fabrics possessing lower values in EM and WT. Meanwhile, compared with knee and thigh regions, the skin pressure at the ankle produced the largest negative trend lines with the increase of EM and WT values (Figure 9a, b). While, for shear stiffness, with an increase of G values, skin pressure were gradually increased, in which skin pressures at the ankle region were always keep higher level.

This result demonstrated that, (a) stocking fabrics with lower values in EM and WT or higher values in G, would produce higher pressure on the skin surface; (b) the gradual changes in material properties (e.g., EM, WT, G) would induce skin pressure gradient distributions; and (c) in the practical wearing, the skin pressure magnitudes at ankle region would be more easily influenced by the changes of materials properties.

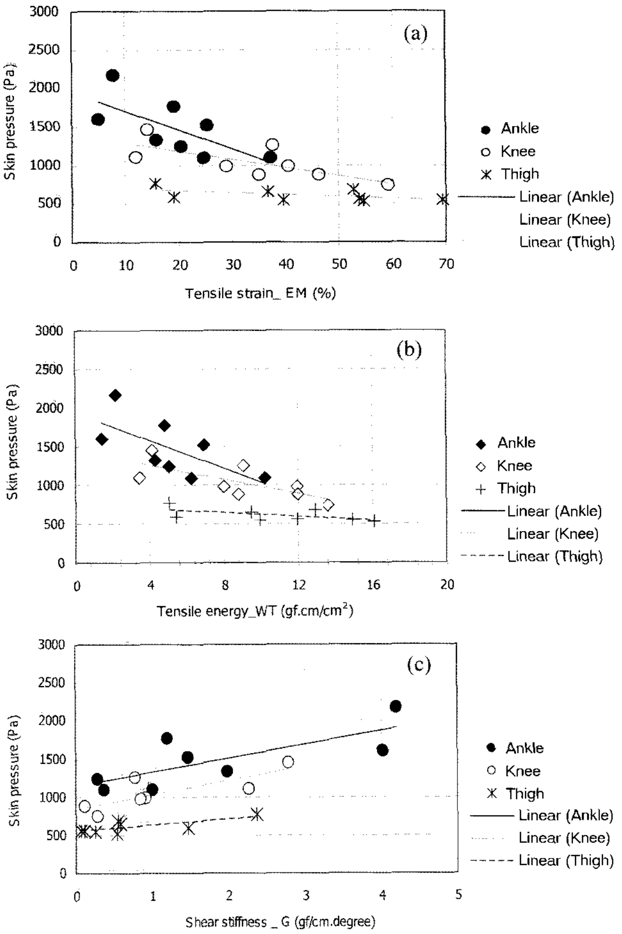


Figure 9. The effects of key material indices on the skin pressure gradient distribution.

Effects of Materials Properties on Skin Pressure Transverse Distributions

From the above analysis, we knew that the tensile energy was significantly correlative to skin pressure gradient distribution, consequently, the index WT was taken for example here to investigate the effects of material properties on skin pressure transverse distribution (Figure 10).

In wear trials, the mean skin pressure at sixteen points located in four regions (ankle, calf, knee, and thigh) and four directions (anterior, medial, posterior, lateral) applied by GCSs had been determined. In Figure 10, we can see that with an increase of WT values, the corresponding skin pressures were decreased from ankle to thigh region. However, at the same region, skin pressure applied by the fabric with same tensile property (i.e., WT) produced pronounced differences among four different directions ($P < 0.05$, by ANOVA analysis).

For example, at ankle region, the WT values of tested GCSs fabrics was about 5 gf · cm/cm, while, the skin pressures at four directions exerted were 1954.99 (anterior), 1623.70 (posterior), 1313.89 (lateral), and 889.92 (medial) (Pa), respectively. Meanwhile, we found that the higher skin pressure were all distributing in the anterior side of the leg, and the differences on skin pressure among four directions were gradually reducing from the ankle to the thigh.

We considered that the above results were related to the anatomic structure of human leg. Figure 10(b) showed the Magnetic resonance imaging (MRI) images of three cross-sections of a healthy subject's leg. We can see that the underlying bone shapes, the proportions of soft tissue and muscles are very different among the ankle, knee and thigh cross-sections, which inducing their different circumferential contours and skin surface elasticities, thus influencing contacting condition between skin and stocking fabric.

For ankle region, its cross-section was close to be elliptic, where the anterior and Achilles's tendon regions possessed greater curvatures. From Figure 10(a), we found that the ankle produced higher pressure at the anterior and posterior directions beneath the fabric with the same material property. For the knee cross-section, the highest skin pressure also occurred in the patella (anterior knee) region with greater curvature. While, for thigh region, its cross-sectional contour was close to rotundity, thus fewer differences on skin pressure occurred among their four directions.

Meanwhile, we considered that the thickness of subcutaneous soft tissue would influence the skin-stocking interface elasticity. Giele and his colleges had found that the skin pressure exerted at bony prominences was more than three times than that exerted at soft tissue area [8]. From Figure 10(b), we can see that, at ankle and knee regions, thinner soft tissue layers existed between skin surface and underlying bone, especially at anterior knee and anterior ankle, which would harden interface texture between skin-stocking. Compared with them, most of the thigh region was taken up by soft tissue. Therefore, in Figure 10(a), we can see that, under the fabrics with same material property, larger differences on skin pressure among four directions occurred in the ankle region with bony prominences. This could be also one reason resulting in skin pressure more evenly distributing at four directions at thigh cross-section. These reasons could be also used to explain why skin pressure at ankle region was more influenced by the changes in material properties.

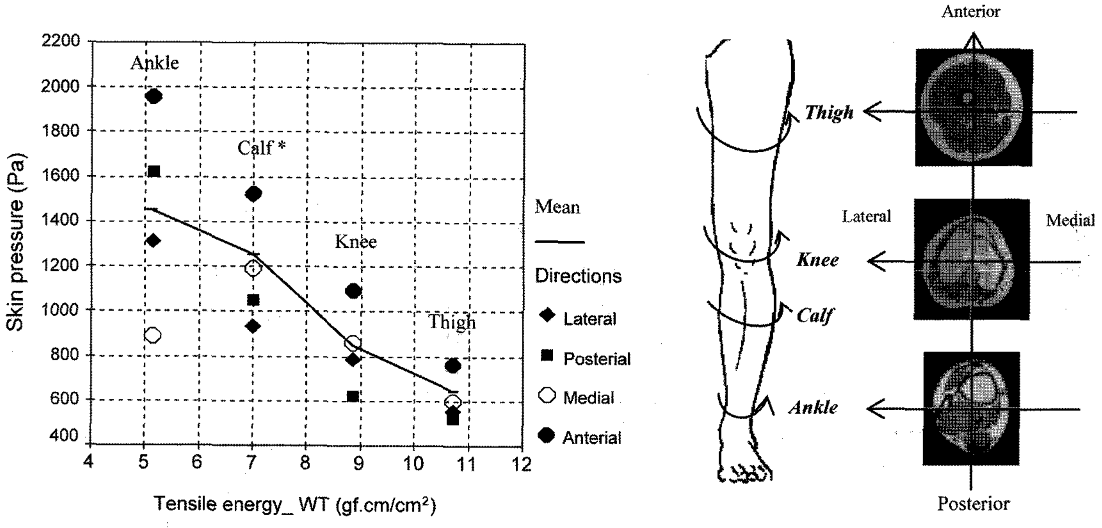
Conclusions

Through investigating the fabric structural characteristics and material properties at different locations along different GCSs hoses, and analyzing their effects on corresponding skin pressure lognitudinal and transverse distribution by wear trials, we conclude that,

Structural characteristics and material properties of stocking fabrics were not uniform along the hoses, but a gradual variation from ankle to thigh regions, which significantly influenced the corresponding skin pressure gradient distributions;

Tensile (WT, EM) and shearing properties (G) generated most significant differences among ankle, knee and thigh regions along the stocking hose, which significantly influenced the skin pressure lognitudinal gradient distribution.

More material indices generating significant gradual changes occurred in the fabric wale direction along stocking hose, meaning that materials properties in wale direction would



* WT value at calf region was assumed to be the mean value between ankle and knee regions.

(a) Correlation between WT values and sixteen specific skin pressures

(b) The different cross-sections along human leg

Figure 10. The effects of material properties on the skin pressure distributions at different transverse cross-sections of human leg.

exert more important impact on the skin pressure gradient performances. And, the greater tensibility and smoother surface of fabric in wale direction would contribute to put stocking on and off, and facilitate wearers' leg extension-flexion movements.

The indices of WT and EM of stocking fabrics in series A have strong linear correlations with skin pressure longitudinal distribution, which largely related to their better performances in gradual changes of material property. While, shearing (G, 2HG), bending (B) and weight (W) properties have medium linear correlations with skin pressure gradient distribution.

Skin pressure applied by the fabric with same material properties produced pronounced differences among four different directions around the cross-sections of human leg, especially at the ankle region; and, the skin pressure magnitudes at ankle region were more easily influenced by the materials properties, which were considered to be largely related to the anatomic structure of human leg.

Acknowledgement

The authors would like to thank Research Grant Council (GGC) through the project PolyU 5157/02 and the Hong Kong Polytechnic University through the project A188/YD31 to support this research, and thank Mr. S. X. Wang, Ms. M. Sun, and all the subjects for their help in this study.

References

1. B. Sigel, A. L. Edelstein, L. Savitch, J. H. Hasty, and W. R. Felix Jr., *Arch. Surg.*, **110**(2), 171 (1975).
2. N. L. Browse, B. T. Jackson, M. E. Mayo, and D. Negus, *Br. J. Surg.*, **61**(3), 219 (1974).
3. C. Jungbeck, K. Peterson, G. Danielsson, and L. Norgren, *Phlebology*, **16**, 117 (2002).
4. A. J. Best, S. Williams, A. Crozier, R. Bhatt, P. J. Gregg, and A. C. Hui, *J. Bone. Joint Surg. Br.*, **82**(1), 116 (2000).
5. A. J. Van Geest, J. C. Veraart, P. Nelemans, and H. A. Neumann, *Dermatol. Surg.*, **26**(3), 244 (2000).
6. H. M. Hafner, M. Eichner, and M. Junger, *Zentralbl. Chir.*, **126**(7), 551 (2001).
7. R. Liu, Y. L. Kwok, Y. Li, T. T. Lao, X. Zhang, and X. Q Dai, *Dermatol. Surg.*, **31**(6), 615 (2005).
8. H. P. Giele, K. Liddiard, K. Currie, and F. M. Wood *Burns*, **23**(2), 137 (1997).