The Effect of Structural Parameter on Pressure Behaviour of Tubular Bandage

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1 Introduction

Compression therapy is the most widely used treatment for venous leg ulcer (VLU), and it has been utilised in different forms for more than four centuries [1]. The compression therapy can be given by different through compression bandages, compression hosiery; IPC (Intermittent pneumatic compression therapy), but out of these compression bandaging is widely used [2]. There are wide varieties of compression bandages available, according to the requirement of pressure, a suitable bandage has to be selected for the specific problem based on required pressure level. [3].

Different types of compression materials have different compression characteristic and the ability of a bandage to maintain pressure is determined by the elastomeric properties of the yarns and the structure of the fabric [4].

The main function of compression materials is to exert an external pressure on limb, which leads to better venous blood flow [5]. It is important to maintain the required level of pressure because excessive pressure can lead to tissue damage, pressure sores and necrosis. Reverse gradient compression is likely to worsen the condition as it increases the pressure in the veins. Limb damage or treatment failure may result in limb amputation [6]. A direct relation exists between extension and applied force. For the given compression materials, the higher the stretch percentage, the higher the pressure. The capacity and efficiency of a material to sustain pressure is greatly dependent on its ability to maintain this internal stress which depends on compression materials structure, material type, amount of elastane, etc.

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It is desired that the compression material should be able to preserve its compressive pressure even after being worn for an entire day and do not lose their elastic stretch recovery. In this respect knitted structure of bandage is more preferred. The flat and circular knitting is used as the knitting techniques to produce compression hosieries [7]. In circular knitting technology, the diameter of the machine and the number of needles is fixed during production of a particular product. These garments are mostly knitted as plain knitted structure. Although knitted compression material is good in sustaining the pressure for longer period but it shows viscoelastic properties and their recovery depends on the drawn ratio [5, 8]. The exerted loads in the production process and during application of fabrics also cause to stretch and let deformations in the fabric. In manufacturing of knitted bandage core spun cotton yarns, with elastane component in the core and cotton in the sheath, have become quite popular, because the cotton fibres covering the elastane core and provide the necessary tactile aesthetics to the wearer along with thermo-physiological comfort and performance characteristics as compared to the conventional yarns [9, 10].

In present work tubular knitted bandage is prepared using core spun yarn of varying lycra denier and its pressure behaviour was analysed at different stretch %, different limb circumference of different hardness. The interactive effect of these parameters on pressure behaviour is also analysed statistically.

2 Material and Methods

Cotton/lycra core spun yarn with three different lycra Denier, i.e 20, 30, 40 Denier. The physical properties of the tubular bandage are shown in Table 1.

The individual and interactive effect of lycra(denier), stitch length(mm), stretch (%), hardness of limb(degree) on tubular bandage pressure was studied at three levels

Table 1 Physical properties of the tubular bandage

	Lycra denier	Stitch length (mm)	Course and Wale per inch		Thickness (mm)	GSM of fabric
			Course	Wale		
Cotton/lycra core spun yarn (40s)	20	2.5	84	41	1.70	171
		3	76	37	2.23	169
		3.5	60	29	2.35	152
	30	2.5	80	40	1.68	205
		3	70	31	2.23	202
		3.5	56	26	2.58	188
	40	2.5	72	31	1.66	142
		3	56	26	1.51	135
		3.5	50	24	2.03	124

Table 2 Design plan of experiment

Factors	Levels
Lycra (Denier)	20
	30
	40
Stitch length (mm)	2.5
	3
	3.5
Stretch (%)	80
	100
	120
Hardness of limb (Degree)	10
	20
	30

using Full Factorial Design (34 = 81 Runs). Various factors have been considered for this study at yarn and fabric stage have been presented in Table 2.

In order to study the individual and interactive effect of each parameter on tubular bandage pressure, response surface regression equations were developed for tubular bandage pressure. The general relationship between the response Y (tubular bandage pressure) and the different parameters is given below as:

$$\begin{aligned} Y = {} & C_0 + C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_{12} \\ & + C_6X_{22} + C_7X_{32} + C_8X_{42} + C_9X_1X_2 \\ & + C_{10}X_2X_3 + C_{11}X_3X_4 + C_{12}X_4X_1 \ldots \end{aligned}$$

where, C_0 is constant and C_1, C_2 … C_9 are coefficient of the regression equation, X_1, X_2, X_3, and X_4 are the parameters, i.e lycra (denier), stitch length (mm), stretch (%), and hardness of limb (degree).

3 Results

3.1 Effect of Lycra Denier on Pressure Behaviour of Tubular Bandage

In order to analyse the effect of lycra denier on pressure, three different deniers (20, 30 and 40 denier) were used for the cotton/lycra tubular knitted fabric production. It was observed that in plain knitted fabrics, when the lycra denier increases, there is a significant increase in pressure values as shown in Fig. 1. This increase in pressure can be explained on the basis of retraction force developed by bandage. As the lycra

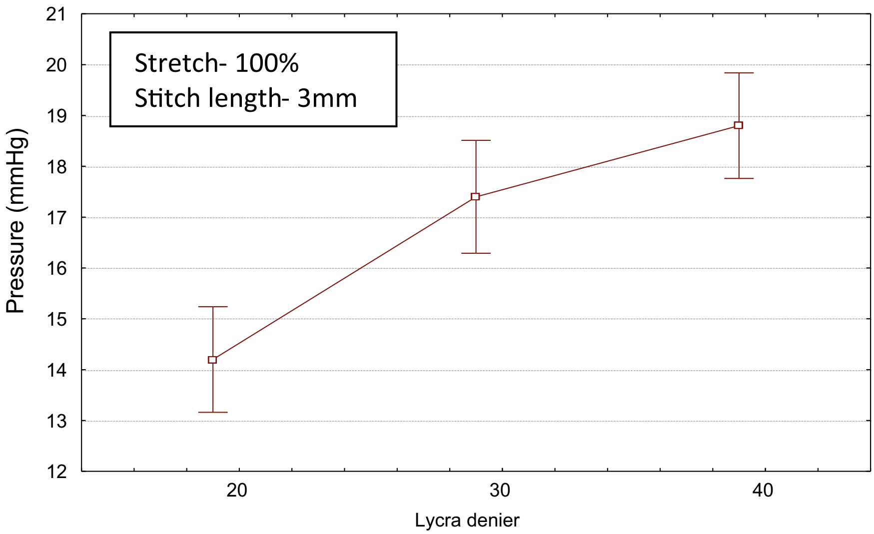

Fig. 1 Effect of lycra denier on pressure behaviour of tubular bandage

denier increases, lycra content in yarn and the weight per unit length of yarn increases which causes the increase in resulting retraction force inside the yarn. Such increase in retraction force offered by each yarn results in the overall increase in retraction force offered by bandage as the pressure offered by bandage is directly related with the retraction force developed by it. Therefore, bandage made of higher lycra denier yarn results in higher pressure generation. The increase in retraction force inside bandage can be explained through load extension graph of such bandages as shown in Fig. 2. From the graph it can be seen that at any extension, bandage with higher lycra denier yarn shows higher load value as compare to bandage with lower lycra denier. Therefore, such higher load in higher lycra denier bandage provides higher retraction force and leave higher pressure.

3.2 Effect of Stitch Length on Pressure Behaviour of Tubular Bandage

As per ANOVA analysis Table 2, it was found that the stitch length is the most important factor which affects the pressure developed by tubular knitted bandage. In Fig. 3, it can be seen that as the stitch length increases the pressure developed by bandage decreases significantly. Thus, the samples with the lowest stitch length exert the highest pressure. The reason for such decrease in pressure with the increase of stitch length can be explained on the basis of stretch ability and retraction characteristics of knitted fabric under tension. Stitch length of knitted fabric basically shows

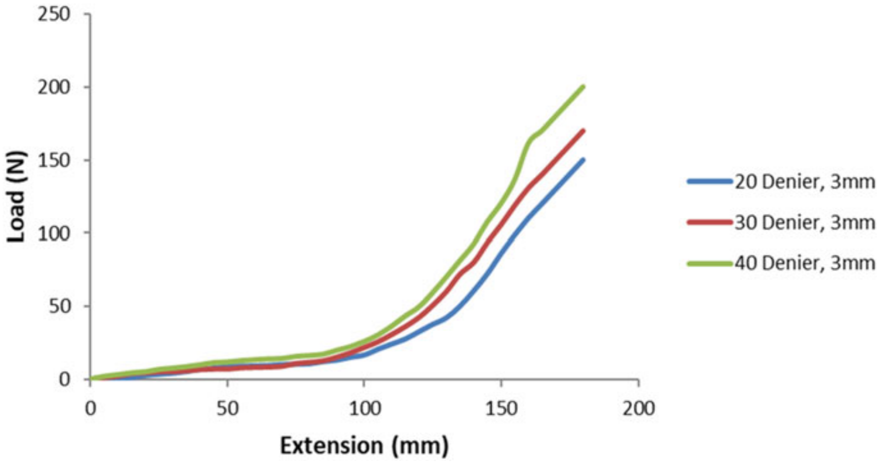

Fig. 2 Load Extension behaviour of three different lycra denier at 3 mm stitch length

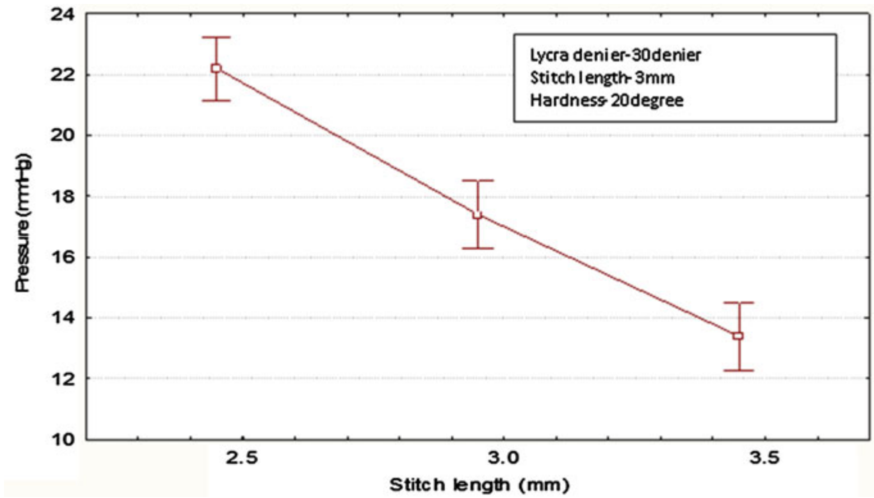

Fig. 3 Effect of Stitch length on pressure behaviour of tubular bandage

its ability to stretch. Higher the stitch length of knitted fabric higher will be its ability to stretch and therefore shows higher extensibility but the retraction force developed by fabric depends on its ability to stretch and stretch %. Higher the ability of fabric to stretch lower will be retraction force experienced by it but higher the stretch % inside fabric higher will be the retraction force. At constant stretch %, fabric with lower stitch length experience more retraction force because it opposes more during its stretch as there is no sufficient length of yarn for its extension within the fabric structure. Therefore, at constant stretch % bandage with lower stitch length results in

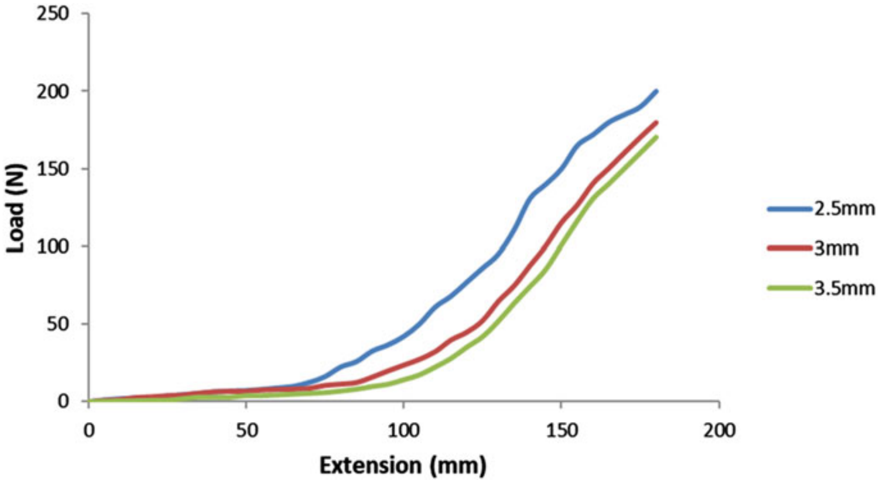

Fig. 4 Load Extension behaviour of 30 denier lycra at three stitch length

more retraction force and so develops more pressure. The increase in retraction force inside bandage can be explained through load extension graph of such bandages as shown in Fig. 4. From graph it can be seen that at any extension, bandage with lower stitch length shows higher load value as compare to bandage with higher stitch length. Therefore, such higher load in low stitch length bandage provides higher retraction force.

3.3 Effect of Stretch % on the Pressure Behaviour of Tubular Bandage

It can be observed from Fig. 5, that as the stretch % inside bandage increases the pressure developed by it increases. It can be explained on the basis of the relation between stretch % and tension developed inside bandage. Stretch inside the bandage is directly related with the tension developed by bandage. It can also be seen from load elongation graph as shown in Fig. 6, that as the elongation % increases the value of load which is basically the tension borne by bandage specimen also increases. Therefore, with the increase of stretch % tension inside bandage increases and so the resulting pressure offered by bandage also increases.

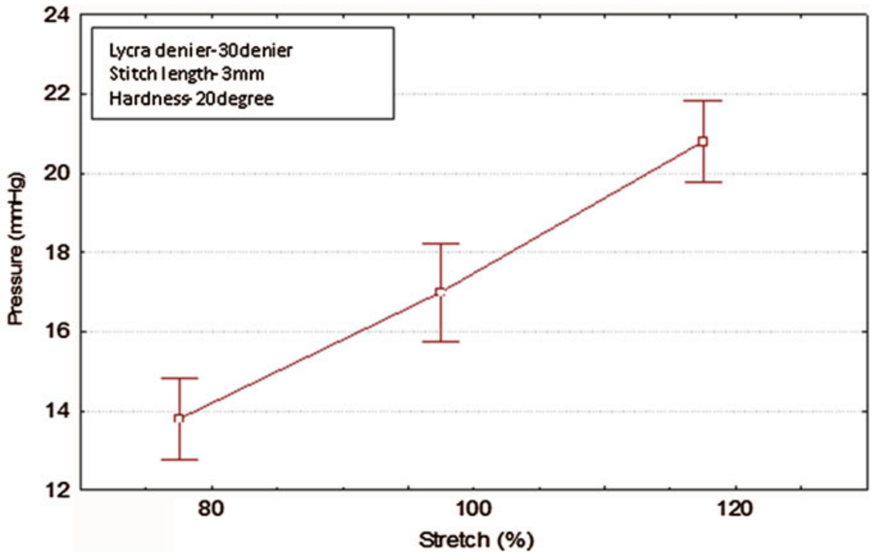

Fig. 5 Effect of Stretch % on the pressure behaviour of tubular bandage

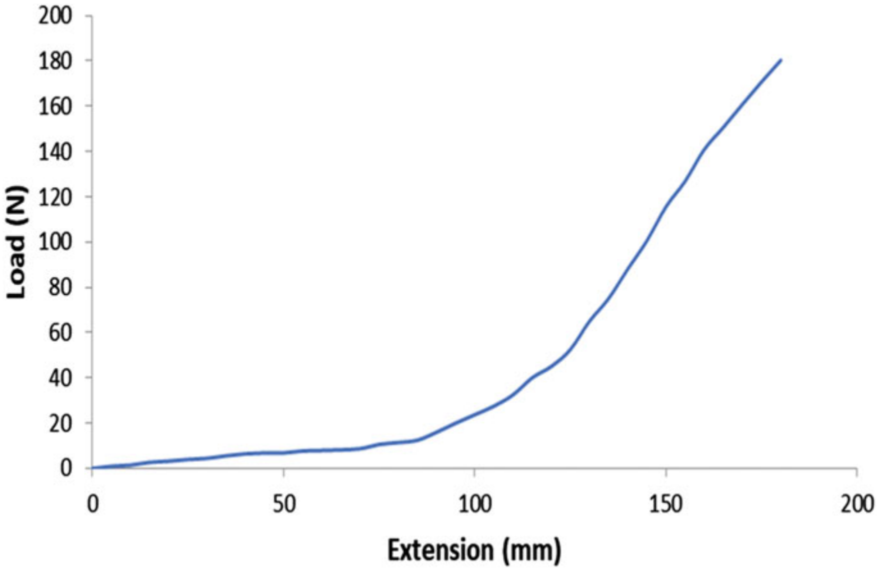

Fig. 6 Load Extension behaviour of 30 denier lycra at 3 mm stitch length

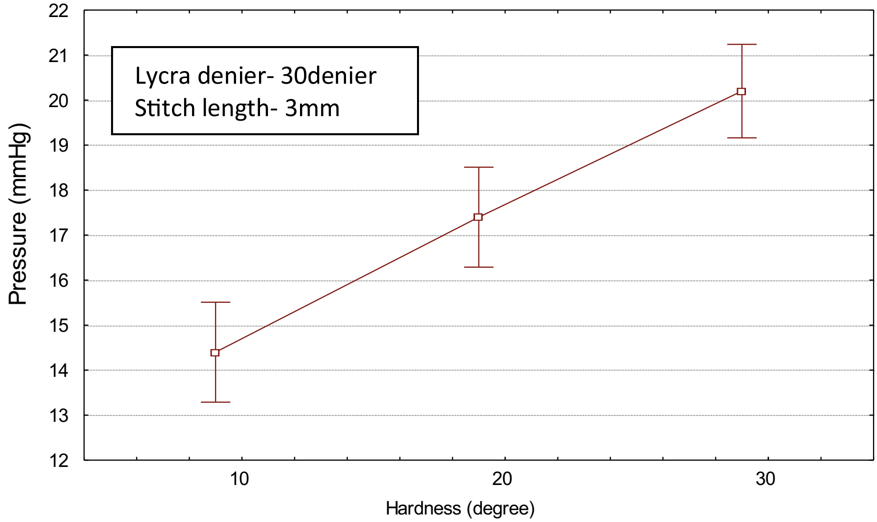

Fig. 7 Effect of limb hardness on pressure behaviour of tubular bandage

3.4 Effect of Limb Hardness on Pressure Behaviour of Tubular Bandage

It can be observed from Fig. 7, that as the hardness of limb circumference over which the bandage is to be applied increases the pressure developed by bandage also increases. The reason for such increase in pressure can be explained on the basis of reaction force experienced by bandage from the surface of limb. When the bandage is applied on harder limb the reaction force offered by the surface of limb becomes more as compare to softer limb therefore pressure sensor senses higher pressure at harder surface.

3.5 Combined Effect of Different Parameters on Tubular Bandage Pressure

From the above section it has been concluded that the change in individual parameter directly affects the pressure developed by bandage. But interaction effect of two or more parameters also has important role in contributing to pressure applied by bandage. It can be observed from ANOVA Table 2, that the interaction of different parameters also has significant importance on the pressure behaviour of the tubular bandage.

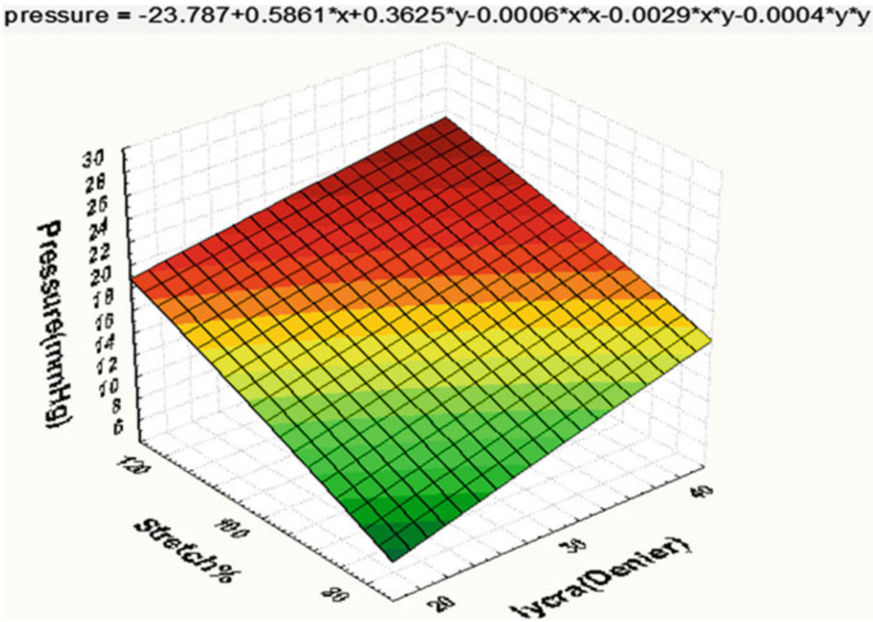

Fig. 8 Interaction effect of stretch % and lycra denier on tubular bandage pressure

3.5.1 Interaction Effect of Stretch % and Lycra Denier on Tubular Bandage Pressure

It can be observed from Fig. 8, that with the increase in stretch (%) and lycra denier, pressure developed by bandage also increases. The value of pressure is lowest at the lower level of lycra denier and stretch % while it is highest at their higher level. In between these levels the pressure varies with the equation shown in Fig. 8.

3.5.2 Interaction Effect of Stitch Length and Lycra Denier on Tubular Bandage Pressure

It can be observed from Fig. 9, that with the increase in stitch length pressure developed by bandage decreases but it increases with the increase of lycra denier. While considering their interaction effect, value of pressure is highest at the lower level of stitch length and higher level of lycra denier while it is lowest at higher level of stitch length and lower level of lycra denier. In between these levels the pressure varies with the equation shown in Fig. 9.

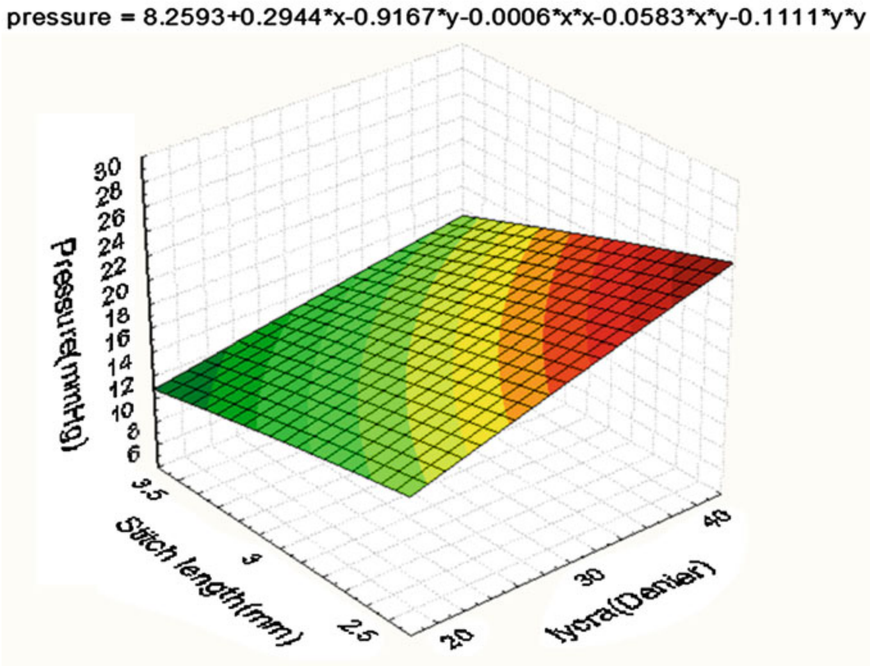

Fig. 9 Interaction effect of stitch length and lycra denier on tubular bandage pressure

3.5.3 Interaction Effect of Limb Hardness and Lycra Denier on Tubular Bandage Pressure

It can be observed from Fig. 10, that with the increase of limb hardness and lycra denier the pressure developed by bandage also increases. The value of pressure is lowest at the lower level of limb hardness and lycra denier while it is highest at their higher level. In between these levels the pressure varies with the equation shown in Fig. 10.

3.5.4 Interaction Effect of Stretch % and Stitch Length on Tubular Bandage Pressure

It can be observed from Fig. 11, that with the increase in stretch %, the pressure developed by bandage increases but it decreases with the increase of stitch length. While considering their interaction effect, value of pressure is highest at the lower level of stitch length and higher level of stretch % while it is lowest at higher level of stitch length and lower level of stretch %. In between these levels the pressure varies with the equation shown in Fig. 11.

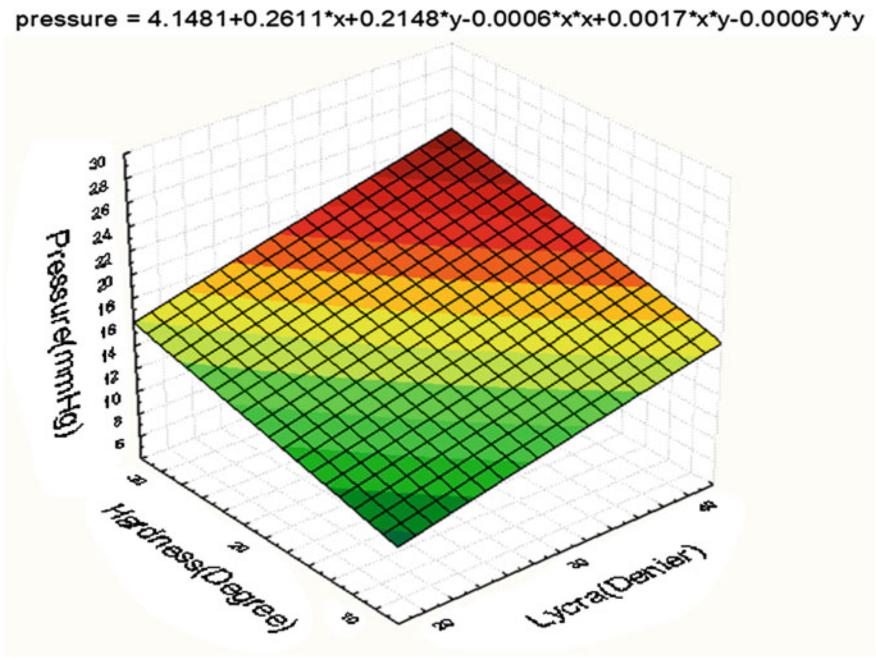

Fig. 10 Interaction effect of limb hardness and lycra denier on tubular bandage pressure

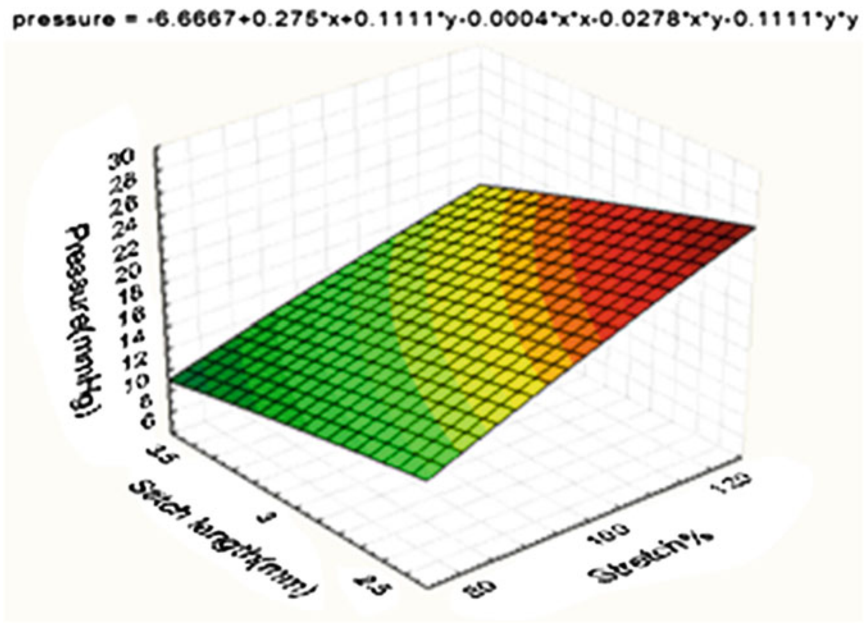

Fig. 11 Interaction effect of stretch % and stitch length on tubular bandage pressure

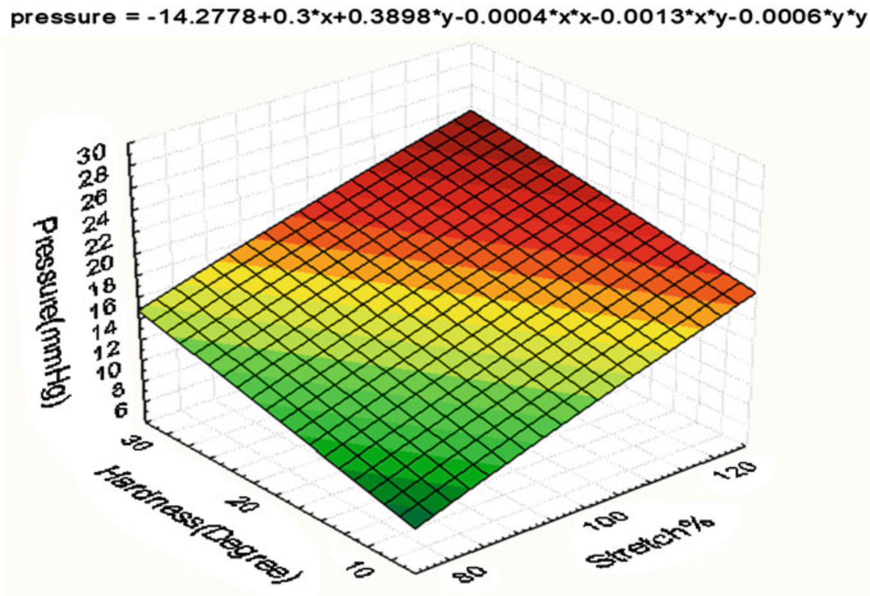

Fig. 12 Interaction effect of limb hardness and stretch % on tubular bandage pressure

3.5.5 Interaction Effect of Limb Hardness and Stretch % on Tubular Bandage Pressure

It can be observed from Fig. 12, that with the increase of limb hardness and stretch % the pressure developed by bandage increases. The value of pressure is lowest at the lower level of limb hardness and stretch % while it is highest at their higher level. In between these levels the pressure varies with the equation shown in Fig. 12.

Analysis of variance was carried out to find the importance of each parameter and their contribution in imparting overall tubular bandage pressure.

However, the contribution of each parameter on tubular bandage pressure has been calculated from Eq. (1) and shown in Table 3.

$$\text{Contribution } (\%) = \frac{\left[\mathrm{SS}_p - (df * \mathrm{MS}_e)\right]}{\mathrm{TSS}} * 100 \tag{1}$$

where SS_P = Sum of square of the parameter, df = Degree of freedom of the parameter, MS_e = Mean square of pooled error, TSS = Total sum of square.

Table 3 Contribution (%) of parameters on tubular bandage pressure-ANOVA

Property	Parameters	Contribution (%)
Pressure (mmHg)	Lycra	20
	Stretch%	40
	Stitch length	20
	Hardness	16
	Lycra*stretch%	1
	Lycra*stitch length	0.8
	Stretch%*stitch length	1.1
	Lycra*hardness	0.2
	Stretch%*hardness	0.4
	Stitch length*hardness	0.3

From Table 3, it is recognised that stretch (%) has almost 40% contribution in imparting overall bandage pressure

4 Conclusion

The pressure developed by tubular bandage depends mainly on its structure and construction parameters. In the present study, all the parameters including lycra denier, stretch %, stitch length and hardness of limb has significant impact on pressure developed by tubular bandage. With the increase in the hardness of the surface of limb, the resulting pressure developed by bandage also increases. It is mainly due to more reaction force offered by the harder surface as compared to softer one. The increasing stretch % results in the pressure developed by bandage since more tension developed by the bandage at higher stretch %. As compare to other constructional parameters, stretch (%) of tubular bandage has most significant impact on bandage pressure. From ANOVA analysis it is concluded that stretch (%) has almost 40% contribution in imparting overall bandage pressure whereas stitch length, lycra denier and limb hardness has 20%, 20% and 16% contribution respectively.

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