(REFEREED RESEARCH)

THE EFFECTS OF INLAY YARN AMOUNT AND YARN COUNT ON EXTENSIBILITY AND BURSTING STRENGTH OF COMPRESSION STOCKINGS

DOLGU İPLİK MİKTARI VE İPLİK NUMARASININ KOMPRESYON ÇORAPLARININ ESNEKLİK VE PATLAMA MUKAVEMETİNE ETKİSİ

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ABSTRACT

In this study, an experimental work is presented to determine the effects of body and inlay yarn counts and inlay yarn amount on the extensibility and the bursting strength of knitted compression stockings. For this purpose calf high compression stockings were produced, and then bursting strength and extensibility of these stockings were tested.

The results reveal that, when the course number of inlay yarns at knit structure increases, there is a significant decrease in course way extensibility values ofcompression stockings. Bursting strength values of compression stockings knitted with coarse body and/or inlay yarns were higher than that of compression stockings with fine body and/or inlay yarn. The compression stockings with coarse inlay yarns have the highest course way extensibility values. As the result of correlation analysis, we confirmed that there was the strong correlation between “fabric way strain” which obtained by extensibility test and “the strain” which obtained by bursting strength test (correlation factor: 0.70).

Key Words: Compression stockings, Bursting strength, Extensibility, Inlay knit structure.

ÖZET

Bu makalede, uygulanan örgü yapısı ile çorabın üretiminde kullanılan zemin ve dolgu iplik numaralarının kompresyon çoraplarının esneklik ve patlama mukavemetine etkilerinin incelenebilmesi amacıyla yapılmış deneysel bir çalışma sunulmuştur. Bu amaçla işletme şartlarında diz altı tipte kompresyon çorapları üretilmiş, çorapların patlama mukavemeti ve esneklik değerleri ölçülmüştür.

Testler sonucunda, kompresyon çorabının örgü raporunda yer alan dolgu ipliği sıra sayısı arttıkça çorapların sıra yönlü esneklik değeri azalmaktadır. Kompresyon çoraplarının bilek bölümlerinde, zemin ve/veya dolguda kalın iplik kullanılması durumunda patlama mukavemetinin daha yüksek olduğu görülmüştür. Dolguda kalın iplik kullanıldığı durumda çorapların sıra yönlü esneklik değeri daha yüksek çıkmaktadır. Esneklik testinden elde edilen kumaş yönlü deformasyon ile patlama mukavemeti testinden elde edilen deformasyon değerleri arasında yüksek korelasyon bulunmaktadır (korelasyon katsayısı 0.70).

Anahtar Kelimeler: Kompresyon çorapları, Patlama mukavemeti, Esneklik, Dolgu iplikli örgü yapısı.

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1. INTRODUCTION

The main function of veins, which have one-way valves, channel the blood back into the heart. If these valves malfunction, blood does not flow efficiently and the veins become enlarged because they are congested. These incidents in varicose veins can lead to deep vein thromboses, or more lethal injuries such as embolies if the clot reaches vital organs (kidneys, lungs, heart, brain) (1). Compression stockings are a recognized effective nonsurgical option to prevent and treat lower limb varicose veins (2). These stockings, exerting an external pressure on limbs, reduce the vein diameter and increase blood flow (3).

Knitting techniques used to produce compression hosiery are flat knitting and circular knitting. These techniques provide “the control of the course wise elasticity” with different knitting structures and materials (4). In circular knitting technology, the diameter of the machine and the number of needles are fixed during production of a particular product. Diameter of the product can be changed during knitting by altering the tension of the inlay yarn and, to a lesser extent, by varying stitch length or using machines with different diameters. Compression stockings are knitted with two different yarn systems: The body yarn and inlay yarn. The body yarn delivers the thickness and stiffness of the knitted fabric; the inlay yarn produces the compression (consists in exerting an external pressure on legs). Inlay yarns are produced by wrapping polyamide or cotton around a stretchable core such as latex or elastane. Higher garment compression is mainly achieved by increasing the thickness of the elastic core of the inlay yarn. Compression stockings are mostly knitted as a RL-plain knitted structure. The knitted elastomeric fabrics used to treat the veinous disorders may be of two types: inlaid knitted structure or floatted structure (1,5).

There are many styles of compression hosiery, ranging from socks to pantyhose. Medical compression stockings of the "low, medium and high" compression classes differ in the intensity of pressure exerted on the limb. In all classes the pressure rate decreases from the ankle area with %100 to about %70 around the knee and finally %40 in the thigh (6). High quality compression stockings can exert positive effects only if it fits properly, i. e. longitudinal and circumferential measurements must take the particular anatomy of the leg, and should be exerted a uniform pressure on the limb. They mustn't prevent movements of the patient. They should be breathable. Even after being worn for an entire day, the compression stockings maintains its compressive pressure over many hours and does not loose its elastic stretch recovery (7,8).

In textile (9,10) and medical (1,11,12) literature, the techniques, which were usually used for the measurements of the pressure exerting on the limb, were investigated, and experimental studies were given. In medical literature, experimental studies were performed with the pressure sensor, which is placed between the leg and the compression stockings.

In textile literature (9,10) and standards (15-17), several testing methods like HATRA, HOSY, EMPA, MST are used for the compression and extensibility properties of compression stockings. Attempts were made to produce a European Standard (draft standard: ENV 12718), but consensus could not be achieved.

Özdil (2008), investigated thermal comfort which is very important parameter for usage performance of socks (13). Marmaralı, Ozdil and Kretzschmar (2007), measured thermal properties of half plated and full plated elastic plain knitted fabrics (14).

Unlike the previous studies, in this article, an experimental work is presented to determine the effects of body and inlay yarn counts and knit structure on the extensibility and bursting strength of the knitted compression stockings. The extensibility properties were measured in accordance with TS ENV 12718 Medical Compression Hosiery Standard. Bursting strength of compression stockings were measured with ball-bursting tester.

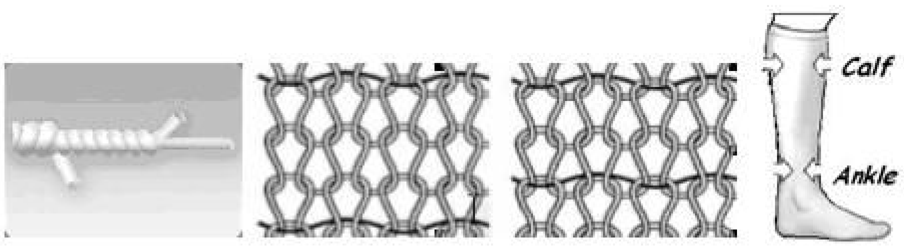
2. MATERIAL AND METHOD

2.1. Material

For the work, calf high compression stockings were knitted on a L04 MJ model Lonati circular knitting machine

Table 1. The properties of body and inlay yarns

Body Yarn Structure (Textured)	Yarn Count-Fibre Type	Inlay Yarn Structure (Double-Covered)	Yarn Count-Fibre Type
	70 Den 68 Filament Nylon		169 Den(Core:70-Elastane+Cover:40 Nylon)
	40 Den 13 Filament Nylon		253 Den (Core:90-Elastane+Cover:70 Nylon)



(a) (b) (c) (d)

Figure 1. a) Inlay yarn structure, b) The type A of knitting structure c) The type B of knitting structure d) Type of compression stockings

Table 2. The structural parameters of compression stockings

Knit Type	Yarn Count (Denier)		Course and Wale per cm (1/cm)				Thickness (mm)		Loop Length (mm)			
	Body	Inlay	Course		Wale				Inlay		Body	
			Ankle	Calf	Ankle	Calf	Ankle	Calf	Ankle	Calf	Ankle	Calf
A	70	253	26	18	29	22	0,78	0,77	1,26	2,41	1,78	3,22
B	70	253	21	16	25	18	0,67	0,76	1,95	2,50	2,72	3,31
A	40	169	27	24	14	13	0,71	0,68	2,33	2,50	2,08	3,25
B	40	169	24	18	17	15	0,68	0,72	2,03	2,81	2,12	3,46
A	40	253	19	16	29	23	0,80	0,81	1,16	2,66	1,43	3,10

with a gauge of 28, diameter of 4 inches and 400 needles with RL-inlaid knitting technique. The inlay yarn and knitting structures of compression stockings knitted for the study are shown in Figure 1. The properties of yarns are given in Table 1 and the properties of compression stockings are given in Table 2.

2.2. Method

Dry relaxation process was applied to the compression stockings samples. After the samples were taken off the knitting machine they were laid on a smooth and flat surface in standard atmospheric conditions for one week.

The following properties of the fabrics were measured after dry relaxation state: Course and wale per cm, fabric thickness, loop length, extensibility and bursting strength. The extensibility properties were measured in accordance with TS ENV 12718. This European prestandard specifies requirements and gives test methods for medical compression hosiery. In this standart, the load of 5daN was applied to the specimen within 30 seconds for extensibility test. Stretcher pins describe in the standart were not used in the experiment due to the run problem which occurs when the stretcher pins are used. For this test, three specimens were cut in both test directions (course and wale way) of size 100 mm long by 50 mm wide at measuring points ankle and at the uppermost measuring points calf (keeping the stitches and courses straight). The specimens were overlocked the lengthwise edges of the test pieces in the stretch direction with highly stretchable overlock seams. The upper yarn of the overlock stitch was Eloflex. The specimens were clamped with 50 mm clamping length in the clamps of an Instron 4301 tensile tester. The extensibility (%) is calculated as follows:

$$\text{Extensibility}(\%) = 100.\ (l_1\text{-}l_0)/\ l_0$$

l_0: Distance in mm of measuring marks or clamps in an unloaded condition(50mm)

l_1 Distance in mm of measuring marks or clamps after loading

Bursting strength experiments of the compression stockings were carried out on an Instron 4301 tensile-compressive tester which has a ball burst apparatus in accordance with ASTM D 6797-07.

Table 3. The results of SNK tests for bursting strength and extensibility of compression stockings;*

	Bursting Strength (lbf/in^2)	Extensibility (%)	
		Course	Wale
Loop Length			
Ankle	34,27b	171,59a	204,67a
Calf	28,73a	176,96a	229,95a
Yarn Count			
Fine	17,96a	140,18a	276,28b
Coarse	45,04b	208,36b	158,34a
Knitting Structure			
Type A	31,25a	183,66b	181,89a
Type B	31,75a	164,89a	252,73b

* Different letters next to the counts indicate that they are significantly different from each other at 5 % significance level.

Table 4. The results of SNK tests for bursting strength and extensibility of compression stockings;*

	The effects of inlay yarn count and loop length			The effects of body yarn count and loop length		
	Bursting Strength (lbf/in^2)	Extensibility (%)		Bursting Strength (lbf/in^2)	Extensibility (%)	
		Course	Wale		Course	Wale
Loop Length						
Ankle	22,82b	192,98a	223,53a	38,70b	264,4a	145,76a
Calf	16,79a	209,63a	209,33a	27,89a	276,9a	166,02a
Yarn Count						
Fine	17,76a	114,32a	242,43b	21,86a	288,3b	190,43b
Coarse	21,86b	288,3b	190,43a	44,74b	253,0a	121,35a

* Different letters next to the counts indicate that they are significantly different from each other at 5 % significance level.

To calculate bursting strength of compression stockings, “stress values” which obtained by compressive test were used. “strain values”, which obtained by tensile test in accordance with TS ENV 12718, were used to calculate extensibility values of compression stockings. The extensibility test was carried out in course and wale way directions while compressive test was applied in both test directions at the same time. So, the values of bursting strength were obtained more quickly than that of extensibility test. Because of this reason, the correlation analysis was performed in order to observe the relationship between results of “fabric way strain (over-all strain)” which obtained by extensibility test and “the strain” which obtained by bursting strength test. The fabric way strain was calculated as follows:

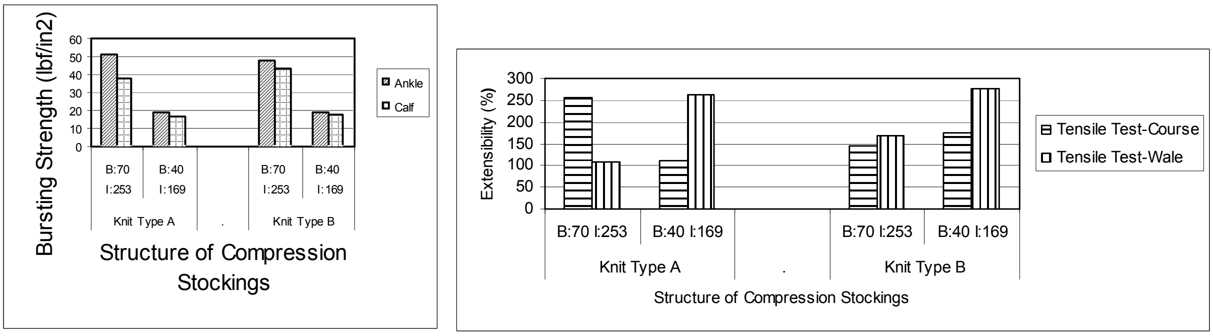
$$\text{Fabric way strain} = \sqrt{(\text{course way strain x wale way strain })}$$

The SPSS 13.0 statistical package was used for all statistical procedures. The statistical analyses were carried out using randomized three-factor analysis of variance as a fixed model in order to determine the significance of the factors (knitting structure, loop length -at the ankle or calf- and body and inlay yarn counts) on extensibility and bursting strength values.

In order to determine the effects of the inlay or body yarn count and loop length on extensibility and bursting strength values of compression stockings, completely randomized two-factor analysis of variances were carried out. The means were compared by Student-Newman-Keuls (SNK) tests. All test results were assessed at a confidence level of at least 95% (at most 5% significance level). The treatment levels were marked in accordance with the mean values and any levels marked by the same letter showed that they were not significantly different.

Table 5. The strain values of the compression stockings measured by extensibility test and bursting strength test

Knit Type	Yarn Count (Denier)		Strain Values Measured by Extensibility Test (%)						Strain Values Measured by Bursting Strength Test (%)	
	Body	Inlay	Course Way		Wale Way		Fabric Way			
			Ankle	Calf	Ankle	Calf	Ankle	Calf	Ankle	Calf
A	70	253	254,5	251,5	108,6	134,1	166,2	183,6	2573,7	2413,0
B	70	253	143,6	183,9	168,2	222,4	155,4	202,2	2556,7	2799,0
A	40	169	111,6	117,0	264,1	220,7	171,7	160,7	2263,7	2238,7
B	40	169	176,7	155,4	277,7	342,5	221,5	230,7	2847,3	2915,7
A	40	253	274,3	302,3	182,9	197,9	224,0	244,6	2680,33	2583,0



(a) (b)

Figure 2. (a) Bursting strength values versus structure of compression stockings (b) Extensibility values versus structure of compression stockings

3.RESULTS

The results of Student-Newman-Keuls (SNK) tests for bursting strength and extensibility of compression stockings with different knitting structures, yarn counts and loop length are summarised in Table 3. SNK test results of the compression stockings knitted with different inlay or body yarn count and loop length for bursting strength and extensibility for A type of structure are given in Table 4.

4. DISCUSSION

4.1. The Effects of Knitting Structure, Yarn Count and Loop Length on Extensibility and Bursting Strength of Compression Stockings

The results of the analysis of variance and SNK test for bursting strength and extensibility values are:

- **Knit Structure:** According to the variance analysis results for compression stockings, knitting structure was a significant factor affecting wale and course way extensibility of compression stockings, but the effect of knitting structure is insignificant on bursting strength. The number of inlay yarns at knit structure in type B were higher than that in type A (Figure 1-b). When the number of inlay yarns at knit structure increases, there is a significant increase in wale way extensibility values, but a significant decrease in course way extensibility values.

- **Body and inlay yarn count:** The results of the analysis of variance for bursting strength and wale and course way extensibility values reveal that the effect of body and inlay yarn count is significant in compression stockings.

Bursting strength values of compression stockings knitted with both coarse body and inlay yarn were higher than that of compression stockings with both fine ones. The compression stockings with fine inlay yarns have the highest fabric and wale way extensibility values (Figure 2-b).

-**Loop Length** (at ankle or calf)**:** According to the variance analysis results for compression stockings, loop length was a significant factor affecting bursting strength of compression stockings. When the tightness of compression stockings (ankle part) increases, there is a significant increase in bursting strength values (Figure 2-a).

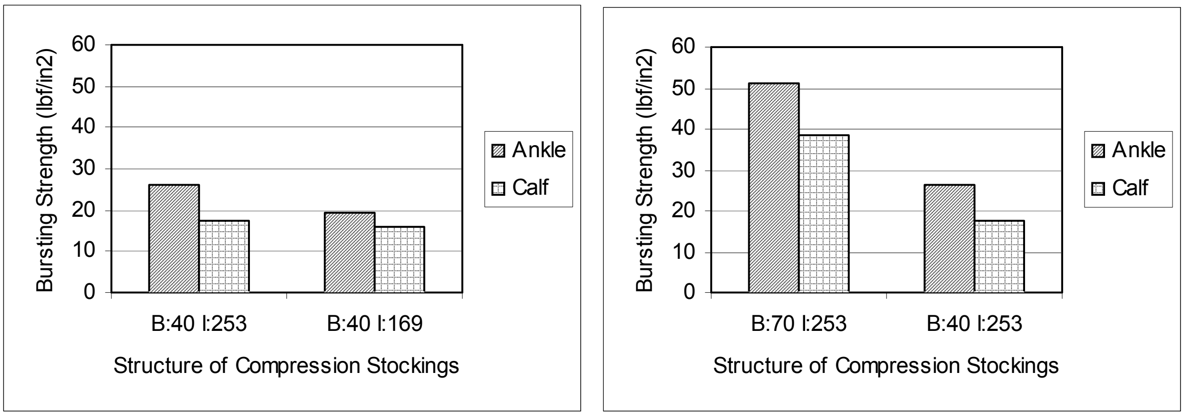
The correlation analysis was performed in order to observe the relationship between extensibility and bursting strength tests. Correlation analysis confirmed linear relationship with a high value of correlation coefficient (r≈0.70) between results of fabric way strain which obtained by extensibility test and the strain which obtained by bursting strength test.

4.2. The Effects of Inlay Yarn Count and Loop Length on Extensibility and Bursting Strength of Compression Stockings

The results of ANOVA for extensibility and bursting strength of compression stockings with type A knit structure revealed that the effect of loop length on course and wale way extensibility is insignificant. But inlay yarn count was a significant factor affecting bursting strength and wale and course way extensibility of compression stockings. According to the SNK test results given in Table 4, bursting strength and course way extensibility values of compression stockings knitted with coarse inlay yarns were higher than that of compression stockings knitted with fine inlay yarn (Figure 3a, 4).

4.3. The Effects of Body Yarn Count and Loop Length on Extensibility and Bursting Strength

The results of ANOVA for extensibility and bursting strength of compression



(a) (b)

Figure 3. Bursting strength values versus structure of compression stockings knitted with different (a) inlay (b) body yarn counts and loop lengths

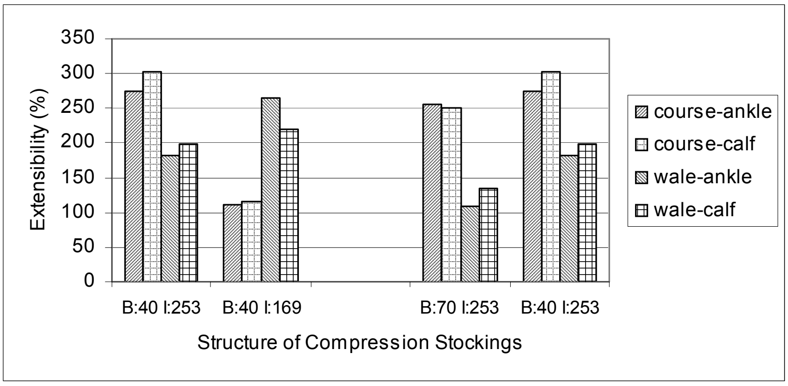


Figure 4. Extensibility values versus structure of compression stockings knitted with different inlay or body yarn counts and loop lengths

stockings with type A knit structure revealed that the effect of loop length on course and wale way extensibility is insignificant. Body yarn count was a significant factor affecting bursting strength and wale and course way extensibility of compression stockings. The compression stockings with coarse body yarns have the highest bursting strength values and the lowest extensibility values (Figure 3b, 4).

5. CONCLUSION

Up to 20% of the population may suffer from varicosities to different degrees, with women being five times as likely as men to develop symptoms [18]. Medical compression stockings are one of the most widely used mechanical compression approaches to relieve venous disorders of the lower limb as a result of their convenience and ease of use [19]. The objective of this study is to investigate the effects of body and inlay yarn counts and knit structure on the extensibility and bursting strength of the knitted compression stockings. When the results are examined, the following conclusions can be drawn.

The effect of knit structure

* The effect of knit structure on bursting strength of compression stockings is insignificant.

* When the number of inlay yarns at knit structure increases, there is a significant increase in wale way extensibility values, but a significant decrease in course way extensibility values.

The effects of body and/or inlay yarn counts

* Bursting strength values of compression stockings knitted with coarse body and/or inlay yarn were higher than that of compression stockings with fine body and/or inlay yarn.

* The compression stockings with coarse body yarns have the lowest course and wale way extensibility values. Course way extensibility values of compression stockings knitted with coarse body and inlay yarn were higher than that of compression stockings knitted with both fine body and inlay yarn for A type of stucture. The compression stockings with coarse inlay yarns have the lowest wale way extensibility values. Based on these results, we concluded that inlay yarn is very effective on course way extensibility value which is more important on the production of compression stockings.

The effect of loop length

- When the tightness of compression stockings (ankle part) increases, there is a significant increase in bursting strength values.

The testing method

* Correlation analysis confirmed linear relationship with a high value of correlation coefficient between

results of “fabric way strain” which obtained by extensibility test and “the strain” which obtained by bursting strength test. The experimental period of bursting strength test is less than that of extensibility test. Also, the specimens of bursting strength test can be ready easily. Based on these results, we concluded that bursting strength test gives an idea for extensibility of the compression stockings .

We have discussed “how this experimental investigation supports the better design of the compression stockings” and “how this experimental investigation effects the prediction of compression stockings properties” in the discussion section.

There has been a growing demand for compression stockings for several purposes like living more healthy and treating the patients with vein diseases (for example lymphodema, deep vein thrombosis and varicose veins). An appreciation of effects of knitting structure (amount of inlay yarn), body and inlay yarn counts, can assist medical doctors in selecting the most appropriate compression hosiery for their patients. And this experimental investigation also can help the better design of compression hosiery for treating the different diseases. Furthermore, it will be useful to carry out studies about the influence of body and inlay yarn counts and inlay yarn amount on the pressure of knitted compression stockings.

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REFERENCES

1. Gaied, I., Drapier, S., Lun, B., 2005, “Experimental Assessment and Analytical 2D Predictions of the Stocking Pressures Induced on a Model Leg by Medical Compressive Stockings”, Journal of Biomechanics, Vol. 39, Issue 16, pp.3017-3025.
2. Geest, A.J., Veraart, J.C.J.M., Nelesmans, P., 2000, “The Effect of Medical Elastic Compression Stockings with Different Slope Values on Edema”, Dermatol Surgery, Vol.26, pp. 244-247.
3. http://www.sigvaris.com
4. Karaca, E., 2006, Medical Textiles Course Notes, U.Ü. Textile Eng. Department, Bursa.
5. Çeken, F. and Kayacan, Ö., 2006, “An Investigation on The Production Techniques and Elasticity Properties of Knitted Bandages”, Tekstil Maraton, (2), pp.60-68.
6. Clark, M. and Krimmel, G., 2006, “Lymphoedema and The Construction and Classification of Compression Hosiery”, British Journal of Nursing, Vol. 16, Issue 10, pp.588-592.
7. Legner, M., 2005, II. International Technical Textiles Congress, ISBN:441-224-3, pp.42-52.
8. Wienert, V., Gerlach, H., Gallenkemper, G., 2007, “Medical Compression Stocking”, Journal der Deutschen Dermatologischen Gesellschaft (JDDG), Vol. 26, Issue 5, pp.410-415.
9. Liu, R. and Kwok, Y. L., 2005, “Objective Evaluation of Skin Pressure Distribution of Graduated Elastic Compression Stockings”, Dermatol Surgery, Vol. 31, pp. 615-624.
10. Maklewska, E., Nawrocki, A., Ledwoń, J., 2006, “Modelling and Designing of Knitted Products Used in Compressive Therapy”, Fibres&Textiles, Vol. 14, pp. 111-113.
11. Blättler, W., Lun, B., Uhl, J. F., 2007, “Determinants of Pressure Exerted by Medical Compression Stockings”, Phlebologie, Vol. 36, pp. 237-244.
12. Partsch, H., Winiger, J., Lun, B., 2004, “Compression Stockings Reduce Occupational Leg Swelling”, Dermatol Surgery, Vol. 30, pp. 737-743.
13. Özdil, N., 2008, “A Study on Thermal Comfort Properties of The Socks” Tekstil ve Konfeksiyon, Vol:18(2), pp.211-216.
14. Marmaralı, A., Özdil, N., Kretzschmar, S.D. 2007, “Thermal Comfort Properties of Plain Knitted Fabrics with Elastic Yarn” Tekstil ve Konfeksiyon, Vol:17(3), pp.211-216.
15. Turkish Standard (TSE), 2006, Medical Compression Hosiery TS ENV 12718.
16. European Committee for Standardization (CEN), 2001, Non-active Medical Devices. Working Group 2 ENV 12718: European Prestandard ’Medical Compression Hosiery.’ CEN TC 205 Brussels: CEN.
17. RAL Deutsches Institut für Gütesicherung und Kennzeichnung e. V., 2000, Medical Compression Hosiery Quality Assurance RAL-GZ 387.
18. Whitley, L., 2002, “Graduated Compression Hosiery”, Patient Care in Community Practice - A handbook of non-medicinal healthcare, Edited by Robin J Harman, Pharmaceutical Pr, London, (63-77)
19. Liu, R., Kwok, Y. L., 2007, “Skin Pressure Profiles and Variations with Body Postural Changes Beneath Medical Elastic Compression Stockings”, Dermatol Surgery, Vol.46, pp. 514-523.

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