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Effect of yarn type on performance of diabetic socks

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In this study, seven different samples have been knitted in jersey and piquet structures using various antibacterial yarns. Cotton, polyamide, lyocell, polyester, acrylic, viscose and their blends have been used to prepare samples. Samples are tested for thermal conductivity, air permeability, water vapour permeability, coefficient of friction, abrasion resistance and recovery after compression. Acquired data are evaluated to determine the most appropriate type of yarn to be used for the diabetic socks. Test results show that antibacterial 100% polyester yarn is the optimum yarn for a diabetic sock among all the investigated yarns. This yarn has high air and water vapour permeability. It shows low coefficient of friction, high abrasion resistance, and high recovery rate after compression.

Keywords: Acrylic, Antibacterial yarn, Clothing comfort, Cotton, Diabetic foot, Diabetic sock, Lyocell, Polyamide, Polyester, Viscose

1 Introduction

Diabetes mellitus is a chronic disease that occurs either when the pancreas does not produce enough insulin, a hormone that regulates blood sugar level in the body, or when the body cannot effectively use the insulin it produces[1]. Diabetes seriously affects many systems of the body. Diabetic foot is one of the most encountered complications of diabetes. The World Health Organization has defined the diabetic foot as "The foot of a diabetic patient that has the potential risk of pathologic consequences, including infection, ulceration, and/or destruction of deep tissues associated with neurologic abnormalities, various degrees of peripheral vascular disease, and/or metabolic complications of diabetes in the lower limb"[2]. International Diabetes Federation[3] stated that diabetic foot and complications in lower limb affect approximately 40-60 million people with diabetes worldwide.

Neuropathy and high plantar pressure are the two most common causes of foot ulceration[4]. The insensitivity of the feet, caused by neuropathy, results in absence of painful stimuli, such as high temperatures, foreign objects in the shoe and unsuitable footwear, which leads to the inability of protection of the feet[5]. In the case of diabetic ulcers, healing impairment is caused by several intrinsic factors (e.g. neuropathy, vascular problems and other complicating systemic effects dueto diabetes) and extrinsic factors (e.g. wound infection, callus formation and excessive pressure to the site)[6]. Proper socks help support the feet to guard against extrinsic factors.

Healthcare personnel usually advise their patients to wear socks made of natural fibres, such as cotton and wool. However, Feldman and Davis[7] revealed that advice of healthcare professionals often based on convention rather than on scientific evidence. In a study conducted by Cüreklibatır Encan[8], jersey and piquet structures were determined as proper fabric structures for a preventive diabetic sock and a sock model was developed.

In this research, possible effects of various antibacterial yarns on clothing comfort and physical properties of diabetic socks are investigated to find out the optimum yarn type for a preventive diabetic sock.

2 Materials and Methods

In this investigation, different samples of socks were knitted using seven types of materials (Table 1). Fibre samples considered as suitable for sock production were included in the research. Moreover, an elastic yarn (70 den nylon/20 den elastane) was fed to the needles beside the ground yarns in all samples.

Besides cotton yarn, three different antibacterial yarns were also used in Socks A, B and C. These yarns were added to fabric structures in certain

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Table 1 — Characteristics of the yarns

Sock code	Fibre	Fibre %	Yarn property	Active ingredient for antibacterial protection	Yarn count Ne	Yarn production method	Yarn twist T/m	Tensile strength, N	Breaking elongation,%
A	Cotton	95			30/1	Ring	770	2.45	7.47
	Synthetic yarn[a]	5	AB[b]	Silver	76/1 × 2 plies	Textured multifilament		1.29	43.01
B	Cotton	90			30/1	Ring	770	2.45	7.47
	Polyamide	10	AB[b]	Silver	152/1 × 4 plies	Textured multifilament		1.38	26.00
C	Cotton	80			30/1	Ring	770	2.45	7.47
	Lyocell	20	AB[b]	Zinc	30/1	Rotor	820	1.72	9.45
D	Polyester	100	AB[b]	Silver	70/1 × 2 plies	Textured multifilament		2.46	29.73
E	Viscose/acrylic	50/50	AB[b]	Zinc	30/1	Ring	615	1.53	17.77
F	Acrylic/PES/ viscose	35/35/30	AB[b]	Zinc	30/1	Ring	615	2.86	18.99
G	Acrylic	100	AB[b]	Zinc	30/1	Ring	615	3.35	37.56

[a]Not disclosed.[b]Antibacterial.

percentages, as suggested by their producers, to produce antibacterial socks according to the reports given below:

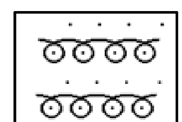
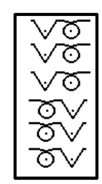
Sock A — 19 courses cotton + 1 course synthetic yarn
Sock B — 18 courses cotton + 2 courses polyamide yarn
Sock C — 16 courses cotton + 4 courses lyocell yarn

Similar yarn counts were selected for all yarn materials to compare the characteristics of the socks. However, antibacterial yarns, used in Socks A, B, and D, were thinner than the rest of the yarns used in the study. To ensure similar yarn count with other yarns, these yarns were fed to the needles as a two-ply in Sock A, four-ply in Sock B and two-ply in Sock D. Antibacterial yarn, used in Socks E and F, were bought as blended yarns.

In the previous research of Cüreklibatır Encan[8], knit structures frequently used in socks [jersey, rib (2×2), piquet and terry] were tested for fabric weight and thickness, thermal conductivity, air permeability, water vapour permeability, coefficient of friction, abrasion resistance and recovery after compression characteristics. Results revealed that jersey and piquet structures provide more advantages and a new diabetic sock model was developed accordingly. Therefore, in this study effects of antibacterial yarn type in jersey and piquet structures were investigated.

Characteristics of the sock samples are given in Table 2. All samples were knitted using Da Kong single cylinder sock machine (E14, 156 needles, 3[3/4]"), while keeping the same machine settings.

Table 2 — Characteristics of socks

Sock structure	Sock code	Mass per unit area, g/m^2	Thickness mm	Stitch diagram
Jersey	A	268	1.21	 Elastane amount: 1.5%
	B	266	1.24	
	C	271	1.23	
	D	205	1.05	
	E	276	1.31	
	F	255	1.23	
	G	250	1.24	
Piquet	A	246	1.43	 Elastane amount: 2.5%
	B	247	1.45	
	C	243	1.48	
	D	202	1.28	
	E	255	1.46	
	F	243	1.36	
	G	245	1.43	

All samples were conditioned for at least 24 h and the tests were conducted in standard atmosphere conditions (20 ± 2°C temperature, 65% ± 4relative humidity). All the samples of sock were home-washed at 40°C as suggested by Gooijer and Stamminger[9] and ISO 6330:2012 (E). Instead of using detergent, soap powder was preferred to wash the socks for patients with diabetes as recommended by doctors. The samples were dried by hanging. According to related standards, yarn twist (TS EN ISO 2061), tensile strength and breaking elongation of yarns (TS EN ISO 2062), fabric weight (TS EN 12127) and thickness (TS 3374), thermal conductivity (Alambeta instrument), air permeability (TS 391 EN

ISO 9237), water vapour permeability (BS 7209), coefficient of friction (Frictorq instrument), abrasion resistance (BS EN 13770) and recovery after compression[10] (TS 3378) values were measured. Antibacterial and antifungal efficacy tests were conducted following ISO 20743for jersey fabric structure.

Test results were evaluated using the software PASW Statistics 18 with a 95% confidence interval. The statistical method analysis of variance (ANOVA) was applied to determine the statistical importance of the variations. The probability values or p-values were examined to determine whether the parameters were significant or not. If the p-value of a parameter is greater than 0.05 ($p>0.05$), the parameter was accepted as insignificant and was ignored. When the p-value was stated as lower than 0.05 ($p<0.05$), then Student-Newman-Keuls (SNK) post-hoc test was used for homogeneous variance and Tamhane's T2 post-hoc test was used for heterogeneous variance. Independent Samples t-Testwas employed to compare fabric structures because ANOVA test cannot be applied when the variable count is less than three.

3 Results and Discussion

Table 3 shows the test results of the socks, where the mean values are marked with the letters 'a', 'b', and 'c' incrementally. The letters'a' and 'c' represent the lowest and highest values respectively. If the mean values were not significantly different, they were marked with the same letter.

3.1 Thermal Conductivity

Thermal conductivity is the property of a material that indicates its ability to conduct heat[11]. Therefore, thermal conductivity may affect either sweating or chilling of the feet.

The analyses described above show that there is a statistically significant difference between the thermal conductivity values of the socks produced from different materials for both jersey ($p=0.000$) and piquet ($p=0.000$) structures. As shown in Table 3, Sock A (95% cotton, 5% synthetic yarn) has the highest and Sock G (100% acrylic) has the lowest thermal conductivity values for both fabric structures. These results are compatible with the findings of Kawabata and Rengasamy[12]. The lowest thermal conductivity values in case of Sock G can be explained by the lower twist value and the hairy surface of the acrylic yarn, and consequently, the air trapped between these protruding fibres.

Test results show that differences in thermal conductivity values for jersey and piquet socks are found statistically insignificant ($p=0.263$).

3.2 Air Permeability

Air permeability determines the ability of air flow through the fabric[13]. The higher the air permeability, the higher will be the ventilation of feet. Ventilation of the feet helps keeping them dry.

Table 3 — Test results of socks

Fabric structure	Sock code	Thermal conductivity W/mK		Air permeability l/m^2s		Water vapour permeability, %		Coefficient of friction		Abrasion resistance cycle	Recovery after compression %
		Value	Std. dev.	Value	Std. dev.	Value	Std. dev.	Value	Std. dev.		
Jersey	A	0.061 c	0.0023	391 c	22.89	96.87 a-b	0.0270	0.3690 a	0.0028	350	68.3
	B	0.059 c	0.0016	391 c	10.44	97.40 a-b	0.0393	0.3682 a	0.0047	500	65.9
	C	0.056 c	0.0013	421 d-e	15.39	93.44 a-b	0.0181	0.3602 a	0.0027	350	67.8
	D	0.051 b	0.0006	434 e	13.75	101.45 b	0.0362	0.3711 a	0.0237	450	70.4
	E	0.051 b	0.0009	345 a	15.55	94.18 a-b	0.0243	0.3770 a-b	0.0090	225	71.4
	F	0.047 a	0.0008	409 d	10.07	93.57 a-b	0.0365	0.3826 a-b	0.0064	425	67.7
	G	0.045 a	0.0007	361 b	15.53	91.80 a	0.0235	0.3966 b	0.0061	275	70.4
Piquet	A	0.059 c	0.0011	640 c	23.22	93.44 a-b	0.0328	0.4104 a	0.0090	150	60.1
	B	0.057 c	0.0009	635 b-c	40.37	96.17 b	0.0189	0.4098 a	0.0078	250	60.5
	C	0.056 c	0.0005	637 b-c	69.13	95.70 b	0.0246	0.4132 a	0.0062	150	59.7
	D	0.048 b	0.0008	644 c	32.71	96.69 b	0.0088	0.4094 a	0.0096	300	66.3
	E	0.048 b	0.0012	520 a	17.17	92.11 a-b	0.0233	0.4026 a	0.0062	300	65.7
	F	0.046 a-b	0.0008	595 b	18.23	88.14 a	0.0000	0.4014 a	0.0106	375	64.1
	G	0.045 a	0.0002	502 a	8.88	88.37 a	0.0410	0.4196 a	0.0062	225	68.7

The mean values are marked with the letters 'a', 'b' and 'c', incrementally. The latters 'a' and 'c' represent the lowest and highest values respectively.

Statistically significant differences are found between the air permeability values of the socks produced from different materials in both jersey (p=0.000) and piquet (p=0.000) structures. Sock E (50% viscose, 50% acrylic) and Sock G (100% acrylic) have the lowest air permeability values in jersey and piquet structures respectively. This situation can be explained with the relatively more hairy structure of acrylic yarns because of the lower twist levels and higher fabric weights. These findings are compatible with the research conducted by Değirmenci and Çoruh[14]. High air permeability value of Sock D (100% polyester) is considered as the result of its low fabric weight, minimum fabric thickness, smoother yarn surface and low hairiness, which leads to higher porosity and easier air passage.

The difference between the air permeability values of jersey and piquet structures is found statistically significant (p=0.000).The cause of higher air permeability values of piquet structure is the high porosity which leads to easier air passage because of the existence of tuck stitches.

3.3 Water Vapour Permeability

Water vapour permeability which is defined as the rate at which vapour moves through a fabric, is one of the key factors in determining the breathability of textile surfaces[15]. Bacteria can grow faster in a wet environment, resulting in higher risk of infection[16]. As water vapour permeability increases, sweat can evaporate more easily.

Statistical analyses show that the difference between the water vapour permeability values of jersey (p=0.025) and piquet (p=0.002) socks knitted from different materials is significant. According to the results, Sock D (100% polyester) has the highest water vapour permeability value owing to its low fabric weight, smooth yarn surface and low hairiness of yarn; whereas, Sock G (100% acrylic) has the lowest water vapour permeability value because of the acrylic fibre content and low twist level.

The difference between water vapour permeability values of jersey and piquet structures is found statistically significant (p=0.043). Lower fabric thickness values of jersey structure are the reason for higher water vapour permeability.

3.4 Coefficient of Friction

The frictional force is the resistance to the relative motion of one object while sliding over itself or another object. The friction coefficient of fabric is a parameter that determines the degree of fabricsmoothness and comfort[17]. As friction can lead to foot ulceration[18], socks with low coefficient of friction becomes a necessity.

According to the statistical evaluation, there is a significant difference between the coefficient of friction values of the socks produced from different materials in jersey (p=0.017) structure. The coefficient of friction values of Sock C (80% cotton, 20% lyocell) and Sock G (100% acrylic) have the lowest and highest values respectively in jersey structure. The coefficient of friction value of Sock C is low because of less hairiness and less thin-thick places in used ring-spun cotton. Additionally, high twist levels of cotton yarn and lyocell yarn contribute to the less hairiness. The high coefficient of friction value of Sock G is the result of its acrylic content and low twist level. However, the difference between yarn materials for piquet structure is insignificant (p=0.186). It is thought that the effect of surface roughness on the friction coefficient is more important than the effect of yarn type.

The statistical evaluation shows that there is a significant difference between the coefficient of friction values of the socks produced in jersey and piquet structures (p=0.000). It is observed that the fabric structure has a more important effect on the coefficient of friction than the type of yarn. This result is compatible with the findings of Ke *et al.*[19].

3.5 Abrasion Resistance

Abrasion resistance is the ability of a fabric to resist surface wear caused by flat rubbing contact with another fabric[20]. Abrasion resistance defines the lifespan of socks.

Sock B (90% cotton, 10% polyamide) and Sock E (50% viscose, 50% acrylic) have the highest and lowest abrasion resistance values respectively for jersey structure (Table 3). Polyamide fibre is considered the reason for the higher abrasion resistance of Sock B, because of its relatively higher breaking elongation value. This result is compatible with the findings of Ertekin and Marmaralı[21]. On the other hand, in piquet structure, Sock F (35% acrylic, 35% polyester, 30% viscose) has the highest abrasion resistance, while Sock A (95% cotton, 5% synthetic yarn) and Sock C (80% cotton, 20% lyocell) have the least values. For Sock A and Sock C, the relatively lower breaking elongation values of cotton and lyocell fibres are the reason for being the least resistant in piquet structure.

When the abrasion resistance results of fabric structures are investigated, it can be seen that jersey structure generally has higher abrasion resistance values. As tuck stitches can easily cling to other surfaces and drawn away, the existence of tuck stitches in piquet structure decreases abrasion resistance. As a result, it may be stated that the fabric structure has a higher impact on abrasion resistance than material.

3.6 Recovery after Compression

Recovery after compression is the measure of fabric resilience, also known as the work of recovery, it shows how well the fabric recovers when the applied force is withdrawn. High plantar pressure is one of the most prevalent risk factors of foot ulceration[4]. The higher a sock recovers from compression, the better it protects the feet from the negative effect of plantar pressure.

Table 3 shows that Sock E (50% viscose, 50% acrylic), Sock D (100% PES) and Sock G (100% acrylic) for jersey structure and Sock G (100% acrylic) for piquet structure have the highest recovery values after compression. The high recovery values after compression of acrylic fibre are considered to be caused by the high resilience characteristics and low specific flexural rigidity of this fibre as mentioned in previous research[22, 23].

It is observed that jersey structure has higher recovery values after compression than piquet structure for all socks made of different materials (Table 3). This situation can be explained by the less resilience ability of tuck stitches than loops.

3.7 Antibacterial and Antifungal Efficacies

It is observed that antibacterial polyester yarn used in Sock D is the optimum yarn type for diabetic socks, considering its following characteristics:

- Average thermal conductivity, highest air and water vapour permeability, low coefficient of friction, high abrasion resistance, high recovery after compression values in jersey structure,
- Low thermal conductivity, high air permeability, highest water vapour permeability, low coefficient of friction, high abrasion resistance, high recovery after compression values in piquet structure.

Fungal infection is a common medical problem for diabetics[24]. The antifungal efficacy of yarn in Sock D, characterised as an antibacterial yarn by its producer, also has been tested as per the related standards. Results have been interpreted according to the R-value. The tested sample is categorised as bacteriostatic/fungistatic when R-value is ≤ 2. Table 4 represents that yarn in Sock D has both bacteriostatic (against *K. pneumonia* and *S. aureus*) and fungistatic (against *C. albicans*) effects, which means that it prevents bacteria and fungi from reproducing.

Table 4 — Test results of antibacterial and antifungal efficacies

Organisms	R	Acceptance criteria
K. pneumonia (ATCC 4352)	0.23	≥ 2 log
S. Aureus (ATCC 6538)	0.18	≥ 2 log
C. Albicans (ATCC 10231)	0.43	≥ 2 log

A clinical wear trial with the participation of patients with diabetes is conducted to determine the efficiency of the developed sock knitted using selected yarn[25]. It is observed that the results are promising in terms of both plantar pressure and user satisfaction.

4 Conclusion

Test results reveal that yarn used in Sock D is the optimum yarn for a diabetic sock among the investigated yarns. This selected yarn (i) prevents feet from overheating or chilling with its average thermal conductivity, (ii) helps avoid sweating and wetting owing to its high air and water vapour permeability, (iii) protects feet from ulcer formation with its low coefficient of friction, (iv) provides a longer lifespan for the sock with high abrasion resistance, and (v) supplies more comfort and protection with its high recovery rate after compression. Additionally, it prevents bacteria and fungi from reproducing, which also leads to protection of feet from ulceration.

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