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Modified Cotton Socks – Possibility to Protect from Diabetic Foot Infection

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ABSTRACT

Diabetes has become a major public health problem and grows rapidly in the most developed countries of the world. Beside genetic and environmental factors, lifestyle habits play an important role in the development and progression of diabetes mellitus. According to the World Health Organization (WHO) about 15% of diabetic patients develop a foot ulcer in need of medical care. Infection is a serious complication and it is the major responsible cause of lower limb amputation. In this paper the possibility to protect from diabetic foot infection with modified cotton socks. Therefore, the socks made of modified cotton yarn by natural minerals and active carbon were investigated in vitro (fabric hand – friction and adsorption) and in vivo (3 IDDM, 4NIDDM, 3 GDM to sweat and fabric hand) to accomplish highest possible level of comfort for diabetic patients. Antimicrobial protection to Gram positive, Gram negative and micro fungi was determined as well. For durability all the characteristics were investigated after 15 washing cycles.

Key words: *diabetes mellitus, diabetic foot, socks, zeolite, minerals, active carbon, antimicrobial protection, adsorption, fabric hand*

Introduction

Diabetes mellitus and its chronic complications are the major public health problem and grow rapidly in the world. Over 366 million people are currently affected worldwide with diabetes mellitus, and by the year 2030 the number of diabetic patients will increase to 552 million. Number of people with diabetes increase in all countries, but 80% live in the most developed countries, and newly industrialized countries[1]. In Croatia, the prevalence of diabetic patients aged between 18 and 65 is 6.5% of population. In 2010 the number of Croatian people with diabetes was approximately 316000, of which 190000 diagnosed, while almost 123000 stays undiscovered[2].

It is well known that beside genetic factors, environmental and lifestyle habits play an important role in the development and progression of diabetes mellitus, especially type 2. Physical inactivity, unhealthy diet, smoking and alcohol, well known risk factors for developing diabetes type 2, contribute to bad regulation of existing diabetes mellitus[3]. Lifestyle and nutrition of diabetic patients are very far from guidelines of the World Health Organization (WHO). On the other hand, body weight and physical activity are critical factors for diabetes prevention in persons with normal and impaired glucose tolerance. They are very important in the regulation of the disease and development of its chronic complications as well[3,4].

There are several types of this disease different by origin, treatment and clinically[5]:

- Type 1 – insulin-dependent »juvenile-onset« diabetes (IDDM), an auto-immune disease where the body's immune system destroys the insulin-producing beta cells in the pancreas. Commonly appear under age of 40, and is triggered by environmental factors such as viruses, diet or chemicals in people genetically predisposed.
- Type 2 – non-insulin dependent diabetes (NIDDM), »adult-onset« diabetes, is characterized by insulin resistance and relative insulin deficiency. The disease is strongly genetic in origin but lifestyle factors such as excess weight, inactivity, high blood pressure and poor diet are major risk factors for its development. People with type 2 diabetes are twice as likely to suffer cardiovascular disease.
- Gestational diabetes mellitus (GDM) is first diagnosed during pregnancy through an oral glucose tolerance test. Risk factors for GDM include a family history of

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diabetes, increasing maternal age. While the carbohydrate metabolism disturbance usually returns to normal after the birth, the mother has a significant risk of developing permanent diabetes while the baby is more likely to develop obesity and impaired glucose tolerance and/or diabetes later in life.

– Other special types.

Type 2 diabetes is the most common form of diabetes, affecting 85–90% of all people with the disease; only 8% are the people with diabetes type 1. The rest goes to the other types of the disease. Regardless on type, postulates for diabetes treatment are the same – nutrition, exercise, self-control, per oral hypoglycemic drugs, insulin. Following these five postulates in the most cases diabetes can be well regulated, and the micro and macro vascular complications, that make the main problem to patients and the biggest expense to insurance companies, postponed. According to ADA (American Diabetes Association) diabetes direct expenses in the USA currently are 174 billion USD. The expenses of invalidity, absence from work, or death are not included in this calculation[6]. In Croatia, diabetes mellitus treatment is great financial burden as well. Latest data for the year 2009 state that only Croatian Institute for Health Insurance spent 2.5 billion HRK (11.49% of budget) to diabetes treatment, 85.72% was spent on diabetic complication treatment, while 14.28% was spent on patient control for drugs and insulin[2]. The expenses of invalidity, absence from work, or death are not included in this calculation as well.

A higher risk of cardiovascular events in people with diabetes is a consequence of risk factors, such as dyslipidemia, hypertension, hyperglycemia, hyperinsulinemia. Increased oxidative stress with creation of end products of glucolisation, thrombosis and fibrinolysis leads to progression of atherosclerosis and occurrence of cardiovascular events[5]. According to the World Health Organization (WHO) about 15% of diabetic patients develop a foot ulcer[7]. Ulcers on diabetic foot are the result of diabetic neuropathy and ischemia. Neuropathy is characterized by loss of protective sensation and biomechanical abnormalities. Loss of sensation in the foot can allow unperceived trauma, contributing to plantar ulceration in areas of high pressure points of foot. Present sweating disorder contributes to the skin vulnerability as well.

Circulation disorder reduces blood flow resulting in necrotic tissue that is a good foundation for infection[8]. Diabetic foot infection is common complication of diabetic patients, responsible for large number of lower limb amputation[7]. From diabetic foot ulcers the coagulase-negative staphylococcus, enterobacteria and aerobe streptococcus are isolated[9]. Enterobacteria have fecal origin; they are Gram negative bacteria that include pathogens such are *Escherichia coli, Proteus spp, Klebsiella spp, Salmonella, Yersinia pestis* etc. Anaerobic microorganisms are more common at severe infections[9]. Micro fungi and viruses are very rare in diabetic foot infection, but they are responsible for unpleasant foot odors.

Textiles are an excellent substrate for bacterial growth under appropriate moisture and temperature conditions, resulting in the most unpleasant odors, stains, deterioration in products that lead to loss of storage and transportation, allergic reactions, diseases and infections and more. On the other hand, it can give antimicrobial protection, providing long lasting freshness and sense of security and welfare of consumers[10–14]. Modern way of life and work contributes to the growth of microbes. Rapid development of antimicrobial treatment been notified in recent years. Antimicrobial agents should be effective against microorganisms, but not adversely affect the man and the environment. Should be resistant to care products, keep all the material properties, and of course, simple to use. Act to kill (bactericide) or prevent the development of (bacteristatic) microorganisms. They differ in chemical structure, mode of action (migrating or non-migrating), stability, efficiency, safety, price. Migratory agents diffuses from the product and come in contact with germs, they consume them and destroy the chemical cell (poisons). The disadvantage is that after some time microorganisms can adapt to them. Best known as bis-chlorinated phenols (triclosan), organic compounds (TBT, tributyl tin oxide), organometallic complexes of heavy metals (Pb, Hg, As, etc), Ag & Cu zeolites, chitin, azalides, antiseptics and others. Non-migrating agents bond to the product and micro-organisms do not consume them, but mechanically attack the cell wall. Remain effective for the entire life of the product and do not create adaptive organisms. These are organofunctional silane, N-halamine, Aegis® technology and more[14–16]. Antimicrobial treatment in textiles are commonly used for hosiery, sportswear and work clothes, shirts, towels, underwear and other textiles for bedrooms, hygiene and medical (surgery), textile, inside shoes, filters, geotextiles, wipes, dusters and more. At first glance it appears easy to accomplish good antimicrobial protection if you have a good antimicrobial agent, but the persistence of such processing is a bigger problem. It should not be ignored that all available agents are not dermatological acceptable[10–16].

Since textile can provide good antimicrobial protection, long lasting freshness and sense of security, in this paper the possibility to protect from diabetic foot infection with modified cotton socks. For protective socks it is important that they have no seams on the fingers and not adhering to the foot, in order to reduce friction and skin irritation, should be made of the finest fibers that effectively control the moisture, in order to provide the highest possible level of comfort[17–20]. In Italy, the stockings developed superior technology; Reflex® (Intersocks) made from synthetic fibers and processed with Aegis® technology[20]. In this paper the socks made from a modified cotton yarn with natural minerals and activated carbon, were investigated *in vitro* (hand, adsorption, friction) and *in vivo* (sweat, hand) to accomplish highest possible level of comfort for diabetic patients. The antimicrobial protections, as well as comfort for diabetic patients were investigated even after 15 washing cycles.

Materials and Methods

This paper deals with the possibility to protect from diabetic foot infection with modified cotton socks. For that purpose, four sets of the winter and summer socks were made on a single knitting machine. Labels and properties of socks are collected in Table 1.

TABLE 1
SAMPLES PROPERTIES

Sample	Description	Yarn	Mass per surface area [g/m^2]	Knit
1	Winter	Cotton	240	Double
2	Summer		225	Single
1M	Winter	Cotton/ Minerale™	241	Double
2M	Summer		226	Single
1AC	Winter	Cotton/ Cocona®	241	Double
2AC	Summer		226	Single
1Z	Winter	Cotton/ TMAZ	248	Double
2Z	Summer		228	Single

First set was made of pure cotton yarn. Second set was made of Minerale™ yarn (Cocona inc) blended with cotton yarn. Minerale™ yarn is yarn embedded with crushed volcanic minerals. Third set was made of Cocona® yarn (Cocona inc) blended with cotton yarn. The Cocona® yarn, originally patented in the USA, is infused with activated carbon from coconut shells. Fabrics made from Cocona® yarns are lightweight, comfortable and retain all other product features, such as stretch and washability for the life of the product. As a complementary technology to Cocona®, Minerale™ fabrics provide a means to have pure white, pure colors, and finer denier fabrics. Fourth set of socks was made of modified cotton yarn with tribomechanical activated natural zeolite (TMAZ). TMAZ is produced in patented machine by tribomechanical processing for high activation of zeolite, and implemented as micro- and nanoparticles to cotton yarn during the mercerization process similar to cationisation, suggested by Grancaric, Tarbuk et al.[14–16,21,22].

For the durability of the characteristics accomplished by yarn modification all the properties were determined before and after 15 washing cycles according to ISO 6330:2000[23] using ECE standard detergent without FWA's.

The antimicrobial protection against Gram positive *Staphylococcus aureus* and Gram negative *Klebsiella pneumoniae* bacteria was determined according to EN ISO 20645:2004[24], and to micro fungus *Candida albicans* according to EN 14119:2003[25]. Both of these methods are based on creation of inhibition zone, *H,* that can be calculated from Specimen diameter, *d*, and Specimen activity, *D,* according to the equation (1):

$$H = \frac{D-d}{2}[mm] \qquad (1)$$

The comfort of diabetic patients was determined *in vitro* and *in vivo*. For the purpose of *in vivo* comfort measurement 10 diabetic patients were selected – 3 IDDM, 4 NIDDM, 3 GDM.

One of the most important comfort characteristic is fabric hand. It is usually defined as »the subjective assessment of a textile material obtained from the sense of touch«[22] or according to AATCC EP 5 as »the tactile sensation or impressions which arise when fabrics are touched, squeezed, rubbed or otherwise handled«[26]. A critical assessment of hand is usually relation between subjective assessment and objective measurement of eight physical properties – four related to bending, two to shearing, fabric drape and friction. Fabric hand was determined according to subjective and objective (coefficient of kinetic friction) evaluation. For the subjective evaluation (*in vivo*) there are defined guidelines in AATCC EP 5 in which 10 evaluators performed subjective hand evaluation and ranked fabrics according the physical attributes of hand. For objective measurement of dynamic or kinetic friction coefficient, μ_{kin}, fabric surface tester FRICTORQ[22], was used. A circular fabric sample of radius, *r*, is clamped and forced to rotate around a vertical axis at a constant angular velocity while a vertical load, *P*, is concentrically applied by a static upper body by means of three small contact sensors, placed in a circle at 120°. Friction coefficient is then proportional to the level of the dragging torque, *T*. Contact pressure of approximately 3,5 kPa is constant during the test. The torque signal is digitalized through an electronic interface and fed into a personal computer where dynamic or kinetic friction coefficient, μ_{kin}, is worked out and displayed, according to[22]:

$$\mu_{\mathrm{kin}} = \frac{T}{P \cdot r} \qquad (2)$$

The most important characteristic for the comfort, besides the fabric hand, is the liquid adsorbility (sweat, water, surfactant). Therefore, the water adsorption of cotton fabrics was determined through Water Retention Value (WRV) according to DIN 53814:1961[27]. Adsorption of 0.001 M ionic surfactant – anionic Na-dodecyl sulphate (NDDS) and cationic N-cetyl pyridinium chloride (N-CPC) was determined by potentiometric titration[21,28] using autotitrator Titrino 736 (Metrohm). Ion selective electrode responding to surfactant concentration applying titrants: Hyamine 1622 (benzetonium chloride) and NDDS was used. *In vivo* diabetic patients evaluated sweating during wearing the socks for 10 hours.

Results and Discussion

The possibility to protect from diabetic foot infection with socks made from a modified cotton yarn with natural minerals and activated carbon was researched. Therefore, winter and summer socks were produced from cotton and cotton blends. The socks antimicrobial properties against Gram positive bacterium *Staphylococcus aureus*, Gram negative *Klebsiella pneumoniae* and the micro fungi *Candida albicans* were tested according to standardized methods. Antimicrobial activity of winter cotton socks modified with activated carbon is shown in Figure 1. The textile sample, round in shape, was covered with culture medium in the Petri dish. During the incubation, knitted fabric has rolled, but the results are still evident. According to standard it is necessary to move the test samples from substrate to determine activity. That means that it is not necessarily to have the inhibition zone for antimicrobial activity, and it is sufficient that under the sample the culture did not grow, what is clearly shown in Figure 1. The results of the antimicrobial activities of all specimens before and after 15 washing cycles are collected in Table 2.

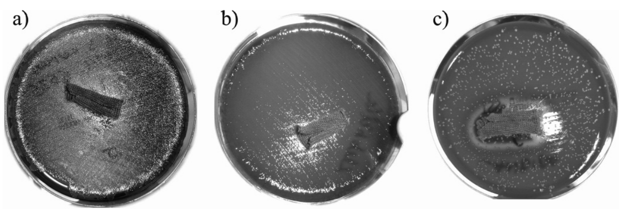

Fig. 1. Antimicrobial activity of cotton winter socks modified with activated carbon (1AC) – a) Staphylococcus aureus, b) Klebsiella pneumoniae, c) Candida albicans.

From the results shown in Table 2 is evident that unmodified cotton socks (samples 1 and 2) do not show any activity to any microorganism. Modification of cotton yarn with natural minerals (sample 1M), and active carbon (sample 1AC), results in minor antibacterial activity to Gram positive *Staphylococcus aureus* but only for winter socks, whilst modified cotton yarn during mercerization with natural zeolite (samples Z) shows activity for both, summer and winter socks. On the other hand, there is a significant activity to the Gram negative bacterium *Klebsiella pneumonia* for cotton blend with Cocona® yarn (samples AC). All socks made from cotton blend with Cocona® yarn showed activity regardless of the sock thickness (winter and summer socks). However, socks made from a modified yarn with natural minerals (samples M), show activity only for winter socks (1M). The socks made of TMAZ implemented cotton yarns (samples Z) showed activity for both thickness, as well. All socks made from modified cotton, regardless of natural minerals/zeolite and active carbon, show significant activity against micro fungus *Candida albicans*. It should be noted stronger activity using modified activated carbon yarn (samples AC), which comply with EN 14119:2003 show not only activity, but also a zone of inhibition. Considering durability, for winter socks protective ability stays unchanged even after 15 washing cycles.

It is to point out that summer and winter socks were made of the same yarn, however, thickness of sock itself played an important role. In the thicker sock more mineral/zeolite/active carbon particles are present, since more fibers and therefore accessible active groups are present in the thicker sock, resulting in better antimicrobial activity. The mineral/zeolite/active carbon particles do not give direct antimicrobial effect. They create the conditions of dry environment in the socks, absorbs moisture, as a great adsorbents, preventing the development/growth of microorganisms.

As it was said for socks is important that they reduce friction and skin irritation, and should be made of the finest fibers that effectively control the moisture, to provide the highest possible level of comfort. Therefore, subjective *in vivo* evaluation performed 10 diabetic patients (3 IDDM, 4 NIDDM, 3 GDM) according to AATCC EP 5 guidelines; and objective evaluation of fabric hand by kinetic friction coefficient, μ_{kin} determination. The results are presented in Table 3.

From the results in Table 3 it is quite evident that the cotton yarn modification effects fabric hand. All the evaluators reported that unmodified cotton socks are slightly softer having smooth surface that modified ones regardless of thickness or particles for cotton yarn modification. These attributes equalize with the wearing and washing; all the cotton socks after 15 washing cycles become soft

TABLE 2
ANTIMICROBIAL ACTIVITY OF MODIFIED COTTON SOCKS BEFORE (0W) AND AFTER 15 WASHING (15W) CYCLES

Sample	Staphylococcus aureus				Klebsiella pneumoniae				Candida albicans			
	Activity		H [mm]		Activity		H [mm]		Activity		H [mm]	
	0W	15W	0W	15W	0W	15W	0W	15W	0W	15W	0W	15W
1	–	–	0	0	–	–	0	0	–	–	0	0
2	–	–	0	0	–	–	0	0	–	–	0	0
1M	+	+	0	0	+	+	0	0	+	+	0.5	0.4
2M	–	–	0	0	–	–	0	0	+	+	0	0
1AC	+	+	0	0	+	+	0	0	+	+	0.5	0.5
2AC	–	–	0	0	+	–	0	0	+	+	0.5	0.4
1Z	+	+	0.4	0.2	+	–	0	0	+	+	0.2	0
2Z	+	+	0.2	0.1	+	–	0	0	+	+	0	0

H – inhibition zone

TABLE 3
SUBJECTIVE (*IN VIVO)* AND OBJECTIVE *(IN VITRO)* EVALUATION OF COTTON SOCKS HAND BEFORE (0W) AND AFTER 15 WASHING (15W) CYCLES

Sample	Evaluation of socks hand									
	In vivo								*In vitro**	
	Compression		Bending		Shearing		Surface		μ_{kin}	
	0W	15W	0W	15W	0W	15W	0W	15W	0W	15W
1	Softer	Soft	Limp	Limp	Firm	Firm	Smooth	Smooth	0.260	0.265
2	Softer	Soft	Limp	Limp	Firm	Firm	Smooth	Smooth	0.232	0.235
1M	Soft	Soft	Limp	Limp	Firm	Firm	Little bit rough	Smooth	0.255	0.249
2M	Soft	Soft	Limp	Limp	Firm	Firm	Little bit rough	Smooth	0.245	0.238
1AC	Soft	Soft	Limp	Limp	Firm	Firm	Little bit rough	Smooth	0.244	0.240
2AC	Soft	Soft	Limp	Limp	Firm	Firm	Little bit rough	Smooth	0.241	0.237
1Z	Soft	Soft	Limp	Limp	Firm	Firm	Little bit rough	Smooth	0.247	0.244
2Z	Soft	Soft	Limp	Limp	Firm	Firm	Little bit rough	Smooth	0.238	0.237

*20 measurements, p>0.05

and smooth. It can be assumed that some particles of natural mineral and active carbon incorporated in cotton yarn are washed out resulting in better hand of cotton socks. The objective measurement of dynamic coefficient of friction confirms that. Even though the natural minerals and active carbon particles were incorporated in cotton yarn structure, the friction coefficient was almost the same as on unmodified cotton socks. It can be noticed that the friction of modified socks is even slightly lower than the friction of untreated cotton yarn for all winter socks. After 15 cycles washing of modified cotton socks all the coefficients resulted in lower value, confirming lower friction and better hand. Contrary, it is evident that unmodified cotton socks have higher friction coefficient as a result of wear down.

Ten diabetic patients tested socks *in vivo* for 10 hours and reported subjective above the sweat and odor. Regarding the moisture content objective measurement of water and ionic surfactant adsorption were performed. The results are collected in Table 4.

Subjective assessment of comfort by 10 diabetic patients led to the same conclusion regardless on type of diabetes – IDDM, NIDDM, GDM. In unmodified cotton socks they sweat a lot having odor after 10 h, while wearing the modified ones they did not sweat and there was no odor regardless on particles used for cotton yarn modification. The situation changed after 15 washing cycles – socks made of cotton yarn modified with active carbon still retain its properties, while the ones modified with natural minerals lose some particles leading to lower absorbency

TABLE 4
SUBJECTIVE (*IN VIVO)* AND OBJECTIVE (*IN VITRO)* EVALUATION OF THE ADSORBILITY OF COTTON SOCKS BEFORE (0W) AND AFTER 15 WASHING (15W) CYCLES

Sample	Adsorbility of cotton socks									
	In vivo				*In vitro**					
	SWEAT		ODOR		WRV [%/g sock]		0.001 M NDDS [%/1 g sock]		0.001 M N-CPC [%/g sock]	
	0W	15W	0W	15W	0W	15W	0W	15W	0W	15W
1	Sweat a lot	Sweat a lot	Odor	Odor	31.0	25.5	14.0	14.2	90.0	92.3
2	Sweat a lot	Sweat a lot	Odor	Odor	30.1	24.3	6.3	6.8	80.9	85.6
1M	No sweat	Sweat	No odor	Odor	33.1	30.1	10.6	11.2	55.6	52.1
2M	No sweat	Sweat	No odor	Odor	32.2	29.8	12.0	12.4	55.4	51.8
1AC	No sweat	No sweat	No odor	No odor	39.2	38.6	9.5	9.6	47.9	49.1
2AC	No sweat	No sweat	No odor	No odor	37.6	37.2	9.4	9.6	48.0	49.3
1Z	No sweat	No sweat	No odor	No odor	35.3	33.3	10.3	10.0	62.2	64.1
2Z	No sweat	Sweat	No odor	Odor	32.1	31.7	10.8	10.7	62.5	63.8

*10 measurements, p>0.05

and perspiration which lead to sweat and odor. Additionally, the pregnant women having gestational diabetes mellitus have reported of not having micro fungi on their feet like most of the other pregnant women stationed in the same hospital. This could be expected but it was still surprising since the research took one month.

Similar results showed objective measurements of adsorption presented in Table 4. In general adsorption of water, surfactant and dyes occurs primarily on the available-OH groups of cotton cellulose. Since increasing of their number increases the cotton adsorption, winter sock which has more fibers and therefore more accessible active groups, has slightly higher adsorption. Dissociation of surface acidic functional groups (–OH, –COOH) of cotton cellulose show a negative charge, therefore it adsorbs significantly higher amounts of cationic than anionic surfactant. From the results it can be seen that modification of cotton yarn increase water adsorption from 31% to 33% for natural minerals and to 39% for activated carbon. Adsorption of surfactants on the textile fibers is very complex mechanism, which occurs mainly by electrostatic interactions between surfactant surface groups and specific accessible fiber groups. Cotton is negatively charged in neutral aqueous solutions, so in adsorption process it is necessary to overcome potential barrier of the negatively charged fiber surface[20,27]. Therefore the adsorption rate of anionic surfactant NDDS is low as result of electrostatic repulsion interactions. Modification of cotton yarn with natural minerals, natural zeolite and activated carbon led to smaller adsorption of cationic surfactant N-CPC suggesting the neutralization of surface which improves the sock comfort. It is to point out that these properties remain even after 15 washing cycles.

These results confirm that by modification of cotton yarn the conditions of dry environment in the socks are made, preventing the development/growth of microorganisms. Cocona® yarn rapidly moves perspiration over an enormous surface area, which is created by the pores of the activated carbon from coconut. Minerale™ yarn, as well as TMAZ implemented in cotton during mercerization, has increased surface area, acting as great adsorbents. Increasing surface area creates improves wicking and perspiration, picking it quickly up off the skin. All modified cotton socks absorb moisture and give no odor. It is to assume that organic odor molecules are attach to the carbon/activated zeolite surface. Since the active carbon is a major adsorbent the achieved results are the best.

Conclusion

Socks made from cotton yarn provide some comfort but do not provide antimicrobial protection. Modifying yarn with natural minerals and activated carbon antimicrobial protection can be achieved, particularly against micro fungi *Candida albicans*. However, modifying cotton during mercerization with TMAZ results in good antibacterial activity to Gram positive *Staphylococcus aureus*. The mineral/zeolite/active carbon particles do not give direct antimicrobial effect, but create the conditions of dry environment, preventing the growth of microorganisms. Since the active carbon is a major adsorbent, the best antimicrobial protection is achieved with the cotton socks modified with it. At the same time, those socks show better adsorption and almost the same or even better lower friction which leads to better comfort. The achieved properties remain even after 15 washing cycles. All diabetic patients that tested in vivo modified cotton socks reported of better comfort and freshness regardless of diabetes type. Therefore, it is to recommend using such modified cotton socks for all those who lead active and healthy life, as well as diabetes patients.

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MODIFICIRANE PAMUČNE ČARAPE – MOGUĆNOST SPRIJEČAVANJA INFEKCIJE DIJABETIČKOG STOPALA

S A Ž E T A K

Šećerna bolest (dijabetes) je postala važan zdravstveni problem i brzo raste u najrazvijenijim zemljama svijeta. Osim genetskih čimbenika i utjecaja okoliša, navike igraju važnu ulogu u razvoju i progresiji šećerne bolesti. Prema podacima Svjetske zdravstvene organizacije (WHO), u oko 15% dijabetičara razvije se vrijed na stopalu te imaju potrebu za medicinskom skrbi. Ova infekcija je ozbiljna komplikacija i glavni je uzrok amputacije donjih ekstremiteta. U ovom radu istražena je mogućnost zaštite od infekcije dijabetičkog stopala modificiranim pamučnim čarapama. U tu svrhu istražene su čarape izrađene od modificirane pamučne pređe prirodnim mineralima i aktivnim ugljenom *in vitro* (opip – trenje i adsorpcija) i *in vivo* (3 IDDM, 4NIDDM, 3 GDM na znoj, miris i opip) kako bi ostvarili najveću moguću razinu udobnosti za dijabetičare. Također je određena antimikrobna zaštita od Gram pozitivnih i Gram negativnih bakterija te mikrogljivica. U svrhu istraživanja postojanosti, sva svojstva ispitana su nakon 15 ciklusa pranja.