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ANALYSIS OF PRESSURE PARAMETERS IN ORTHOPEDIC FOOTWEAR FOR PEOPLE SUFFERING FROM DIABETIC FOOT SYNDROME

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ABSTRACT

The paper examines the anthropotechnical design of orthopedic footwear for patients with diabetic foot syndrome. A 3D distance knitted fabric is used for the shoe insert. For the purpose of the research, a 7 mm thick knitted fabric with transverse elasticity of 76 kPa was designed and produced on a double-bar warp knitting machine. With the use of the FreeMed Professional strain gauge mat, the pressures exerted by the foot on a „bare" walking surface and on the surface equipped with the distance knitted fabric were measured and compared, proving that in the latter case the unit pressure on the patient's foot decreased by 25%. The obtained measurements provide a good starting point for further research on the optimization of loads on the human foot, in case of various lower limbs diseases, including anatomical changes, as well as and in relation to people who are physically overloaded due to working in standing position or being in constant motion.

KEYWORDS

diabetic foot, 3D distance knitted fabric, strain gauge mat.

INTRODUCTION

Diabetes mellitus is a serious disease which is more and more common and many medical specialists classify it as social disease [1,2]. The number of people suffering from diabetes in Poland and all around the world is growing dynamically. According to the estimates made by the International Diabetes Federation (IDF), in 2020 there were over 400 million adults with diabetes in the world. Diabetes mellitus may lead to the development of diabetic foot syndrome and due to the complications resulting from the violation of biochemical processes in the human body, may cause tissue degradation, non-healing wounds, physical deformities of the feet, gait disturbances and, in the worst cases, may result in complete amputation of the limb [3–5].

Footwear worn by people suffering from diabetic foot syndrome should be designed so as to evenly distribute the loads exerted on the foot, eliminating pressure peak points to avoid blood circulatory disorders and obstruction of blood supply [6].

The main purpose of the research presented in the paper was to analyze surface distribution of pressure exerted by the human foot on the shoe sole equipped with an orthopedic insert made of a 3D distance knitted fabric.

The methods of measuring pressure exerted on the human foot by his own body weight in the static and dynamic system are mainly based on rigid or flexible measuring platforms equipped with sensors for pressure measurements [7].

MATERIALS AND METHODS

The research material for this work is a prototype of a shoe insert in the form of a 3D distance knitted fabric. It was assumed that an insole with such a structure will enable the achievement of the goal described above, i.e. even distribution of pressure exerted on the foot.

The design and construction simulation of the tested knitted fabric were carried out using the ProCad Warpknit software. The visualization of the designed fabric is shown in Fig. 1. The resulting structure consists of: 1-rib based pillar stitch, 2-weft stitch, 3-pillar stitch with inner layer connectors, 4-rib based tricot stitch 5-mixed pillar stitch, 6-weft stitch. The distance knitted fabric was produced on the Nippon K. Mayer LTD double-bar warp knitting machine RMDU6, needle gauge E18, owned by the Department of Knitting Technology and Textile Machines of the Lodz University of Technology.

The actual structure of the knitted fabric was identified using a stereoscopic microscope equipped with an OPTO-TECH X2000 digital camera, Fig. 2.

Structural parameters of the knitted fabrics: weft and warp density Pr = 102 courses /100mm, Pk = 75 wales /100 mm, surface density Mp = 692 g/m^2, diameter of PES monofilament forming the spacer layer d = 0.15 mm, fabric thickness g = 6.9 mm.

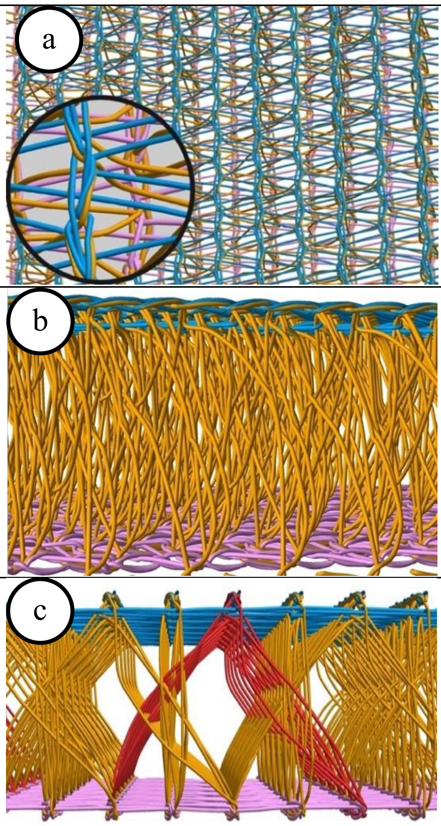

Fig. 1. Computer simulation of knitted fabric structure: a) top view, b) cross-section along courses, c) cross-section along wales.

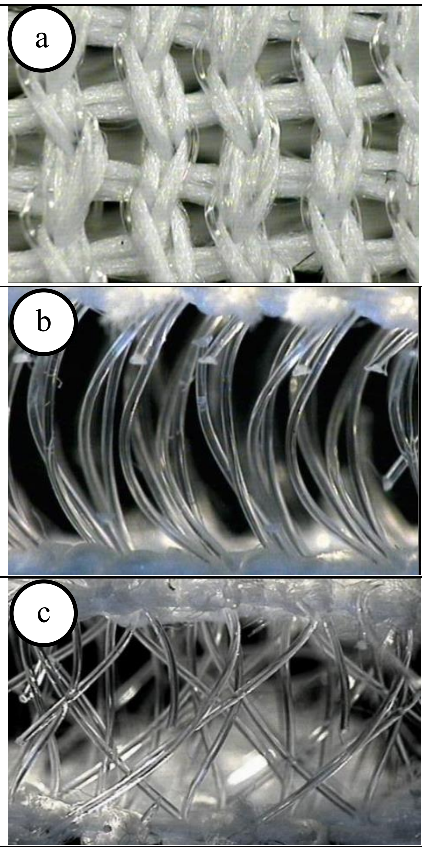

Fig. 2. Microscope photos of knitted fabric: a) surface of knitted fabric b) cross-section along courses, c) cross-section along wales.

For the tested knitted fabric, the transverse elastic modulus was measured using a HOUNSFIELD H50K-S testing machine, equipped with a measuring head with a maximum force of 5 kN. Young's modulus for the tested fabric equals 75.5 kPa.

To measure the foot pressure distribution on the surface, a 380 cm long FreeMed Professional strain gauge mat was used with an active track of 180x50 cm. The platform evaluates the reaction of surface forces under both static and dynamic conditions. The device makes it possible to test the correctness of foot pressure on the surface, body balance (posturographic examination), the correctness of eye-hand coordination and gait and movement disorders. The mat is equipped with square resistance sensors with measurement frequency of 250-400 Hz and dimensions of 5×5 mm (Fig. 3).

Fig. 3. FreeMed Professional strain gauge.

The FreeMed strain gauge mat is compatible with the FreeSTEP Professional software which enables comprehensive analysis of the patient's movements.

In the first phase of the study the measurements were carried out for a person standing barefoot, and they constitute a reference point for the subsequent values. In the next step, pressure measurements were made for the variant of the distance knitted fabric described above. The tested person was a healthy 24-year-old male weighing 73 kg. In standing position he demonstrated a certain asymmetry of loads: the load on the left foot equalled 29 kg, while on the right foot it was 34 kg.

RESULTS AND DISCUSSION

The maps showing loads (pressure) distribution on the feet under static conditions for the reference variant (the foot placed directly on the measuring mat) and when the foot is placed on the distance knitted fabric are presented in Figure 4. The maps of surface pressure distribution for the two presented variants differ in the foot contact area with the ground. The colour differentiation from red to dark blue shows the decreasing pressure differences.

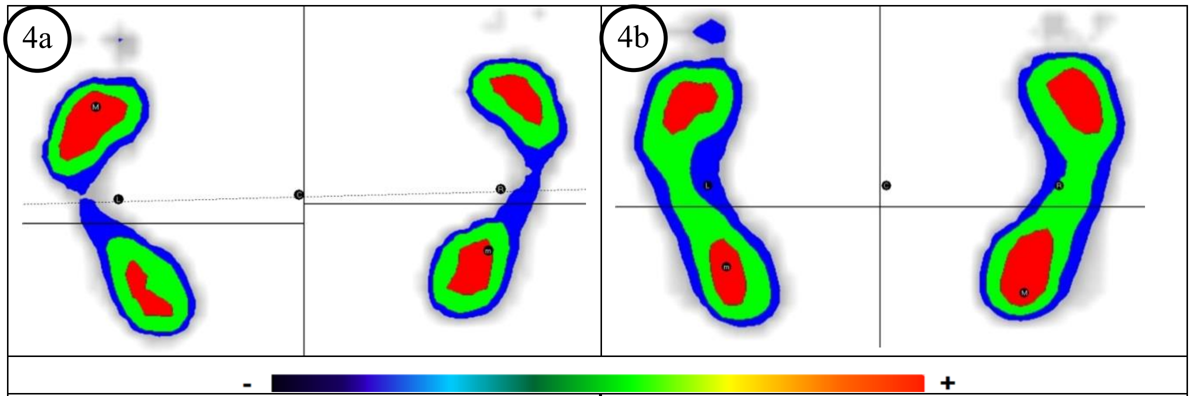

Fig 4a. Distribution of pressure exerted on feet placed directly on measuring mat.	**Fig 4b. Distribution of pressure exerted on feet placed on distance knitted fabric.**

In the Free Step Professional environment, full reports from the series of static and dynamic tests were automatically obtained, including the locations and values of maximum pressures, percentage load of the feet with the patient's body weight, percentage pressures exerted by the forefoot and hindfoot, feet contact areas with the ground and percentage load in six areas for each foot.

Dynamic tests enable a more thorough analysis of pressure distribution. They include four additional phases of the foot support, starting when the heel contacts the ground and ending when the toes are lifted up. The values of the foot pressure on the ground are presented in Table 1.

Table 1. Pressure exerted on researcher's foot.

FREEMED STRAIN GAUGE MAT							
Barefoot static measurement				**Barefoot dynamic measurement**			
Left foot		Right foot		Left foot		Right foot	
Pa, kPa	Pmax, kPa	Pa, kPa	Pmax, kPa	Pa, kPa	Pmax, kPa	Pa, kPa	Pmax, kPa
27.1	49,9	26.3	46.3	64.5	180.8	73.1	187.9
Knitted fabric - static measurement				**Knitted fabric - dynamic measurement**			
Left foot		Right foot		Left foot		Right foot	
Pa, kPa	Pmax, kPa	Pa, kPa	Pmax, kPa	Pa, kPa	Pmax, kPa	Pa, kPa	Pmax, kPa
18.2	34.4	19.3	35.6	51.6	129.8	50.8	147.9

The analysis of static pressures exerted by the right and left foot placed on a distance knitted fabric showed a decrease in the pressure values compared to the situation when the feet were placed directly on the measuring mat. The decrease in the maximum pressure values equaled 27%, while the average pressure dropped by 30%. When the measurements were performed under dynamic conditions (when the patient was walking), the decrease in pressure values is also observed. For the maximum values it equals 20.5% and for average pressure it amounts to 25.3%.

This analysis clearly shows that while using an additional layer in the form of a distance knitted fabric the pressures exerted on the patient's feet are reduced by ¼.

CONCLUSION

The new technologies and materials in the form of 3D distance knitted fabrics may be applied in orthopedic footwear for people with diabetic foot syndrome. This research can also be worthwhile in anthropotechnical design of footwear for people with birth or acquired defects involving feet, patients after partial foot amputation, and for those suffering from circulatory disorders in the lower limbs. Orthopedic insoles made of distance knitted fabrics can be widely used in work shoes for physically overloaded people who mostly work in standing position or are in constant motion, for example for salesmen, doctors, waiters or teachers. A more advanced method of designing insoles made of distance knitted fabrics involves personalizing their structure and properties in relation to the foot anatomy and specific needs of the users.

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