Analysis of Openwork Knitwear Used for Hernia Mesh Manufacturing

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Abstract
The paper presents research aimed at the production of mesh implants used in the treatment of abdominal hernias: knitted monofilament fabric, optimal pore diameter min. 75 µm, preferably over 1 mm, mass per unit area – less than 35 g/m². The influence of differentiation factors on mechanical parameters of the knitted fabrics was analysed. Seven variants were produced varying in the weave, linear mass of yarn and accuracy. The knitted fabrics were subjected to thermal or thermo-mechanical treatment in a two-stage process. The data obtained were analysed using parametric statistical tests. It was shown that in order to obtain an appropriate ratio of surface mass to mechanical strength at the break/size of pores, it is necessary to use a braid which allows to obtain uniformity of the pores. The braid shall be made of low-precision material and of extra linear mass. It is possible to model the strength parameters with the help of the accuracy and/or thermal treatment. The treatment has less influence on the strength parameters. The use of mechanical treatment during thermal stabilisation significantly affects the elasticity of the knitted fabric without having a significant impact on the strength of the knitted fabric.

Key words: *polypropylene, knitted implant, biomaterial, thermal stability, mechanical treatment, accuracy.*

Introduction

In hernia treatment, the biggest problem is to create an implant that mirrors the physical and mechanical properties of the patient's native tissues in terms of tensile strength and elongation. This is mainly due to the fact that the soft tissues of the abdominal cavity are characterised by a multidirectional variation in their physical and mechanical properties [1]. Therefore the production of a knitted fabric reflecting this multidirectional characteristic is still a major engineering challenge.

An implant for hernia surgery should be of an adequate strength and biocompatibility as well as of an appropriate shape. So far, in clinical practice, polypropylene materials in the form of monofilament yarns and macroporous knitted fabrics made of them are well known and verified [2-4]. The trend of using innovative techniques in designing the shape of medical devices that give the effect of personalisation is observed [5-7].

The aim of this study was to investigate the influence of knitting production parameters and finishing treatment conditions on knitted fabrics as well as to select knitted fabrics with required physical and mechanical properties predisposing them to being used as hernia meshes, i.e. to determine their strength, deformation, surface mass and the surface of the openwork.

The subject of the study are openwork, macroporous knitted fabrics with an effective porosity > 1 mm. The Amid classification categorises the meshes for surgical applications according to the following parameters [5, 6]:
- I – macroporous over 75 µm, monofilament;
- II – a pore size of at least one dimension of less than 10 µm;
- III – large pores or small pore components, multifilament yarn;
- IV – meshes with sub-microscopic pores.

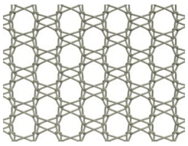
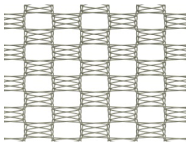
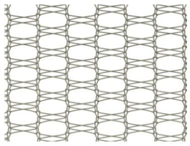
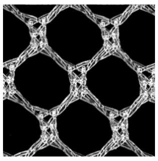
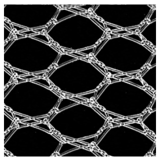
Group I meshes are less likely to cause infection and erosions. Pores above 75 µm will allow macrophages to infiltrate and may favour neovascularisation [8, 9].

Such characteristics of the openwork is one of the conditions of high biocompatibility of mesh implants, as successive layers of cells: granulocytes, macrophages (inflammatory cells), angiogenesis and cells of the fibrosis process – fibroblasts and collagen – cause an overgrowth of pore light. The smaller the pore size, the smaller the so-called neutral zone (i.e. the effective space after the implant has overgrown with cells), which increases the risk of seroma formation or infection [10, 11]. Pores with a larger surface area are characterised by the fact that the effectiveness of overgrowing with connective tissue will be higher, thus promoting a smaller inflammation reaction.

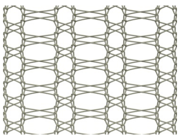
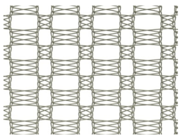
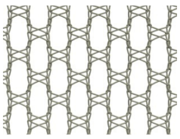
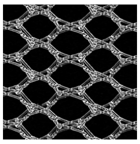
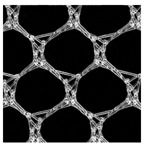
Another aspect that characterises knitted mesh implants is their surface mass [g/m²]. Aiming to achieve ultra-lightness of the mesh is linked to its higher biocompatibility [11-13]. The current division of mesh implants for hernia surgery is based on the following classification according to surface mass: ultralight up to 35 g/m², light up to 35 ÷ 70 g/m², standard up to 70 ÷ 140 g/m² and heavy up to 140 g/m² [14, 15]. This aspect of the surface mass of the mesh is the result of the braid and characteristics of the yarn used. In order to achieve a low surface mass, it is neces-

Table 1. Characteristics of the knitted fabrics and basic knitting parameters: a) braids K, M, I & P, b) braids X, Y & Z.

a)

Coding (braid/ accuracy/ needle)	K/13/2 K/12/2 K/11/2	M/23/4 M/22/4 M/21/4 M/20/4	M/19/4 M/18/4 M/17/4 M/16/4	I/23/4 I/15/4 I/10/4	P/22/4 P/21/4 P/20/4 P/19/4	P/18/4 P/17/4 P/16/4 P/15/4
Yarn type	46 dtex	46 dtex		72 dtex	46 dtex	
Braid	I:100/122/233/211// II:233/211/100/122//	I: 101/233/102/453/322/453// II:454/323/453/101/232/102//			I: 101/233/453/321// II:454/322/101/233//	
Braid in the real course of the yarn						
Picture of knitted fabric 's right side						

b)

Coding (braid/ accuracy/ needle)	X/22/3 X/20/3 X/18/3	Y/22/3 Y/20/3 Y/18/3	Z/22/2 Z/20/2 Z/18/2
Yarn type	46 dtex	46 dtex	46 dtex
Braid	I: 343/211/101/122// II:101/233/343/321//	I: 343/212/343/101/122/102// II:101/232/102/344/322/344//	I: 211/122/100/122/212/233// II:122/211/233/211/122/100//
Braid in the real course of the yarn			
Picture of knitted fabric's right side			

sary to use a braid which allows for large openwork, a high degree of porosity and the use of yarns of low linear weight.

The novelty element in the present article is the development of new knitted fabric structures with a given pore size; both elements have an impact on such physical and mechanical properties as elasticity and tensile strength. The article intends to correlate the impact of the temperature and stabilisation time on physical and mechanical parameters, taking into consideration the preliminary tensile stress of the knitted fabric. The result of the research was an optimisation of manufacturing and thermal stabilisation conditions which guarantees obtaining a safe result in the use of the medical device. The article is the first which presents a multi-angled approach to the analysis of preliminary treatment of knitted fabric and its bearing on the performance parameters obtained.

Therefore one of the objectives of the research presented was to develop knitted meshes which would be characterised by a large size of pores and, at the same time, appropriate physical and mechanical parameters. In order to meet this challenge, the yarns selected previously were of 46 dtex and 72 dtex in weight. The minimum pore size was established as 1 mm. It was expected that the use of such yarns would result in producing knitted fabrics with the characteristics desired.

Materials and methods

As a result of work on the optimisation of knitted fabric, 6 variants of braids were developed using different manufacturing parameters, i.e. knitting accuracy using 46 dtex yarn (***Table 1***). These braids were made by combining tricot and satin patterns (***Table 1***). The braid selected was reconstructed using yarn of a higher linear mass (72 dtex). The knitted fabrics were made on a HKS 3 (KARL MAYER, German) machine with a gauge of 28 with the use of two needles.

The selection of thermal processing parameters was made with the use of a customised TRICOMED SA (Poland) heating device, which allows to control the temperature in the chamber with an accuracy of 1 °C. Knitted fabrics were placed on frames and subjected to preliminary thermal treatment under the following conditions: 130 °C for 30 sec. to homogenise the residual internal stresses resulting from the knitting process. The trial knitted fabrics underwent appropriate heat treatment at temperatures of 158 °C, 165 °C, 168 °C and 170 °C. Temperatures higher than 165°C caused a significant decrease in the strength parameters of the knitted fabrics. However, the study also included a temperature of 162 °C, which is slightly higher than the optimum temperature, in order to assess more accurately the effect of temperature on the mechanical characteristics of knitted fabrics. The time for specific stabilisation was 1.5 min. The proper thermal treatment aims at giving the fabrics new functionalities. After removal from the stabiliser, the knitted fabrics were cooled in the air. The knitted fabric selected from the variants developed was then subjected to extended stabilisation treatment, i.e. temperature and preliminary tensile stress causing an increase in directional elongation up to 4%. For this purpose, a knitted fabric with an appropriate tension, expressed as a percentage of its length, was placed on a stationary needle-operated frame.

The knitted fabrics which underwent thermal treatment were evaluated for mechanical parameters, i.e. breaking force F [N] and elongation at break L [%]. The tests were carried out with the use of an INSTRON tensile machine (system ID: 3345L3302 Type: Electro-Mechanical Single Range) under the following test conditions: test sample width 5 cm, preload 0.5 N, tensile speed 100 mm/min. and seating length 100 mm. The selection of test methodology was developed on the basis of the EN ISO 13934-1 standard.

The data obtained were analysed using STATISCICA software, which relied on ANOVA analysis of the main factors to investigate the interaction between the influence of differential factors (stability accuracy and/or temperature) on me-

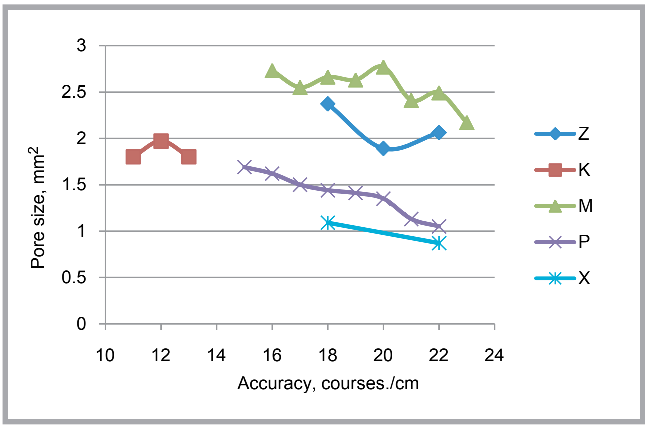


***Figure 1.** Analysis of pore size in dependence on the type of variant, with a minimum surface area of pores of 1 mm^2.*

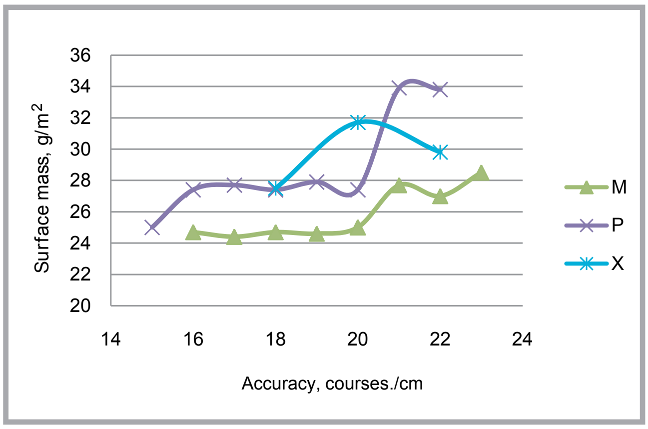


***Figure 2.** Analysis of the surface mass in dependence on the type of variant, with a maximum surface mass of 35 g/m^2.*

chanical parameters: tensile strength (F) and tensile elongation (L). In order to assess the effect of accuracy on mechanical parameters (F, L), single-factor ANOVA analysis was used (post hoc, Tukey test). The same tests were carried out in order to assess the influence of thermal treatment (158 °C, 162 °C) on the mechanical parameters (F, L) of the knitted fabrics selected. The method described is also used to assess the effect of a braid at a single accuracy for M and P braid combinations and for X, Y, Z braid combinations. Single factor ANOVA analysis was also used to assess the effect of mechanical processing (stretching during the stabilisation process) of a selected variant of knitted fabrics. The conditions of normal distribution and homogeneity of variances were checked for each analysis. The confidence interval was 95%.

The knitwear parameters shown in ***Table 1*** are those relating to braid, accuracy and gauge, respectively. For example, variant K/11/2 should be read as follows: variant of braid K, knitting with an accuracy of 11 r./cm, during knitting, every second needle was supplied with yarn.

Test results

Results of tests on heat-treated knitted fabrics

Changes in the mean values and standard deviations are presented in ***Table 1***, together with the division into the variant produced and the mechanical parameter tested. Characteristics of the mechanical properties were prepared for both the transverse and longitudinal directions of the knitted fabrics. A test of breaking force [N] and elongation at break [%] was carried out in dependence on the direction and is presented for variants M, P, X, Y and Z in ***Table 2*** (see pages 80-81).

The tests also take into account the pore size in dependence on the type of heat-treated variant developed. According to the literature [9, 10], the minimum diameter of pores should be min. 1 mm^2. As shown in ***Figure 1***, variants X and P, knitted fabrics of a high degree of accuracy (P/21/4-P/22/4), have a too small pore size – near the minimum. The variant with the highest pore surface is made of knitted fabrics M and Z. Variants >M/21/4, Z/18/2 and Z/22/2 have a pore surface of more than 2.0 mm^2 and, depending on the variant of the braid, analysis of the surface mass indicates that knit M has the lowest value of surface mass (***Figure 2***).

Analysis

Assessment of the effect of accuracy and temperature on mechanical properties

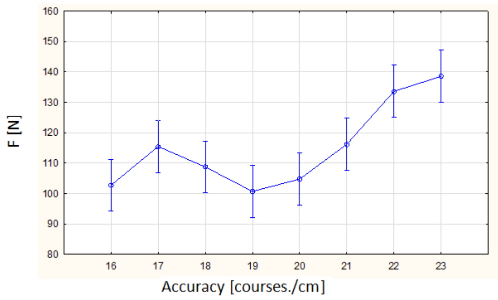
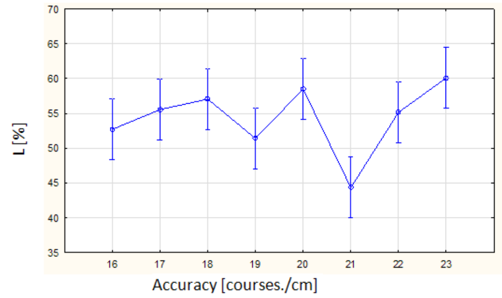
In order to assess the influence of differential factors (accuracy, temperature) on mechanical properties (F, L) of the knitted fabrics processed, an analysis of knitted fabrics M and P was performed (***Table 3,*** see page 82).

Three zero hypotheses were used to investigate the interaction between the differentiating factors:

- $H_0(1)$: temperature (A) does not change mechanical parameters F and L
- $H_0(2)$: accuracy (B) does not affect the change in mechanical parameters F and L
- $H_0(3)$: there is no interaction between the levels of factor A and B, i.e. the response of the tested variable to one factor is the same at all levels of the other factor

ANOVA analysis for factor systems showed that the following hypothesis $H_0(1\text{-}3)$ can be rejected with $p<0.05$. This means that temperature as well as accuracy have a significant influence on the change in mechanical parameters of the breaking force in both the transverse and longitudinal directions for both knitted fabrics tested – M and P. As shown in ***Table 3***, the assessment of the interaction between the factors is illustrated by an intersection in the diagram (***Table 3***). Evaluation of the interaction between the factors differentiating the strain at break showed that for variant M the temperature in the longitudinal direction will not affect the variation ($p > 0.05$, no grounds for rejection of $H_0(1)$). The lack of interaction between accuracy and temperature was also demonstrated ($p > 0.05$, no grounds for $H_0(3)$ rejection). However, in this case, a significant influence of the accuracy on the strain at break was demonstrated ($p < 0.05$). This means that the main factor differentiating the parameter tested will be the accuracy of the knitted fabric. In the transverse direction of knitted fabric M, the deformation is influenced by both the processing temperature and accuracy ($p<0.05$). For knitted fabrics P, a transverse study of the interaction of factors that differentiate the strain at break (L) showed that temperature does not affect the change in strain ($p>0.05$, no grounds for rejection $H_0(1)$). On the other hand, it was shown that accuracy will have a significant influence on the change in the strain value ($p<0.05$). However, results of the study of the interaction between the accuracy and temperature turned out to be interesting. It was shown that despite the lack of influence of the temperature factor

Table 2. *Evaluation of mechanical parameters: breaking force and strain at break for variants M, P, X, Y and Zin dependence on the accuracy applied during knitting processes.*

<table>
<tr><th rowspan="2">Variant</th><th colspan="2">Breaking force, F [N]</th></tr>
<tr><th>Transverse direction (P)</th><th>Longitudinal direction (W)</th></tr>
<tr><td>M</td><td>
</td><td>
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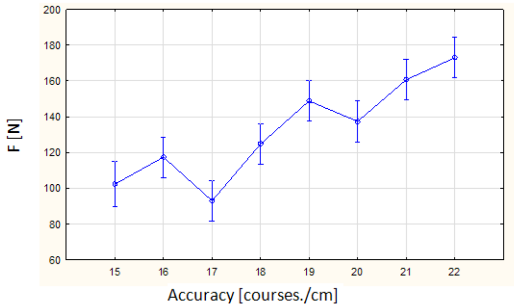
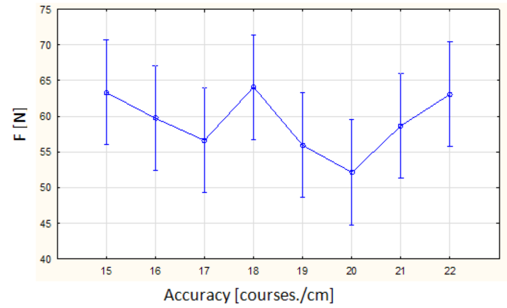
<tr><td>P</td><td>
</td><td>
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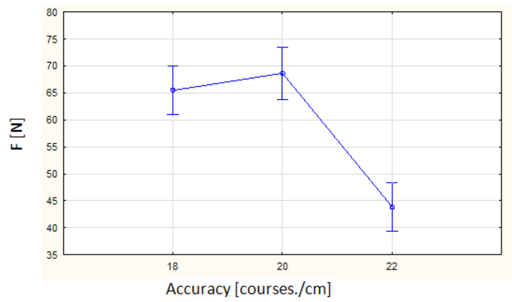
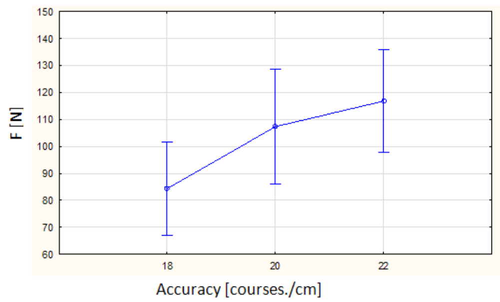
<tr><td>X</td><td>
</td><td>
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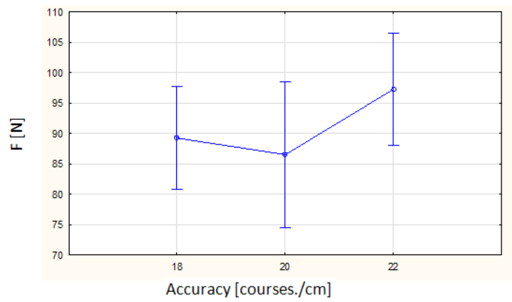
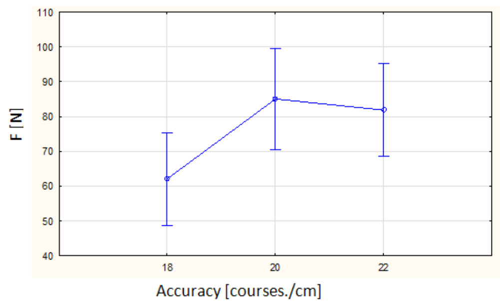
<tr><td>Y</td><td>
</td><td>
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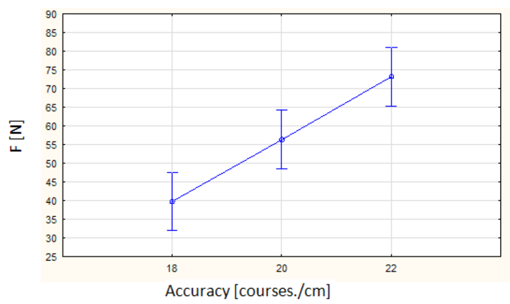
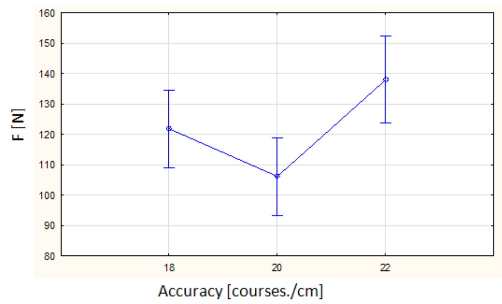
<tr><td>Z</td><td>
</td><td>
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<table>
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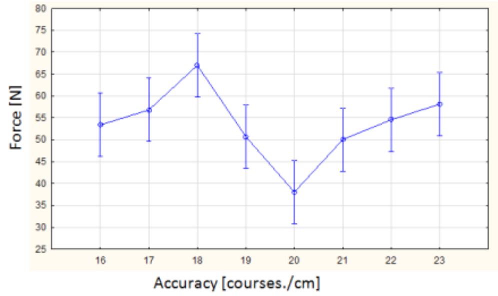
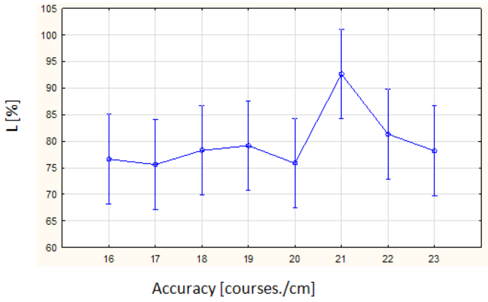
<tr><td>M</td><td>
</td><td>
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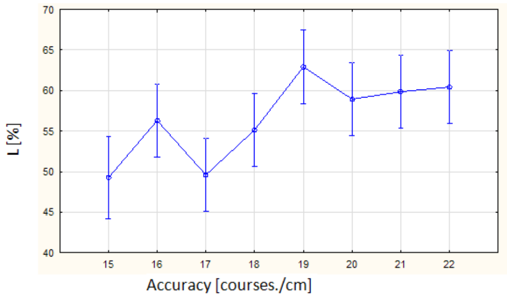
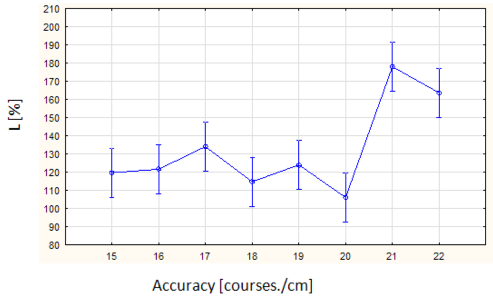
<tr><td>P</td><td>
</td><td>
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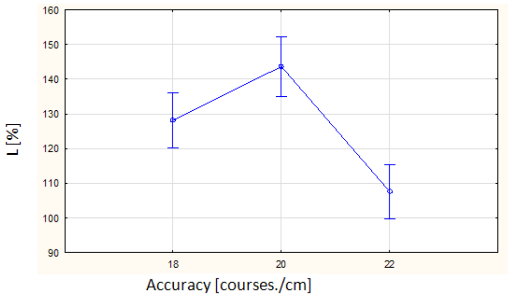
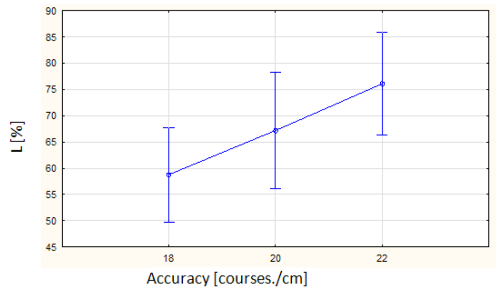
<tr><td>X</td><td>
</td><td>
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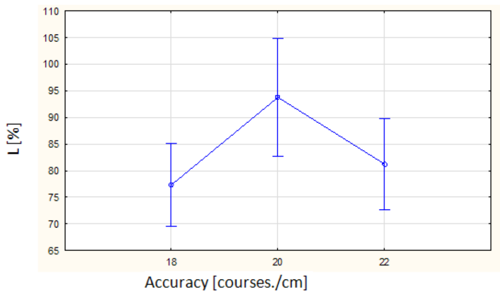
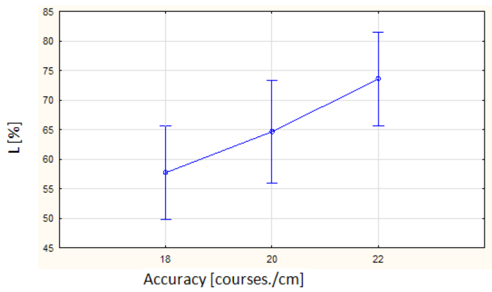
<tr><td>Y</td><td>
</td><td>
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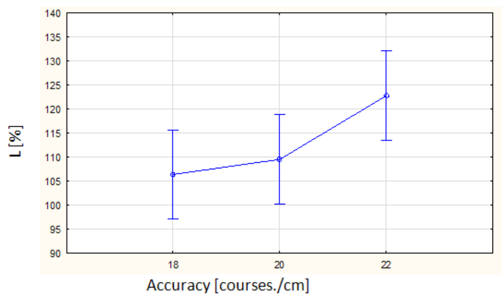
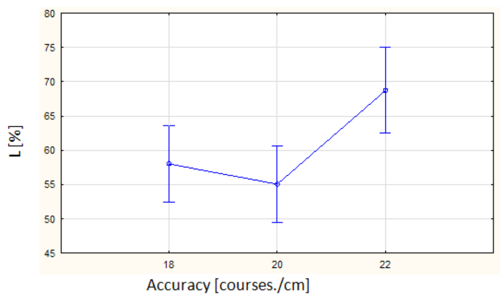
<tr><td>Z</td><td>
</td><td>
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Table 3. *Analysis of the interaction between the temperature of the thermal treatment and the accuracy for the characteristics of knitted fabrics tested.*

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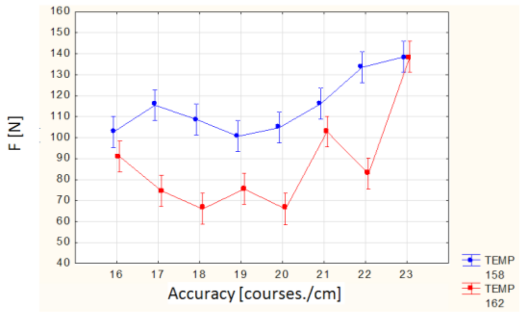
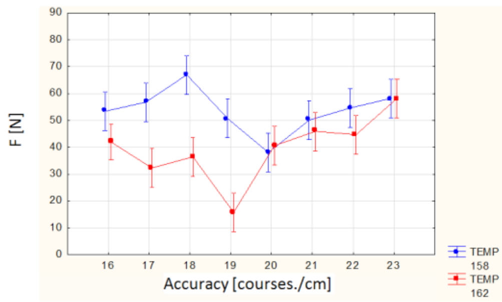
<tr><td>M</td><td>
</td><td>
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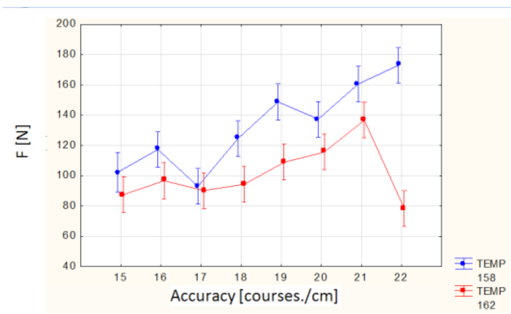
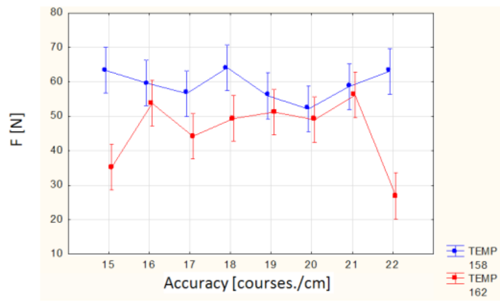
<tr><td>P</td><td>
</td><td>
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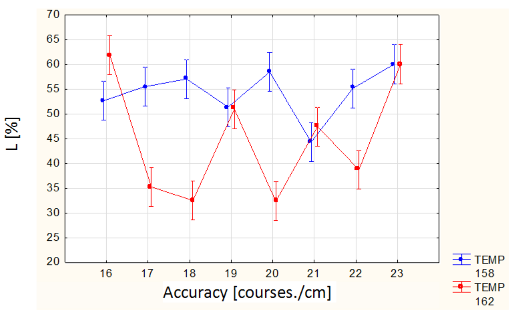
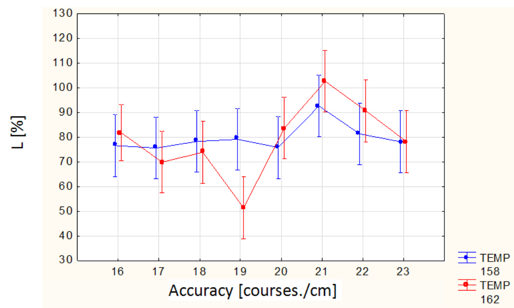
<tr><th>Transverse direction (P)</th><th>Longitudinal direction (W)</th></tr>
<tr><td>M</td><td>
</td><td>
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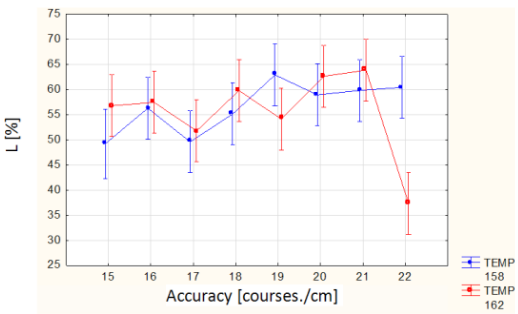
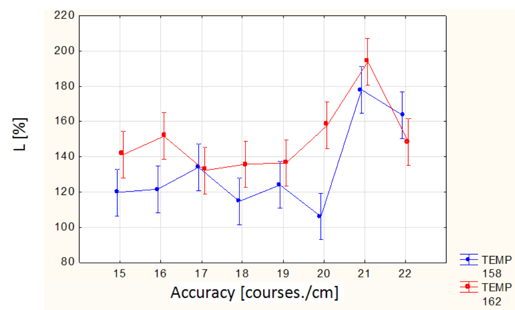
<tr><td>P</td><td>
</td><td>
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</table>

on deformation, the interaction of accuracy and temperature will have a significant influence on the change in the deformation parameter ($p < 0.05$).

For the longitudinal direction, all zero hypotheses 1-3 ($p < 0.05$) shall be rejected. This means that both the temperature and change in knitting accuracy will have a significant effect on the change in deformation.

Evaluation of the effect of accuracy on mechanical properties

An assessment of the influence of accuracy on mechanical parameters of knitted fabrics was made by examining knitted fabrics M and P. They were showed that accuracy has a significant influence on each of the parameters studied – F and L. Verification of this analysis was carried out using a post-hoc test. The partial factor Etha- Square (η2) was investigated to determine the extent to which accuracy affects the parameters evaluated – F and L. Individual averages were evaluated using the Tukey test. The following hypotheses were applied: the zero hypothesis (H_0) and alternative hypothesis (H_1):

- H_0: $m_1 = m_2$
- H_1: $m_1 \neq m_2$

For knit M, significant differences were found between the strengths of 22-23 r./cm and of the other of 16-20 r./cm in the transverse direction. No significant difference in mean values can be indicated between 16-21 r./cm ($p > 0.05$).

The η^2 factor indicates that the effect of the differential factor – accuracy – can be estimated at about 71% (***Table 4***).

In the longitudinal direction, the most different variants were those with an accuracy of 18 r./cm and 20 r./cm in relation to the others. In this case, the changes in the mean strength for individual accuracy can only be 54%. explained (***Table 4***).

For the deformation properties in the transverse direction, it was shown that the most different variant is the one with an accuracy of 21 r./cm in relation to the others. The η^2 factor indicates that the effect of the accuracy variation factor can only be estimated at approximately 54%. (***Table 4***).

If the knitted fabric is deformed in the longitudinal direction, it is demonstrated that there are no grounds for rejecting the H_0 zero hypothesis ($p > 0.05$). This means that in this case the effect of accuracy on the change in L parameter is not statistically significant, even though the average for the 21 r./cm accuracy variant is the highest. This is confirmed by factor η^2. For knitted fabric P the effect of accuracy is more important than for knitted fabric M. In the transverse direction an increase in accuracy causes an increase in the breaking force F (***Table 1***). The Tukey test indicates that accuracy has a significant influence on the differentiation of F ($p < 0.05$). Knitted fabrics with closures of 15-16 r./cm differ significantly from those with closures of 19-22 r./cm. For the longitudinal direction it is shown that the breaking force does not significantly depend on the set accuracy ($p > 0.05$).

For none of the variants of knitted fabric P were there grounds to reject H0. Moreover only for 23% (***Table 4***) is it possible to indicate the relation between the change in resistance of the knitted fabric to tearing (breaking force) and the change in accuracy. An examination of the effect of the differentiating factor on the value of strain at break indicates that the zero hypothesis can be discarded laterally and an alternative hypothesis can be adopted. This is related to the fact that the average of the variant with an accuracy of 17 r./cm differs significantly from most other variants. In this case, the change in strain at break (L) can be explained by a change in accuracy of 51%, which is not a strong indication of the differentiating factor. The longitudinal tensile strain test indicates that accuracy plays a statistically significant role ($p < 0.05$) and its effect is determined as approximately 76% (***Table 4***). The P knit variants, which differ significantly from the other types, have closures of 22-23 r./cm.

Table 4. *Estimated effect of differential accuracy on F and L parameters of knitted fabrics M and P in the longitudinal (W) and transverse (P) direction. Significantly different statistics p are marked in bold, for which H_0 should be discarded.*

Variant	Breaking force F, N		Elongation at break L, %	
	P	W	P	W
	η^2			
M	**0.71**	**0.54**	**0.54**	0.28
P	**0.85**	0.23	**0.51**	**0.76**

Table 5. *Statistical analysis of the significance of the effect of accuracy on individual mechanical parameters in the longitudinal (W) and transverse (P) directions. Significantly different statistics p are marked in bold, for which H_0 should be discarded.*

Variant	Breaking force F, N		Elongation at break L, %	
	P	W	P	W
	η^2			
X	**0.85**	**0.40**	**0.76**	**0.40**
Y	0.22	**0.35**	0.40	**0.40**
Z	**0.78**	**0.55**	**0.41**	**0.56**

For variant Y, both for parameters F and L in the longitudinal direction, it is shown that H_0 should be discarded, even though no significant differences between the averages were indicated by repeated comparisons. This may mean that the averages will be materially different, while the wide range of errors will be the same for each accuracy. This may mean significant heterogeneity of the variant and, as a result, problems with the reproducibility of parameters.

For variants X and Z, a significant influence of accuracy on each mechanical parameter tested – F and L was demonstrated for both directions (***Table 5***). However, the Staged Square Factor (η^2) indicates that this model can only be explained by changing the accuracy to about 35-56% for deformations. For the strength this model can be 76-85% explained (except for the Z variant in the longitudinal direction, where the model is 41%.explained)

Evaluation of the effect of temperature on mechanical properties

The influence of the temperature of the treatment was also determined on the basis of an assessment of the interaction between the differential factors. For this purpose, on the basis of previous statistical analyses, selected knitted fabrics of type M (M/23/4, M/20/4 and M/16/4) were compared. Variant K was also examined to check and confirm the correctness of previous analyses. Correct analysis means that the model presented can be used for knitted fabrics with different weave sizes.

The following zero hypothesis (H_0) and alternative hypotheses were used (H_1):

- H_0: $m_1 = m_2$
- H_1: $m_1 \neq m_2$

Statistical results show that the temperature significantly affects the strength of the knitted fabrics in both the transverse direction (M/23/4-M/16/4, K/12/2-K/11/2) and longitudinal direction (M/23/4-M/20/4, K/13/2-K/11/2). Exceptions are knitted variants M/16/4 and K/13/2, for which the effect of the treatment temperature on the average breaking force in a given direction was

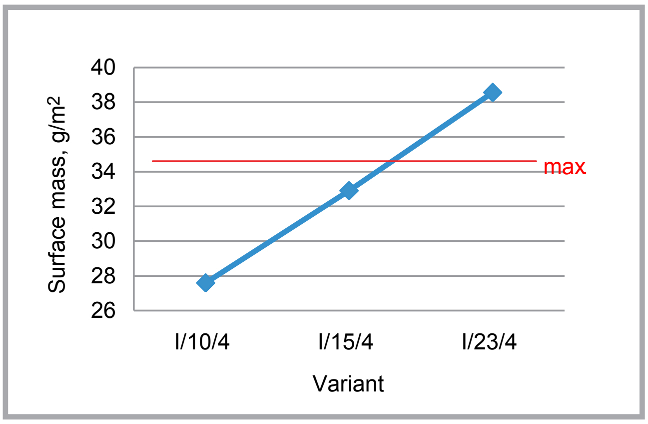

Figure 3. *Analysis of the surface mass in dependence on the type of variant I with a maximum surface mass of 35 g/m².*

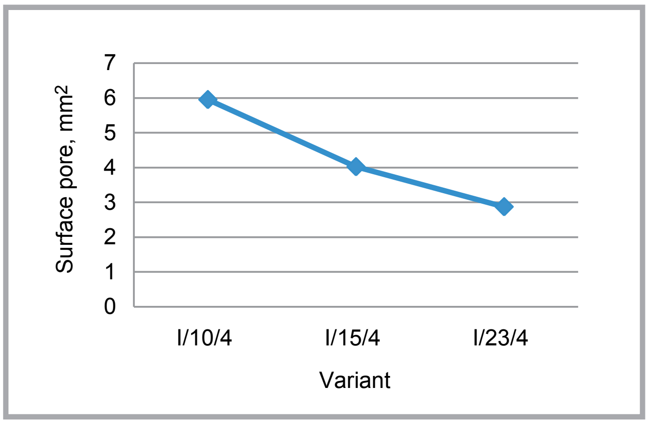

Figure 4. *Analysis of the pore size in relation to the type of option I for a minimum surface area of pores of 1 mm².*

Table 6. *Analysis of the influence of temperature 158 °C and 162 °C on parameters F and L in the longitudinal (W) and transverse (P) directions. Significantly different statistics p are marked in bold, for which the following H_0 should be rejected.*

Variant	Breaking force F, N		Elongation at break L, %	
	P	W	P	W
	p			
M/23/4	**<0.05**	**<0.05**	**<0.05**	**0.05**
M/20/4	**<0.05**	**<0.05**	>0.05	>0.05
M/16/4	**<0.05**	>0.05	**<0.05**	**<0.05**
K/13/2	>0.05	**<0.05**	>0.05	>0.05
K/12/2	**<0.05**	**<0.05**	0.05	**<0.05**
K/11/2	**<0.05**	**<0.05**	**<0.05**	**>0.05**

Table 7. *Analysis of the effect of the strand on parameters F and L at the same accuracy in the longitudinal (W) and transverse (P) directions. Significantly different statistics p are marked in bold, for which the following H_0 should be rejected.*

Variant	Breaking force F, N		Elongation at break L, %	
	P	W	P	W
	η^2			
18	**0.89**	**0.78**	**0.85**	0.00
20	**0.84**	0.39	**0.85**	0.31
22	**0.89**	**0.65**	**0.87**	0.17

Table 8. *Analysis of the influence of linear mass on the parameters F and L for the same strand in the longitudinal (W) and transverse (P) direction. Significantly different statistics p are marked in bold, for which the following H_0 should be rejected.*

Variant	Breaking force F, N		Elongation at break L, %	
	P	W	P	W
	η^2			
15-16 r./cm	**0.89**	**0.92**	0.10	**0.70**

Table 9. *Analysis of the effect of the stretch applied on parameters F and L for variant I in the longitudinal (W) and transverse (P) directions. Significantly different statistics p are marked in bold for which the following H_0 should be rejected.*

Variant	Breaking force F, N		Elongation at break L, %	
	P	W	P	W
	η^2			
I/10/4	0.19	0.16	0.30	**0.47**
I/15/4	0.29	0.15	**0.56**	**0.39**
I/23/4	0.32	0.08	0.28	**0.36**

not demonstrated (***Table 6***). The statistical value in these cases is $p > 0.05$. When assessing the effect of heat treatment on the deformation parameters of variant K in particular, no significant effect can be indicated. In most cases there is no reason to reject H_0. For knitted fabric M, only for the M/20/4 type does the temperature not affect the L property in either the transverse or longitudinal direction ($p > 0.05$).

Evaluation of the effect of a strand on mechanical properties at the same accuracy

The use of different strands has a different effect on the mechanical performance of the knitted fabrics (F, L). In order to test the veracity of this statement, the effect of the strand on the mechanical properties in the longitudinal and transverse directions was evaluated for a given magnitude of accuracy. Variants X, Y & Z were selected for the tests, as well as the following accuracies: 18 r./cm, 20 r./cm and 22 r./cm. The following zero hypothesis (H_0) and alternative hypotheses were used (H_1):

- H_0: $m_1 = m_2$
- H_1: $m_1 \neq m_2$

The results show that the model 80-90% explains the influence of changes in the type of weave on the mechanical properties of the knitted fabrics. In the transverse direction, the effect of the type of strand on the breaking force F and the strain at break is significant, but in the longitudinal direction it is no longer so obvious. The strength of the model is weaker (***Table 7***) than for the transverse direction, and for a accuracy of 20 r./cm there were no grounds to reject H_0.

In this case, there were no grounds for rejecting H_0 for any accuracy, which means that if the mechanical parameters can be modelled laterally by changing the strand, there are no such grounds in the case of the longitudinal direction. Changing the strand has little effect on the deformation parameters in the longitudinal direction.

Comparison of the effects of the texture of yarns on the mechanical characteristics of knitted mesh

Due to the largest surface pores as well as the lowest surface mass, knitted fabric M was selected for further tests in order to select appropriate strength parameters. The weave of variant M was made with the use of yarn of 72 dtex, i.e. linear mass. The variant manufactured was marked as I. The knitted fabrics compared were stabilised under the same conditions.

The effect of using different diameters of yarns on the mechanical properties of the knitted fabrics (F, L) in the longitudinal and transverse directions was evaluated for a given value of accuracy. The test was carried out for an accuracy of 15-16 r./cm (***Table 8***).

Statistical analysis shows that the diameter of the yarns used has a significant influence on the breaking force F in particular. This model can be about 90% explained. In the case of rupture strain, there is no reason to reject the zero hypothesis for the transverse direction ($p > 0.05$). This means that the deflection is not significantly different from that of knitted fabrics made from yarns of 46 dtex or 72 dtex. For the longitudinal direction, there is a significant statistical difference between the averages for these two types of knitted fabrics ($p < 0,05$). This model can be 70% Explained.

Analysis of knitting variant I

Knitted variant I was extensively stabilised. The tension applied was evaluated using single-factor ANOVA analysis (analysis post hoc, Tukey test).

Single factor ANOVA data analysis showed that the stretch applied did not statistically affect the parameters of different knitting variants in the range of breaking force F in both the transverse and longitudinal direction ($p > 0.05$, no grounds for rejecting the zero hypothesis). This is completely different in the case of the distortion at break. The use of tension in the longitudinal direction significantly affects the change in L parameter for the longitudinal direction, and in the case of variant I/15/4 – also in the transverse direction (***Table 9***). However, the strain variation model based on η^2 can only be explained in less than half of cases.

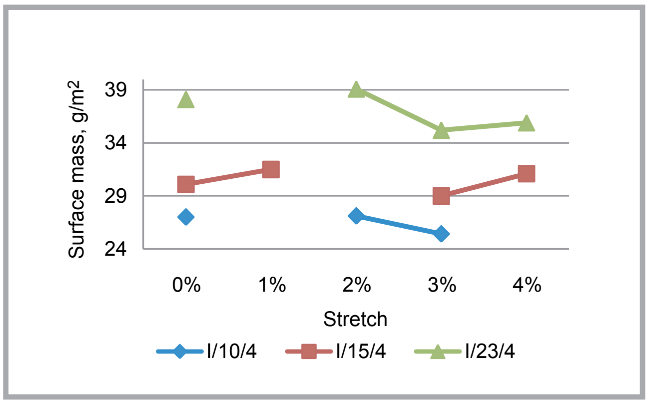

Figure 5. *Analysis of the effect of the magnitude of the tension on the area mass for the three options I.*

Analysis of the surface mass of the newly produced variant I indicates that type I/10/4 – I/15/4 meets the requirements of a maximum value of 35 g/m^2, while the lowest surface mass is characteristic of variant I/10/4 (***Figure 3***); at the same time, it is characterized by the largest surface of pores, i.e. approx. 6 mm^2 (***Figure 4***). Each of the variant I's developed meets the minimum requirements for pore sizes.

For variant I/10/4, a slight reduction in the area weight to 25 g/m2 was possible with a maximum stretch of 3% in the longitudinal direction (***Figure 5***). Greater tensile strength could not be achieved. The use of 4% stretch for variants I/15/4 and I/23/4 resulted in an upward trend in surface mass, which may be due to the process of applying the knitting to the frame itself. When using long stretches, it is possible that by stretching in the longitudinal direction, the knitted fabric starts to taper in the transverse direction, balancing the surface mass. Of the knitted fabrics that underwent tensile treatment, 3% seem to be of optimum stress in the longitudinal direction. An effective increase in the stretch will be possible with machine stretching.

Summary

In order to select a suitable knitted fabric for the purpose of a hernia mesh implant, six types of weave were developed, which were reconstructed using polypropylene yarns of 46 dtex and 72 dtex linear mass. Evaluation of selected thermal treatment parameters allowed to indicate the value of a treatment temperature of 158 °C as a condition for obtaining optimal conditions.

The investigations of the combined effect of accuracy, temperature of heat treatment and strand u conducted allowed to indicate that strength parameters can be influenced by the use of factors differentiating in the longitudinal and transverse directions, while in the case of modelling the strain parameter, it did not show such a significant relationship. On the basis of the studies conducted on extended stabilization, it was shown that knitted material deformation is statistically significant due to the stretch introduced, which does not significantly affect the change in mechanical properties. In addition, it was shown that the use of pre-stretching affects the use of surface mass and an increase in the surface area of the openwork, thus increasing the biocompatibility of knitted fabrics.

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