A Method for Proper Choice of Hernia Meshes Based on Their Mechanical Behavior

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Abstract— **A method for proper choice of hernia meshes, based on a criterion which specifies the type of the hernia mesh with mechanical properties closest to those of the human abdominal fascia has been proposed. Sensitivity analysis of the method was performed. Based on the results of three type of meshes it was established that the best mechanically compatible mesh was Surgimesh with filament diameter 0.14 mm .**

Keywords— **hernia meshes, human abdominal fascia, mechanical behaviour.**

I. Introduction

Synthetic meshes have become a common means to repair all types of abdominal hernias. The advantages of prosthetic meshes include a decreased operating time, smaller incision, better long-term durability, good handling properties. The use of synthetic meshes leads to reduction of post-operative pain, length of recovery and rate of recurrences [1]. During the manufacturing process however, the mechanical properties of tissues which they enforced or replaced are not accounted for.

The mechanical compatibility between the hernia meshes and the abdominal wall layers plays an important role in avoiding postoperative complications. These complications are preventable and required understanding of mechanical properties of prosthesis. The published data on hernia mesh-related complications after hernia operations and the discrepancy between the mechanical properties of synthetic meshes and human fascia showed that the augmentation of mesh elasticity influences limitation of abdominal wall mobility and improve the comfort of the patients [2]. The textile analysis of the used hernia meshes showed that their mechanical stability excess several times the necessary theoretically evaluated physiological strength [3]. The mean distension of anterior abdominal wall at 16N is in range 11% -32%, while common mesh material showed 4%-16% distention [4].

In view of the fact that the commercially available hernia meshes are made of relatively stiff material the hypothesis of our study is that main characteristic of the mechanical compatibility between fascia and hernia meshes is the similarity of their elastic module in the physiological range of deformations. The aim of this study is to propose a method for evaluation of synthetic hernia meshes compatibility, based on stiffness matching.

II. Materials and methods

Uniaxial tests on samples from fascia transversalis and umbilical fascia, (part of abdominal fascia) and polypropylene (PP) hernia meshes were performed. An investigation was done using displacement rate-controlled Instron type testing device - a computer-controlled machine FU1000/E with load cell 500 N, minimal value of the load of 20g and minimal value of the displacement of 0.1mm. For the purposes of this study an elongation rate of 0.13 mm/sec was used.

The fascia samples were harvested from non-herniated subjects. The average age of the subjects was 66.5 years in the range of 46-87 years. The investigation included 96 specimens taken from 16 donors - 5 females and 9 males. The mechanical properties of human abdominal fascia transversalis (FT) and umbilical fascia (UF) samples were tested in two orthogonal directions – parallel to collagen fibers (L1 direction) and perpendicular to them (L2 direction).

Two commercially available polypropylene (PP) hernia mesh brands were used - knitted reinforcement monofilament hernia mesh Surgimech, with two filament diameters – 0.14 mm and 0.2 mm (Aspi Medical, France) and Tecnomesh, produced by TecnoMedic GmbH, Germany. For each brand, ten samples were studied. Five specimens were loaded in direction L1 (parallel to the column of loops) and five were loaded in direction L2 (along the rows of loops).

A. Criterion for selection of the optimal synthetic hernia mesh

The proposed criterion for evaluation of compatibility between mesh and the abdominal wall layers in the physio-

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logical range of deformation up to 10% was based on the values of an objective function $F_{\min}$ [5]. We accept that optimal synthetic hernia mesh is one, which mechanical parameters minimize the following objective function:

$$F_{\min} = \rho^{L1,L1}W_1 + \rho^{L1,L2}W_2 + \rho^{L2,L1}W_3 + \rho^{L2,L2}W_4 \quad (1)$$

$\rho^{P,Q}$ is defined as the mean square distance of secant elastic module $E^{K}_{n,j}$ of fascia and hernia mesh at 5% and 10% engineering strain. For example $\rho^{L1,L2}$ is defined as:

$$\rho^{L1,L2} = \sum_{n=1}^{2} [\frac{E^{L1}_{n,f} - E^{L2}_{n,m}}{E^{L1}_{n,f}}]^2 \quad (2)$$

where $E^{K}_{n,j}$ are the values of the secant modulus for the tested samples of fascia or hernia meshes in directions L1 and L2. ($j = f$ for a fascia, $j = m$ for a mesh, $K = L1, L2$); $E^{K}_{1,j}$ are the values of secant modulus when ε = 5 %,while $E^{K}_{2,J}$ are the values of the modulus at ε=10%. The left upper index of $\rho^{L1,L2}$ denotes that the first secant modulus reveal the stiffness of fascia in L1 direction, while right upper index is connected with the hernia mesh in L2 direction. W_i (i=1..4) are weighted coefficients, which satisfy the following condition:

$$W_1 + W_2 + W_3 + W_4 = 1 \quad (3)$$

Accepting that two investigated directions are equally important for load bearing in the abdominal wall, then the following values of the coefficients were used:

$$W_1 = 0.25; \quad W_2 = 0.25, \quad W_3 = 0.25, \quad W_4 = 0.25 \quad (4)$$

In case when longitudinal or transverse direction was accepted as more pronounced, then the values of the weighted coefficients were proposed as:

$$W_1 = 0.4; \quad W_2 = 0.4, \quad W_3 = 0.1, \quad W_4 = 0.1 \quad (5)$$

or

$$W_1 = 0.1; \quad W_2 = 0.1, \quad W_3 = 0.4, \quad W_4 = 0.4 \quad (6)$$

The function $F_{\min}$ was calculated independently for FT and UF. The compatibility of the hernia meshes was than evaluated on the basis of values of the objective function $F_{\min}$.

III. Results

The experimental data for hernia meshes and human abdominal fascia were represented as stress-stretch ratio relationships [5,6,7]. From obtained curves the mean values of secant elastic modulus $E^{K}_{n,j}$ for hernia meshes and abdominal fascia were calculated. They are presented in Table 1,2 and 3 accordingly. The symbol SM14 denote Surgimesh samples with filament diameter 0.14 mm, while a symbol SM20 denote Surgimesh with filament diameter 0.20 mm.

It was established that the mechanical properties of FT and UF are similar (Table 3) [5,6]. The secant elastic module of investigated meshes are lower than those of the abdominal fascia in the range of physiologic deformations in longitudinal direction and between 2-13 times higher in transverse direction [5,6,7].

Table 1 Mean values of elastic module for hernia mesh Surgimesh

$E_{(i)}$[MPa]	SM14L1	SM14L2	SM20L1	SM20L2
$E_{(5)}$	7.62±1.09	6.58±1.34	6.24±1.02	25.56±1.5
$E_{(10)}$	5.35 ±0.84	8.33±1.44	5.67±0.71	24.15±1.28

Table 2 Mean values of elastic module for hernia mesh Tecnomesh

$E_{(i)}$[MPa]	TML1	TML2
$E_{(5)}$	7.22±0.34	12.63±2.53
$E_{(10)}$	6.31 ±0.26	11.08±2.53

Table 3 Mean values of elastic module for fascia

$E_{(i)}$[MPa]	FTL1	FTL2	UFL1	UFL2
$E_{(5)}$	8.42±5.74	2.82±2.16	8.32±5.26	2.52±0.58
$E_{(10)}$	9.42 ±4.71	3.33±1.75	10.41±3.24	3.31±0.67

According to the accepted criterion in this study the optimal mesh is those for which the value of objective function has a minimum. The comparison between abdominal fascia and hernia meshes was accomplished on the bases of

obtained values. The type of the hernia mesh which mechanical properties are closest to those of the human abdominal fascia was specified. The values of the objective function $F_{\min}$ for nine sets of weight coefficients were calculated. In order to understand how the coefficients W_i affected the function response, the sensitivity analysis was performed. We specified the values of coefficients within the equal sized interval (0.05-0.45). It was supposed that $W_i, i = 1 \div 4$ changed in stepwise manner in the interval of admissible values. .Results from the sensitivity analysis are presented on a Fig. 1. They allow the comparison of the impacts of weight coefficients on the values of $F_{\min}$.

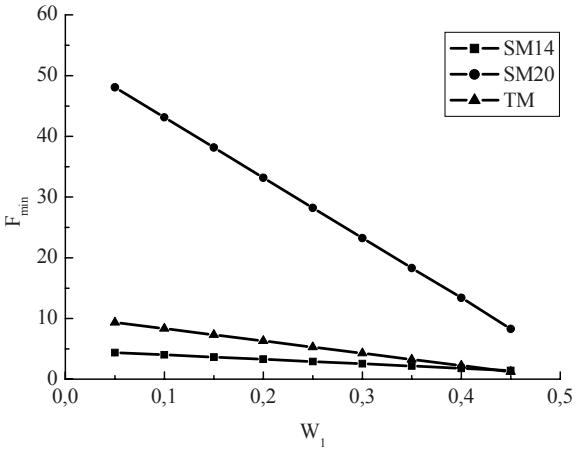

Fig.1 The influence of weight coefficients on the values of objective function. $F_{\min}$, calculated for FT and investigated hernia meshes. $W_1 = W_2$, $W_3 = W_4$. While the values of W_1 and W_2 increase from 0.1 to 0.45, the values of W_3 and W_4 decrease according to the relationship $W_j = (1 - W_1 - W_2)/2$, j=3,4.

The analysis of the obtained results demonstrated that regardless of the choice of the weight coefficients, hernia mesh SM14 possessed the mechanical properties, which were closest to that of fascia transversalis. Tecnomesh is the other mesh which properties were very close to those of fascia. The sensitivity analysis for SM20 showed that the mechanical compatibility of that mesh strongly depended on the W_i. The best coincidence appeared when the mechanical behavior of fascia in L2 direction is neglected. This case is not applicable in surgery, therefore the SM20 can not be recommended for medical applications.

The mechanical properties of FT and UF are similar, so the values of the objective function for UF is very close to values presented in Fig.1 (not shown) [5]. The values of sensitivity index (SI) proposed by Hoffman and Gardner were calculated for coefficients W_1 and W_2 [reviewed in 8] .It was obtained that SI $\in (2.07 - 5.65)$ for FT and SI $\in (5.24 - 5.89)$ for UF. As the SI gives information about the relative sensitivity of results to parameters, it can be summarized that objective function is more sensitive to W_1 and W_2 when umbilical fascia is investigated.

.IV. Conclusions

The proposed method for comparison of the mechanical properties of human fascia and hernia meshes can serve as a practical tool to make recommendations about selection of the optimal synthetic hernia meshes. It was established that the best mechanically compatible mesh was Surgimesh14.

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