AN EVALUATION OF THE LONG-TERM MECHANICAL BEHAVIOUR OF HERNIA MESHES

MIGLENA KIRILOVA  
Institute of Mechanics, BAS  
e-mail: m.kirilova@imbm.bas.bg

DESSISLAVA PASHKOULEVA  
Institute of Mechanics, BAS  
e-mail: dessip@imbm.bas.bg

VASIL KAVARDZHIKOV  
Institute of Mechanics, BAS  
e-mail: kavarj@imbm.bas.bg

ABSTRACT. Time-dependent variations in elasticity of polypropylene mesh Surgimesh (SM) used in surgery were revealed using tensile experiments. Mesh specimens cut two months after their expiration dates were investigated and secant modulus at 5% deformation was calculated. Tissue samples from human abdominal fascia were divided into two age group up to 65 years (24 samples) and between 66-90 years (51 samples). Tensile tests were applied on fascia samples and secant modulus at 5% strain were determined. The secant modules of both materials were compared. It was shown that the elastic properties of SM increase in the process of aging and approach the mechanical properties of the fascia samples from 45-65 age group in longitudinal and transversal direction.

KEY WORDS: Hernia meshes, tensile experiments, elastic properties

1. Introduction
The synthetic meshes have many applications in surgical treatment of hernia, transvaginal incontinence, reconstruction of pelvic floor, acute abdominal wall loss because of trauma and/or infection, abdominal wall repair after tumour resection, congenital abdominal wall defects, stoma prolapsed, gastroplasty or ileostomy [1, 2]. The success of the surgical operation depends in a great extent on the mechanical behaviour of used hernia mesh. The tensile and visco-elastic properties of different type of meshes have been presented in various studies [3-6]. The use of biomaterials for hernia markedly reduces the recurrence rates but also change abdominal wall mechanics, which leads to high rates of local wound complications and restriction of mobility by the mesh [7]. The long-term response of some hernia meshes was evaluated using “in vivo” animal and human models [1, 9-12]. Long-term incorporated polypropylene mesh in humans however has been investigated only for a tissue response [12]. Usually hernia meshes are implanted before their expiration date according to instruction for use from the manufacturer and remain in abdominal
cavity years after operation. The question about alteration of mechanical properties of hernia meshes after their expiration date is not properly studied.

This investigation was performed in order to study the long-term changes of elasticity of Surgimesh (Aspi Medical, France) and compared them with the elasticity of human layers. It is known that synthetic meshes change their elastic properties as a result of physical ageing but to our knowledge no study to date compared the effects of this age on elastic properties of hernia mesh Surgimesh (SM) with elastic properties of abdominal layers.

2. Materials and method
Polypropylene knitted reinforcement monofilament hernia mesh Surgimech (Aspi Medical, France) was investigated (Fig. 1a, 1b). 20 samples before and 20 samples two months after expiration date were used in tensile tests. Uniaxial tests were performed using a testing machine FU1000e at 0.87 mm/sec rate of elongation. The mesh specimens (10x70 mm) were cut in two perpendicular directions - along the rows of loops (T - transversal direction) and parallel to the column of loops (L - longitudinal direction). From the calculated stress - stretch ratio curves the secant modulus at 5% strain - $E_{(5)}$ was determined. The values of $E_{(5)}$ for human fascia were obtained after tensile testing of 85 samples from 13 donors. (The average age of the subjects was 66.3 years in the range of 45 - 87 years.) The specimens were divided into two age groups - up to 65 years (Age group A- 10 samples cut in L direction and 14 samples in T direction) and between 66-90 years (Age group B- 35 samples in L and 26 samples in T direction). The mean values of secant modulus and standard deviation for investigated samples were calculated.

3. Experimental results
The experimental curves obtained after tensile tests of Surgimesh are presented in Fig.2. They revealed isotropic behaviour of Surgimesh up to 6% strain before expiration date and orthotropic behaviour after 3% strain two months after ED (Fig.2). The isotropic behaviour of SM was reported previously in [6]. The results clearly demonstrated the influence of physical age on the elasticity of investigated hernia mesh in both directions.
An evaluation of the long-term elastic behaviour...

Fig. 2 Stress - stretch ratio curves for Surgimesh, two months after expiration date (ED).

Mean stress-stretch ratio curves of fascia transversalis (FT) published in [13] were compared with obtained experimental curves for Surgimesh (Fig. 3a, b). It is seen that two months after expiration date the properties of SM are closer to mechanical properties of FT in transversal direction after 3% strain. The obtained results shown that elastic properties of SM increase in the process of aging and approach the mechanical properties of the fascia samples from 45-65 age group in longitudinal and transversal direction.

Fig. 3 Comparison of experimental curves obtained for fascia transversalis (FT) and Surgimesh before expiration date and two months after expiration date: (a) in longitudinal direction; (b) in transversal direction.

The values of secant modulus of SM are presented in Table 1. It is seen that they decrease in both direction of loading - from 7.06 MPa to 4.1 MPa in longitudinal direction and from 7.46 MPa to 5.1 MPa in transversal direction.

<table>
<thead>
<tr>
<th>Direction</th>
<th>$E_{(5)}$ for SM before ED [MPa]</th>
<th>$E_{(5)}$ for SM after ED [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>7.06±1.09</td>
<td>4.10±0.94</td>
</tr>
<tr>
<td>T</td>
<td>7.46±1.34</td>
<td>5.10±2.25</td>
</tr>
</tbody>
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From our tensile experiments we determined the secant modulus of fascia samples divided in two age groups - up to 65 years (age group A) between 66-90 years (age group B) in L and T directions (Table 2). The results show that the secant modulus $E_{(5)}$ for the younger group A is more than two times lower than $E_{(5)}$ for B group in longitudinal direction (5.77 MPa vs. 12.01MPa) while the values of modulus for T direction are the same (3.17 MPa vs. 3.02 MPa).

Table 2. The values of secant modulus $E_{(5)}$ for fascia

<table>
<thead>
<tr>
<th>Direction</th>
<th>$E_{(5)}$ for group A [MPa]</th>
<th>$E_{(5)}$ for group B [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>5.77±4.01</td>
<td>12.01±9.92</td>
</tr>
<tr>
<td>T</td>
<td>3.17±2.98</td>
<td>3.02±2.13</td>
</tr>
</tbody>
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4. Discussion
The elastic properties of hernia mesh Surgimesh after its expiration date were analyzed. The physical aging changed mechanical behaviour of this mesh from isotropic up to 6% strain to isotropic up to 3% strain and orthotropic at higher strains (Fig. 2). The results reveal asymmetry of elasticity in the different directions. The increase of physical aging leads to a decrease of secant modulus of SM.

Time-dependent variations in elasticity of polypropylene mesh Surgimesh used in surgery were compared with the elasticity of human fascia. The hernia meshes in both directions become more elastic but their elastic properties are not close to elastic properties of this abdominal layer. In transversal direction the value of $E_{(5)}$ for SM exceeds about two times the physiological elasticity of fascia from A and B groups. The elastic properties of hernia mesh in both directions approaches the elastic properties of the fascia from 45-65 years old patients two months after expiration date, but are far from elastic properties of fascia in longitudinal direction from B group.

The long-term mechanical properties of hernia meshes were evaluated from many authors using animal model. The influence of physical age on the elastic properties of hernia meshes depends on their structure, pore size, type of used material, filament diameter, coatings of the surface or number of layers. This is the reason for big diversity of the reported results after long-term implantation of polypropylene meshes.

Dora et al. investigated time dependent variations in biomechanical properties of different materials including cadaveric fascia, autologous fascia and PP mesh SPARC in the rabbit model [10]. All biomaterials were explanted after 2, 6 and 12 weeks and the changes of tensile strength, stiffness (force required to elongate samples), shrinkage and distortion were evaluated. It was observed that the stiffness of polypropylene mesh increased from its baseline.

Ferrando et al. evaluate the post implantation changes in biomechanical response of PP meshes – Marlex placed in the abdominal wall of rats for 30 days [14]. He reported that no difference in stiffness of the samples before and after implantation was found.
Cobb et al. performed textile analysis of three PP meshes in porcine model (Marlex, Prolene Soft and Ultrapro) and assessed their stiffness pre-implantation and 5 months post-implantation [15]. The authors reported that only one mesh – Ultrapro (lightweight) exhibited significant reduction of its stiffness.

The mechanical behaviour of hernia meshes should reproduce the behaviour of abdominal wall. This means that the existence of mechanical compatibility between tissue layers and hernia meshes is necessary condition for successful outcome of operation. The evaluation of mechanical compatibility of some hernia meshes used in surgical practice in Bulgaria has already begun and this study continues the work presented in the previous one [16].

Our results indicated that Surgimesh is not able to mimic the elastic response of the healthy abdominal fascia at 2 months after expiration date. The mechanical compatibility of this mesh will be improved if transversal direction of the mesh is implanted parallel to collagen fibres of the tissue.

Our study has some limitations. The long-term changes in elasticity of hernia meshes were determined for two months only. They should be investigated increasing interval after expiration date.

Only one commercial mesh was investigated. The textile analysis of other hernia meshes would be useful for two reasons – to see if an elastic property of other hernia meshes increase over time and to find those meshes which mechanical properties matched the properties of human abdominal fascia.

5. Conclusions
The results for the elasticity of polypropylene mesh after its expiration date were presented. The secant modulus of SM decreases in the process of aging and the elastic properties of SM approach the mechanical properties of the fascia samples from group A. The results suggest that further ageing of hernia mesh will affect its long-term elasticity which should be investigated.

REFERENCES


