Bulletin of Experimental Biology and Medicine, Vol. 149, No. 4, October, 2010

EXPERIMENTAL METHODS FOR CLINICAL PRACTICE

Impact of Position of Light Mesh Endoprosthesis with Anisotropic Structure for the Efficiency of Anterior Abdominal Wall Reconstruction

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Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 149, No. 4, pp. 424-428, April, 2010
Original article submitted August 19, 2009

Mechanical testing of light mesh endoprosthesis Ultrapro for stretching and bending resistance showed strong anisotropy of the material along and across the loop columns. Ultrapro endoprosthesis was placed parallel and perpendicularly to the midline during plastic repair of a hernial defect in rats. Six months after surgery, the development of hernias and violation of endoprosthesis structure were observed in the group with longitudinal orientation of the endoprosthesis. Transverse orientation of the endoprosthesis led to fortification of the defect site. However, the meshes were in some cases misshapen and formed folds across the loop columns, because of insufficient bending rigidity and elasticity of the material.

Key Words: *surgical meshes; mesh endoprosthesis; anterior abdominal wall hernia; plastic repair of hernial defect; Ultrapro Mesh*

The majority of modern surgical meshes are manufactured by the knitwear industry. All knitwear materials are characterized by anisotropic structure, that is, their deformation resistance is different in different directions [5]. Hence, the resistance of jersey material is largely determined by the orientationt of structural elements to maximum mechanical exposure [1].

Light meshes differ from standard mesh endoprostheses (ME) by not only lesser material consumption and higher elasticity, but also by lesser rigidity and strength, which can reach the minimum permissible level in one of directions in this highly anisotropic material. Recent independent randomized clinical trials showed an increase in the incidence of hernial relapses after application of light meshes [3,6]. Presumably, the relapses developed because anisotropy of the knitwear structure and the direction of the predominant muscle loading were neglected during implantation.

We studied the relationship between the orientation of Ultrapro light surgical mesh and anisotropic knitwear structure and the efficiency of plastic repair of experimental middle myofascial defect.

MATERIALS AND METHODS

The mechanical characteristics of Ultrapro ME were evaluated in two directions (along and across the loop columns) by the minor strip method by a single axis stretching until rupture [2] and by the loop bending test [4]. The trials were carried out on a Texture Analyser TA.XT*plus* (Stable Micro Systems Ltd.) using Exponent 32 Version 4.01 software. Due to blue strip label of knitwear material along the loop columns, it was easy to control the orientation of Ultrapro ME.

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Stretching resistance trials were carried out on 4 fragments of the meshes cut out along and across the loop columns (blue strips), 7.0×2.5 cm in size. The specimens were fixed by the strip method with clamps located at a distance of 50 mm and stretched until rupture at a rate of 1 mm/sec. Breaking load (tensile strength) and relative breaking strain were evaluated on computer diagrams of stretching. The load was calculated as the ratio of stretching effort (Newton, N) to specimen width (mm). The breaking load index was used for comparative evaluation of the mesh strength characteristics, because many authors persuasively proved that it was virtually impossible to correctly measure cross-section area of the jersey sample and hence, to estimate the strain emerging in it [2,5]. The breaking strain (deformation of the sample at the moment of rupture) was estimated as the proportion of absolute breaking strain to the initial length of the sample, expressed in percent. The uniformity coefficient (C) was calculated for each parameter (P). This coefficient characterized the intensity of material anisotropy along and across the loop columns and was equal to the ratio of minimum to maximum values of the parameter ($C=P_{min}/P_{max}$).

Testing of ME bending resistance in each direction was carried out on 4 samples 11×4 cm fixed (in the form of 40 mm-high loops) in the lower clamp. The loop was compressed by 15 mm at a rate of 2 mm/sec with a polished disk (50 mm in diameter) connected via a rod adapter to a mobile traverse, after which the disk was returned to the initial position at the same velocity (Fig. 1, *a*). The characteristics of mechanical properties in the loop test were rigidity and bending elasticity. Bending rigidity was determined as an effort (centinewton, cN) needed for the loop bending modification (flattening) by 15 mm. The rigidity in this case was regarded as the capacity of the material to resist changes in the size under the effect of an external force. Bending stiffness was calculated in percent as the ratio of loop unbending work to bending work (Fig. 1, *b*). The loop unbending work corresponded to the area under the lower curve (*2-3*), compression work to the area under the upper curve (*1-2*). Elasticity characterized the capacity of the material to restore the initial size after deformation.

Middle myofascial defect in the anterior abdominal wall (2.5×1.5 cm) was created in 15 male rats (450-480 g) under general anesthesia directly before implantation of Ultrapro ME. The rectus abdominis muscles were partially dissected, the transverse fascia and the peritoneum were spared. In 10 animals, the defect was closed with a mesh (40×30 mm) placed between the aponeurosis and transverse fascia. In group 1 (*n*=5), the loop columns were positioned along the midline and in group 2 (*n*=5) perpendicularly to it. In 5 control rats, the defect was not repaired, only the skin was sutured. After 6 months, the animals were sacrificed. A catheter was inserted into the abdominal cavity and intra-abdominal pressure was smoothly elevated to 30 mm Hg (hernial test). The anterior abdominal wall was dissected and transferred onto the examination table with illumination. The geometrical parameters of the mesh were measured, after which the changes in mesh structure were studied under a Motic SMZ-168T microscope. Then a strip 15-20 mm wide and 30-35 mm long passing through the defect area was cut out perpendicularly to the midline from each anterior abdominal wall. The strips were tested for stretching until rupture on a TA.XT*plus* texture analyzer at a working distance of 20 mm. The threshold

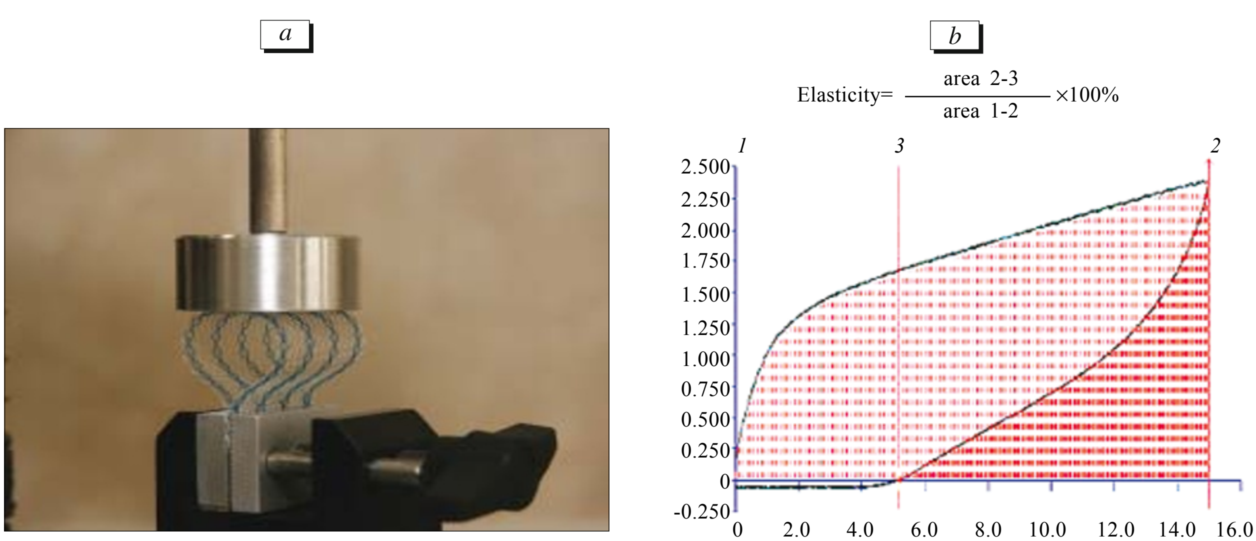

Fig. 1. Loop test. *a*) compression of Ultrapro ME specimen bent in a loop; *b*) compression-unbending diagram and formula for estimation of bending elasticity. Ordinate: intensification (cN); abscissa: displacement (mm)

strength (tension of the sample preceding its rupture; MPa) and destruction deformation (in percent) were evaluated. The tension was calculated as the effort proportion to the sample transverse section area in the thinnest part of the sample. The use of the tension parameters made it possible to compare the mechanical properties of specimens of different size.

Statistical analysis was carried out using Statistica 8.0 software with Student's *t* test. The differences were considered significant at $p<0.05$.

RESULTS

The stretching diagrams (Fig. 2, *a*) show that the initial Ultrapro ME specimens in the longitudinal direction were sufficiently strong (4.16±0.73 N/mm) with very little elongation until rupture (36.4±1.7%); their strength in the opposite (transverse) direction was low (1.43±0.09 N/mm) and they were highly stretchable (104.9±6.2%). Uniformity coefficients estimated for the strength and deformation parameters in rupture were below 0.5 (0.34 and 0.35, respectively) and hence, objectively confirmed pronounced anisotropy of the Ultrapro ME jersey structure.

According to the loop test, the transverse bending rigidity (6.03±0.34 cN) was almost 3-fold higher than the value for longitudinal direction, which was extremely low (2.06±0.90 cN), the uniformity coefficient of the rigidity parameter being just 0.34. The bending elasticity along and across the loop columns also differed significantly, but the differences in the means were not so great (66.4±0.5 and 59.2±4.7%).

Six months after the operation hernial formations were shown by elevation of intra-abdominal pressure in all controls. In group 1 (longitudinal Ultrapro position), the hernial test detected a small hernia in one animal. Its cause was shown by stereomicroscopy: extensive destruction of ME in the center of the defect (Fig. 3, *a*). In two other animals of this group, stereomicroscopy showed ruptures in the mesh (5 and 8 mm long), in two cases solitary loops and chains were damaged (Fig. 3, *b*). In group 2 (transverse position of Ultrapro), no hernial formations were detected. Stereomicroscopy showed shrinkage of the loops in chains and increase in transverse size of the jersey cells without impairment of the ME tricot structure (Fig. 3, *d*). Changes in the geometrical sizes of implanted ME were uniform in both groups: shrinkage by length and stretching by width (Table 1).

These changes were more pronounced in group 1 and were caused by lateral overstretching of the implants. In group 2, extension of the implants by width resulted from rearrangement of mobile elements in the structure of the material during the initial period of treatment, while shrinkage by length was caused by the formation of transverse folds of the mesh at the site of the defect in some animals (Fig. 3, *c*) and, presumably, by inflammatory shrinkage. It is noteworthy that in another study performed by us (results are not published), Ultrapro ME folds formed in virtually 100% cases if the endoprostheses were implanted onto the peritoneal surface perpendicularly to the midline. The formation of folds in transverse positioning of Ultrapro ME can be explained by liability of the mesh material to bending (according to the loop test) in the direction of least rigidity and elasticity in the absence of sufficient mechanical support by the myofascial tissues from the outside and inside.

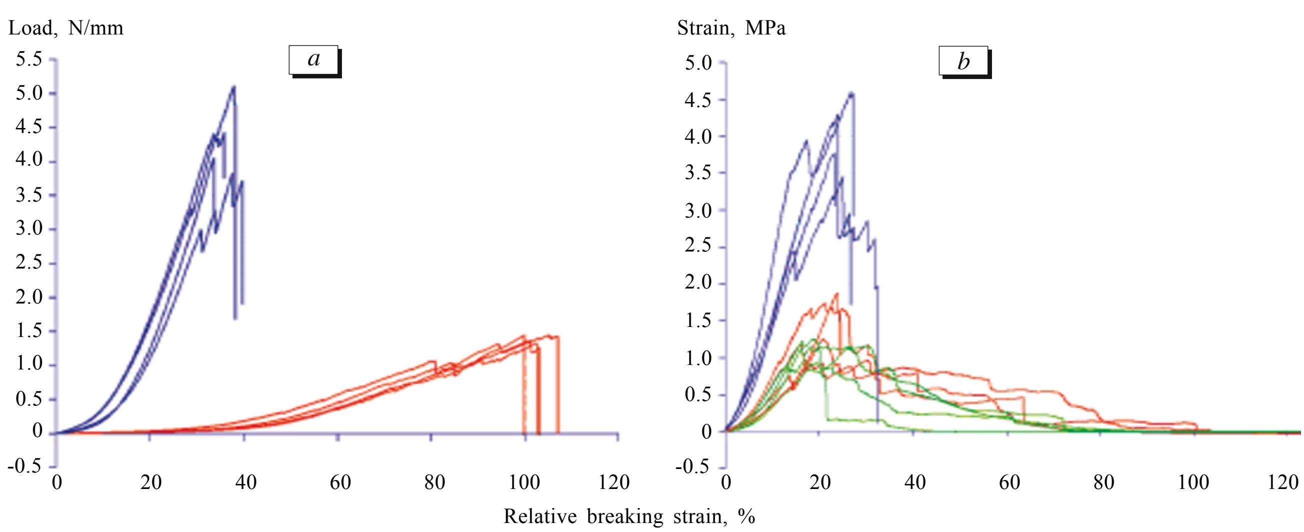

Fig. 2. Stretching diagrams. *a*) loading-deformation diagrams for specimens of Ultrapro ME cut out along (blue lines) and across the loop columns (red lines); *b*) tension-deformation diagrams for specimens of myofascial defects in rats. Blue lines: transverse position of ME; red lines: longitudinal position; green lines: hernial sac tissue.

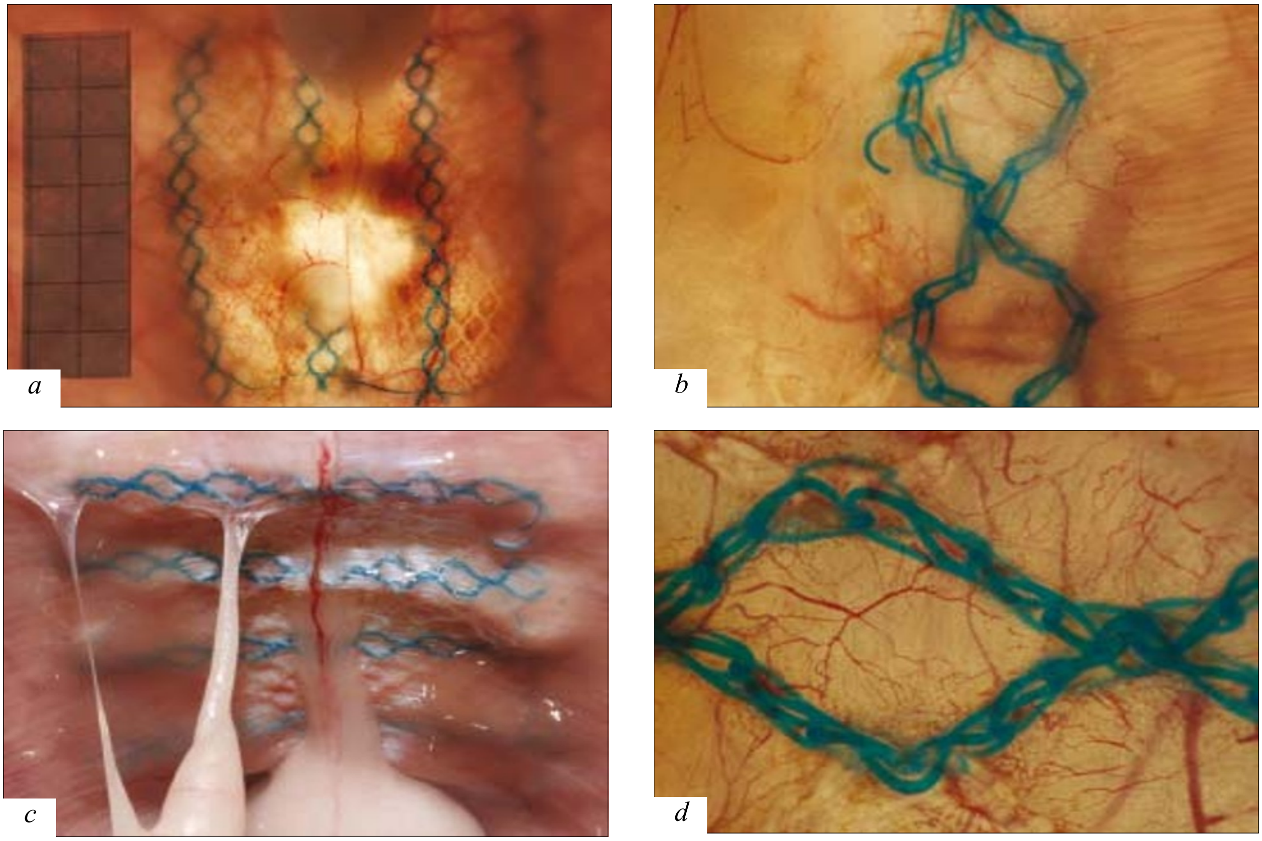

Fig. 3. Changes in Ultrapro ME structure 6 months after plastic repair of myofascial defect. *a*, *b*) longitudinal orientation; *c*, *d*) transverse orientation. *a*) ME destruction with formation of hernia. Macrophotograph of the anterior abdominal wall in transmitted light; *b*) longitudinal rupture with impairment of loops and chains. Stereomicrophotograph, ×10; *c*) transverse fold (from the abdominal cavity). Macrophotograph; *d*) shrinkage of loops in chains and deformation of the cell. Stereomicrophotograph, ×20.

Mechanical stretching tests of specimens of the anterior abdominal wall (Fig. 2, *b*) showed that the threshold strength of strip samples from group 1 and control virtually did not differ and was 1.5±0.3 and 1.3±0.4 MPa. In the transverse direction, the mesh specimens were initially not sufficiently strong, while the developing connective tissue layer by mechanical characteristics corresponded to the hernial sac tissues. In group 2, the mesh specimens were maximally strong (Fig. 2, *b*). The mean threshold strength (4.0±0.8 MPa) was significantly higher than in group 1 and control and indicated fortification of the defect area. Stretching deformations in rupture virtually did not differ between groups 1 and 2 (29.4±12.2 and 32.3±11.0%). The initially greater stretchability of Ultrapro ME in the transverse direction was leveled after the formation of connective tissue layers enveloping the prostheses and development of cicatricial cords at the site of the mesh rupture in group 1. The mean breaking strain in the control (21.9±6.5%) was significantly lower than the corresponding values in both experimental groups, because strips cut out from the hernial sac consisted mainly of not strong and not elastic cicatricial tissue.

TABLE 1. Changes in Geometrical Sizes of ME (% of Initial Size) 6 Months after Implantation (*M*±*m*)

Group	Length	Width	Area
1 (longitudinal position)	92.9±2.9*	119.5±3.7*	111.3±6.4*
2 (transverse position)	94.7±5.2	106.1±0.7*+	100.7±5.8+

Note. $p<0.05$ compared to: *initial size, +group 1.

Hence, Ultrapro meshes implanted to the anterior abdominal wall to the site of median defect experienced mainly lateral stretching and maximum bending along the midline. Application of the Ultrapro mesh with its loop columns perpendicularly to the midline led to shrinkage of the knit structure elements and to fortification of the anterior abdominal wall, because the lateral muscle efforts during stretching worked in the maximum strength and minimum mobility directions of connections of the structural components (threads and chains). However, if the mesh is applied this way, poor rigidity and insufficient elasticity of the mesh for transverse bending of the loop columns become the factors promoting the formation of transverse folds. If the Ultrapro mesh was oriented with its loop columns along the midline, there were no folds, but deformation of the implant width developed, leading to appearance of damage and ruptures of the knit structure. The strength of connections of the weft and chain threads in the transverse direction was insufficient to resist the breaking load.

Anisotropy of the tricot structure and predominant directions of bending and stretching deformations should be taken into consideration in implantation of light meshes. Light meshes with highly anisotropic structure (Ultrapro ME) can be used for fortification of a hernial defect so that the strongest and most rigid elements of the structure are oriented along the direction of the maximum muscular efforts. In order to prevent plication, additional bending rigidity should be created by placing the light meshes into spaces between the muscles or fascia.

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