EXPERIMENTAL METHODS FOR CLINICAL PRACTICE

Comparison of the Results of Hernia Defect Plasty with Standard and Light Surgical Meshes with Identical Knitted Structure

M. V. Anurov, S. M. Titkova, and A. P. Oettinger

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Standard and light surgical meshes with identical knitted structure: Parietene Standard/Parietene Light and Premilene/Optilene were chosen for hernioplasty in 20 rats. Six months after surgery, the complications were primarily related to inflammation in groups with implanted standard meshes and with prosthesis deformation in groups with light meshes. The character of complications was determined by characteristics of knitting structure and mechanical proprieties of surgical meshes.

Key Words: *hernia defect plasty; surgical meshes; mesh endoprosthesis; Optilene Mesh; Parietene Ligh; Parietene Standard*

Complications developing after hernioplasty with mesh endoprosthesis (ME) are primarily determined by large volume of implanted foreign material [3]. In this connection, heavy (>90 g/m^2) and standard ME (70-90 g/m^2) are now replaced with light and ultralight ME with a surface density of 35-25 g/m^2. According to numerous reports, these endoprostheses apart from reduced amount of foreign material are characterized by elasticity values close to the physiological elasticity of the anterior abdominal wall (AAW) [2,3]. These improvements should theoretically promote integration and reduce the severity of inflammatory foreign body reaction. However, reduction of the weight of surgical meshes made of a knitted fabric even without changing the type of weaving affects all their structural characteristics and mechanical properties, which can affect the efficiency of AAW plasty.

Department of Experimental Surgery, Institute of Fundamental and Applied Biomedical Studies, N. I. Pirogov Russian State Medical University, Moscow, Russia. ***Address for correspondence:*** anurov-m@yandex.ru, anurov@rsmu.ru. M. V. Anurov

Here we studied the dependence of the results of hernia defect plasty with standard and light ME of similar weaving structure on their structural parameters and mechanical properties.

MATERIALS AND METHODS

Two pairs of surgical meshes from different manufacturer's were chosen for the study. Each pair consisted of light and standard warp-knitted meshes of similar structure made of monofilament polypropylene threads. The first pair was presented by Parietene Standard and Parietene Light ME (Sofradim-Covidien) and the second pair by Premilene and Optilene LP (B. Braun).

Middle myofascial defect with partial dissection of the rectus muscle of the abdomen (the transverse fascia and the peritoneum were not cut) was modeled in 20 male Wistar rats weighing 460-530 g divided into 4 groups. The defect was closed with one of the four test ME by the sublay technique with wales positioned along the midline. The animals were sacrificed after 6 months. AAW was excised and changes in mesh structure were evaluated under Motic SMZ-168T stereomicroscope; transparency distribution of the connective tissue and the density of vascular network were determined. The size of ME was measured by computer planimetry. Histological sections of AAW from the zone of the myofascial defect replaced with the mesh were stained with hematoxylin and eosin.

Structural characteristics of knitted fabrics and their mechanical properties were compared in both ME pairs. Weaving structure of ME was analyzed under a stereomicroscope using Motic Images Plus 2.0 software for image recording and analysis. The number of courses and wales per 50 mm was determined and the diameter of threads and surface porosity of the materials were measured. Surface density (g/m^2) was calculated after weighing four 10×10-cm specimens of each mesh on an analytical balance.

Mechanical properties of ME were studied on a TA.XT*plus* Texture Analyser (Stable Micro Systems Ltd.) in tension and bending tests. The tests were performed across and along the wales (4 specimens for each direction). Uniaxial tension test was performed by the method of small strips [1]. Tensile strength and elongation at break were determined. Elongation at a strength of 16 N/cm, elastic limit, and elastic elongation were measured. The elongation of the sample at a maximum physiological strength of 16 N/cm characterized the arbitrary stiffness of ME. The lower was sample strain, the more stiff was the ME material. Elastic limit was found as the point of deviation of the strength curve from a straight line drawn from the origin of coordinates. Elastic limit corresponded to the strength causing maximum reversible strain of the material (elastic elongation).

In the loop test, bending stiffness and springiness of the material were determined, and its tendency to folding was evaluated from these two parameters. A critical combination of values was stiffness below 3 cN at springness <60%; in our previous study we showed that repeated bending of ME along the critical parameters after implantation led to the formation of folds [1].

The data were processed statistically by Student's *t* test using Statistica 6.0 software; the differences were significant at $p<0.05$.

RESULTS

Six months after implantation, some complications were revealed in groups with standard and light ME. Complications resulting from pronounced inflammation in the early postoperation period (3-4 weeks) were observed after implantation of standard meshes. In one rat of Parietene S group, extensive destruction of the transverse fascia and peritoneum covered with hypertrophied omentum was found in the zone of the muscle defect on the inner side of ME (Fig. 1, *a*). In Premilene group, a ligature fistula connected with the lower edge of the mesh via a subcutaneous passage appeared (Fig. 1, *b*). In animals implanted light meshes, the complications were related to pronounced deformation changes in the implants. In all animals of Parietene L group, the mesh formed one or two transverse folds. Since the material was spent for fold formation, the length of all meshes decreased by 14.6% ($p<0.05$) and in 3 cases, small hernias appeared under the lower edge of the mesh (Fig. 1, *c*). The transverse fold additionally stiffened the ME, therefore their width increased by only 4.3%. For comparison, the width of Parietene S ME increased by 7.4% without changes in their length. In Optilene LP group, the width of ME increased by 12.6% ($p<0.05$) and their length decreased by 12.9% ($p<0.05$); this led to displacement of the lower edge of the mesh to the zone of the defect in all animals and determined the formation of marginal hernia in 2 cases (Fig. 1, *d*).

Stereomicroscopy revealed equal distribution of the connective tissue and well-developed vascular network in zones of the ME-replaced defect in Parietene S and Parietene L groups. In Parietene L group, clusters of small vessels in mesh pores and around loops were noted (Fig. 2, *a*). Stereomicroscopy of the defect zone in Premilene group showed the presence of connective tissue cords bringing together the loops of some wales, which led to shortening of the implants by 10% ($p<0.05$) at their unchanged width. In Optilene LP group, clusters of small vessels were seen and mesh courses were brought together. The distance between the vertical loops in each fourth course decreased by 10-15% (Fig. 2, *b*). Approaching of the loops correlated with shortening of ME.

Histological examination of light meshes revealed numerous, sometimes extensive hemorrhages formed at different terms and containing hemosiderophages and more pronounced foreign body inflammatory reaction compared to standard meshes. Cell infiltrates were characterized by higher count of neutrophil and eosinophil leukocytes in Optilene LP group and the presence of numerous giant foreign body cells in Parietene L group (Fig. 2, *c, d*).

Lesser material consumption of Parietene L and Optilene LP ME was achieved due to the use of thinner theads. Surface density of light ME little differed and was about 2-fold lower than surface density of standard analogs (Table 1). Parietene L material was characterized by denser packing of the elementary units compared to Parietene S (Fig. 3, *a*, *b*) The number of courses and wales was higher by 33 and 26%,

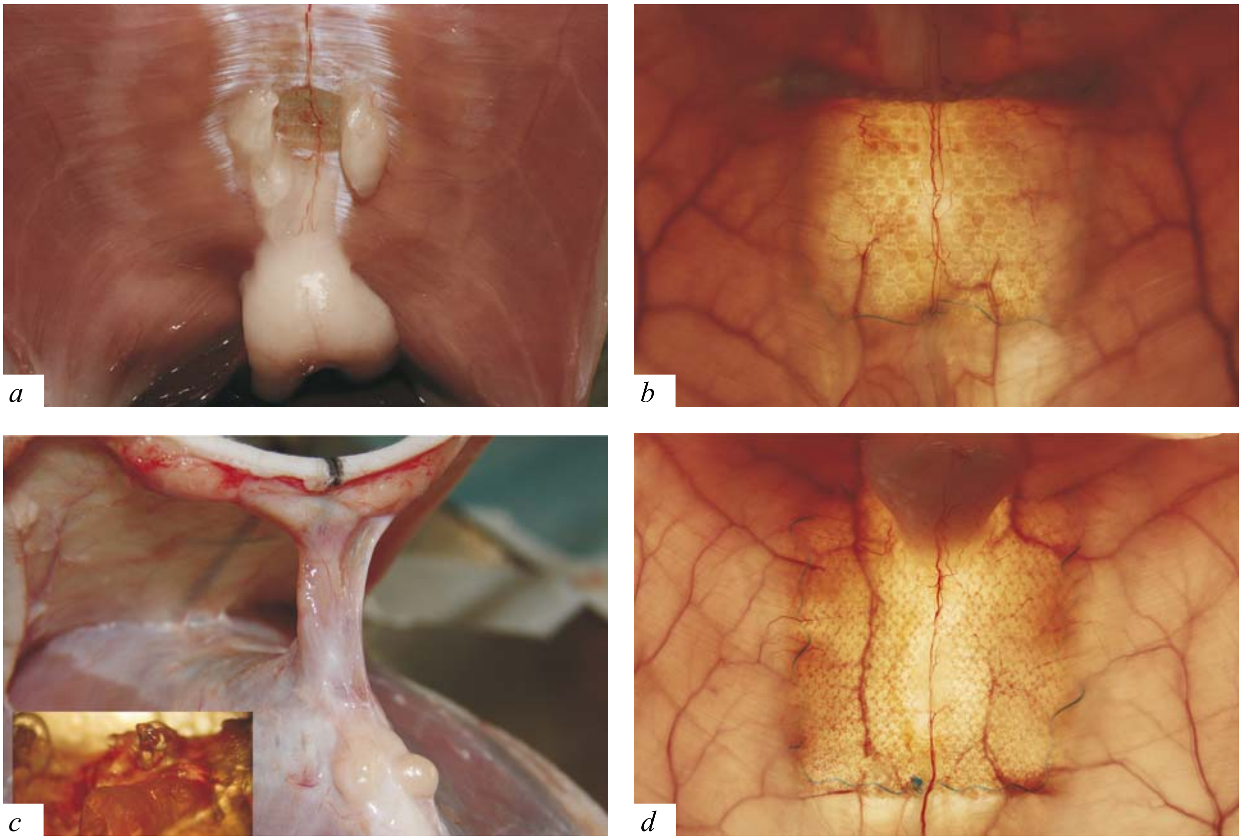

Fig. 1. Complications in groups with standard and light ME 6 months after implantation. *a*) extensive destruction of the transverse fascia and peritoneum in Parietene S group; *b*) ligature fistula in Premilene group; *c*) transverse fold and formation of a hernial defect in Parietene L group; *d*) widening and shortening of ME with the formation of a marginal hernia in Optilene LP group.

respectively, therefore, surface density parameters differed by only 6% (Table 1). Optilene LP knitted fabric had looser structure than Premilene. Analysis of the weaving pattern in this pair revealed repeats consisting of 4 courses: two courses with loops tilted to the right at great (course 1) and low (course 2) angles and two courses with loops tilted to the left at great (course 3) and low (course 4) angles. In contrast to standard mesh, Optilene LP had larger loops in low-tilt courses and smaller loops in great-tilt courses. Moreover, reduced loops lay almost horizontally (Fig. 3, *c, d*). Due to these changes, the number of courses and wales decreased by 3 and 8%, respectively, and low-tilt loops became more mobile. Surface density increased by 10% compared to Premilene (Table 1).

Despite different knitted structure of Parietene S and Premilene ME, they exhibited similar mechanical properties (Table 2). In the loop test, both meshes demonstrated high bending stiffness and springiness. Uniaxial tension test revealed pronounced anisotropy of the meshes with predominance of stiffness in the longitudinal and springiness in the transverse directions. A peculiarity of Premilene ME was excessive stiffness along the wales.

In the first pair of Premilene ME, the light mesh showed low bending stiffness in both directions and low springiness in the longitudinal direction (Table 2). The meshes with wales oriented along the midline were subjected to maximum bending force in the direction corresponding to low stiffness and insufficient

TABLE 1. Structural Characteristics of ME (*M*±*SD*)

Parameter	Parietene Standart	Parietene Light	Premilene	Optilene LP
Thread diameter, μ	141.3±3.5	88.9±3.1*	142.0±4.5	101.0±3.1*
Surface density, m^2/g	72.2±0.6	37.2±0.5*	80.2±3.0	37.9±0.4*
Surface porosity, %	58.7±2.7	64.7±2.0*	53.6±0.5	63.6±0.3*

Note. Here and in Table 2: *p<0.05 compared to standard analogs.

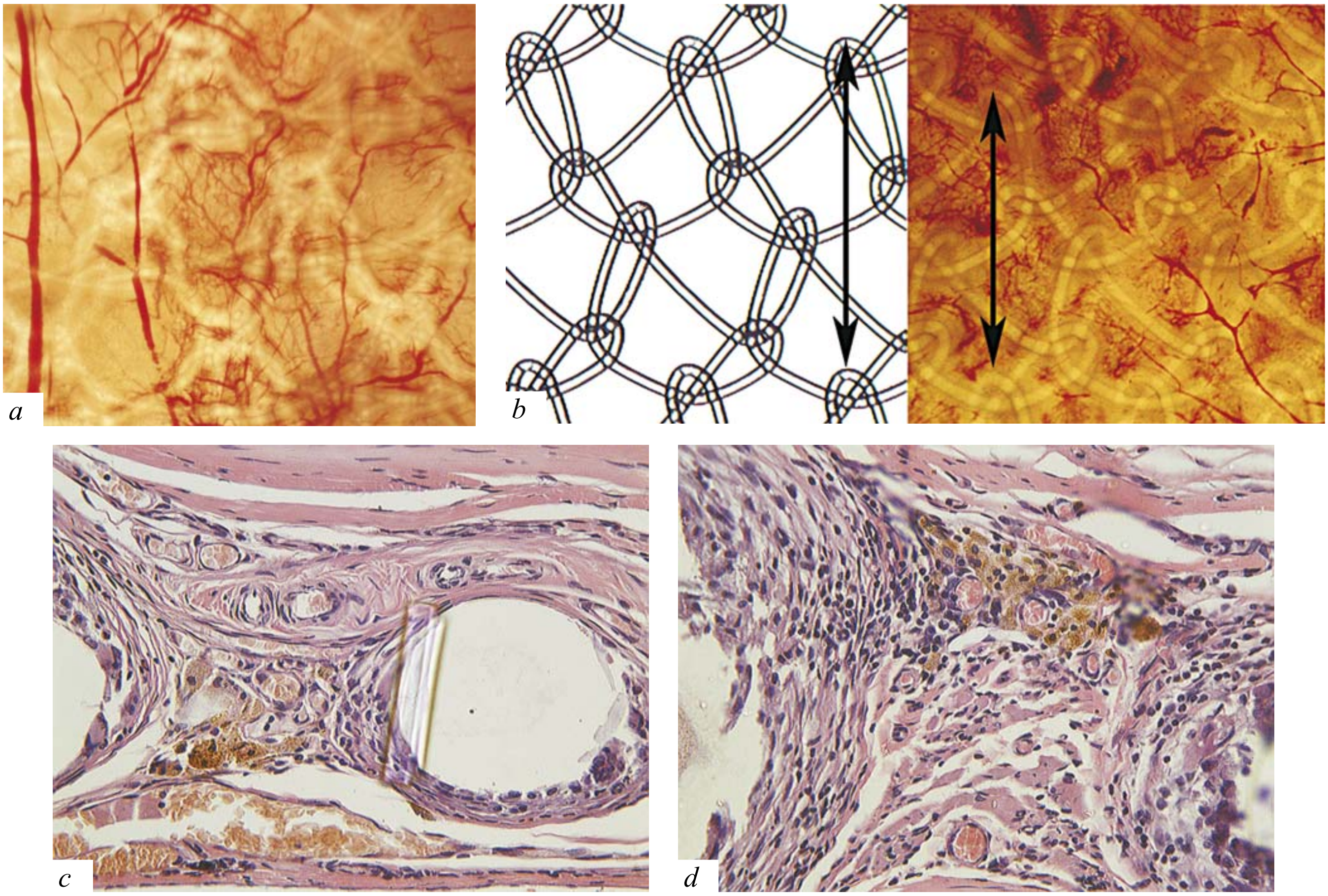

Fig. 2. Microscopic picture of a myofascial defect repaired with ME. *a*) clusters of small vessels in pores and around loops of Parietene L (stereomicrophotograph, ×15); *b*) approaching of the wales of Optilene LP ME (stereomicrophotograph, ×15); *c, d*) inflammatory infiltrations and small hemorrhages in Parietene L ME (*c*) and Optilene LP thread knots (*d*, microphotograph, ×400). Hematoxylin and eosin staining.

TABLE 2. Mechanical Properties of ME during Bending and Tension (*M*±*SD*)

Parameter			Parietene Standart	Parietene Light	Premilene	Optilene LP
Bending	Stiffness, cN	along wales	5.7 ±0.1	2.2±0.3 *	6.7 ±1.7	2.0±0.2 *
		across wales	6.1±0.4	2.1±0.1 *	5.1 ±0.3	1.9±0.2*
	Springiness, %	along wales	64.5±0.8	59.3±2.6*	73.9±3.3	70.8±4.1
		across wales	80.3±0.2	75.6±3.1	77.3±0.3	75.5±2.4
Tension	Tensile strength, N/cm	along wales	50.7±6.7	28.5±4.8*	72.2±13.3	27.0±2.3*
		across wales	47.3±2.5	30.7±2.8*	54.7±8.7	23.4±4.3*
	Elongation at break, %	along wales	67.8±13.0	72.2±6.4	64.0±6.9	66.2±4.8
		across wales	103.0±4.9	100.8±3.3	123.7±2.3	119.5±8.3
	Elongation at 16 N/cm	along wales	29.8±3.5	50.9±3.3*	23.1±5.5	50.0±0.8*
		across wales	57.3±1.5	70.4±0.9*	61.0±13.1	97.5±2.5*
	Elastic limit, N/cm	along wales	7.5 ±1.1	2.9±0.7*	9.9±3.2	1.1±0.1*
		across wales	4.6±0.3	1.8±0.2*	5.0±0.9	0.9 ±0.1 *
	Elastic elongation, %	along wales	13.3±1.6	14.0±3.0	15.8±2.6	14.8±1.2*
		across wales	23.8±2.8	16.2±1.2*	26.2±2.9	19.8±0.7*

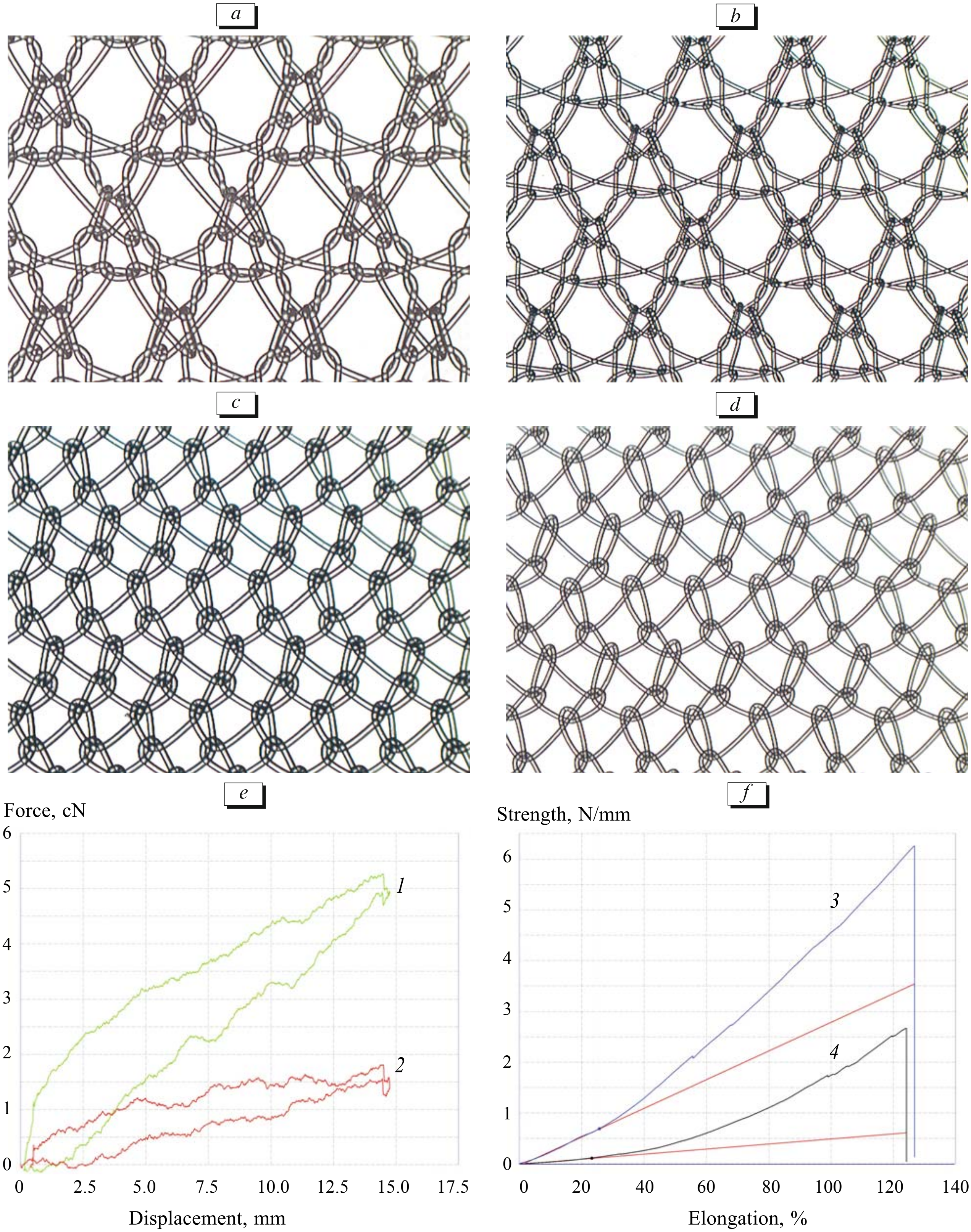

Fig. 3. Knitting structure of two pairs of ME and bending and tension strain diagrams. *a, b*) drawn-thread work on the basis of satin weaving with open loops: Parietene S (*a*) and Parietene L ME (*b*). Stereomicrophotograph, ×10. *c, d*) satin weaving with closed loops: Premilene (*c*) and Optilene LP ME (*d*). Stereomicrophotograph, ×10. *e*) compression-decompression diagrams of longitudinal Parietene S (*1*) and Parietene L ME samples (*2*). Decrease in bending stiffness and springiness in Parietene L ME; *f*) tension-elongation diagrams of transverse Premilene (*3*) and Optilene LP (*4*) ME samples. Loss of springiness in Optilene LP ME. Projection of points 1 and 2 on abscissa and ordinate axes corresponds to elastic elongations and elastic limits of samples, respectively.

springiness (Fig. 3, *e*), therefore transverse folds appeared 6 months after transplantation in all the animals of the Parietene L group. In uniaxial tension test, the decrease in tensile strength in both directions was lower than material reduction. Tensile strength parameters for Parietene L were high, while elongations at break were similar in light and standard meshes (Table 2). Due to more dense knitted structure with low anisotropic properties, the material of the light mesh retained its capacity to resist the applied strength. At a strength of 16 N/cm, the elongation across and along the wales of Parietene L increased by 1.7 and 1.3 times, respectively (Table 2), and constituted 70% of elongation at break. Parietene L in both directions did not come to the pre-rupture phase at a strength of 16 N/cm, which usually occurs for knitted fabrics at a strength constituting 75% of elongation at tensile strength. In sites of elastic deformations, the elastic limits for Parietene L were by 2.6 times lower than for standard mesh. The material of light mesh appreciably lost its springiness only in the transverse direction (Table 2), which was determined by less strong bonds between structural elements across the wales. After implantation, displacements of the loops and laps caused by side load to the meshes probably injured newly formed vessels and led to the appearance of numerous small hemorrhages.

In the second pair of ME, the loop test revealed considerably decreased bending stiffness in the light mesh Optilene LP, but in contrast to Parietene L it retained high springiness both along and across the wales (Table 2) and no folds were formed after implantation. Uniaxial tension test revealed considerably reduced tensile strength and pronounced anisotropy of the knitted structure, which sharply impaired its capacity to resist transverse strength. The relative elongation of Optilene LP across the wales at a strength of 16 N/cm approximated 100% and preceded sample break. Pronounced changes in mechanical properties were also detected at initial tension. Extremely low elastic limits along and across the wales were associated with relatively high values of elastic elongation (Table 2), which attested to the loss of tension springiness (Fig. 3, *f*). Low springiness was determined by loose knitting structure with high loop mobility. Transverse loads easily brought the courses together and decreased the size of Optilene LP ME along the wales. Moreover, mobile loops injured the adjacent tissues causing small hemorrhages and maintaining the inflammatory reaction around the majority of knots.

Thus, reduction of the amount of the implanted material led to changes in mechanical properties of ME: to a critical decrease in tensile stiffness across the wale in Optilene LP and bending springiness along the wales in Parietene L. Deformation of ME sometimes with the formation of marginal hernias was observed in all animals with implanted light meshes. Moreover, high mobility of structural elements in light ME across the wales was the cause of injury to the young granulation tissue with the formation of small hemorrhages and the formation of a large number of neutrophil leukocytes and macrophages in the infiltrate [4]. For reducing the risk of hernia relapse and decreasing the intensity of the inflammatory reaction, the peculiarities of deformation behavior of light meshes should be taken into account. During plasty of the midline defects, Parietene L and Optilene LP ME should be positioned with wales across the midline, which will help to avoid folding of Parietene L and shortening of Optilene LP. Moreover, orientation of the wales along predominating strengths will lead to compaction of the structural elements and strengthening of bongs between them, which finally will reduce the damaging effects of the loops and laps on the forming connective tissue. Marking along the wales can facilitate visual control of ME positioning.

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