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Comparison of Biomechanical Properties of Light Mesh Endoprostheses with Different Structural Characteristics

M. V. Anurov, S. M. Titkova, M. D. Polivoda, N. N. Shchyogoleva*, L. M. Mikhalyova*, I. G. Tsitovich, N. V. Galushkina**, and A. P. Ettinger**

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Three types of light mesh endoprostheses with different jersey structure were implanted into the anterior abdominal walls of 18 rabbits. Changes in the geometrical size and mechanical properties of the prostheses detected 3 months after implantation largely depended on the jersey structure and distribution of mature connective tissue in the structure of the material.

Key Words: *mesh endoprosthesis; surgical mesh; hernioplasty*

Due to modification of the jersey patterns, light mesh endoprostheses (NE) for hernioplasty were created, containing 2-3-fold less polymer and inducing minimum foreign body reaction [1,4]. New light constructions are characterized by high elasticity and do not limit mobility of the anterior abdominal wall (AAW), which is their obvious advantage (from the functional viewpoint) in comparison with the standard surgical nets [2,4].

The efficiency of hernioplasty is determined by stability of mechanical properties of implanted prosthesis and the composition of connective tissue layer enveloping it [4]. Significant reduction of materials consumption results in deterioration of the light NE strength and rigidity [5], and repeated stretching and bending loading, to which the prostheses are exposed after implantation in the AAW, can lead to deterioration of their strength and deformation characteristics. Inflammatory response to operation trauma and tissue reaction to the implant result in filling of its textile pattern with the connective tissue [3]. The properties of the jersey pattern are essential for the process of connective tissue formation, while tissue distribution can modify the mechanical characteristics of the prosthesis.

We studied the biomechanical properties of light NE with different jersey structure 3 months after implantation to the rabbit AAW.

MATERIALS AND METHODS

Three types of light NE differing by jersey structure (Fig. 1, *a-c*) were implanted in the AAW of male rabbits (3-3.5 kg; *n*=18). The animals were divided into 3 groups, 6 per group, depending on the type of implanted NE. The nets (60-50 mm) were implanted under the posterior aponeurosis leaflet with the loop columns positioned along the midline and fixed by continuous suture along the perimeter. Three months after the operation, the animals were sacrificed. The AAW was transferred onto a focusing screen of the stage and the length, width, and area of the implant were measured by computer plani-

Russian State Medical University; *Laboratory of Clinical Morphology, Institute of Human Morphology; **Department of Jersey Technology, A. N. Kosygin Moscow State Textile University. ***Address for correspondence:*** anurov@rsmu.ru. M. V. Anurov

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metry. Strips 35×20 mm were then cut out from each AAW in the longitudinal and transverse directions; the mesh with a layer of the connective tissue was removed from each strip and its strength was tested on a rupture device. Rupture trials of longitudinal and transverse specimens of NE jersey were carried out. Histological sections of AAW were stained after van Gieson, microphotographs were made, the thickness of the resultant connective tissue layer was measured using Motic Images Advanced 3.2 software, and the proportion of mature connective and fatty tissue in large pores and partial content of mature connective tissue at the site of NE nodes were evaluated. The data were statistically processed using Student's t test; the differences were considered significant at $p<0.05$.

RESULTS

Low surface density of the 3 jersey NE varied from 33 to 41 g/m^2 (Table 1). Type 1 NE were made from thin threads 92±3.9 μ in diameter by the open loop filet pattern. Its specific feature was even distribution of the structural elements around 1.5×1.5 mm pores and their symmetrical orientation by coordinates (Fig. 1, *a*). Type 2 NE were knit from "standard" threads 139.7±3.6 μ in diameter by the closed loop atlas-atlas incomplete pattern. Peculiar features of this pattern are asymmetry and heterogeneous filling of the material. Heterogeneity of the structure was characterized by the presence of large (2.5×2.7 mm) pores and small cells with the formation of "nodular" connections and by alternation of single and double loops in the loop columns (Fig. 1, *b*). Type 3 NE had only large rhombus pores (3.2×32.3 mm) with sides formed by loops of two chains and shoot wires from Polyglekapron-25 resorbable copolymer (Fig. 1, *c*). Symmetrical components consisted of numerous interwoven threads, forming large nodes between each other. orderly structure of the material was filled extremely heterogeneously. The diameter of chain threads was 94.1±5.1 μ, that of resorbed shoot wires 135.0±5.5 μ. It is noteworthy that the structure of patterns 2 and 3 NE was characterized by better surface and volumic porosity (Table 1).

Planimetric study 3 months after implantation showed that the geometrical sizes of NE changed least of all in group 1 (Fig. 2, *a*). Stretching of prosthesis by 10% (width) and shrinking by 2.3% (length) resulted in a moderate increase of their areas (by 6.8%). In group 2, the prostheses became 12.4% wider and shrank by 10.2% of their initial length, and therefore planimetry showed 90% rotation of the rectangular implants (Fig. 2, *b*), their areas remaining virtually unchanged (-1.8%). In group 3, the prostheses lengths did not differ from the initial value, but the rectangles transformed into

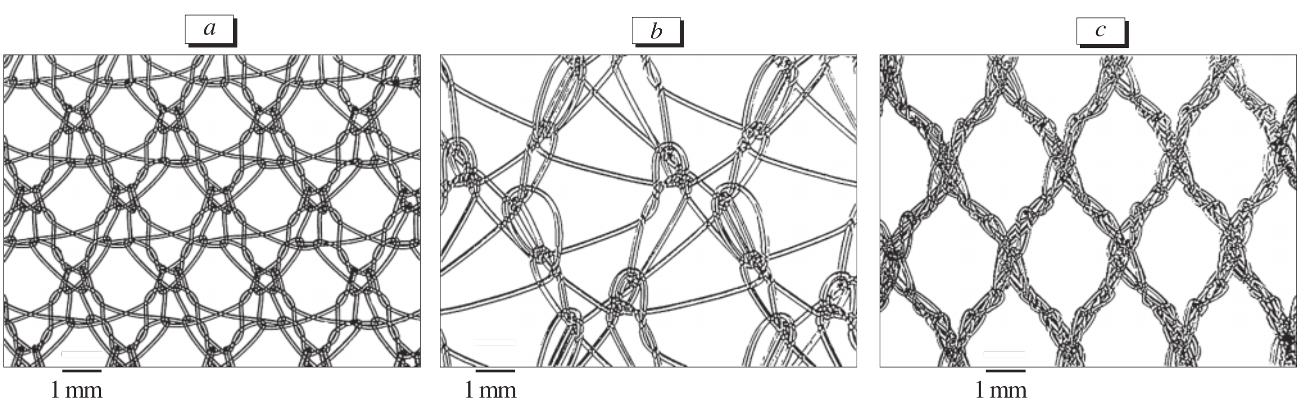

Fig. 1. Scheme of NE jersey patterns. *a*) type 1 NE; *b*) type 2 NE; *c*) type 3 NE.

TABLE 1. Structural Parameters of Implanted Light NE ($M\pm m$)

NE type		Surface density, g/m^2	Cloth thickness, mm	Surface porosity, %	Volumic porosity, %
1		36.7±0.5	0.39±0.01	66.7±1.3	89.5±0.5
2		40.6±0.5	0.55±0.01	69.1±1.1	92.0±0.2
3	PP	33.1±0.4	0.51±0.02	76.6±0.3	93.1±0.3
	PP+PG	56.1±1.8	0.61±0.03	69.5±0.8	91.3±0.2

Note. PP: polypropylene portion; PG: Polyglekapron-25 shoot wire.

squares because of 17% widening, their area increasing by 19% (Fig. 2, *c*).

Rupture trials also showed great stretching of the prostheses width or across the loop columns. For pattern 1, the percentage of elongation in the longitudinal and transverse directions was within 8%, for pattern 3 this value approached 25%, and for pattern 2 it reached 49%, with the values differing 2.2 times from the initial ones. Uneven elongation of pattern 2 NE was due to double loops in the columns, which limited stretching of samples in the longitudinal direction.

Evaluation of the rupture efforts for the initial pattern 1 NE strips cut longitudinally and across the loop columns showed close values of specific strength (22±3 and 24.5±1.7 N/cm). For pattern 2 NE more intense rupture efforts were needed in the direction along the loop columns (28.5±3.1 and 23.0±3.4 N/cm). Pronounced differences were recorded for pattern 3 samples, a 3.6 times more intense rupture effort being needed for the longitudinal *vs.* transverse strip (56.0±5.5 and 15.5±1.6 N/cm). The rupture loading in the transverse direction was below the minimum permissible specific strength (16 N/cm), calculated for fortification of the fascia in plastic repair by local tissues [4]. Three months after implantation the strength of group 1 samples, collected together with connective tissue, reached the mean values of 31.1±4.7 and 31.5±8.1 N/cm ($p<0.05$), which in fact corresponded to estimated specific strength of 32 N/cm, needed for AAW reconstruction [4]. In group 2, the longitudinal samples corresponded to the needed strength level after 3 months, despite a negligible increase in rupture efforts to 32.2±4.4 and 25.0±6.2 cm in both directions. In group 3, the samples moderately loosened in the longitudinal direction (49.0± 6.5 N/cm) because of partial resorption of shoot wires and became stronger in transverse direction (18.2±7.0 N/cm; $p>0.05$), slightly surpassing the minimum permissible level. However, pronounced difference between the strength values along and across the loop columns (2.7 times) was retained.

Morphometric analysis of histological sections showed even distribution of mature connective tissue in the layer formed in animals of groups 1 and 3. However, the percentage of mature connective tissue in the pores connecting the textile structure of the nets was significantly higher in group 1 (Table 2). Disproportional formation of mature connective and fatty tissue was detected in group 2. Pronounced growth of mature connective tissue with foci of starting hyalinosis and fibrosis were located inside the nodular connections, large pores being filled with mainly adipose tissue (Table 2). The thickness of the layer enveloping NE in groups 1 and 2 was significantly more than in group 3. In group 1 it formed at the expense of connective tissue cords alternating with fatty layers, while in group 2 it was formed by excessive fatty tissue growth (Fig. 3, *a*, *b*). A lesser thickness of the "prosthetic" layer with low content of mature connective

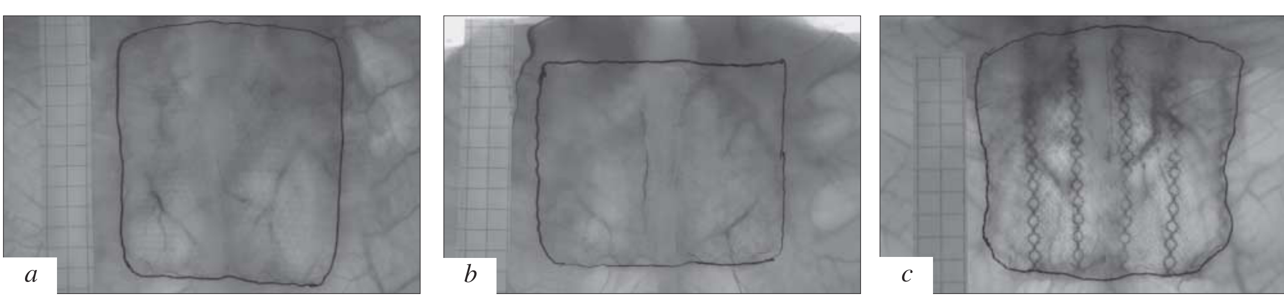

Fig. 2. Planimetric study. NE deformation. *a*) type 1 NE; *b*) type 2 NE; *c*) type 3 NE.

TABLE 2. Morphometric Analysis of Connective Tissue (*M*±*m*)

Group	Thickness of layer, μ	NE node area		Large NE pores	
		mature connective tissue, %	threads, %	mature connective tissue, %	fatty tissue, %
1	911±220***	27.8±8.7	37.8±13.4	26.0±9.9**,***	60.9±11.8
2	1139±230***	37.1±9.5*,***	40.2±13.5	12.9±6.8	81.1±8.7*,***
3	634±167	24.2±8.1	42.7±12.0	18.9±6.0	74.2±5.9

Note. $p<0.05$ *vs.* *group 1, **group 2, ***group 3.

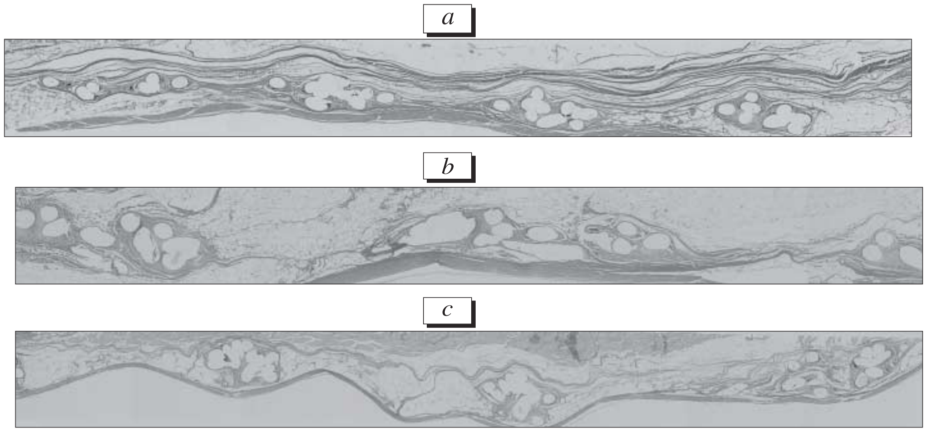

Fig. 3. Formation of connective tissue layer enveloping the NE jersey structure. *a*) group 1 (pattern 1 NE; *b*) group 2 (pattern 2 NE; *c*) group 3 (pattern 3 NE). van Gieson staining. Panoramic microphotographs are constructed from 8 shots (×100).

tissue in group 3 (Fig. 3, *c*) was most likely due to stubborn active inflammation round resorbed threads.

Edgewise stretching deformation of all NE patterns presumably resulted from maximum stretching because of the AAW lateral muscles maximum loading and insufficient elasticity of jersey materials across the loop columns. Pattern 3 NE exhibited the least strength in the transverse direction in rupture tests and the greatest stretching deformation in experiments. The thinnest "prosthetic" layer with low content of mature connective tissue formed in group 3. The strength of this layer was just negligibly higher than the minimum permissible level, and therefore, emergence of breaks can be expected in the structure of these prostheses after a longer period of observation or exposure of the samples to more intense efforts. High concentration of structural elements in some places of the loop columns and uneven stretching of pattern 2 NE caused disproportionate formation of connective tissue. Cicatricial cords formed along the loop columns, contracting the prosthesis length, while the adipose tissue grew in large pores. Eventually, the prosthesis shrank significantly by length without fortification of the jersey pattern. We can expect that implantation of pattern 2 NE with loop columns located across the midline will reduce stretching deformation without "wrinkling" the implant. More or less homogeneous structure of pattern 1 NE and symmetrical location of its elementary components provided the isotropy of the material and largely determined the least deformation of the implants. Even distribution and high content of mature connective tissue in the layer adjacent to the implant improved the strength of prostheses in both directions.

Hence, mechanical characteristics and structure of the light NE jersey materials are essential for the formation of mature connective tissue and determine the geometrical sizes and strength of the prosthesis after implantation.

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