ECRONICON OPEN ACCESS

EC CLINICAL AND EXPERIMENTAL ANATOMY

Research Article

Impact of Mechanical Characteristics of the Vascular Patch on the Formation of the Periprosthetic Capsule

Lipatov VA[1] and Severinov DA[2]*

[1]*Operative Surgery and Topographic Anatomy Department, Kursk State Medical University, Russia*

[2]*Department of Pediatric Surgery and Pediatrics, Faculty of Post Degree Education, Kursk State Medical University, Russia*

***Corresponding Author**: Severinov DA, Department of Pediatric Surgery and Pediatrics, Faculty of Post Degree Education, Kursk State Medical University, Russia.

Received: October 09, 2019; **Published:**November 08, 2019

Abstract

Introduction: The current stage of development of medical technologies is characterized by the progressive growth of the number of new medical devices. Renovation has also touched one of the most intensively developing branches of medicine-cardiovascular surgery.

Materials and Methods: As a material for experimental studies we used new and previously known samples of vascular patches representing the textile mesh.

Results: During the research it was found out that the thickness and bulk porosity of vascular implants correlated inversely with the proportion of macrophages and thus their predecessors (monocytes) in the cellular layer of the connective tissue capsule. On the contrary, such characteristics as surface density and mass of samples directly correlated with the described cellular features. That is, the severity of the exudative phase of the aseptic inflammation depended directly on the abovementioned characteristics of mylar prostheses in our experiment.

Conclusion: Surface density and sample mass directly correlated with the proportion of macrophages and monocytes in the capsule's cellular layer, while the thickness and volume porosity of mylar prostheses reversely correlated with this parameter; thickness and surface density of implants directly correlated with the proportion of fibroblastic cells.

Keywords: *Biocompatibility; Capsule; Physical and Mechanical Properties; Surgical Porosity; Bulk Porosity; Surgical Implant*

Introduction

The current stage of development of medical technologies is characterized by the progressive growth of the number of new medical devices. Renovation has also touched one of the most intensively developing branches of medicine-cardiovascular surgery [6]. In particular, many modifications have been implemented into the production of vascular patches and prostheses. This led to the necessity of searching the up-to-date methods and materials for production of inert new-generation vascular implants with the most positive physical and mechanical and structural properties [10]. According to foreign authors, these parameters play a fundamental role in the formation of the organism response to the implantation of polymeric mesh implants. It is assumed that the reaction severity can vary due to a complex of various features determined by the manufacturing company [11]. Therefore, we consider it important to study both structural and physical and mechanical characteristics of vascular patches. It will help to define the directions for manufacturing modifications in the sphere of development of materials used for reconstructive surgeries.

Purpose of the Study

To investigate the impact of mechanical characteristics of a vascular patch on the formation of a periprosthetic capsule.

Materials and Methods

In the pilot studies the new samples of vascular patches developed by Lintex LLC (St. Petersburg), representing the warp mesh, have been used as materials. The sample characteristics and the response of tissues to the implantation of a woven mylar mesh with the same thickness manufactured by PTGO Sever LLC (St. Petersburg), as well as the warp gelatin-impregnated mesh manufactured by B. Braun company (Germany) were studied for comparison.

Tests were conducted using standard techniques: GOST 12023-86 (ST SEV 997-88)-thickness determination; GOST 8847-85-analysis of strength characteristics (breaking strength and breaking stretch during monoaxial extension; breaking strength and breaking extension during biaxial extension); GOST 8846-87-determination of surface density [8]. Rigidity was determined by evaluating the degree of sample deflection under the impact of the proper weight using a tensometric method-the IZh-3 device [3].

The method of evaluation of bulk porosity of vascular patches was based on determining the volume of a body with an irregular spatial shape by liquid displacement. Surgical porosity of samples was determined at a pressure of 120 mm Hg by perfusing water through 1 cm^2 of the mesh [7].

Considering the heterogeneity of walls of woven and warp materials impacting the permeability of an implant mesh, we estimated the roughness factor of patch surface. For this purpose, we microphotographed the implants in the reflected light. Using the licensed version of the Adobe Design Premium CS5.0 software, the ratio of black to white pixels was calculated. All digital images were processed using the identical action algorithm [10].

15 samples of each type were studied.

In vivo experiments were conducted on 75 Wistar male rats weighing 200 - 250g, without visible disease signs. Animals were divided into three equal groups according to the number of vascular patches used in the study, so each group contained 25 animals.

Under the general anesthesia, according to international standards of humane treatment of animals (The European convention "On Protection of Vertebrate Animals Used for Experiments or in Other Scientific Purposes", Strasbourg, 1986), in sterile conditions of the surgery unit of the Department of Operational Surgery and Topographical Anatomy named after Prof. A.D. Miasnikov of Kursk State Medical University (Russia), skin sections were made in rats through dermal and subcutaneous fatty layers along the abdominal midline. Two pockets were formed bluntly between the muscular and skin layers on both sides of the median section up to 3.5 cm deep and long throughout the whole section. The sample of a vascular patch sized 1 x 1 cm was placed into each formed pocket. The surgical wound was sutured tightly capturing the muscular layer along the midline to isolate pockets containing experimental samples. The postsurgical wound was treated with antiseptics (Figure 1).

Animals were sacrificed on Day 14 by anesthetic overdose. In each case the autopsy with excision of sites of anterior abdominal wall to the right and to the left of the midline in the locations of implants. The obtained biological material was fixed in 10% neutral formalin solution. After fixing the smaller pieces of mesh with fragments of implanted endoprostheses were excised, and after washing, dehydration, treatment with paraffin using a standard technique and microtoming, the slices with the thickness of 10-12 microns were stained using the Mallori and Hematoxylin and eosin staining [1].

Microscoping and microphotographing of samples were conducted for a morphometric assessment of histologic changes using the optical system consisting of a Leica CME microscope and a DCM- 510 eyepiece chamber (with x100 and x400 magnifications); the photos were saved in the FUTURE WINJOE software included in the software package of an eyepiece chamber.

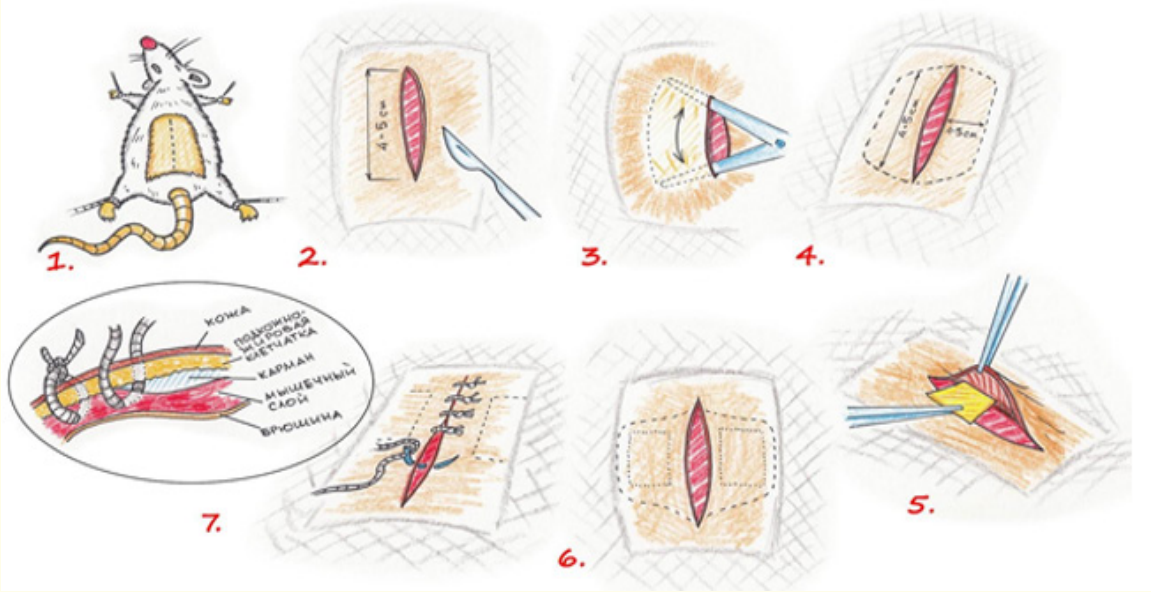

Figure 1: *The scheme of implantation of vascular patch samples into the subcutaneous fatty tissue of rats.*

In microphotos the following was estimated: fibrous capsule structure, the presence and intensity of her layers, degree of collagen fibers maturity. The structure of the capsule's cellular layer directly adjacent to the endoprosthetic threads. The fibrous tissue cells were differentiated based on karyological signs. The percent ratio of the specified representatives of the cellular population was calculated after counting 100 cages in several non-crossing fields of view [9].

Statistical processing of the obtained results was conducted using the methods of descriptive statistics: mean values (arithmetic means, modes, and medians); variation statistics: standard deviations and standard errors of means; the method of confidential intervals was used to determine the significance of mean differences. Differences of mean values at $p \leq 0.05$ [2] were considered statistically significant. During the creation of a correlation matrix the Pearson square method was used. The licensed version of the table editor Microsoft Excel 2010 was used as a software environment.

Results

We have conducted a pilot study of physical and mechanical properties of implant samples. The data on measurements of physical and mechanical parameters are systematized and presented in table 1.

Main purpose of B. Braun samples' treatment with firm gelatin was the decrease of surgical porosity and, thus, the decrease of intraoperative blood loss. However, this modification explains several essential drawbacks of such samples, such as high rigidity and low durability, as well as insignificant bulk porosity (one of the main properties defining the biological porosity and processes of biointegration of an implant into the structure of the vascular wall) [11].

Having the minimum surface density and rigidity, samples manufactured by Lintex company have sufficient durability. In our opinion, these positive physical and mechanical properties will promote processes of integration of these patches into a vascular wall, minimizing the response of bodily tissues to implantation.

	Sample "Lintex"	Sample "Sever"	r*	Sample "B. Braun"	r
Thickness, **μ**m	523.3 ± 3.59	253.7 ± 3.71	< 0.001	415.3 ± 6.25	< 0.001
Surface density, g/cm^2	0.036 ± 0.026	0.05 ± 0.012	> 0.05	0.05 ± 0.02	< 0.05
Mass of the sample sized 1 **x** 1 **c**m, g	0.038 ± 0.0009	0.03 ± 0.0004	< 0.05	0.04 ± 0.0029	< 0.05
Bulk porosity, %	44.60 ± 0.026	23.37 ± 0.02	< 0.001	5.21 ± 0.02	< 0.001
Surgical porosity, l/min **x c**m^2	1.23 ± 0.02	1.75 ± 0.02	< 0.001	0	-
Breaking strength (longitudinal), N/**c**m	121.5 ± 0.63	296.8 ± 0.36	< 0.001	73.4 ± 0.24	< 0.001
Rigidity (longitudinal), **c**N **x** mm^2	1.34 ± 0.12	2.04 ± 1.74	< 0.001	-**	-
Rigidity (transverse), **c**N **x** mm^2	6.86 ± 0.24	7 ± 0.16	> 0.05	-	-
Roughness factor	66.6 ± 52.53	15.3 ± 6.17	< 0.001	2.69 ± 0.727	< 0.001

Table 1: *Parameters of the physical and mechanical properties of studied vascular patch samples.*

**: Significance level for differences of arithmetic means was determined in relation relative to samples manufactured by Lintex company.*

***: Rigidity of "B. Braun" samples exceeded acceptable limits within which the measurements may be conducted using the chosen method.*

During the light microscopy of samples with side illumination, the roughness factor was determined. This parameter was maximum when analyzing the measurements of surfaces of samples manufactured by Lintex company (66.6 ± 52.53), which was almost 4.35-fold higher than values determined for samples manufactured by Sever company ($p < 0.01$) and 24.76 higher than for those of B. Braun company ($p < 0.01$).

During the light microscopy of histological specimens from animals in the experimental group where the response of tissues to implantation of Lintex company samples, it was detected that in all animals a fibrous capsule was formed around prosthesis threads, this capsule consisted mainly of elements of the dense fibrous connective tissue (DFCT). The capsule had a clear two-layer structure. The external fibrous layer of a capsule (Figure 2) was the most one expressed. Also, the complete integration of a capsule into the abdominal wall tissues should be pointed out-in all preparations it was not possible to define the border between the fibrous layer of a capsule and the fascias of muscles (Figure 3) surrounding her.

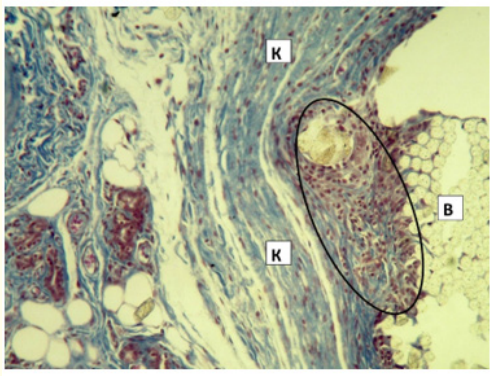

Figure 2: *A capsule surrounding the prosthesis made of Lintex material. 14 days after the implantation into the anterior abdominal wall. In the photo prosthetic fibers (B) and a two-layer capsule (K) are shown. The oval designates the accumulation of cells in a "decompression zone". Mallori staining. Microphotograph, x100 magnification.*

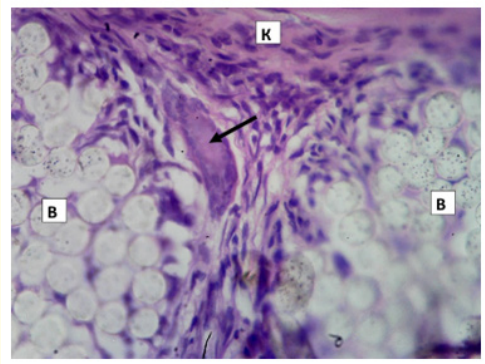

Figure 3: *A capsule surrounding the prosthesis made of Lintex material. 14 days after the implantation into the anterior abdominal wall. In the photo prosthetic fibers (B) and a fibrous capsule (K) are shown. The arrow shows giant cells of foreign bodies (GCFB) with up to 20 nuclei. Hematoxylin-eosin staining. Microphotograph, x400 magnification.*

The analysis of numerical parameters of the capsule's cellular structure (cellular layer) in this series of research showed that more than a half (59.2%) of cells were from a fibroblastic row, while the total number the phagocytic cells and their predecessors reached 25%.

Studying samples from animals using materials manufactured by Sever company showed that the degree of fibroblast differentiation, as well as the degree of collagen fibers maturity decreased from the outside (the most external capsule layers) to the inside, to implant fibers (Figure 4). Thus, the youngest forms of fibroblasts having the classical trapezoid or triangular form with moderately basophilic cytoplasm were located in close proximity to them [4,5].

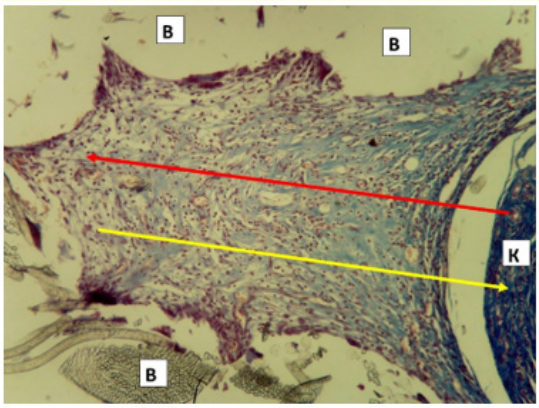

Figure 4: *A capsule surrounding the prosthesis made of Sever material. 14 days after the implantation into the anterior abdominal wall. In the photo prosthetic fibers (B) and a fibrous capsule (K) are shown. The red arrow shows a gradient of increase of the cellular density of cages per area unit; the yellow arrow shows a gradient of collagen fiber maturity. Mallori staining. Microphotograph, x100 magnification.*

It should be noted that the cellular layer of a periprosthetic capsule has a poor connective tissue components (fibroblasts and fibrocytes account for only 32.4%). Obvious prevalence of non-resident cells in the infiltrate allows to define the condition as a prolonged change of the exudative phase to a proliferative one [13].

The expressed response of phagocyting and antigen-presenting cells to Sever material dwelling in animal tissues for 2 weeks was something worth attention: the capsule's cellular layer contained 30% more macrophages and monocytes; the number of giant cells of foreign bodies (GCFB) increased, the level of their cellular and spatial organization (Figure 5) changed.

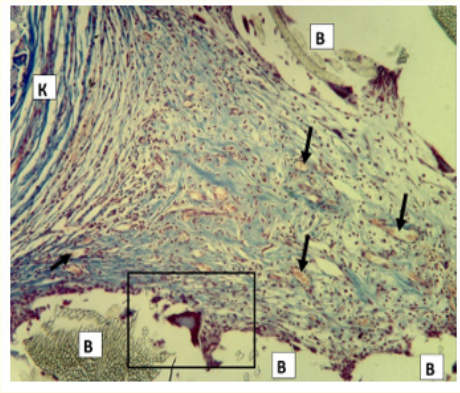

Figure 5: *A capsule surrounding the prosthesis made of Sever material. 14 days after the implantation into the anterior abdominal wall. In the photo prosthetic fibers (B) and a fibrous capsule (K) are shown. Arrows show expanded blood vessels. The selected fragment contains GCFB. Mallori staining. Microphotograph, x100 magnification.*

Microscopic study of slices obtained from animals into whom the material manufactured by B. Braun company was implanted showed that, as in two previous groups, implant material was covered by the fibrous capsule made of DFCT which was fixing and simultaneously bordering it from surrounding structures (Figure 6) [12].

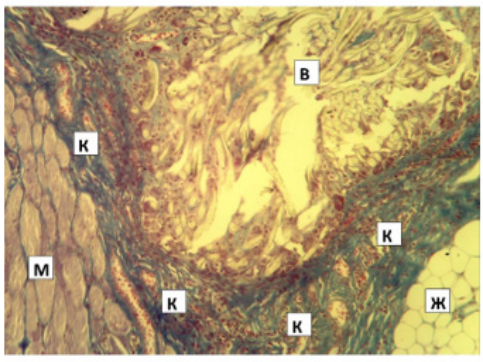

Figure 6: *A capsule surrounding the prosthesis made of B. Braun material. 14 days after the implantation into the anterior abdominal wall. In the photo prosthetic fibers (B), a fibrous capsule (K), an abdominal wall muscle (M), and fatty subcutaneous tissue (Ж) are shown. Mallori staining. Microphotograph, x100 magnification.*

If the fibrous layer of a capsule consisting of organized DFCT practically didn't differ from that noted in other groups, then the cellular layer, on the contrary, was more variable. This variety of organization was represented not only by a relatively more prominent thickness of a cellular layer, but also by a slightly different organization.

Thus, implant threads were separated from a layer with high exudative characteristics by the DFCT layer. Despite essential differences in the organization of the capsule's cellular layer in this experimental group from the group with "Sever" material used, significant differences of the qualitative structure of a cellular layer were almost not present.

Similar to group 2, the relative number of fibroblastic cells was 32%, while the proportion of non-resident cells was 68%.

Discussion

To detect the probable dependences of parameters of tissue response to implantation of the studied samples on their physical and mechanical characteristics, we have constructed a correlation matrix.

The analysis of values of the Pearson correlation coefficient (CC) showed that its value above 0.7 between the studied couple of parameters confirmed the strong communication which can be direct or reverse [6]. As seen in table 1, such characteristics of mylar implants as thickness and volume porosity reversely correlated with the proportion of macrophages and, respectively, their predecessors-monocytes (the parameter of tissue aggressive response to the implant)-in the cellular layer of a connective tissue capsule. The value of the correlation coefficient reached -0.989 and -0.999 respectively.

On the contrary, such characteristics as surface density and sample mass directly correlated with the proportion of macrophages and, respectively, their predecessors-monocytes-in the cellular layer of the connective tissue capsule, with values of the correlation coefficient equal to 0.963 and 0.825 respectively. That is, the severity of the exudative phase of aseptic inflammation depended on the values of the specified characteristics of mylar prostheses in our experiment. It was also found out that the thickness and surface density correlated with the values of the fibroblastic cell proportion in the cellular layer of the connective tissue capsule, with values of the correlation coefficient equal to 0.799 and -0.711, respectively. Consequently, the severity of the proliferative phase of the aseptic inflammation in our experiment depended on the values mentioned above.

Thus, parameters of the morphological structure of a cellular layer of a periprosthetic capsule (number of fibroblastic cells, and number of non-resident cells - monocytes, macrophages) may be sufficiently used as a criterion when developing new samples of mesh endoprostheses for reconstructive operations, namely-replacement or strengthening of tissues, wall defects of hollow organs or walls of serous cavities [8]. It can be achieved by the development of new ways of weaving meshes of implant materials, as well as by the inclusion of new types of synthetic fibers into the implant threads.

Conclusion

1. Lintex samples had the minimum surface density, rigidity, the maximum roughness and sufficient durability (tab. 1); therefore, the physical and mechanical properties of the studied samples (negative to positive) can be represented as follows: "B. Braun" => "Sever" => "Lintex".
2. Changes of inflammatory response stages proceeded quicker in the group of samples manufactured by Lintex company, which was confirmed by the statistically significant increase of the relative number of fibroblasts and the decrease of the number of monocytes, macrophages, neutrophils, eosinophils, lymphocytes in the capsule's cellular layer.
3. Surface density and sample mass directly correlated with the proportion of macrophages and monocytes in the capsule's cellular layer, while the thickness and volume porosity of mylar prostheses reversely correlated with this parameter; thickness and surface density of implants directly correlated with the proportion of fibroblastic cells.

Acknowledgment

Authors didn't get financial support from companies manufacturing the studied samples of vascular patches.

Conflict of Interest

None declared.

Bibliography

1. Avtandilov GG. "Medical morphometry: a guide". Moscow: Meditsina (1990): 384.
2. Alukhanyan OA., *et al*. "Comparative characteristic of new models of vascular patches of polytetrafluoroethylene in the experiment". *Angiologiya i Sosudistaya Khirurgiya* 18.2 (2012): 45-51.
3. Novikov SP., *et al*. "Analysis of physical-mechanical and structural characteristics of artificial blood vessels". *Grudnaya i Serdechno-Sosudistaya Khirurgiya* 4 (2012): 27-33.
4. Biocompatibility. Under the editorship of V. I. Sevastyanov. Moscow (1999): 368.
5. Byzov DV., *et al*. "Biotechnological aspects of creating grafts of arteries". *Biotekhnologiya* 3.3 (2010): 23- 32.
6. Bokeriya LA., *et al*. "The role of experimental studies in the development of new directions and innovative technologies". Byul. NTsSSKh im. A.N. Bakuleva 14.5 (2013): 4-11.
7. Vinokur AA. "Comparative study of new vascular patches of polytetrafluoroethylene (experimental study)". Dissertation. Moscow (2011): 101.
8. Zhukovsky VA. "New directions and opportunities for improving polymeric implants for reconstructive surgery. Modern technologies and possibilities of reconstructive and aesthetic surgery: materials of the II". International Scientific Conference, Moscow (2010): 90-93.
9. Lazarenko SV., *et al*. "Distinctive features of the reaction of the tunica media and tunica intima of the aorta to the implantation of prostheses of various lavas". Kursk Scientific and practical bulletin "Man and his health" 4 (2014): 11-18.
10. Lipatov VA., *et al*. "Physico-mechanical and structural properties of implants designed for operations on the great vessels". *Fundamental'nye Issledovaniya* 11 (2015): 92-98.
11. Yasim A., *et al*. "Gelatin-sealed Dacron graft is not more susceptible to MRSA infection than PTFE graft". *European Journal of Vascular and Endovascular Surgery* 32.4 (2006): 425-430.
12. Kao WJ., *et al*. "Theoretical analysis of in vivo macrophage adhesion and foreign body giant cell formation in strained poly (ether-urethane urea) elastomers". *Journal of Biomedical Materials Research* 28.7 (1994): 819-829.
13. Lipatov VA., *et al*. "Changes of physico-mechanical properties of vascular patches in conditions of chronic experiment in vivo". *Novosti Khirurgii* 27.3 (2019): 249-255.

Volume 2 Issue 10 December 2019