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The Choice of Vascular Implants in Accordance with Age-Related Vessel Changes

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BACKGROUND Today, one of the problems of modern society in the health are the high rates of mortality from cardiovascular disease.
AIM OF STUDY Study of physico-mechanical properties of the vascular implants and aortic wall to support an adequate choice of the plastic material when performing reconstructive surgeries in patients of various age groups.
MATERIAL AND METHODS As an object of study, sections of the anterior wall of the thoracic and abdominal aorta were taken from 30 corpses. Study groups: Group 1 — from 33 to 60 years, Group 2 — from 60 to 92 years. We also evaluated the physical and mechanical properties (finite length, plastic strain ratio, tensile uniaxial load (longitudinal)) of the three vascular implants made of polyethylene terephthalate and polytetrafluoroethylene. Kruskal–Wallis H test was used to determine the significance of differences.
RESULTS The finite length of the aortic wall varies slightly in the study groups, while plastic strain rate of the abdominal aorta in Group 1 was 1.3 times higher than that in the chest. When assessing physical and mechanical properties of thoracic and abdominal aorta, values of “finite length” (1.4 times) and “plastic strain ratio” (1.5 times) were higher in Group 1, and the value of the breaking load indicator is higher in Group 2 compared to Group 1 (1.47 times). The breaking load of the thoracic aorta in Group 1 is 14 H and 27 H lower than the samples of Groups 1 and 3, respectively, but 1.6 times higher than the sample of Group 2. The breaking load of the abdominal aorta of Group 1 is 13 H higher compared to the sample of Group 1 and twice higher compared to the sample of Group 2. The study Group 2 values of breaking load for thoracic aorta are 1.3 times, 2.4 times and 1.16 times higher than respective implant values (sample 1, 2 and 3, respectively).
CONCLUSION We used samples of Group 3 vascular implants for replacement of abdominal aorta and Group 1 implants for thoracic aorta. In study Group 2 vascular implants of Group 3 may be used for abdominal and thoracic aorta replacement due to the proximity of the values of the evaluated characteristics.
Keywords: aorta, elasticity, mechanical properties, age, prosthesis, vascular implant, reconstructive surgery
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PTFE - polytetrafluoroethylene
PET - polyethylene glycol terephthalate

INTRODUCTION

Cardiovascular diseases have been among the main causes of mortality of the population both in the majority of countries of the world and in the Russian Federation (RF) over past decades [1, 2]. According to data on the state of health of the population of the Russian Federation for the last 5 years the proportion of cardiovascular diseases in the general structure of the diseases has reached 33.25%. The high specific weight in the structure of mortality from cardiovascular diseases accounted for diseases of main vessels including the aorta [3, 4]. Chronic and acute diseases of the aorta attract all more attention of researchers in connection with the increase in number of patients with these disorders and the need to develop modern methods of early diagnosis and treatment of [5, 6].

In old age aorta easily undergoes pathological changes, when physiological (age) loss of structural elements of the vascular wall is accompanied with atherosclerosis and / or arterial hypertension, which prolongs regeneration wall of the damaged vessel in the postoperative period in cases of replacement of vessel portion [7-9]. The use of plastic material on the basis of polytetrafluoroethylene (PTFE) is internationally recognized standard in prosthetics aorta. But vascular prostheses of fine celled polyethylene terephthalate (PET) is also very convenient when performing anastomoses, it has sufficiently surgical pore fenestration, promoting better biological compatibility with the tissues of a living organism. The surface of such implants is impervious even at high arterial pressure and at the same time is available for germination tissues of a living organism , which subsequently and form pseudointima [10-12]. Prostheses on the basis of PTFE has higher thromboresistant properties compared to prostheses of lavsan and other modern materials, used for manufacturing widely known synthetic vascular prosthesis. But such vascular prostheses are distinguished by a long process of incorporation due to their solidity, which causes the growth of connective tissue around the prosthesis, forming a dense capsule not between the fibers, but outside [13–15].

However, the search for production material of new models of vascular prostheses by scientific community is actively going on [16, 17]. It should be noted, that prior to each of reconstructive and restorative surgery cardiovascular surgeon selects the prosthesis personally for each patient, taking into account the age and individual features.

The aim is to study physical and mechanical properties of vascular implants and the wall of the aorta, to substantiate an adequate choice of the plastic material in prosthetic and restorative operational interventions in patients of various age groups.

Research objectives:

1. To adapt existing methods of studying physical and mechanical properties of tissues with the help of a bursting machine to assess age changes in thoracic and abdominal aorta , but also in the selection of vascular implants.

2. To study physical and mechanical properties In a comparative aspect (final length, plastic strain index, breaking uniaxial load - longitudinal) sections of the wall of the thoracic and abdominal aorta in different age periods, for the selection of vascular implants.

3. To compare the received data and determine the samples vascular implants, the most suitable for use with prosthetic and restorative operational surgical interventions in a plastic material from patients of various age groups.

MATERIAL AND METHODS

The study was carried out under the supervision of the Regional Ethical Committee at FSBEI HE KSMU of the Ministry of Health of Russian Federation. The retrieval and use of the biological material was carried out in accordance with legal acts applicable on the territory of the Russian Federation, in particular, in the framework of the Resolution of the Government of the Russian Federation of 21.07.2012 number 750 (ed. Dec 17, 2016) "On Approval of Rules of donation of unclaimed bodies, organs and tissues of the deceased of a person for use in medical, scientific and educational purposes, as well as the use of an unclaimed body, organs and tissues of a deceased person for the specified purposes."

Portions of the thoracic aorta front wall (descending portion of the arc of the aorta), and the abdominal aorta (infrarenal above division on *arteria iliaca communis*) of rectangular shape of length 5 and a width of 2 cm, retrieved from the 30 cadavers of male and female gender, dead in age from 33 to 92 years. The retrieval of the material was performed within an hour after the death. The following groups were formed (15 samples of each type, respectively) according to the age periods: Group 1 - from 33 to 60 years, Group 2 - from 60 to 92 years.

During the retrieval of the aorta with the aim of unification and elimination of study failures due to reduction of the wall of the vessel after its complete intersection the vessels holder tool was used for sampling of biological material representing two hemostatic forceps, fixed to the necessary to study distance. This made it possible to take a section of the aorta of a strictly defined length (5 cm) and to reduce the error that occurs after isolating its fragment.

Physical and mechanical properties of vascular implants (length - 5 cm, width - 2 cm) on the basis of PTFE and PET were tested as well, detailed description of which is presented below (Table 1). Samples 1 and 2 are widely used in clinical practice in a plastic material, sample 3 is a new type of vascular patch, developed by a team of authors, together with OOO "Linteks" (Saint-Petersburg).

Table 1

Comparative characteristics of the tested samples

Characteristic	Samples		
	Number 1	Number 2	Number 3
The chemical structure of the fibers	polytetrafluoroethylene	polyethyleneter ephthalate + Ftorlon	polyethyleneterephthalate
Type of fiber weave	Non woven fabric	Woven fabric	Warp knit
Additional processing during production	-	Gelatin	-

During the tests performed with a breaking machine REM-0.2-1 (manufacturer: OOO "Metrotest", Neftekamsk, the Republic of Bashkortostan), we evaluated indicators of physical and mechanical properties of the aorta: finite length, plastic strain index, breaking uniaxial load (longitudinal). The study was based on GOST 8847-85 "Knitted fabrics. Methods of determining breaking characteristics and elongation at loadings, less than breaking loads. The plastic strain index, which characterizes the change in the length of the aorta before and after a load of 100 N, was calculated by the formula:

Ep = *(Lk - Lo) / Lo* 100%,

where *Lk* is the length with the loading, mm; *Lo* is the initial length, mm; Ep - ratio of plastic deformation (Poisson's ratio)

Statistical processing of the obtained data was carried out using the methods of descriptive and variation statistics - calculating the median and 25 and 75 ‰ (*Me* [25; 75]). The *trial*-version of *Statistica* 10 (*Dell Software Company*, *Round Rock*, *Texas*, *United States of America*) was used. To determine statistical significance, nonparametric Kruskal - Wallis test was used. Critical level of importance when checking the statistical hypotheses in this study was 0.05 which is allowable value *p* for medical and biological studies.

RESEARCH RESULTS

According to the results of research we have obtained data, which is given below (Table 2).

Table 2

Physical and mechanical properties of the thoracic aorta, Me [25; 75]

Groups	Indicators		
	Finite length mm	Plastic strain ratio ,%	Tensile load, H
1 (f rom 33 to 60 years)	165.97 [142.73; 180.55]	83.78 [80.79; 86.19]	101.5 [73.4; 112.7]
2 (from 60 to 92 years)	116.29 [112.76; 117.79]	55.86 [5 3.13; 57.06]	149.3 [123.0; 179.5]
p	0 00001 *	0.000003 *	0 0003 *

Notes: * - statistically significant differences, p - the accuracy of differences of physical mechanical properties in Groups 1 and 2

The value of the "finite length" is 1.4 times higher in the Group 1 than in Group 2. The coefficient of plastic deformation in Group 1 is 1.5 times higher than indicators in Group 2. These parameters characterize plasticity and elasticity of the sample (the opportunity to modify the length), which is important for the walls of arteries, as it allows them to adjust to a considerable pressure. The "breaking load", on the contrary, characterizes by the stiffness of the sample, which appeared 1.47 times higher in Group 2 as compared to the Group 1 when assessing properties of the thoracic portion.

According to the data, given in the Table 3, we may note that the values of parameters "finite length" and "plastic strain index", as in the case of evaluation of physical and mechanical properties of thoracic aorta, were higher in Group 1 by 1.5 and 2 times, respectively, as compared to values of Group 2. The rigidity of abdominal aorta samples in Group 2 (137.2 N) were somewhat higher than in Group 1 (128.6 H), which was confirmed by a large value of the "breaking load" parameter (Table 4).

Table 3

Physical and mechanical properties of the abdominal aorta, Me [25; 75]

Groups	Indicators		
	Finite length mm	Plastic strain ratio ,%	Tensile load, *H*
1 (from 33 to 60 years)	173.57 [163.87; 194.46]	106.48 [88.78; 112.58]	128.6 [115.7; 152.7]
2 (from 60 to 92 years)	111.44 [109.34; 117.16]	48.59 [46.63; 53.32]	137.2 [119.2; 197.7]
p	0.000003 *	0.00001 *	0.245

Note: * - statistically significant differences . p - accuracy time differences of physical properties and mechanical properties in Groups 1 and 2

Table 4
Physical and mechanical properties of vascular grafts, Me [25; 75]

Samples	Indicators		
	Finite length mm	Plastic strain ratio , %	Tensile load, H
1 (polytetrafluoroethylene)	68.5 [65.45; 72.36]	37 [34.46; 39.67]	115 [118; 122]
2 (polyethyleneterephthalate + Fluorlon)	69.1 [66.04; 73.13]	38 [35.56; 40.67]	62 [60; 66]
3 (polyethyleneterephthalate)	69.5 [64.34; 74.07]	39 [36.23; 41.56]	128 [136; 130]
p_1	0.000002 *	0.00003 *	0.000001 *
p_2	0.0000001 *	0.0000002 *	0.00001 *
p_3	0.00002 *	0 0003 *	0.000002 *

Note: * - statistically significant differences, p_1 - the significance of differences in the values of the physical and mechanical properties of Group 1 samples compared to Group 2 samples; p_2 - the significance of differences in the values of the physical and mechanical properties of Group 1 samples compared to Group 3 samples; p_3 - the significance of differences in the values of the physical and mechanical properties of Group 2 samples compared to Group 3 samples

Evaluating physical and mechanical properties of vascular implants, we may note, that the finite length of all samples is approximately from 68.5 H (samples № 1) to 69.5 (samples № 3), and the values of index "plastic strain index" increase as follows: samples № 1 →samples № 2 →samples № 3. But breaking load is significantly higher in samples № 3 by comparison with the two other types of implants (twice as compared to samples № 2 and by 1.1 times as compared to samples 1).

DISCUSSION

On the basis of the received data, it can be concluded, that the fiite length of the wall of the aorta varies slightly in groups. Thus, the finite length of the thoracic portion samples in Group 1 are 8 H less, than the abdominal part, and 5 H higher in the Group 2. The values of "plastic strain index" of the abdominal aorta in Group 1 are 1.3 times higher than of the thoracic aorta, and in group 2 the difference is less pronounced - 7.27 H. The breaking load of abdominal aorta in Group 1 exceeds this value of the thoracic aorta by 27.1 H, and in Group 2, on the contrary, we observed greater value assessing the thoracic aorta (12.1 H higher in comparison with abdominal part).

The breaking load is higher in Group 2 (age from 60 to 92 years) as compared to the Group 1 (age from 33 to 60 years), both during the study of physical and mechanical properties of thoracic and abdominal parts. This is confirmed by the presence of statistically significant differences (Tables 2 and 3). The increased breaking load inversely proportional to the values of "finite length" and "plastic strain index", which is associated with reduction of elastically - elastic properties of vascular wall due to age-related changes.

When comparing values of indicators of physical and mechanical properties of the wall of the aorta and a vascular implant we found the following. The finite length of the thoracic aorta in Group 1 is 2.4 times higher than all tested vascular implants, and 1.7 times higher than in Group 2. When evaluating changes in length of abdominal aorta we noted predominance of finite length in Group 1 by 2.5 times the above values of vascular implants, and by 1.7 times in Group 2. The plastic strain index of vascular implants is 2.3 times less as compared to thoracic aorta in Group 1 and 2.9 times in comparison with abdominal part. Values of this parameter in Group 2 and vascular implants also significant - in case the comparison thoracic and abdominal sections with conduits the preponderance of the first ones is observed by 1.4 and 1.2 times.

The breaking load of vascular implants has different values, which makes it impossible to compare them with the study groups. The breaking load of thoracic aorta in Group 1 is 14 N and 27 N less in comparison with samples № 1 (PTFE) and № 3 (PET), but 1.6 times greater than sample № 2. However, the values of "breaking load" of abdominal aorta in Group 1 differ not so much: in comparison with sample № 1 - 13 H longer , sample № 2 - 2-fold greater, which almost corresponds to the value of the sample № 3 (128 H). The Group 2 values of breaking load of thoracic aorta are greater than values of implants by 1.3 times (sample № 1), by 2.4 times (sample № 2), and by 1.16 times (sample № 3).

CONCLUSION

Considering the results of investigation of physical and mechanical properties of the wall of the aorta, one can assume, that the most suitable for abdominal aortic grafts in Group 1 (age from 33 to 60 years) are samples of the vascular implant on the basis of PETF (sample № 3) due to proximity of values evaluated characteristics. At the same time, examples of implants № 1, made on the basis of polytetrafluoroethylene and representing a nonwoven graft, is the most suitable for thoracic aorta replacement.

According to our opinion, in the age period from 60 to 92 years (Group 2) in both considered cases - for prosthetics of abdominal and thoracic sections of the aorta, it is advisable to use vascular implants on the basis of polyethylene terephthalate (sample number 3), so as a breaking load of data samples (128 H) is closest to those in Group 2 (149.3 H and 137.2 H).

FINDINGS

On the basis of the received data, it can be argued, that the finite length of the wall of the aorta is changed slightly in the groups, while plastic strain ratio of abdominal aorta in Group 1 is 1.3 times higher as compared to thoracic section.

Values of "finite length" (1.4-fold) and "plastic strain index" (1.5-fold) in cases of evaluation of physical and mechanical properties of the thoracic and abdominal sections of the aorta are higher in Group 1, and the value of index "breaking load" is higher in Group 2 as compared to Group 1 (by 1.47 times).

Vascular grafts on the basis of polyethylene terephthalate (Sample № 3) may be used for abdominal aorta replacement in Group 1, and samples № 1 (polytetrafluoroethylene) may be used for thoracic aorta replacement. Vascular implants on the basis of polyethylene terephthalate (Sample № 3) may be used in Group 2 in cases of abdominal and thoracic aorta replacement.

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