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CHANGES IN THE MECHANICAL PROPERTIES

OF SYNTHETIC VASCULAR PROSTHESES

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CHANGES IN THE MECHANICAL PROPERTIES  
OF SYNTHETIC VASCULAR PROSTHESES

[Following is a translation of an article by N.B.Dobrova and A.D.Drogaytsev\* in the Russian-language journal Khirurgiya (Surgery), Moscow, No 2, 1963, pp 137-141.]

[v. 34]

The problems of vascular prosthetics acquire an ever greater importance in modern surgery. Difficulties and complications arising in the solution of these problems are connected to a great extent with an insufficient study of the properties and peculiarities of synthetic materials used for angioplasty.

In the appraisal of a substitute for the vascular tubule functioning in the organism, of utmost significance is the investigation of the mechanical properties of the prosthesis since these very properties determine

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[ its ability to fully reproduce the function of the blood vessel. What matters in the first place is the strength and elasticity of the prosthesis.

The strength of prosthetic section of the vessel is of decisive importance for its function. The opinion purporting that tissues of the organism which surround it and are connected with it (including also the fibrous capsule) strengthen its wall may be accepted only with reservation; even though this may be true to a certain extent, yet upon damage of the prosthesis the strength of the capsule is clearly not sufficient to avert ensuing complications (Harrison, Pratt). Thus, the intactness of the prosthetic section is determined exclusively by the strength of the prosthesis itself.

Elasticity is an opposite case. At present, it has been established that the elasticity of the vascular prosthesis changes in connection with formation of the fibrous capsule (Newton, Stokes, Butcher). However, the study of these changes has not been differentiated in accordance with the properties of different materials used in prostheses. Moreover, vascular surgery employs prostheses of various construction, viz., woven, knitted and plaited, as well as in the shape of straight and corru-

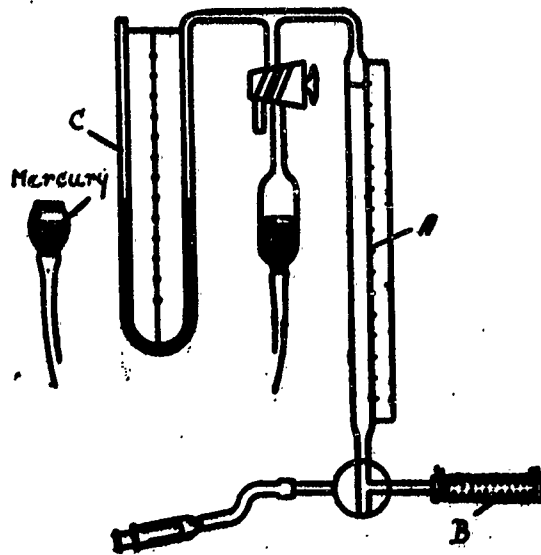


Fig. 1.

gated tubules; the peculiarities of the change of their elasticity are far from having been sufficiently studied.

Taking all this into account, we have set before ourselves

→ AN INVESTIGATION IS MADE ON  
 the task of determining the influence of the properties  
 of the material and construction of the <sup>VASCULAR</sup> prosthesis on the  
 degree of alteration of its elasticity in the organism.

Technique and Results of Experiments. Experiments were carried out using three basic groups of synthetic materials most widely employed in angioplasty, viz., polyamide, polyester and polytetrafluoroethylene. In the

group of polyamide fibers, we have investigated caprone and nylon, in that of polyester fibers - terilen, dacron and lavsan, and in the group of polytetrafluoroethylene - teflon and a new Soviet-produced material, fluorolon, used by us for the first time to make vascular prostheses. We have employed woven, knitted and plaited prostheses (straight and corrugated). We have implanted them into the thoracic aorta of dogs for a period ranging from 3 to 13 months.

Determination of the elasticity of prostheses was effected with the aid of the Hallock-Benson apparatus as modified by us (Fig. 1).

Before testing, the prosthesis was hermetically fixed in the manner shown in the Figure. The burette A, connected with prosthesis B by means of a three-way cock, was filled with water up to the zero (upper) mark. During the experiment, the pressure was continuously increased in the system (under the control of mercury manometer C) from 0 to 200 mm Hg. Whereupon, a part of the water was expelled from the burette A into hermetically closed prosthesis B, and the quantity of water that penetrated into the prosthesis during increase of pressure determined its elasticity (ability of its wall to stretch). The volume of the prosthesis was noted following increase of pressure

by every 25 mm of Hg; the initial volume was calculated from the formula for the volume of a cylinder,  $\pi R^2 L$ , where R is the radius and L is the length of the prosthesis.

The value determined by the percent ratio of the variation of volume ( $\Delta V$ ) upon increase of pressure by 25 mm of mercury column to the whole volume of the prosthesis at a given pressure ( $V_p$ ) characterizes the elasticity of the prosthesis at a given pressure. We took this value as the coefficient of elasticity (CE):

$$CE = \frac{\Delta V}{V_p} 100\%$$

A graph of the variation of the coefficient of elasticity upon increase of pressure from 0 to 200 mm of Hg was plotted for each prosthesis. All prostheses were tested before and after implantation, and thereafter in each case the degree of the change of elasticity (in percent) was determined. Comparison of elasticity was effected at a pressure close to the pressure in the normal aorta (from 100 to 175 mm of Hg).

Fig. 2 gives graphs of variation of the coefficient of elasticity for various prostheses during their investigation before implantation (solid line) and after

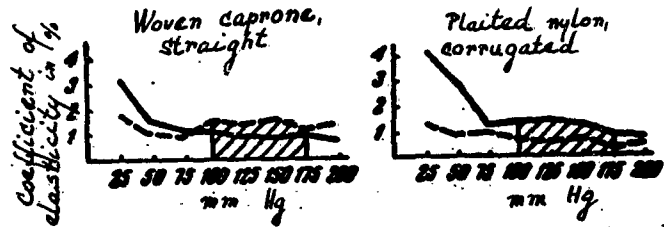


Fig. 2a. Polyamide fibers

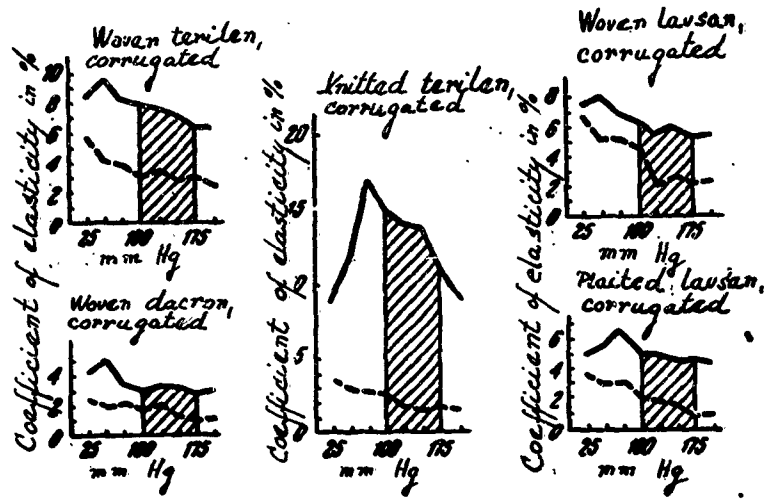


Fig. 2b. Polyester fibers

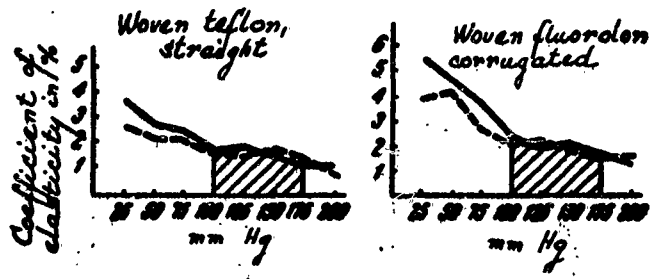


Fig. 2c. Polytetrafluoroethylene fibers

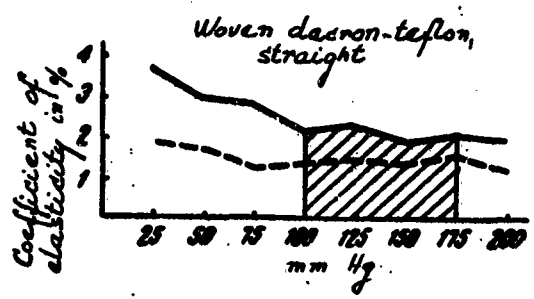


Fig. 2d. Mixed fibers

implantation (dashed line). In each graph are represented the mean values obtained upon testing of specimens of prostheses of the same type. The cross-hatched area designates the pressure range at which the elasticity of the prosthesis was compared before and after implantation. The Table gives data concerning changes in the elasticity of prostheses of each type while they remained in the organism.

Table

Variations of elasticity of investigated prostheses (in percent) while in organism

Group of materials	Name	Construction of prosthesis	Change in elasticity
Polyamide fibers	Caprone	Woven, straight	+27.3
	Nylon	Plaited, corrugated	-56.7
Polyester fibers	Terilen	Woven, corrugated	-55.2
	Terilen	Knitted, "	-86.0
	Lavsan	Plaited, "	-62.3
	Dacron	Woven, "	-53.3
	Lavsan	Woven, "	-54.5
Polytetrafluoroethylene fibers	Teflon	Woven, straight	-1.6
	Fluorolon	Woven, corrugated	-1.8
Mixed	Dacron	Woven, straight	-35.3

Analysis of results. Prostheses from different materials in general produce the same type of reaction in the organism, viz., the formation of a fibrin layer on the internal surface of the prosthesis and of a fibrous capsule surrounding the prosthesis which is joined with it by connective-tissue fibers ingrowing into the pores

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of the prosthesis. The properties of prosthesis functioning in the organism differ essentially from its properties before implantation. The intensity of reaction produced by prosthesis in the organism depends on the chemical properties of the material of which it is made. Consequently, different materials producing reactions of different intensity in the tissues surrounding them lead to nonuniform changes of properties of the prosthesis and, in particular, of its elasticity.

The materials of the group of polytetrafluoroethylene, viz., teflon and fluorolon, are maximally inert in the chemical respect and cause a minimal reaction of the organism. The ingrowth of connective-tissue fibers into pores of the prosthesis is very inconsiderably expressed, contributing to the high stability of mechanical properties of prostheses when they remain in the organism for a long time.

The materials belonging to the group of polyester fibers, viz., terilen, dacron and lavsan, are inferior to teflon and fluorolon as to their chemical stability. The reactions to the presence of these prostheses, and consequently also fibrosis, are expressed much more strongly in connection with which the elasticity of prostheses gra-

dually decreases. Inasmuch as chemical properties of terylen, dacron and lavsan are generally identical, the intensity of reaction is approximately the same. This explains the almost identical decrease of elasticity of prostheses from the above materials, both straight and corrugated ones.

The dependence of the alteration in the mechanical properties of prostheses upon the degree of chemical inertness of the material is also confirmed by the fact that a "mixed" prosthesis, made of dacron and teflon fibers, when tested, showed a lesser decrease of elasticity than a pure dacron prosthesis but a higher one than the prosthesis manufactured from teflon.

Polyamides are the least stable in the chemical respect; implantation of prostheses made from these materials evokes a strong reaction, as a result of which the material undergoes considerable alterations which lead to increase of the extensibility of the caprone prosthesis.

The character of the prosthesis construction also affects its elasticity. The results obtained in testing prostheses before their implantation showed that corrugated prostheses have far greater elasticity as compared with straight ones, while at the same time the woven and plaited

corrugated prostheses exhibited a tendency towards considerable "residual deformation", i.e., after the increase of pressure to 200 mm Hg and its subsequent decrease to 0 the form of prostheses was not fully restored and they remained somewhat extended. During the time they were implanted, the corrugated prostheses decreased their elasticity in various degrees. On one hand we are faced here with the influence of the material (prostheses from polyester fibers decreased their elasticity more than the analogous prostheses from fluorolon), while on the other hand certain differences in their construction must also be taken into account; in the same group of polyesters, the knitted and plaited prostheses decreased their elasticity to a higher degree than the woven ones. The latter fact is explained, in our opinion, by an abundant ingrowing of fibrous tissue into large pores of woven and plaited prostheses.

At the present time, the search is being continued for material which would completely satisfy all specific requirements of angioplasty. Polyamide fibers (caprone and nylon) were recognized as unsuitable for vascular prostheses. As regards polyester and polytetraethylene fibers, opinions differ (Harrison, Szilagyi, Pratt). The analysis of data ob-

tained by us makes it possible to consider that the choice of a maximally inert material is the most correct one, since this property of the material is the most important factor determining the stability of the properties of the prosthesis. At the same time, the preservation of all properties of the prosthesis necessary for its normal function, viz., strength, elasticity and flexibility, depends quite naturally not on the inertness of the material but on the stability and reliability of construction of the prosthesis. Prostheses whose construction is not sufficiently stable (woven, with weakly fixed corrugation) begin to extend before the onset of a pronounced fibrous reaction, and the formation of large pores in their walls creates the danger of hemorrhage. In this respect, woven prostheses with stable corrugation must be considered as much more reliable.

Thus, the preservation of all necessary properties of the vascular prosthesis after its implantation can be realized only by the fulfillment of two conditions: utilization of a material inert in the chemical respect and stable construction of the prosthesis. In the absence of the first condition, the prosthesis undergoes destructive

changes under the effect of ingrowing fibrous tissue; nonfulfillment of the second condition leads to the prosthesis being deformed by the action of mechanical forces through hemorrhage.

At present, the Laboratory for the Application of Polymers in Medicine of the Institute of Cardiovascular Surgery, together with the Central Scientific Research Laboratory of Knitted Wear and Haberdashery Industry, has developed a technique for manufacturing woven prostheses with stable corrugation. The introduction of the new high-quality material - fluorolon - is very promising.

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