

Modified by air plasma polymer tack membranes as drainage material for antiglaucomatous operations

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Abstract. The morphological and clinical studies of poly(ethylene terephthalate) track membranes modified by air plasma as drainage materials for antiglaucomatous operations were performed. It was demonstrated their compatibility with eye tissues. Moreover, it was shown that a new drainage has a good lasting hypotensive effect and can be used as operation for refractory glaucoma surgery.

1. Introduction

Interest in the treatment of refractory glaucoma by implantation of drainages on the basis of various materials is getting enormous due to a high degree incidence of this pathology and its serious complications. The refractory glaucoma accounts about 40 % of all glaucoma pathology. Contraindication for antiglaucomatous operation with the use of an explantodrainage was the absence of intraocular pressure normalization and tonographic indices in refractory glaucoma patients. However, unsuccessful antiglaucomatous operations result, as a rule, from proliferation of connective tissue and obstruction of surgically formed outflow tracts [1–3]. The history of usage of auto- and allodrainages has revealed a number of shortcomings such as a shallow anterior chamber, long-standing postoperative hypotonia, macular edema in an early follow-up, growth of a course connective-tissue capsular, rejection of a transplant, and necrosis of a scleral flap and the conjunctiva, to name but a few [4–6]. Therefore, search for new drainage materials for antiglaucomatous operations is getting quite an urgent problem. Most ophthalmologists of late have given preference to polymer drainages which are easily sterilized, can be kept for a long time and have no immunoallergic effects. Ophthalmological clinic of Saratov State medical University was the first to implant a new drainage [7] in one's capacity a poly(ethylene terephthalate) track membrane was (PET TM) chosen due to a big number of their advantages: low resistance to the flow of the filtered medium, high filtration selectivity, low adsorption of resolved substances, transparency, lack of toxicity, small weight, high strength and elasticity. As nontoxic, this drainage has a relevant certificate and a permit for usage granted by the Department supervising the introduction of new medications and medical equipment.



In this paper we report on experience of using the polymer track membranes with a modified by air plasma surface as a drainage material for antiglaucomatous operations. For experiments poly(ethylene terephthalate) track membranes were used. By preliminary tests it has been found that the membranes of this type are stable to biodestruction and can remain in the intrascleral space for several years. For modification the membrane surface, a treatment by air plasma was applied.

2. Experimental details

In the experiments, PET TM samples with a thickness of 10.0 μm and an effective pore diameter of 0.4 μm (pore density $5 \times 10^7 \text{ cm}^{-2}$) were used. To produce the membrane, poly(ethylene terephthalate) film (Laysan, Russia) with a thickness of 10.0 μm was irradiated by krypton positive ions, accelerated to $\sim 3 \text{ MeV/nucleon}$ at the cyclotron. Then the ion-irradiated film was sensitized with ultraviolet irradiation with a maximum emission intensity at 310 nm. Chemical etching was performed in an alkaline (NaOH) aqueous solution with concentration of 3.0 mol/L at 80 $^{\circ}\text{C}$ for during 4 min. The plasma treatment was performed at a plasma chemical set-up providing a 13.56 MHz RF-discharge. Nitrogen, air and oxygen as well nitrogen and oxygen with various ratios were used as plasma-forming gases. The gas pressure, discharge power and treatment time were varied. The treatment procedure and the scheme of the plasma set-up described in [8]. The both sides of the membranes were subjected to the plasma treatment. The characteristics of the initial and modified membranes were determined with the help of mutually complementary methods described in detail in [8].

Experimental research of the drainage material (for this purpose the membrane samples previously were sterilized by boiling in distilled water or in an autoclave at temperature up to 150 $^{\circ}\text{C}$ was conducted by its implanting in the anterior chamber and sclera layers of the rabbits (33 eyes) for one, two and six months. The clinical analyses 24 patients with refractory glaucoma (24 eyes) after surgical treatment have been performed during six months after the operation. Observation involved patients with refractory glaucoma with different etiology who had gone through two to five antiglaucomatous operations. In this group, deep sclerectomy was followed by a separation of a conjunctive and scleral flap and then by a separation of a conjunctive and scleral flap and then by an incision of deep-lying scleral layers. Next was basal iridectomy. The outer end of the drainage was fixed to the inner scleral layers, and the inner one was implanted the anterior chamber. The operation was completed by a suture placed on the scleral flap and by a continuous suture on the conjunctival flap.

3. Results and discussion

The investigations of the air plasma effect on the PET TM allowed to establish the following. The first, effect of the air plasma on the PET TM leads to etching both the external membrane surface and the surface pore layer that accompanied by decreasing a membrane thickness and increasing an effective pore diameter (table 1). The results of pore's etching of track membranes are illustrated by figure 1. A surface of an initial membrane and modified in plasma membrane are submitted on the microphotographs. It is possible to see, the pore diameter on the surface of modified membranes is increased. As received results shown, the etch rate depends on a discharge parameters, i.e. gas pressure and discharge power – increase in the gas pressure and discharge power lead to rise of the etch rate. The etch rate also depends on the composition of the plasma-forming gas. So, introduction of oxygen into the plasma-forming gas and increasing its concentration lead to increase of the etch rate. The use of pure oxygen as a plasma-forming gas allows one to increase essentially the etch rate. This permits to make the process of gas discharge etching more intensive. The increase of the effective pore diameter causes the increase of porosity, as a results, the modified membranes have better air and water flow rate characteristics. The filtrate volume is higher for the modified membranes (table 1). The second, depending on the choice of the discharge parameters, etching can be executed either in a part of the channel or along the whole length of the pore channels; anyway, the asymmetric track membranes possessing high porosity and flow rate are formed. It is possible use the gas discharge etch method to change the TM structure. The optimum choice of the treatment conditions in plasma allow

to produce the membranes with a high flow rate without changing the selective properties of the membranes.

Another observation is that the plasma effect leads to the formation of a thin layer with increased content of carboxyl groups. This makes the membranes surface hydrophilic. So, the analysis of the FTIR-spectra of the membrane samples processed by air plasma shows an increase in the intensity of the absorption band at 1720 cm^{-1} corresponds to stretching vibrations of the carbonyl in carboxyl groups. The formation of carboxyl groups at the treatment in air plasma at the membrane surface layer can be explained the following way. At the effect of active particles of plasma, a destruction of polymer chains on the surface occurs. A break of the bonds C–O (binding energy is equal to 376 kJ/mol) and C–C (binding energy is equal to 335 kJ/mol) energetically looks more probable. As a result of secondary reactions, end carboxyl groups are formed. The radicals generated at breaking the bonds C–C, apparently, make a recombination, probably with formation of intermolecular bonds. Besides, the plasma prompts morphological changes of the surface relief. Numerous craters appear on the initially smooth surface. It becomes rough. This phenomenon is probably caused by different etch rates for crystalline and amorphous regions. If varying the treatment conditions and duration, the sizes of the craters change. The sizes of the craters change, when varying the conditions of the treatment and duration of the discharge effect.

Table 1. Change of the characteristics for membrane with pore diameter $0.4\text{ }\mu\text{m}$ in the process of treatment by air plasma during 10 min.

Gas pressure (Pa)	Discharge power (W)	Thickness (μm)	Effective pore diameter (μm)	Initial water flow rate at $\Delta P=4\times 10^4\text{ Pa}$ ($\text{ml}/\text{min cm}^2$)	Water contact angle (deg)	Increasing of COOH-groups content (%)
–	–	10.0	0.395	5.4	65	–
0.15	70	9.9	0.405	6.7	20	4
0.25	70	9.8	0.425	7.6	25	7
4.0	70	9.4	0.445	8.4	30	19
10.5	70	9.0	0.460	9.1	35	28

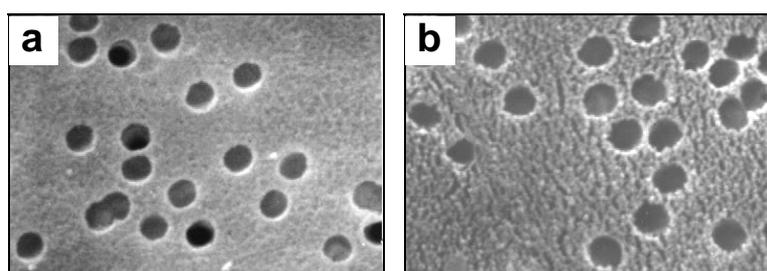


Figure 1. Microphotographs of the surface of the initial PET TM (a) and the membrane after air plasma treatment during 10 min at the gas pressure of 0.26 Pa and discharge power of 100 W (b).

Development of erosion of the membrane surface and their hydrophilization stipulate increase of wettability – the value of the water contact angle for modified membranes essentially decreases (table 1). As our experiments shown, increase of the carboxyl group's content in the membrane surface layer leads to increase of a negative charge on the pore surface. Really, the measurement of the charge of the pore surface shows that at the air plasma treatment of membrane there is an increase of the density of the negative charge on the walls of its pores. So, if the value of charge of the pore surface for the initial membrane is equal to $1.17\times 10^{-2}\text{ Coul}/\text{m}^2$, then for modified membrane (at the gas pressure of 13.5 Pa and discharge power of 300 W) this value is equal to $1.62\times 10^{-2}\text{ Coul}/\text{m}^2$. It is stimulate (and

also development of a roughness of a surface) reduction of proteins adsorption of and others multipliers of intraocular liquids, blood cells, and also allows to avoid formation around of a drainage rough a connective tissue capsule.

The technique of an experimental research was used for 35 patients. In 20 (57.1 %) of these the disease lasted from one to five years, in 15 (42.9 %) over five years. Before this time 17 (48.6 %) patients had underwent antiglaucomatous operations without the use of drainage, 12 (34.3 %) had other surgical interventions, and 6 (17.1 %) persons were operated for the first time. Eight (22.9 %) of 35 patients had traumatic, 4 (11.4 %) – photogenic, 14 (40.0 %) – uveal, and 9 (25.7 %) – vascular glaucoma. In 20 (57.1 %) the anterior chamber angle was opened, and in 15 (42.9 %) it was closed. Ten (28.6 %) subjects had initial, 15 (42.9 %) – advanced, 7 (20.0 %) – far advanced and 3 (8.6 %) – terminal glaucoma. Mean intraocular pressure (IOP) was 38.3 ± 5.2 mm Hg. Tomographic indicators: $P_o = 46.1 \pm 4.2$ mm Hg; $C = 0.09 \pm 0.01$ mm³/min/mm Hg; $F = 2.51 \pm 0.1$ mm³/min; $Bl = 512.2 \pm 71.4$. The operation was preceded by a thorough gonioscopy and choice of a surgical access.

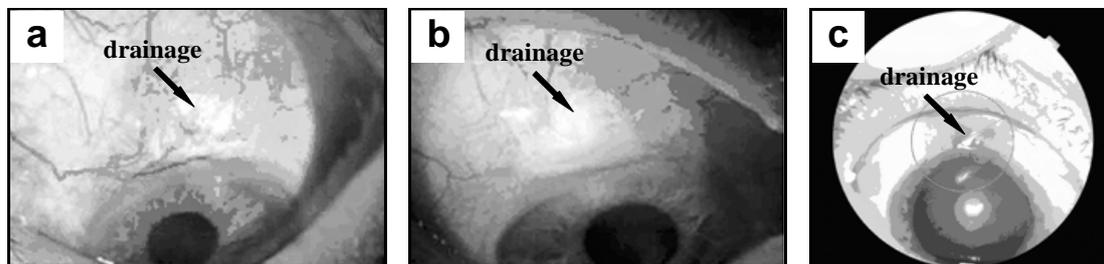


Figure 2. Eyes of the patients after surgical treatment (a, b) and optic coherent tomography of eye after operation (c).

Experimental research has shown that no signs of either inflammation, cell infiltration, neovascularization of cornea and iris or anterior and posterior synechia have been found in eyes during six months after operation (figure 2). Histological research data demonstrate that the reaction of the inflammatory cells to drainage is minimal. The implant does not resolve and keeps its porous structure during up to six months. Fibrosis capsule around the drainage is not exposed. There was not a single case of reaction to drainage. After operations with modified track membranes in all cases filtering blebs were split and plane. In all cases stable hypotensive result was achieved. The follow-up involved 35 patients. A day after the operation, the IOP decreased to $15.5 + 3.5$ mmHg. During the follow-up (from 1 month to 6 months postoperatively) the IOP was within the physiological norm in 35 (100 %) persons. Operations stabilized visual field boundaries in 35 (100 %) persons. Visual acuity improved on the average by 0.1-0.4.

4. Conclusion

Thus, the morphological and clinical studies of modified by air plasma track membranes as drainage clearly demonstrates its compatibility with eye tissues. Moreover, a new drainage has a good lasting hypotensive effect and can be used as operation for refractory glaucoma surgery.

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