Evaluation of the porous structure in polymer tooth implants and its effect of the transport processes

V R Pen¹, Y V Chijov², S I Levchenko¹, O V Pen³ and L E Mascadynov²

¹ Reshetnev Siberian State University of Science and Technology, 31 Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russia
² Prof. Voyno-Yasenetsky’s Krasnoyarsk State Medical University, 660022, 1 Partizana Zheleznyaka street, Krasnoyarsk, Russian Federation
³ Wake Forest University, 1834 Wake Forest Rd, Winston-Salem, NC, USA, 27109

E-mail: 2507@inbox.ru

Abstract: the study focuses on the dynamics of the leaching of the low-molecular fragments from the volume of the polymer composition used in tooth implants. The saturation curves exhibit two characteristic time periods, leading to an assumption that the various transport mechanisms caused by the topology of the microporous structure might be the reason.

The content of the residual acrylic monomers in the polymer tooth implants is currently considered to be one of the most important quality assurance criteria [1, 2, 3]. The maximum allowed concentration in water is 0.01 mg/l [4], in the water extract of the medically-used plastic – 0.25 mg/l [5, 6]. Consequently, the laundering procedure over the length of time determined by the dynamics of the diffusion of the low-molecular fragments of the polymer composition from the product into the laundering solution becomes a necessary technological procedure for the production of the polymer dental structures. The following polymer compositions are studied:

- Sample 1 – Vertex;
- Sample 2 – Protakril
- Sample 3 – Belakril-M XO;
- Sample 4 – Etakril;
- Sample 5 – Ftorax.

They are used to produce the samples in the form of a block with 1 cm height and width and 8 cm length, weighing 8±0.5 g. Samples are prepared in accordance with the instructions for production of the polymer tooth implants and are identical to them in structure and composition. Samples are then submerged into distilled water volume of 42 ml. The experiment is conducted for a duration of 350 minutes.

The concentration of monomers in the solution is measured by conductometry [7]. The dynamics of the extract product accumulation are presented in figures 1-3.
Two distinct characteristic time period regions can be observed on the curves. They correspond to the rapid change in the first region and slower process development in the later period. This behavior can be explained by two separate transport mechanisms. The rapid change is connected with mass transfer in the sub-surface layer, determined by the diffusion in the sub-surface layer porous structures and not connected to the transport mechanisms in the sample depth. The slower change region is correlated with the processes in the deeper porous layer of the sample.

The structure and size of the pores are determined by the method of raster electron microscopy [8].
Investigated samples were 10x10x10 mm in size, with chips running throughout the base of acrylic plastics. The samples were glued onto the metal base with 20 mm diameter with current-conducting tape. The working surface of the samples was covered with thin layers of carbon (10 nm depth) and gold (40 nm depth) with the high definition spraying system K550X (Hitachi, Japan). Prepared samples were studied under the electron microscope TM-1000 (Hitachi, Japan) with the accelerating voltage of 15 kV.

100X magnification factor has proved to be most suitable for the comparison of the characteristics of the pores, including their number, type, size, volume and surface. For separate groups of the pores, the magnification factors of 200X, 250X, 500X and 1000X have been used.

The porous coefficients were calculated with the JMicroVision program. The results are presented in figures 4-6 and table 1. A comparison with the accumulation curves allows to make a conclusion about the lack of correlation between the accumulation speed and the size of the macropores. An assumption can be made that the defining criteria is the degree of connection in the microporous system that is used to conduct the mass transfer of the low-molecular components of the polymer composition.

![Figure 4. Macroporous system, Vertex (a), Protakril (b).](image1)

![Figure 5. Macroporous system, Belakril-M X0 (a), Etakril (b).](image2)
Table 1. A comparison in the polymer’s porosity characteristics.

| Plastic sample | Pore surface (mm$^2$) to the unit surface (100 mm$^2$) | Pore volume (mm$^3$) to the unit surface (100 mm$^3$) | Pore characteristic classification |
|----------------|-----------------------------------------------------|-----------------------------------------------------|-----------------------------------|
| Vertex         | 0.027 (23.04 %)                                      | 0.06 (4.43 %)                                       | Granular, open – 50%, dead-end – 50 % |
| Protakril      | 0.46 (25.2 %)                                        | 1.1 (8.11 %)                                        | Gasous, open – 50%, dead-end – 50 % |
| Belakril-M X0  | 0.008 (0.05 %)                                       | 0.0015 (0.05 %)                                     | Granular, open – 40%, dead-end – 60 % |
| Etakril        | 0.0013 (0.008 %)                                     | 4.3⋅10$^{-7}$ (0.009 %)                             | Compression pores – 100%           |
| Ftorax         | 0.0003 (0.001 %)                                     | 3.7⋅10$^{-7}$ (0.008 %)                             | Compression pores – 100%           |

Thus, a conclusion can be made that:
- The accumulation dynamics can be characterized by the two characteristic time regions defined by the different mechanisms of mass transfer
- The transport mechanism for the polymer matrix volume is assumingly defined by the topology of the microporous structure. The size of the micropores does not seem to be a decisive factor.

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