COMSOL® Experience Of Biomechanical Modeling Of Shells And Plates In Ophthalmology

G. V. Pavilaynen[1], D. V. Franus[1]

1. Saint-Petersburg State University, Saint-Petersburg, Russia

Two main problems are considered:

1. influence of intraocular pressure on stress-strain state of human optic nerve modeled from real microscopic picture as a plate,
2. deformation of a significantly plastic anisotropic plate under hydrostatic loading, which simulates the bending of the section of the central eye nerve when intraocular pressure increases.

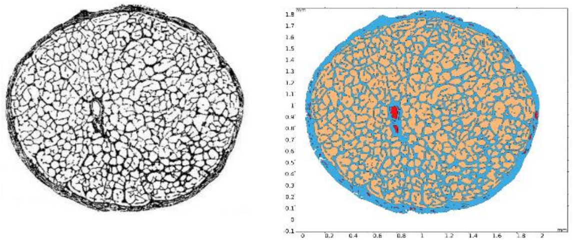

Figure 1. Cross section of the optic nerve - microscopic picture (left) and model (right)

COMPUTATIONAL METHODS:

Cross section of optic nerve is modeled as a plate which is loaded with P_0=80 mmHg, which corresponds, for example, to IOP level during intraocular injection or eyes rubbing. For boundary conditions the outer edge of the plate is pinned.

Fig.1 and fig 2. show that geometry of the model is very difficult with no pattern or simple models.

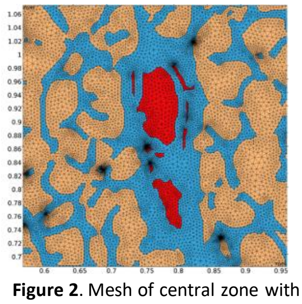

Figure 2. Mesh of central zone with central retinal blood vessels; nerve bundles - orange, walls of blood vessels and septa – blue, blood – red.

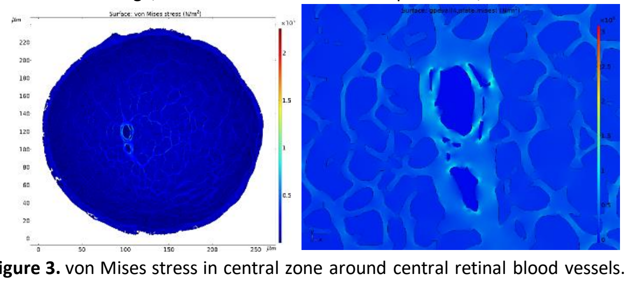

Figure 3. von Mises stress in central zone around central retinal blood vessels.

FE modeling shows that areas next to an aorta and a vein are highly stressed and leads to a reduction in the size of the cross section of the vein and aorta. Which means that high intraocular pressure has negative impact on blood circulation and can lead to different eye diseases.

Figure 4 shows the central cross section of a curved circular plate, which shows following parameters:

- h is the half thickness of the plate,
- x_1, x_2 are the radiuses of the plastic regions on the top and the bottom of the plate respectively,
- a_1, a_2 are the depths of the plastic zones from the bottom and from the top of the plate respectively.

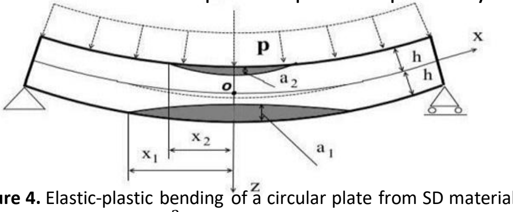

Figure 4. Elastic-plastic bending of a circular plate from SD material

$$A = 2 - \frac{(\sigma_{pz}+\sigma_{cz})^2}{(\sigma_p+\sigma_c)^2}\frac{\sigma_p^2\sigma_c^2}{\sigma_{pz}^2\sigma_{cz}^2} \qquad \beta = \frac{3\sqrt{2-A}}{2}\frac{(\sigma_{cz}-\sigma_{pz})}{(\sigma_{cz}+\sigma_{pz})}$$

$$\sigma_\theta = \sigma_r = \frac{\bar{k}}{a}\left(\frac{1}{sign(z)F} - \frac{2\beta}{3a}\left(1+\frac{1}{F^2}\right) + \frac{4\beta^2}{sign(z)9a^2F}\right)$$

$$a = \sqrt{2-A}, \quad F = 1 - \frac{sign(z)2\beta}{3a}$$

where A - transversal isotropy parameter, where σ_p and σ_{pz} are the yield points for uniaxial tension in the plane of the plate and in a direction perpendicular to the plate, σ_c and σ_{cz} are the yield points by uniaxial compression in the plane of the plate and in a direction perpendicular to the plate, β characterizes the plastic anisotropy property - SD effect.

$$\frac{\sigma_+}{\sigma_p} = \frac{\beta+3}{3\sqrt{(2-A)}}\left(1-\frac{2\beta}{3\sqrt{(2-A)}}\right)$$

$$\frac{\sigma_-}{\sigma_p} = -\frac{\beta+3}{3\sqrt{(2-A)}}\left(1+\frac{2\beta}{3\sqrt{(2-A)}}\right)$$

This asymptotic relations are used to model SD effect.

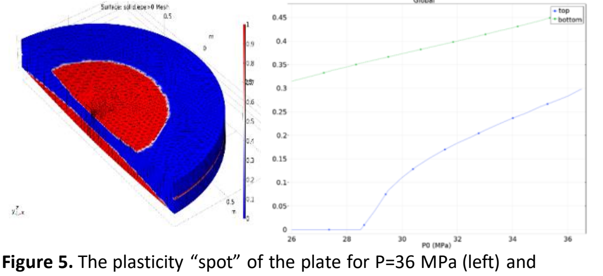

Figure 5. The plasticity "spot" of the plate for P=36 MPa (left) and "spot" radiuses top (blue) and the bottom (green) of the plate.

Numerical modeling and graphical representation of the elastoplastic properties of circular transversely isotropic and plastic anisotropic plates showed that for surface stress functions a solution to the problem of optimizing the selection of the parameters of transversal isotropy and plastic anisotropy under the condition of minimum stresses is possible.

The application of the yield criterion made it possible to construct asymptotic formulas for their calculation, taking into account the transversal isotropy and the SD effect for the elastoplastic bending of a circular plate.

Excerpt from the Proceedings of the 2020 COMSOL Conference in Grenoble