Russian Journal of Biomechanics, Vol. 5, № 1: 73-82, 2001

Russian Journal of Biomechanics
www.biomech.ac.ru

ON THE DEFORMATION OF THE LAMINA CRIBROSA UNDER INTRAOCULAR PRESSURE

S.M. Bauer, E.B. Voronkova

Department of Theoretical and Applied Mechanics, St. Petersburg State University, 2, Library Squire, 198594, Saint-Petersburg, Russia, e-mail: Svetlana.Bauer@pobox.spbu.ru

Abstract. The deformation of the Lamina Cribrosa under intraocular pressure is studied by means of the linear and nonlinear Ambartsumyan's theory of plate and the refined theory proposed by Rodionova, Titaev and Chernykh. Lamina Cribrosa is modelled as a continuos nonuniform transversal isotropic plate.

Key words: Lamina Cribrosa, glaucoma, intraocular pressure, theory of plate

The *Lamina Cribrosa* is the part of a sclera, which is weakened by a system of pores. According to the experimental data [1-3] the site of damage of nerve fibers under glaucoma is just the scleral *Lamina Cribrosa*.

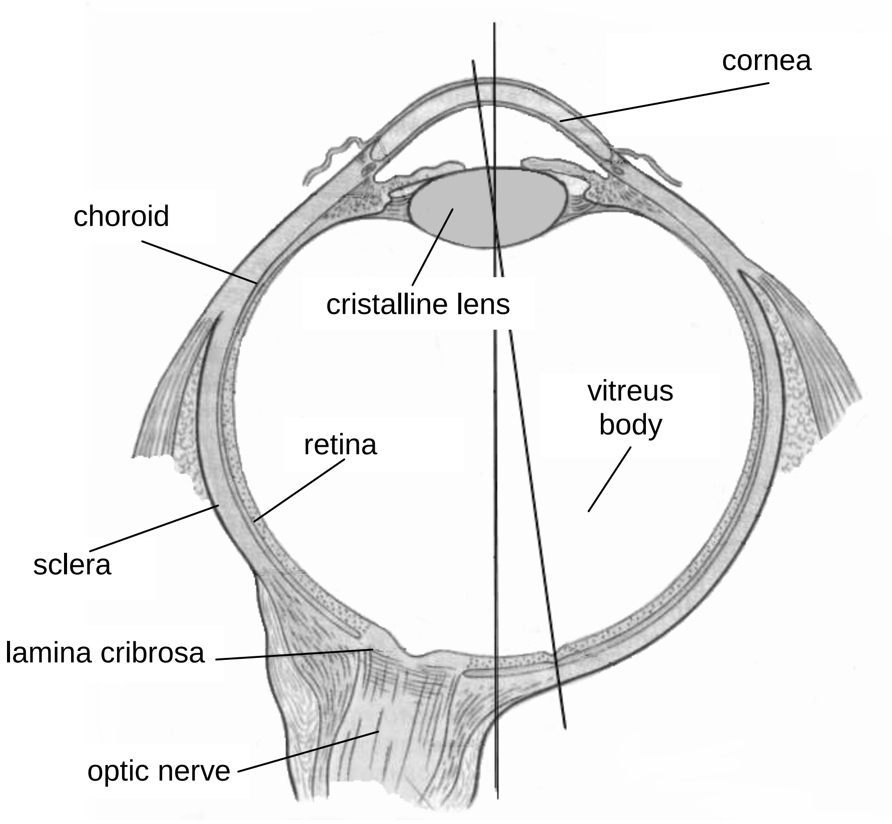

Fig. 1.

It makes the study of the effect of the intraocular pressure on the stress-strain state of the *Lamina Cribrosa* important. The experimental researches have also revealed that the increased pressure does not cause an increase in the size of the scleral canal through which the optic nerve passes (diameter of the *Lamina Cribrosa*). That permits us to consider the *Lamina Cribrosa* as a perforated plate with clamped edges under normal pressure.

In order to describe the stress-strain state of perforated plates these plates are usually represented as continuous plates with reduced parameters [4]. These parameters are defined from the condition, that the average displacements of the "reduced" plate and perforated plate are equal under same loads.

The main problem in the analytical evaluations of the *Lamina Cribrosa* deformations is the lack of the precise data on the mechanical nature of the *Lamina Cribrosa*. Some research data on the average depth of optic disc cupping under fixed values of the intraocular pressure [1-3, 5] and experimental data of special research [6-9] permit to estimate the reduced modulus of elasticity for the *Lamina Cribrosa*.

The deflection of the *Lamina Cribrosa* under uniform normal pressure is studied by means of the linear and nonlinear Ambartsumyan's theory of plates [10] and the refined theory proposed by Rodionova, Titaev and Chernykh [11].

It is assumed that the *Lamina Cribrosa* is a circular plate of radius R with the annular hole of radius δ in the centre of the plate. The lower and upper surfaces of the plate are loaded by the uniform intraocular (p^-) and intraskull (p^+) pressures:

$$\sigma_z = -p^{\pm} \text{ for } z = \pm h/2, \; \tau_{rz} = 0 \text{ for } z = \pm h/2.$$

We also assume that the *Lamina Cribrosa* is a transversal isotropic plate:

$$e_r = \frac{\sigma_r}{E_1} - \frac{\nu}{E_1}\sigma_\theta - \frac{\nu'}{E_2}\sigma_z, \; e_\theta = \frac{\sigma_\theta}{E_1} - \frac{\nu}{E_1}\sigma_r - \frac{\nu'}{E_2}\sigma_z, \; e_z = \frac{\sigma_z}{E_2} - \frac{\nu''}{E_1}\sigma_r - \frac{\nu''}{E_1}\sigma_\theta,$$

$$e_{rz} = \frac{\tau_{rz}}{G'}, \; e_{\theta z} = \frac{\tau_{\theta z}}{G'}, \; e_{r\theta} = \frac{\tau_{r\theta}}{G'}, \; \nu'' E_2 = \nu' E_1, \; G = \frac{E_1}{2(1+\nu)}.$$

Here r, θ are the polar coordinates in the middle surface of the *Lamina Cribrosa*; z is the distance along the normal from the middle surface; E_1 and E_2 are the moduli of elasticity in the tangential and transversal directions, respectively; ν, ν', ν'' are Poisson's ratios (ν describes the shortening in the plane of isotropy under the tension in this plane; ν' describes the shortening in the plane of isotropy under the tension in the direction orthogonal to the plane; ν'' describes the shortening in the direction orthogonal to the plane of isotropy under the tension in the plane); σ, τ are the stresses and e are the deformations in polar coordinates; G and G' are the shear moduli for the isotropy plane and planes orthogonal to this plane.

We assume that due to symmetry the distribution of the stresses does not depend on the angle θ.

According to the Ambartsumyan's theory

$$e_z = 0, \; \tau_{rz} = \frac{1}{2}\varphi(r)\left(\frac{h^2}{2} - z^2\right),$$

$$u_z = w(r), \; u_z = u - z\frac{dw}{dr} + \frac{z}{2}\left(\frac{h^2}{4} - \frac{z^2}{3}\right)\frac{\varphi(r)}{G'},$$

where $\varphi(r)$ is an arbitrary function of r. Here $u_r(r,z)$ and $u_z(r,z)$ are the radial and normal displacements of the plate points, $u_r(r,0) = u(r)$, $u_z(r,0) = w(r)$.

Substituting these expressions into the elasticity relations and then into the equilibrium equations we obtain the governing system of differential equations for functions u, w and φ.

The governing system splits into two subsystems. The first subsystem describes the plane deformations, the second one describes the plate bending. To study the bending problem we consider the system for the functions $w(r)$ and $\varphi(r)$:

$$\frac{d\varphi}{dr}+\frac{\varphi}{r}=-\frac{12P}{h^3},$$

$$P=p^- - p^+, \tag{1}$$

$$E_1(r)\left[\frac{d^3w}{dr^3}+\frac{1}{r}\frac{d^2w}{dr^2}-\frac{1}{r^2}\frac{dw}{dr}\right]+\frac{dE_1}{dr}\left[\frac{d^2w}{dr^2}+\frac{\nu}{r}\frac{dw}{dr}\right]=-\left(1-\nu^2\right)\varphi(r)+\frac{dE_1}{dr}\frac{h^2}{10G'}\left(\frac{d\varphi}{dr}+\nu\frac{\varphi}{r}\right).$$

Let the edge $r=\delta$ be free:

$$r=\delta:\ T_r=0,\ M_r=0,\ N_r=0, \tag{2}$$

and on the other edge the following boundary conditions are imposed:

$$r=R:\ w=0,\ u_r=0,\ -\frac{dw}{dr}+\frac{h^2}{8G'}\varphi=0. \tag{3}$$

Taking into account boundary conditions (2), (3) we can get from equations (1) an expression for $\varphi(r)$:

$$\varphi(r)=\frac{6P}{h^3}\left(-r+\frac{\delta^2}{r}\right) \tag{4}$$

and the equation for deflection $w(r)$:

$$\begin{aligned}&E_1(r)\left[\frac{d^3w}{dr^3}+\frac{1}{r}\frac{d^2w}{dr^2}-\frac{1}{r^2}\frac{dw}{dr}\right]+\frac{dE_1}{dr}\left[\frac{d^2w}{dr^2}+\frac{\nu}{r}\frac{dw}{dr}\right]=\\&=-\frac{6P}{h^3}\left(-r+\frac{\delta^2}{r}\right)\left(1-\nu^2\right)+\frac{dE_1}{dr}\frac{3P}{5G'h}\left(1+\nu+\frac{\delta^2}{r^2}(1-r)\right).\end{aligned} \tag{5}$$

Taking into account (3), we obtain boundary conditions for equation (5) in the form

$$\begin{aligned}&r=\delta:\quad \frac{d^2w}{dr^2}=\frac{6}{5G'h}P,\\&r=R:\quad w=0,\quad \frac{dw}{dr}=\frac{3P}{4G'h}\left(\frac{\delta^2}{R}-R\right).\end{aligned} \tag{6}$$

If $E_1=\text{const}$, then equation (5) has analytical solution

$$w(r)=\frac{3P\left(1-\nu^2\right)}{2E_1h^3}\left(\frac{r^4}{8}+r^2\delta^2-r^2\delta^2\ln(r)\right)+r^2C_1+C_2\ln(r)+C_3,$$

where the unknown constants C_1, C_2, C_1 are evaluated from boundary conditions (6).

As it was noted, the *Lamina Cribrosa* is the part of the sclera, which is weakened by a system of pores. According to experimental data [1-3], the *Lamina Cribrosa* has about 700 holes which occupy about 2/3 of the *Lamina Cribrosa* area.

The survey of research, devoted to calculation of elastic parameters of continuous plate, which has the same stiffness as the perforated plate is given in [4]. Comparing vibration frequencies of plates, perforated by circular holes of different size, the following relation may be obtained

$$D^*=\mu D,\ \mu=\left(1-\frac{S_0}{S}\right)^{7/3}, \tag{7}$$

where S is the area of the plate; S_0 is the part of the area occupied by holes; D^* and D are cylindrical stiffnesses of the continuous and perforated plates, respectively.

According to relation (7)

$$\frac{E}{E_1} \cong 10,$$

where $E = 1.43\ \text{MPa}$ is the Young's modulus of the sclera. One should note that the various values of the sclera Young's modulus (5.0 – 40.0 MPa) in literature depend not only on the domain of scleral shells but also on the age [12].

If the density of the holes increases at the periphery of the *Lamina Cribrosa*, then we may assume that tangential modulus of elasticity decreases approaching the edge of the plate, for example:

$$E_1(r) = \hat{E}_1 e^{-q\frac{r}{R}}.$$

To study the effect of the decreasing rate of function $E_1(r)$ on the form of the deflection the calculation was performed for different $\hat{E}_1$ and q, but for constant average value of E_m:

$$E_m = \frac{1}{R-\delta}\int_{\delta}^{R} \hat{E}_1 \exp\left(-q\frac{\delta}{R}\right) dr .$$

It is clear that $\hat{E}_1$ and q should satisfy the condition

$$E_1(\delta) = \hat{E}_1 \exp\left(-q\frac{\delta}{R}\right) < E .$$

Shear modulus G', which is also dependent on r, is represented in the form

$$G'(r) = kE_1(r).$$

If $E_m = E/10 = 1.43\ \text{MPa}$, then $q = 10$ is the maximum permissible value.

According to experimental studies [1-3, 8, 9] the diameter of the *Lamina Cribrosa* is 1.2-1.7 mm, the thickness of the *Lamina Cribrosa* is 0.1-0.35 mm.

In Table 1 the dependence of the maximum of the displacement (in the centre) on intraocular pressure is represented for the plate with $R = 0.75\ \text{mm}$, $h = 0.2\ \text{mm}$ ($\hat{E}_1 = 12.2\ \text{MPa}$, $q = 7$).

Table 1.

p, mm Hg	15	30	40	50	60	80
$w(\delta)$, mm	0.164	0.328	0.438	0.547	0.656	0.875

One can see that the displacement has order of the plate thickness, and it means that to refine the results one must apply the geometrically nonlinear theory.

The nonlinear theory [10] takes into account the effect of the angles of the normal rotation on the lengthening and shear. If the inner stress-couples are expressed by the stress-function $F = F(r)$:

$$T_\gamma = \frac{1}{r}\frac{dF}{dr},\ T_\theta = \frac{d^2F}{dr^2},$$

then the system of equations for the functions $\varphi(r)$, $F(r)$ and $w(r)$ has the form

$$\frac{d\varphi}{dr} + \frac{\varphi}{r} + \frac{12}{rh^3}\frac{d}{dr}\left(\frac{dw}{dr}\frac{dF}{dr}\right) = -\frac{12P}{h^3},$$

$$\frac{1}{E_1 h}\left[\frac{d^3F}{dr^3}+\frac{1}{r}\frac{d^2F}{dr^2}-\frac{1}{E_1(h)}\frac{dE_1}{dr}\frac{d^2F}{dr^2}+\frac{1}{r^2}\frac{dw}{dr}\right]=-\frac{1}{2r}\left(\frac{dw}{dr}\right)^2, \tag{8}$$

$$E_1(r)\left[\frac{d^3w}{dr^3}+\frac{1}{r}\frac{d^2w}{dr^2}-\frac{1}{r^2}\frac{dw}{dr}\right]+\frac{dE_1}{dr}\left[\frac{d^2w}{dr^2}+\frac{\nu}{r}\frac{dw}{dr}\right]=-\left(1-\nu^2\right)\varphi(r)+\frac{dE_1}{dr}\frac{h^2}{10G'}\left(\frac{d\varphi}{dr}+\nu\frac{\varphi}{r}\right).$$

The solution of the equations (8) with boundary conditions (2), (3) was obtained by the perturbation method [10]. The maximum displacements of the *Lamina Cribrosa* with $\hat{E}_1 = 12.2$ MPa, $q = 7$, $k = 1$ due to the nonlinear Ambartsumyan's theory of plates are given in Table 2.

Table 2.

p, mm Hg	15	30	40	50	60	80
$w(\delta)$, mm	0.161	0.309	0.397	0.476	0.549	0.675

For $p = 40$ mm Hg the difference in the values of the deflection, obtained with linear and nonlinear theories, is about 9 %. This difference increases with the intraocular pressure.

We also analyse the stress-strain state of the *Lamina Cribrosa* using the new refined iterated theory [11], based on the following hypotheses:
the transverse tangential and normal stresses are distributed along the shell thickness according to the quadratic and cubic laws, respectively;
along the shell thickness the tangential and normal components of the displacement vector have the polynomial distributions of the third and the second powers, respectively.

This theory takes into account the rotation of the fibres, their bending and also the change of the fibre lengths.

Following [11], let us introduce for convenience the following variables

$$\nu^* = \frac{E_1\nu'}{E_2(1-\nu)} = \frac{\nu''}{1-\nu}, \quad E^* = \frac{E_2}{1-2\nu'\nu^*}.$$

The plate is again under the uniform normal pressure p. Therefore,

$$\tau_{rz}^{\pm} = \tau_{\theta z}^{\pm} = 0, \quad \sigma_z^{-} = -p^{-}, \quad \sigma_z^{+} = -p^{+} \text{ for } z = \pm h/2.$$

It is supposed [11] that

$$u_r = u^* P_0 + \gamma_1^* P_1 + \theta_1^* P_2 + \varphi_1^* P_3,$$

$$u_r = w^* P_0 + \gamma_3^* P_1 + \theta_3^* P_2,$$

where P_i are the Legendre's polynomials:

$$P_0 = 1, \quad P_1 = \frac{2z}{h}, \quad P_2 = \frac{6z^2}{h^2} - \frac{1}{2}, \quad P_3 = \frac{20z^3}{h^3} - \frac{3z}{h}.$$

The boundary conditions are

$$r = R: \; w^* = 0, \; u^* = 0, \; \gamma_1^* = 0,$$

$$r = \delta: \; T_r = 0, \; M_r = 0, \; N_r = 0.$$

Substituting the deformation and strains in the form of the linear combinations of the Legendre‘s polynomials and using the accepted hypothesis, one can get the system of equations [11]

$$\frac{d^2u^*}{dr^2}+\frac{du^*}{dr}\left(\frac{1}{r}+\frac{1}{E_1}\frac{dE_1}{dr}\right)-\frac{1}{r^2}u^*=-\frac{1}{E_1}\frac{d\nu^*}{dr}T_0,$$

$$\frac{d^2\gamma_1^*}{dr^2}+\frac{d\gamma_1^*}{dr}\left(\frac{1}{r}+\frac{1}{E_1}\frac{dE_1}{dr}\right)-\frac{1}{r^2}\gamma_1^*=\frac{6}{E_1h^2}\left(\frac{P\delta^2}{2r}-\frac{d\nu^*}{dr}M_0-P\frac{r}{2}\right), \qquad (9)$$

$$\frac{dw^*}{dr}=-\frac{2\gamma_1^*}{h}+\frac{6}{5G'h}N_r(r)+\frac{1}{5}\frac{d\theta_3^*}{dr},$$

where

$$T_0=-\frac{h}{2}\left(p^++p^-\right)=-\frac{hP}{2},$$

$$M_0=\frac{h^2P}{10},$$

$$N_r(r)=-\frac{p}{2}r+\frac{p\delta^2}{2r}.$$

The displacement components are

$$\gamma_3^*=\frac{T_0}{2E^*}-\frac{\nu^*h}{2}\left(\frac{du^*}{dr}+\frac{u^*}{r}\right),$$

$$\theta_3^*=\frac{M_0}{2E^*}-\frac{\nu^*h}{6}\left(\frac{d\gamma_1^*}{dr}+\frac{\gamma_1^*}{r}\right),$$

$$\theta_1^*=\frac{h}{6}\frac{d\gamma_3^*}{dr},$$

$$\varphi_1^*=-\frac{N_r}{10G'}-\frac{h}{10}\frac{d\theta_3^*}{dr}.$$

One can find u^*, γ_1^* and then w^* from equations (9).

Table 3.

p, mm Hg	$w(\delta)$, mm		
	1	2	3
20	0.219	0.213	0.183
30	0.328	0.309	0.274
40	0.438	0.397	0.366
60	0.656	0.548	0.548
80	0.875	0.675	0.731
100	1.094	0.782	0.914

The maximum displacements of the *Lamina Cribrosa* with $\hat{E}_1=12.2$ Pa, $q=7$, $k=1$, obtained from the linear (column 1) and nonlinear (column 2) Ambartsumyan's theory of plates and the refined theory (column 3) [11] are given in Table 3.

It is interesting to compare the results, obtained from the linear and nonlinear Ambartsumyan's theories of plates and the refined theory, represented in [11]. Both theories give close results for $w\approx(2\div4)h$ when the difference in results is not more than 8-9 %. The results almost perfectly coincide: if the displacement in the centre of plate is $w \approx 3h$, then the difference in results is only 1-2 %.

We assume for the shear modulus $G'(r)$ in the plates normal to the plane of isotropy that $G'(r) = kE_1(r)$. It is noted in [10], that the value of $E_1(r)/G'(r)$ effects significantly on the stress-strain state of anisotropic plate, and this effect increases with E_1/G'.

Experimental data [1, 2] permit to assume that shear modulus G for plane of isotropy is greater than the shear modulus G' for planes, which are perpendicular to the plane of isotropy. (If $\hat{E}_1(r)/G'(r) \approx 2$, the shear moduli in the plane of isotropy and planes perpendicular to this plane are equal.)

The maximum displacements of the *Lamina Cribrosa* obtained from the refined theory [11] for $\hat{E}_1 = 12.2$ MPa, $q = 7$ and different $E_1(r)/G'(r)$ are given in Table 4.

Table 4.

$p/w(\delta)$	$E_1/G' = 2$	$E_1/G' = 3$	$E_1/G' = 4$
10	0.116	0.141	0.165
20	0.232	0.281	0.331
30	0.348	0.422	0.496
40	0.464	0.563	0.661

One can see that the value of the displacement increase when shear stiffness decreases.

The results of the calculation prove the existence of the essential shear deformation and compression of axons. Moreover the shear deformations are greater than the compressive deformation in two orders. In Fig. 2 the vertical sections of the canals of the deformed plate is plotted. Five canals are chosen on the equal intervals from the centre of the plate to its edge, the centres of the canals are on the same radius.

If the microtubuli uniformly cover the entire plate, then the modulus of elasticity is constant, and in this case the deformed lattice plate under pressure 50 mm Hg has the shape shown in Fig. 3.

If the number of microtubuli (or their total area) increases approaching the edge of the plate (that is typical for the most of the people [1–3]), then the modulus of elasticity decreases away from the centre of the plate and in this case the deformed lattice plate has the form plotted in Fig. 4.

The solutions for the *Lamina Cribrosa* with different degrees of nonuniformity (but constant average modulus of elasticity) show that the greater degrees of nonuniformity lead to the greater shear deformation of the *Lamina Cribrosa*.

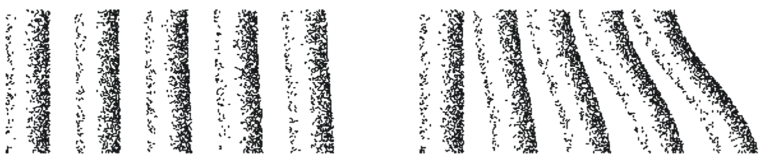

Fig. 2.

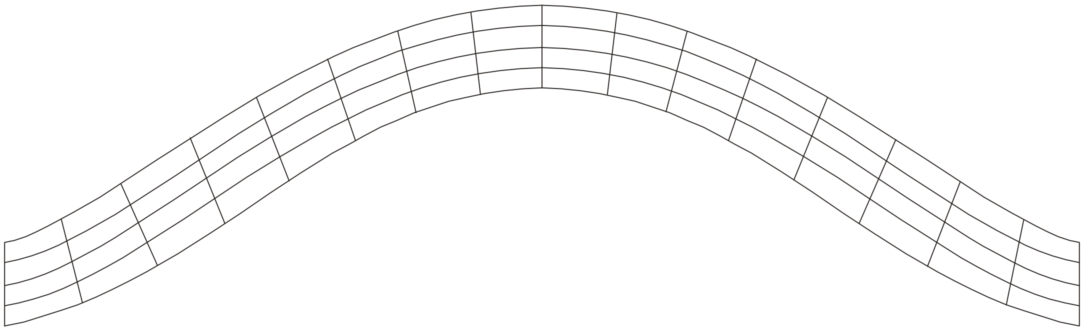

Fig. 3.

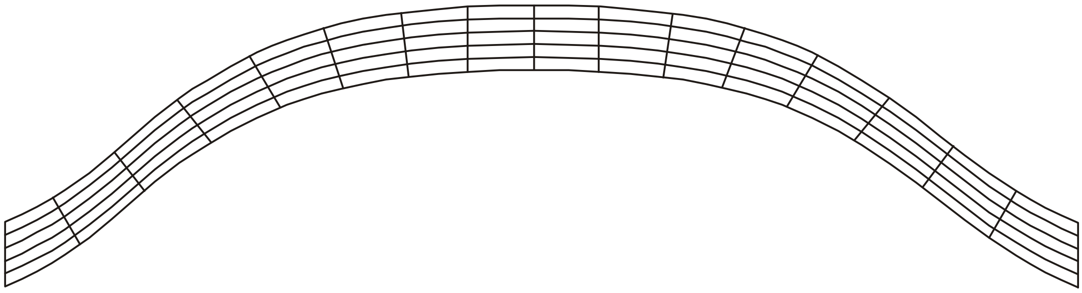

Fig. 4.

In the centre of the plate the deformations are insignificant, i.e. two-three orders less than the deformations at the edge. The deformations of canals attain the maximum in the interval between $2/3R$ and R from the plate centre. So, under increasing of the intraocular pressure the shear and compression of axons, which lead to the atrophy of the optic nerve fibres, occur initially near the edge of the plate.

The problem on the deformation of the *Lamina Cribrosa* was considered in [13]. The *Lamina Cribrosa* was considered as uniform and isotropic in [13] and the authors undertook an attempt to take into account the influence of the tensile forces, which act upon the *Lamina Cribrosa* from the scleral eye shell. We assume that this effect is not essential, since the *Lamina Cribrosa* is significantly softer ($E/E_1 \cong 10$) and 4-5 times thinner than sclera. And as it was noticed according to the experimental data the increasing of pressure does not cause the increase in the size of the scleral canal.

The authors of [13] also suppose that at the edge of the *Lamina Cribrosa* the stresses in the *Lamina Cribrosa* and in the scleral shell are equal to each other, though for the 2D problem the stress-couples should be equalised.

Acknowledgements

The work is supported in part by RFFR, Grant 01-01-00234.

References

1. ВОЛКОВ В.В., СУХИНИНА Л.Б., УСТИНОВА Е.И. **Глаукома, преглаукома и офтальмогипертензия**. Ленинград, Медицина, 1985 (in Russian).
2. НЕСТЕРОВ А.П., ЕГОРОВ Е.А. Глаукоматозная атрофия зрительного нерва. В книге **«Актуальные проблемы офтальмологии»**. Под ред. Краснова М.М., Нестерова А.П., Дыбова С.М. Москва, Медицина, 1981 (in Russian).

3. НЕСТЕРОВ А.П. **Глаукома**. Москва, Медицина, 1995 (in Russian).
4. ГРИГОЛЮК Э.И., ФИЛЬШТИНСКИЙ Л.А. **Перфорированные пластины и оболочки**. Москва, Наука, 1970 (in Russian).
5. МУСТАФИНА Ж.Г., ГЕРНИК В.В. К определению глаукоматозной экскавации зрительного нерва. **Офтальмологический журнал**, 5: 277-278, 1982 (in Russian).
6. QUIGLEY H.A., ADDICKS E.M. Quantitative studies of retinal nerve fiber layer defects. **Arch Ophthalmol**, 100: 807-814, 1982.
7. MOTOLKO M., DRANCE S.M. Features of the optic disk in preglaucomatous eyes. **Arch Ophthalmol**, 99: 1992-1994, 1981.
8. LEVY N.S., CRAPPS E.E., BONNEY R.C. Displacement of the optic nerve head. Response to acute intraocular pressure elevation in primate eyes. **Arch Ophthalmol**, 99: 2166-2174, 1981.
9. YAN D.B., COLOMA F.M., METHEETRAIRUT A., TROPE G.E., HEATHCOTE J.G., ETHIER C.R. Deformation of the lamina cribrosa by elevated intraocular pressure. **British Journal of Ophthalmology**, 78: 643-648, 1994.
10. АМБАРЦУМЯН С.А. **Теория анизотропных пластин**. Москва, Наука, 1987 (in Russian).
11. РОДИОНОВА В.А., ТИТАЕВ Б.Ф., ЧЕРНЫХ К.Ф. **Прикладная теория анизотропных пластин и оболочек**. Санкт-Петербург, Изд-во С.-Петерб. ун-та, 1996 (in Russian).
12. ИОМДИНА Е.Н. Биомеханика склеральной оболочки глаза при миопии: диагностика нарушений и их экспериментальная коррекция. Диссертация на соискание ученой степени доктора биологических наук, Москва, 2000 (in Russian).
13. DONGI H., ZEQIN R. A biomathematical model for pressure-dependent lamina cribrosa behavior. **Journal of Biomechanics,** 32: 579-584, 1999.

О ДЕФОРМАЦИИ РЕШЕТЧАТОЙ ПЛАСТИНКИ ГЛАЗА ПРИ ИЗМЕНЕНИИ ВНУТРИГЛАЗНОГО ДАВЛЕНИЯ

С.М. Бауэр, Е.Б. Воронкова (Санкт-Петербург, Россия)

Решетчатая пластинка глаза – это часть склеры, ослабленная большим количеством отверстий. Экспериментальные данные показывают, что при повышении внутриглазного давления явления, ведущие за собой атрофию зрительного нерва, происходят именно в области решетчатой пластинки. В связи с этим изучается напряженно-деформированное состояние решетчатой пластинки глаза при изменении внутриглазного давления.

Решетчатая пластинка рассматривается как неоднородная трансверсально–изотропная круглая пластинка с защемленным краем. Задача о прогибе такой пластинки под действием нормального давления решается в рамках линейной и геометрически нелинейной общей уточненной теории С.А. Амбарцумяна, а также по новой уточненной итерационной теории деформаций анизотропных пластин, предложенной в монографии В.А. Родионовой, Б.Ф. Титаева, К.Ф. Черныха. Нелинейная теория С.А. Амбарцумяна и новая уточненная итерационная теория дают близкие результаты - их разность не превосходит 8-9 % при прогибах порядка $2h-4h$.

Расчеты показывают, что в центре пластины деформации незначительны, они на два-три порядка меньше, чем на краю. Наибольшие деформации каналов наблюдаются на расстояниях от $2/3R$ до R от центра пластины, поэтому при возрастании внутриглазного давления атрофия нервно-зрительных волокон, вызванная сдвигом волокон и их сдавливанием, происходит в первую очередь вблизи края пластины, что соответствует характерному сужению поля зрения при глаукоме.

Если число "отверстий" (или площадь, ими занимаемая) увеличивается при приближении к краю пластины, что характерно для большинства людей, то предполагается, что модуль упругости убывает при приближении к краю. Такое

строение решетчатой пластины ведет к большим деформациям сдвига и, таким образом, к большему нарушению зрительных функций на периферии. Библ. 13.

Ключевые слова: решетчатая пластинка, глаукома, внутриглазное давление, теория пластин

Received 19 January 2001