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ON FORMULATION OF THE PROBLEM ON DEFORMATION OF THE LAMINA CRIBROSA

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Abstract. The form of an eye is determined by the outer shell, the sclera. The Lamina Cribrosa is a part of sclera, where the optic nerve fibers pass through and where the layer of sclera becomes thinner and many little pores appear. The experimental data show that under glaucoma the visual field changes due to the dystrophy and then atrophy of the optic nerve fibers, which are deformed just at the level of the LC. This makes the analysis of the stress-strain state of the LC under the changing the intraocular pressure (IOP) very important. The purpose of the present paper is to compare the deformations obtained with two models: the shell structure (sclera and LC) and the LC only. In both models the stuctures are subjected to normal pressure. The effect the increasing of the IOP on the diameter of the scleral ring and also the effect of the deformations of the scleral eye shell on the deflections of the LC are studied. The comparison of the results obtained for the combined shells and for the simplified structures where the effect of the scleral shell on the LC is neglected shows that the difference in the maximal deflection values of the LC is not more than 2 %. So, presumably, the deformation of the LC may be analyzed separately from the deformation of the scleral shell. Such approach may help taking into account the peculiarities of the structure of the LC, for example, its anisotropy and non-uniformity.

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

The form of an eye is determined by the outer shell, the sclera. The Lamina Cribrosa (LC) is a part of sclera, where the optic nerve fibers pass through (see Fig.1) and where the layer of sclera becomes thinner and many (more than 400) little pores appear.

The experimental data [1-4] show that under glaucoma the visual field changes due to the dystrophy and then atrophy of the optic nerve fibers, which are deformed just at the level of the LC. This makes the analysis of the stress-strain state of the LC under the changing the intraocular pressure (IOP) very important. In some works, for example, [3,4] the deformations of the LC were examined by means of analysis of the experimental data and clinical experiments. At the same time the development of the mathematical model, describing the behavior of the LC under changing of the IOP, is of the interest and importance.

The experimental research [4] shows that the increasing the IOP does not cause the increasing the size of a scleral canal through which the optic nerve passes (diameter of the LC). Besides, the LC is not so stiff as the sclera, and it allows modelling of the LC [5] as non-homogeneous transverse orthotropic plate with clamped edge under normal pressure. In [6] the LC was assumed to be homogeneous and isotropic and an attempt was made to take into account the effect of the tensile force generated by the scleral eyeshell on the LC.

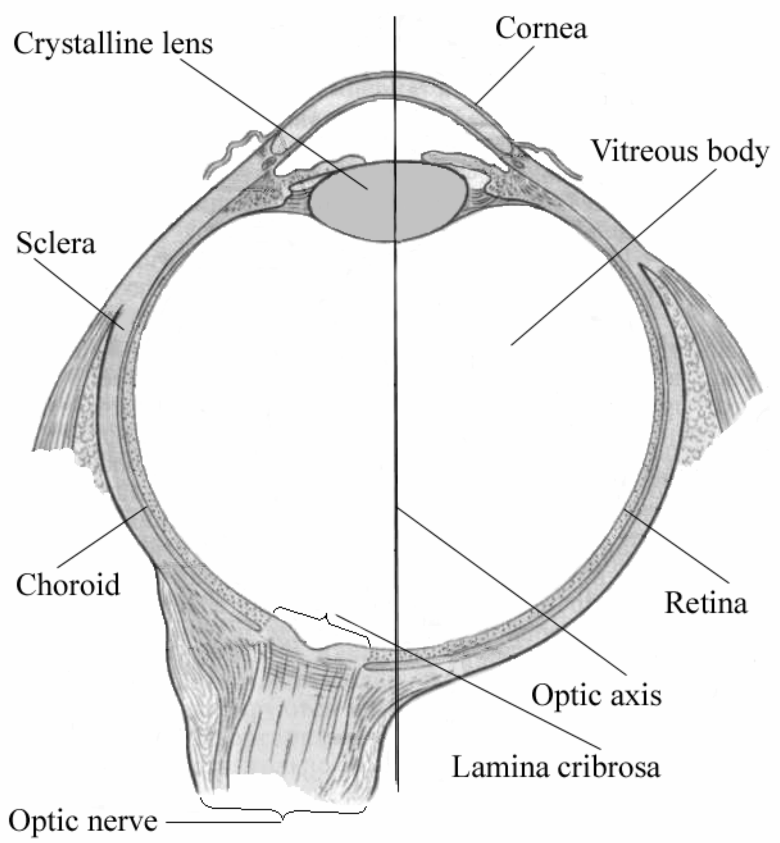
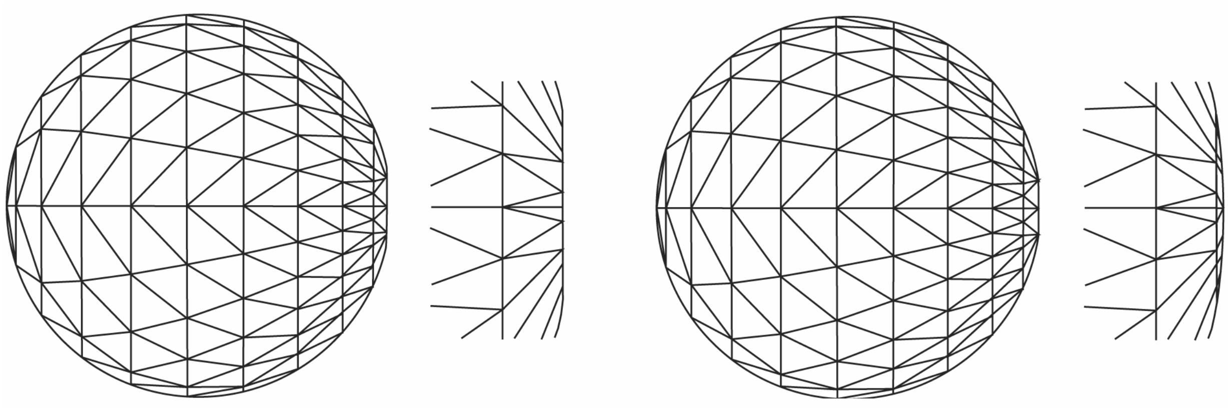

Crystalline lens
Cornea
Vitreous body
Sclera
Choroid
Retina
Optic axis
Lamina cribrosa
Optic nerve

Fig. 1



a b

Fig. 2.

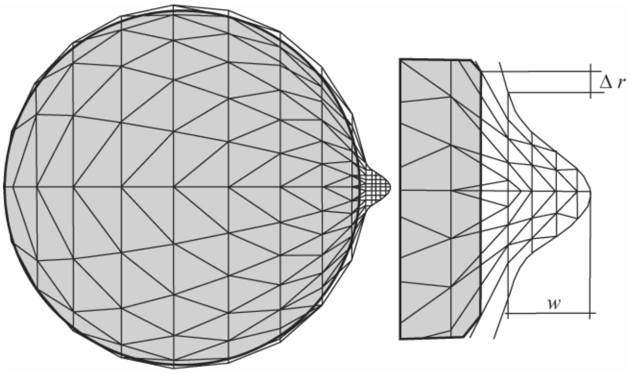


Fig. 3.

Table 1.

P, mm Hg.	15	30	40	50	60	80
w_1, 10^{-2} mm	0.88	1.75	2.34	2.92	3.50	4.67
w_2, 10^{-2} mm	0.85	1.69	2.26	2.82	3.39	4.52
Δr_1, 10^{-2} mm	0.063	0.125	0.167	0.209	0.250	0.333
Δr_2, 10^{-2} mm	0.062	0.125	0.166	0.208	0.249	0.332

Table 2.

P, mm Hg.	15	30	40	50	60	80
w_1, 10^{-2} mm	0.86	1.73	2.30	2.88	3.46	4.61
w_2, 10^{-2} mm	0.84	1.67	2.23	2.78	3.34	4.46
w, 10^{-2} mm	0.86	1.73	2.30	2.88	3.46	4.61

The purpose of the present paper is to compare the deformations obtained with two models: the shell structure (the sclera and the LC) and the LC only. In both models the stuctures are subjected to normal pressure. The effect of the increasing the IOP on the diameter of the scleral ring and also the effect of the deformations of the scleral eye shell on the deflections of the LC are studied.The eye shell is modelled as an elastic isotropic spherical shell of the constant thickness $H = 1$ mm and radius $R = 12$ mm, and the LC as the isotropic plate of the constant thickness $h = 0.2$ mm and radius $r = 0.75$ mm. Two problems of deformation of the combined shell are considered. In the first problem the LC is assumed to be plane (Fig 2a), in the second the LC is assumed to be slightly convex with a radius of the curvature equal to the radius of the curvature of the sphere (Fig.2b). Below the variables of the first and second problems have the subscripts 1 and 2 correspondingly. In the analysis it is assumed that the scleral Young's modulus is equal to 14.3 MPa, and the Poisson ratio is equal to 0.4. The LC has the Young's modulus 1.43 MPa, which is in the order less than that of scleral shell and the Poisson ratio equals to that of the scleral shell.

For the numerical analysis the finite element package ADINA (900 nodes) has been used. In Fig. 3 one can see the deformation of the scleral shell with the plane LC. In Table 1 both the maximal values of the deflections w_1 and w_2 and of the changing the radius of the LC Δr_1 and Δr_2 depending of the IOP are presented correspondingly for models (1) and (2).

One can see in Table 1 that the value of the radius changing the LC is in the order less than the value of its deflection, i.e. the diameter of the scleral ring changes slightly with the IOP. This result well agrees with the experimental data. The deflection in the center of the plate circular isotropic shell with the clamped edges under normal pressure may be determined by formula $w = \frac{pr^4}{69D}$, where $D = \frac{Eh^3}{12(1-\nu_1^2)}$ and ν_1 is the Poisson ratio. In Table 2 both the values of the maximal pressure for the plane, w_1, and the convex LC, w_2, and the value of the deflection, w, calculated by the analytical formula are included.

The comparison of the results obtained for the combined shells and for the simplified structures where the effect of the scleral shell on the LC is neglected shows that the difference in the maximal deflection values of the LC is not more than 2 %. So, presumably, the deformation of the LC may be analyzed separately from the deformation of the scleral shell. Such approach may help taking into account the peculiarities of the structure of the LC, for example, its anisotropy and non-uniformity.

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К ВОПРОСУ О ПОСТАНОВКЕ ЗАДАЧИ О ДЕФОРМАЦИИ РЕШЕТЧАТОЙ ПЛАСТИНКИ ГЛАЗА

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Форму глазного яблока определяет наружная оболочка – склера. Недалеко от заднего полюса через склеру выходит зрительный нерв. Этот участок склеры, истонченный и ослабленный множеством мелких отверстий, через которые проходят нервные волокна, называют решетчатой пластинкой.

Имеющиеся экспериментальные данные говорят о том, что при глаукоме атрофия зрительного нерва происходит именно в области решетчатой пластинки. Это делает задачу о напряженно-деформированном состоянии решетчатой пластинки глаза при изменении внутриглазного давления актуальной. В работе проводится сравнение решений задачи о деформации составной оболочки (склеры и решетчатой пластинки) и отдельно задачи о деформации решетчатой пластинки под действием нормального давления. Изучается влияние увеличения внутриглазного давления на диаметр склерального кольца, а также влияние деформации сферической оболочки глаза на величину прогиба решетчатой пластинки.

Сравнение результатов, полученных для составных оболочек и упрощенных задач, показывают, что разница в значениях максимальных прогибов не превосходит 2 %. Таким образом, деформацию решетчатой пластинки, по-видимому, можно изучать отдельно от деформации склеральной оболочки. Такой подход может помочь учесть возможные особенности строения решетчатой пластинки – ее анизотропию и неоднородность. Библ. 6.

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

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