Novel eye schematic model and its application in radial gradient index intraocular lens design

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The aim of these studies was to devise a new eye schematic model which would have a minimal level of spherical aberration. The outgoing point was the eye model described by Kooijman. The objective was achieved by introducing a Gaussian type radial gradient index distribution lens. The investigations showed a simple relationship between the axial length of the model and the values of refractive indices along the axis of the lens and in the equatorial plane. Additionally, knowledge of the dependence of the gradient index distribution coefficient on the values of the axial and equatorial refractive indices permits determination of the individual aberrations for each patient based only on a measurement of axial length or match an eye schematic model to an examinated eye individually. The algorithm of such a match was proposed. The lenticular index distribution presented in this schematic model eye has the potential for creating individual intraocular lens designs.

1 Introduction

The optical system of the eye is complex and elegant but aberrations, reducing optical quality exist. Spherical aberration (SA), astigmatism, and chromatic aberration have the greatest effect on retinal imagery; other off-axis aberrations play a smaller role.

Each of existing eye schematic models [1], was mainly introduced to estimate the optical aberrations of the real eye. Although most of them don't even presume the actual optical properties of the eye (i.e. gradient index distribution in the crystalline lens medium), they predict the aberrations of the real eye quite well.

The relative paucity of models of the gradient index lens results from difficulties in measuring the lenticular index distribution. Ellipsoidal, isoindicial surfaces have been used to describe the three-dimensional distribution of the refractive index in the lenses of rabbits and cats respectively [2,3]. However, in the human lens, this model does not seem to be appropriate.

2 Purpose

The aim of our study was to introduce an eye schematic model with gradient index distribution which would have the minimal spherical aberration (SA) and due to that it would have an application in the gradient index intraocular lens (IOL) design. The simplest way to minimize the SA seems to be the use of a refractive index that varies only with distance from the optic axis. Although this model would not have the very same aberrations as the real eye, but it would help to design the personal gradient index IOL which should minimize the aberrations of the other optical parts of the particular patient's eye and improve its visual performance.

3 Method

This model relies on the model previously introduced by the authors [4], with the difference that the refractive index is a function of the second power of the distance R from the optical axis:

$$n(R) = n_1 - (n_1 - n_2)\left[\frac{1-\exp(-\gamma R^2)}{1-\exp(-\gamma R_{\max}^2)}\right] \quad (1)$$

which is a function of Gaussian type. n_1 and n_2 are refractive indices: along the optic axis and at the equator respectively; γ is the gradient index distribution coefficient and $R_{\max}$ is the equatorial radius of the lens. The remaining data concerning surface shapes, distances, and refractive indices of cornea, aqueous humor and cilliary body are taken from the Kooijman eye schematic model [5].

The algorithm of raytracing described by Sharma *et al.* [6] was used and the spot diagrams in two important image planes were calulated. These planes were:

- plane at the distance of paraxial focus;
- plane at the distance of minimal geometrical spot size.

For a given pair of indices n_1, n_2, the value of γ coefficient was optimized to assure the zero distance between these two planes. Then the distance of these planes from the corneal apex was defined as axial eye length (AEL).

4 Results

Fig. 1. shows the relation between parameter γ, refractive index n_1, and the difference between refractive indices $\Delta n = n_2 - n_1$.

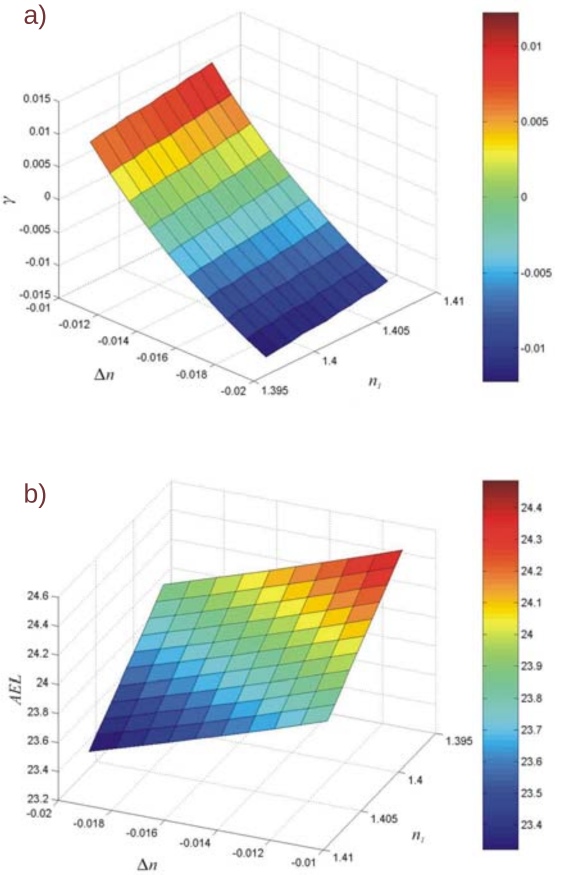

Fig. 1. Optimized value of coefficient parameter (γ) (a) and axial eye length (AEL) (b) plotted against refractive index along the optic axis (n_1) and difference between refractive indices (Δn).

The surface from the fig. 1b can be easily and with a great precision approximated with a plane. The result of this approximation describes the following equation:

$$AEL(n_1, \Delta n) = -62.671 n_1 + 59.178 \Delta n + 112.605 \quad (2)$$

The results show that there are many combinations of AEL, n_1, Δn and γ for which the plane of paraxial focus and plane of minimal variance are coincident. This indicates that there is a number of optimum variations of the proposed eye model. The SA for particular four of these parameters is shown in the fig. 2.

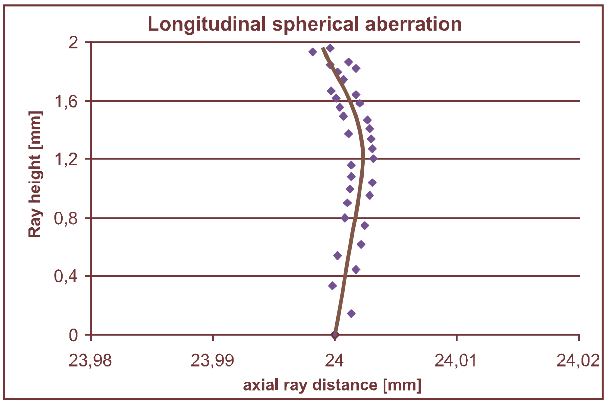

Fig. 2. Longitudinal SA calculated for particular values of parameters: n_1=1.403, n_2=1.39153, γ=0.009558, AEL=24.00mm.

5 Conclusions

By introducing the radial gradient index in the crystalline lens medium into the Kooijman eye schematic model, a set of optimal eye models was obtained. This means that it can be used to determine the individual aberrations for each patient based only on a measurement of the axial eye length. Knowing the AEL and assuming the value of axial refractive index, one can match the model to the particular's eye. This creates unlimited possibilities in the modelling of intraocular lenses with a gradient index distribution.

References

[1] Atchison D.A., Smith G., "Chromatic dispersions of the ocular media of human eyes" in *Vision Research* **35**: 2529-2538 (1995)

[2] Nakao S., Fujimoto S., Nagata R., Iwata K., "Model of Refractive-Index Distribution in the Rabbit Crystalline Lens" in *Journal of the Optical Society of America* **58**: 1125-1130 (1968)

[3] Jagger W.S., "The refractive structure and optical properties of the isolated crystalline lens of the cat" in *Vision Research* **30**: 723-738 (1990)

[4] Siedlecki D., Kasprzak H., Pierscionek B.K., „Schematic eye with a gradient-index lens and aspheric surfaces" in *Optics Letters* **29**: 1197-1199 (2004)

[5] Kooijman A.C., "Light distribution on the retina of a wide-angle theoretical eye" in *Journal of the Optical Society of America* **73**: 1544-1550 (1983)

[6] Sharma A., Vizia Kumar D., Ghatak K.A., "Tracing rays through graded-index media: a new method" in *Applied Optics* **21**: 984-987 (1982)