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Biomechanical Analysis of Parameters Influencing Pressure-Volume Relationship in the Human Eye

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Abstract

Purpose: To study the effects of different mechanical properties of the sclera and the cornea, such as their anisotropy, non-uniformity, and deflections in their spherical shapes on pressure-volume relationship.

Methods: Correlations between the intraocular pressure (IOP) and the intraocular volume (IOV) were found for spherical and ellipsoidal orthotropic layers by means of 3D-theory of elasticity. Subsequently, the corneoscleral shell of the eye was modeled as a conjugated shell consisting of two segments. The sclera and the cornea are generally assumed to be the parts of the orthotropic elliptic shells with different geometrical and mechanical properties.Relationship between IOP and IOV was obtained for three mechanical models with following problem statements: 1) sclera and cornea are assumed to be soft shells; 2) sclera and cornea are supposedto be orthotropic shells with small modules of elasticity in the thickness direction; for this model calculations were made due to applied shell theory by Chernykh; 3) sclera and cornea are modeled as 3D elastic solids with FEM/ANSYS (ANSYS, Inc.,Canonsburg, PA). The calculations were performed for different sets of parameters for all three mechanical models and were compared to clinical data.

Results: Transversal isotropic shells of revolution of different shapes (modelling the sclera) with equal initial volumes showed linear pressure-volume relationship, while proportionality factor (K) is minimal for a spherical shell (emmetropic eye).If the ratio of the axial length (AL) and the equatorial diameter of the shell (D) increases (the case of a shell modelling a myopic eye), then factor K increases up to 5-10%. If the ratio AL/D decreases (for a shell modelling a hyperopic eye), then factorK starkly increases up to 100%. The same effect was observed for the 2-segments model.

Conclusions: Both the orthotropic properties of the sclera (the ratio of two tangential modules of elasticity) and the non-uniformity of the sclera have a significant effect on the character of the pressure-volume relationship and, thus, on the rigidity of the human eye. Geometric and elastic properties of the cornea also affect the relationship, although to the less extent.