NONLINEAR ANALYSIS OF THE BEHAVIOUR OF THE HUMAN CORNEA

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INTRODUCTION

The biomechanical properties of the human cornea are fundamental to our understanding of corneal behaviour in response to keratorefractive surgery and aspects of corneal physiology where mechanics plays an important role. Recent research on the whole corneal structure has showed that the mechanical behaviour of the cornea is rather complicated [1-3]. The unexpected non-uniform distribution of strain in the meridian direction of the cornea measured in experiments indicates that the corneal has regionally different mechanical properties. The principal causes for the regional variability in mechanical properties of the human cornea may include the variability of the elastic modulus of fibrils, the reinforcing ratios of collagen fibrils, the orientation of fibrils, and/or the sequential recruitment of fibrils [3,4]. Previous studies showed that the diameter of fibrils is constant in the centre and para-centre, while there is increased variability in the diameter of fibrils in the corneal periphery. In the limbus, the diameter of fibrils increases. Unfortunately, no accurate quantitative determinations on the regional variation in the volume fraction of collagen fibrils are available, although variations possibly are small.

METHODS

The cornea is approximated as a spherical cap with a variable thickness. The radius of curvature of the mid-surface of the shell is assumed to be R = 7.86 mm. The horizontal diameter of the mid-surface of the shell at the edge is assumed to be D_b=15 mm (see Fig.1). The corneal thickness is assumed to increase linearly from h_{min} = 0.5 mm at the centre to h_1 = 0.66 mm at the limbus and to h_2 = 1.0 mm at the edge. The cornea is subjected to the intra-ocular pressure of p = 2.135 kPa. The boundary of the shell is assumed to be hinged at the edge. In the present nonlinear analysis the cornea is assumed to be perfectly axial-symmetric and the analysis is performed within the cross-section by using axial-symmetric plane elements.

The cornea material is modeled as an orthotropic, nonlinear elastic material with principal axes defined as in the directions of meridian and circumference. Since the reinforcing ratios of the collagen fibrils vary from the central region to the limbus the overall orthotropic moduli in meridian and circumference are not constants. The stress-strain equation in the uni-axial stress state, in the principal axes is assumed as [5]:

$$\sigma = \alpha\varepsilon^2 + \beta\varepsilon \qquad (1)$$

where σ and ε are the stress and strain, α and β are constants. The nonlinear stress-strain equations for a three-dimensional orthotropic material can be derived based on the uni-axial stress-strain equation (1).

The problem is solved using the nonlinear finite element analysis program (Femlab). Because of axial-symmetry, only half of the cornea within the axial-symmetric plane is analyzed.

RESULTS AND DISCUSSION

Fig.1 shows the deformation of the cornea and corresponding von Mises stress distribution in the cross-section. The high stresses are found mainly in the areas close to the limbus and the edge where the boundary is fixed. More results and the comparisons between the model predictions and experimental results will be shown in the conference presentation. Results on the parametric studies will also be provided in the presentation.

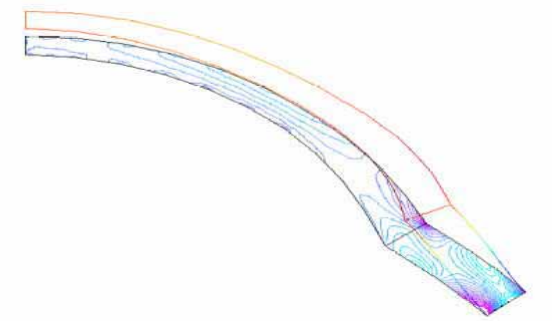

Fig.1 von-Mises stress distribution and deformed shape of the cornea subjected to intra-ocular pressure.

CONCLUSIONS

This paper presents a numerical investigation on the mechanical behaviour of human corneas by using a nonlinear finite element analysis method. After verification, the FE model is used to examine both normal and keratoconic corneas. Future extensions of this research will include the interaction between the stress analysis model and the flow model of corneal hydration [6]. The research presents here is part of a long term project to develop accurate predictive tool that can assist the clinical management.

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