NUMERICAL MODELLING OF THE INDENTATION OF THIN CORNEAS

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INTRODUCTION

The cornea performs two major functions: to protect the inner contents of the eye and to refract light. To do so, the cornea must maintain its strength and transparency. The main structural component of the cornea is the stroma, which provides most of the cornea's strength, and helps give the eye its shape. The refractive power of the cornea is determined by its index of refraction and by its radius of curvature, and accounts for over two-thirds of the optical power of the eye.

The topography of the cornea is predominantly dependent upon the material stiffness properties and thickness of the cornea. Corneal diseases can affect corneal thickness and stiffness, e.g. keratoconus, and can lead to changes in topography, causing visual impairment. There is also a need to understand the effects of corneal thinning in myopic cornea, in response to photorefractive surgery, where the cornea is artificially thinned with a laser to improve the optical properties of the eye. Hence an understanding of the biomechanical behaviour of the cornea is vital for the development of predictive tools to aid clinical management of patients.

Corneas with reduced thickness and stiffness will affect the accuracy of the indentor techniques used for estimating intraocular pressure (IOP), which are part of the process of diagnosis for disease states such as glaucoma. It is accepted in clinical practice that applanation tonometry (which uses a cylindrical indentor) becomes unreliable following photorefractive keratectomy and is unreliable in keratoconic subjects.

The overall aim of this research is the development of finite element models of the cornea, to assess the effects of photorefractive surgery and corneal thinning disease on the accuracy of clinical indentor techniques. This work is described below.

METHODS

Numerical analysis of thin corneas has been carried out using finite element analysis of axisymmetric models, subject to indentation. Two approaches were adopted: (1) where the pressure due to an indentor was applied as a boundary condition and (2) where the indentor was explicitly modelled. The thickness and stiffness of corneal models were varied for different intraocular pressures, above and below normal physiological levels. The resulting changes to corneal topography and thickness were then compared. Simple linear elastic material behaviour was assumed for both the cornea and indentor.

Calibration exercises were conducted to compare finite element predictions with clinical observations. An example is shown in Figure 1, which is a simulation of an applanation tonometer test on a cornea. A cylindrical indenter is pushed into the cornea and applanates the eye, leading to local deformation. The undeformed and deformed meshes are shown in Figure 1.

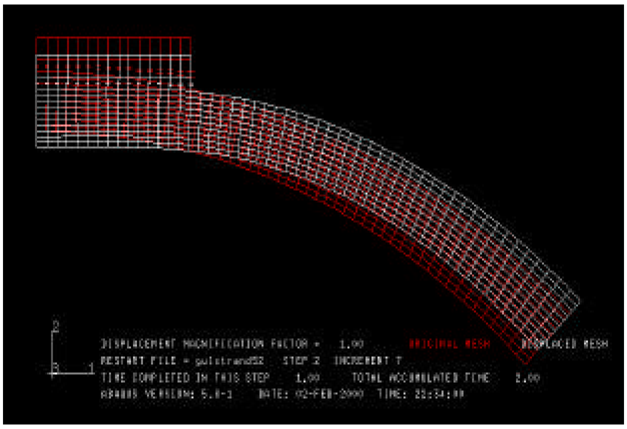

Figure 1: Finite element simulation of a Goldmann tonometer test showing undeformed and applanated eye

RESULTS AND DISCUSSION

Finite element analysis was carried out to assess the variation in predicted intraocular pressure (IOPG) from applanation tonometry compared to the true intraocular pressure (IOPT) as specified by the model boundary conditions, for various pressures, material thickness and stiffness. This variation can be expressed using the modification factor (K) below (after Orssengo and Pye, 1999):

$$K = \frac{IOPG}{IOPT} \qquad (1)$$

A plot of central corneal thickness versus correction factor (K), for an applied (true) intraocular pressure of 15 mmHg (2.5 kN/m^2) using a uniformly distributed load (to simulate the indentor) and a fully explicit model of the indentor is shown in Figure 2. This is compared with data from a review of the clinical literature produced by Doughty and Zaman (2000). This data represents the average correction of measured intraocular pressure from applanation tonometry required for healthy eyes with a 10% change in central corneal thickness. The shaded region shown in Figure 2, shows the data which represents the maximum and minimum corrections required. The results indicate that the finite element analysis shows a strong correlation to the clinical studies. In addition, the prediction where the indentor is modelled explicitly produces better results, which can be attributed to the effects of the linear interface between the cornea and indentor. Further improvements of the corneal model (e.g. nonlinear elasticity) would provide better correlation with the data.

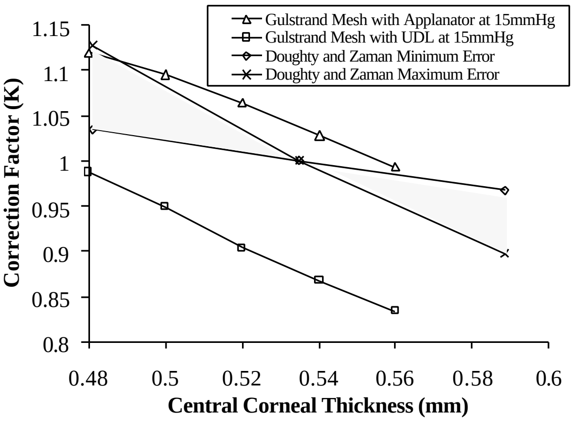

Figure 2 : Comparison of correction required to find true IOP from applanation tonometry for numerical and clinical data

SUMMARY

It has been shown that the biomechanics of the thin corneas can be represented reasonably accurately with a finite element models and compare favourably with clinical data. With further development this may provide a simple method of correcting tonometry readings for thin corneas to help improve clinical management of patients.

REFERENCES

Doughty, M.J. and Zaman, M.L., (2000) Human Corneal Thickness and Its Impact on Intraocular Pressure Measures. A Review and Meta-analysis Approach. *Surv Ophthalmol.* 44. 367-408.

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