PATIENT SPECIFIC FINITE ELEMENT ANALYSIS OF HUMAN CORNEAL LENTICULES: AN EXPERIMENTAL AND NUMERICAL STUDY

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Introduction

In recent years, the prevalence of myopia has increased, and projections suggest that it will affect more than half of the world's population by 2050 [1]. The number of elective refractive surgeries has also risen, estimated at a 30% yearly increase. The cornea's curvature shape is the primary determinant of ocular refraction; therefore, evaluation and quantification of its biomechanical properties is necessary for accurate refractive procedures. Because it is difficult to obtain human samples, few studies have characterized young human corneal tissue [2]. Lenticule extraction surgeries provide a source of young cornea samples. The purpose of this study is to mechanically test and numerically model human corneal lenticules obtained from CLEAR surgery patients and to improve material modeling using a physiological description of its microstructure.

Methods

Five corneal lenticules from four patients (27 y- 30 y) were included in the study and uniaxially tested within 24 hours of surgery (KEK approval 2021-00145). (Fig 1a). Using preoperative data and surgical parameters a finite element mesh of the lenticule was created using GMSH 4.0 and ABAQUS 2020. The Holzapfel Gasser Ogden (HGO) material model was used to describe the cornea as a fiber-reinforced material [3]. Additionally, the angular integration approach was used to model the isotropic in-plane and aligned out-of-plane dispersion of the fibers, allowing for a more accurate representation of the microstructure and mechanics of the cornea. A Bayesian optimization algorithm was also used to obtain the best fit between the experimental and numerical results by adjusting the mechanical parameters of the model. The optimization was performed for each patient individually (patient-specific) and simultaneously for all patients (general model).

Results

The force-displacement response under uniaxial loading showed a typical non-linear behavior for all samples. From the finite element analysis, the von mises stress is uniform in the central region but increases near the attachments, where the experimental failures were also found (Fig 1b). Optimization of the mechanical parameters resulted in a good agreement with the experimental data for both the general and patient-specific fits (Fig. 2). The optimal parameters for the general model are C_{10} = 24 kPa, k_1 = 4.98 MPa and k_2 = 40.34.

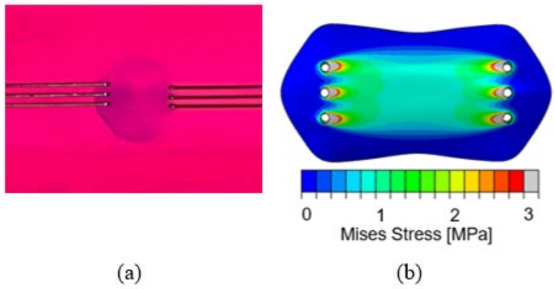

Figure 1(a): Experimental setup of uniaxial extension. (b) Von Mises stress at 10 % strain, on the finite element mesh of the lenticle under traction.

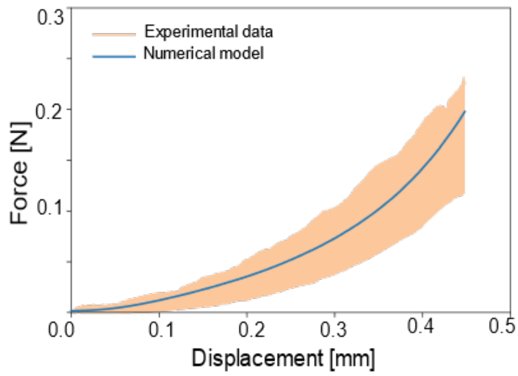

Figure 2: The numerical model with general fitting parameters (blue line) lies within the experimental range of the 5 patients (orange area)

Discussion

The study considers patient-specific geometry and physiologic fiber dispersion to estimate the hyperelastic behavior of human corneal stroma. The study demonstrates the small benefit of the patient-specific fitting over simultaneous parameter optimization. The results of the study can be used to improve the prediction of the mechanical behavior of the young cornea after refractive surgery. The stress-strain data obtained in this study are within the range of the literature [2]. One of the limitations of the study is that it includes only five lenticules from four patients with similar correction ranges, which does not represent the overall population.

References

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2. Liu T et al, J. MBBM, 2020.
3. Holzapfel G.A. et al, J Elasticity, 2000.

Acknowledgements

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