Poster Presentation
Track 20: Biomechanics of Organs

Abstract: 4378

Citation: Journal of Biomechanics 2006; Vol. 39 Suppl. 1, page S635

Biomechanical modeling of the pathogenesis of keratoconus

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Keratoconus is a disease characterized by corneal thinning and protrusion, which results in a conical appearance of the cornea causing blurred vision. Several biomechanical models of the cornea were previously developed, but none was employed for studying keratoconus. In this study, three-dimensional finite element (FE) simulations were conducted to analyze the biomechanical factors contributing to the conical shape of a keratoconic cornea. Models of keratoconic corneas were compared with a normal cornea model to evaluate the level of distortion from normal corneal deformation under ocular pressure (16 mmHg). We assumed orthotropic linear elastic tissue mechanical properties, and a decreased stiffness of the keratoconic cornea, expressed in both its meridian elastic and shear moduli. We also considered corneal thinning in keratoconus (apex thickness 0.5 and 0.2 mm in normal and keratoconic corneas, respectively). The FE analyses resulted in deformed corneal shapes as well as tissue strain and stress distributions. Since a deformed corneal shape may affect the quality of vision, we used a Matlab code to extract a Diopter power (calculated from the radii of curvature of the anterior and posterior deformed corneal surfaces) from each FE simulation case. Sensitivity analysis indicated that three important factors influence the pathogenesis of keratoconus: the meridian elastic modulus of the cornea, the shear modulus perpendicularly to the corneal surface, and corneal thickness. Specifically, as the meridian modulus and shear modulus of the cornea decrease owing to degradation of the normal collagen fibril structures, a conical shape of the cornea emerges which distorts vision and rise Diopter power. Corneal thinning was shown to be associated with shifting of the corneal apex, which further exacerbates the condition. If thinning occurs locally, then shift of the apex occurs at the reduced thickness location, which is typically inferior and medial to the cornea center. The present FE studies allowed characterization of the biomechanical interactions in keratoconus, toward understanding the aetiology of this poorly studied malady.