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Assessing biomechanics of aqueous veins and perilimbal sclera in crosslinked porcine globes using multiwavelength photoacoustic imaging

Guan Xu; John Riesterer; Linyu Ni; Erik Krawczyk; Wonsuk Kim; Huaizhou Wang; Sayoko Eileen Moroi; Alan Argento

+ Author Affiliations & Notes

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Abstract

Purpose : The inability to predict the outcome of micro-invasive glaucoma surgeries (MIGS) on lowering intraocular pressure (IOP) is a critical barrier to providing safe and effective interventions for patients. To address this critical barrier, our goal is to advance knowledge on the dynamic mechanisms of the distal aqueous humor drainage in the aqueous veins in the perilimbal sclera. We have developed an optical resolution photoacoustic (PA) microscopy system for resolving the deformation of aqueous veins and perilimbal sclera in porcine and human eyes in three dimensions (3D) as a function of IOP. In this study, we will induce variations of the biomechanical properties in whole eye globes by crosslinking and examine the performance of our methods.

Methods : Whole porcine eyes were treated with 5% genipin for crosslinking. During the imaging experiment, the globes were first pre-conditioned to a physiological state, then perfused at a constant flow rate with 0.25% indocyanine green (ICG) to steadily increase the IOP under continuous monitoring. PA images were taken at 5 mmHg IOP intervals at 790 and 1200 nm wavelengths, targeting the ICG-perfused aqueous veins and collagen-rich perilimbal sclera, respectively. The displacement of the spatial features within the tissue components were tracked throughout the image series. Strain fields in each tissue components were calculated using a finite element analysis (FEA) method.

Results : The biomechanical tensile tests on perilimbal tissue samples determined that the genipin crosslinking procedure results in moderately altered tissue stiffness (tangent modulus) and viscoelastic relaxation times. Results from preliminary whole globe experiments show strain gradients at the vein-sclera interface in untreated whole globes. Studies are ongoing to examine the performance of the PA and strain analysis methods to discern biomechanical differences in the observed tissue components of the untreated and crosslinked globes.

Conclusions : PA imaging combined with data driven FEA will advance understanding of the tissue biomechanics of the complex aqueous veins-perilimbal scleral system and role in IOP regulation. Advancing this knowledge on biomechanics and aqueous humor dynamics will enable clinicians to improve MIGS outcomes by choosing the appropriate surgery for a given patient based on characteristics of the distal outflow system.

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