Photoacoustic imaging and finite element strain analysis as novel tools for assessing the roles of aqueous veins and perilimbal sclera in intraocular pressure regulation

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Background and Objective

There has been growth in the micro-invasive glaucoma surgeries (MIGS) to manage glaucoma by lowering intraocular pressure (IOP). The inability to predict the outcome of MIGS is a critical barrier to providing safe and effective interventions for patients. To address this critical barrier, our purpose is to advance knowledge on the aqueous humor dynamic mechanisms of the distal drainage in the aqueous veins in the perilimbal sclera. We developed an imaging technology to visualize the aqueous veins and perilimbal sclera in three dimension (3D) that will assist in understanding the biomechanical behaviors of the tissue components and their roles in IOP regulation.

Methods

Photoacoustic (PA) imaging generates acoustic signals from tissue components using their characteristic optical absorption spectra [Fig. 1(a)]. Combining high optical sensitivity and deep acoustic penetration, PA imaging is an ideal tool for visualizing the tissue components in the anterior segment of the eye. We developed an optical resolution multiwavelength PA microscopy (PAM) system. The system was examined in a porcine eye with its aqueous veins perfused with indocyanine green. The displacement of the spatial features within the tissue components in the porcine eyes were tracked during change of IOP. A finite element analysis (FEA) method was developed that computed strain fields from the displacement data.

Results/Discussion

As shown in Fig. 1, the system has demonstrated the ability to resolve the 3D architecture of the aqueous veins and the texture of the sclera containing collagen and lipid components. Preliminary results in Fig. 2 show the capability of the imaging system in quantifying the strains field in aqueous veins as a function of IOP.

Conclusion

PAM combined with FEA is a potential tool to advance the understanding of the biomechanical behaviors of the complex aqueous veins-perilimbal scleral system in IOP regulation. Studies are ongoing to establish the relationship between vein strains, IOP, depth and size. 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 the distal outflow system.

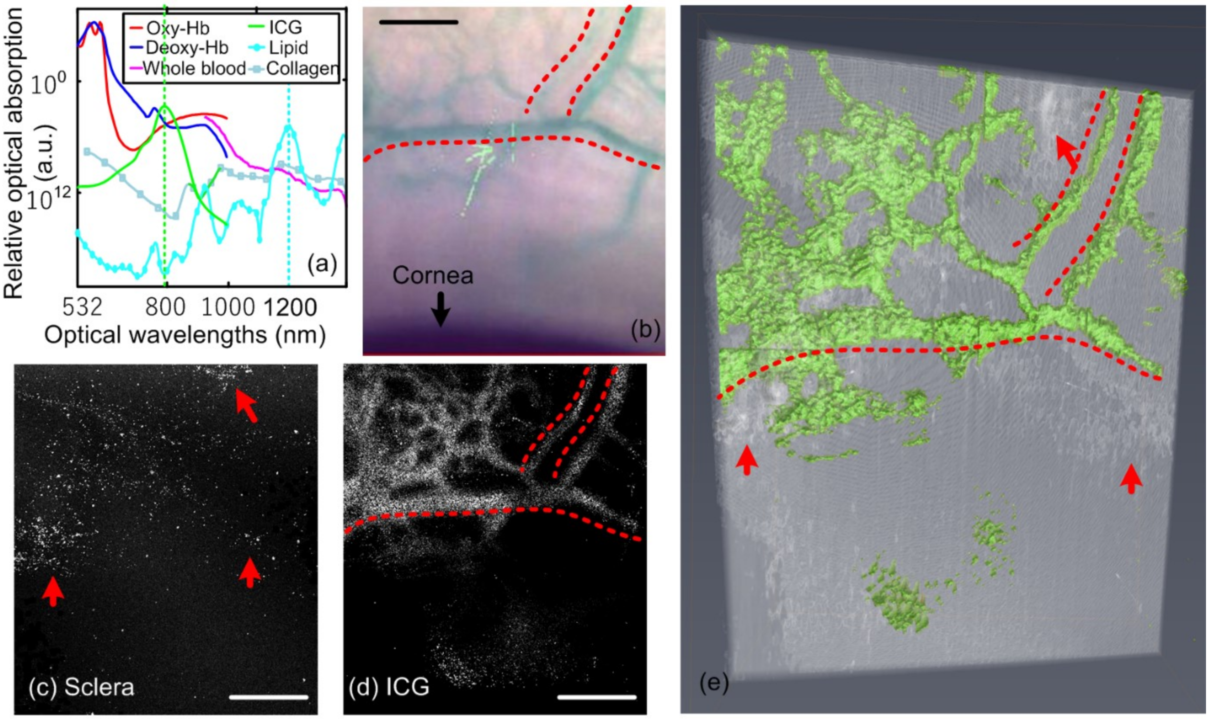

Fig. 1 Resolving aqueous veins and the surrounding scleral tissue using optical contrast enhancement by ICG and PAM. (a) Relative optical absorption spectra of relevant tissue components. (b) Picture of perilimbal scleral tissue in the nasal area of an eye perfused with 5% ICG. (c-d) PA images of scleral tissues and aqueous veins taken at 1200 nm and 790 nm, respectively. (e) Pseudocolor image co-registering (c) and (d) in 3D with aqueous veins in green and sclera in white/gray. Scale bars are 500 μm. The red dashed lines mark the same vessels in (b)(d)(e). The red arrows mark the spatial/texture features within the sclera in (c)(e).

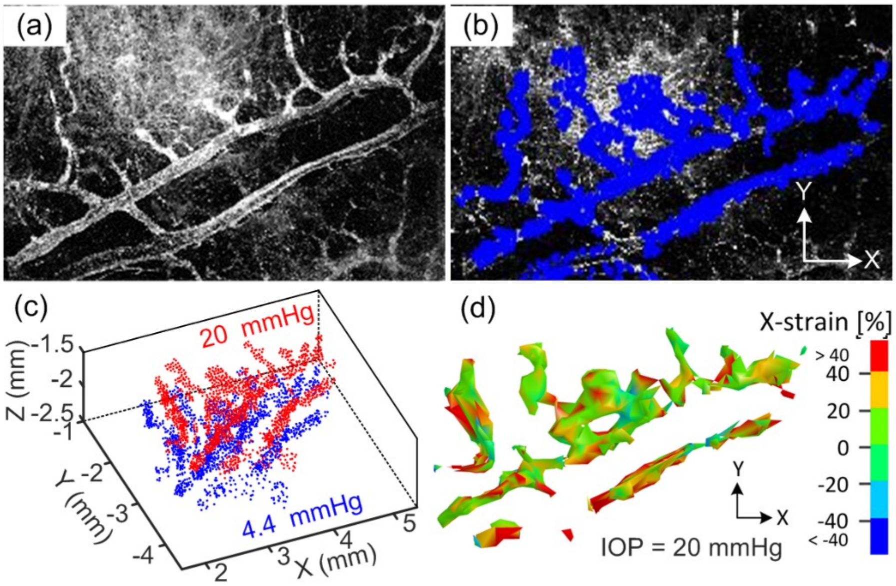

Fig. 2 PAI-FEA of aqueous veins. X and Y are along the azimuthal directions of the globe; Z is the radial direction. (a) PA images. (b) Tracked points marked on the PA images. (c, h) Tracked points at the beginning (blue) and the end (red) of one perfusion cycle. (e) Strain maps calculated by LS-DYNA overplayed on the finite element meshes at the end of the perfusion (i.e. red points).