Larger lamina cribrosa depth is associated with larger lamina cribrosa shear deformation during IOP elevation

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Purpose

Lamina cribrosa (LC) depth is a key anatomical feature implicated in the pathophysiology of glaucoma. Although LC depth has shown promise as a structural biomarker for glaucoma, the mechanistic detail remains unclear. We investigated the relationship between LC depth and LC and peripapillary sclera (PPS) deformation during intraocular pressure (IOP) elevation using a human donor eye model.

Methods

Human donor globes (N=21) were imaged using a 50MHz ultrasound probe (Vevo2100). A 3D volume (9.7 × 9.7 × 5 mm) centered at the optic nerve head (ONH) was imaged when IOP was raised from 15 to 30 mmHg at 2-5 mmHg steps. Radial frames were reconstructed, and the Bruch's membrane opening (BMO), PPS and LC surfaces were manually marked using a custom software (Multiview, Fig. 1). LC depth was measured as the distance from LC anterior surface to the BMO line in each radial frame. 3D displacement fields were calculated using a correlation-based speckle tracking algorithm. PPS and LC radial (ε_{rr}), meridional ($\varepsilon_{\varphi\varphi}$), circumferential ($\varepsilon_{\theta\theta}$), and shear ($\varepsilon_{\varphi r}$, $\varepsilon_{\theta r}$, and $\varepsilon_{\theta\varphi}$) strains were calculated. Strains in PPS/ONH conjunction (a 100 μm area over the nerve boundary) were also calculated.

Results

LC depth was significantly correlated with LC shear strains $\varepsilon_{\varphi r}$ (R=0.453, P=0.039), $\varepsilon_{\theta r}$ (R=0.463, P=0.035), and $\varepsilon_{\theta\varphi}$ (R=0.424, P=0.055), conjunction shear strains $\varepsilon_{\varphi r}$ (R=0.446, P=0.043), $\varepsilon_{\theta r}$ (R=0.479, P=0.028), and $\varepsilon_{\theta\varphi}$ (R=0.570, P=0.007, Fig. 2), and PPS meridional strain $\varepsilon_{\varphi\varphi}$ (R=0.473, P=0.030). Other strains were not significantly correlated with LC depth.

Conclusions

Our results showed that a larger LC depth was associated with larger shear deformation in LC and the PPS/ONH conjunction area. Presumably, excessive shear deformation could contribute to optic nerve damage. This finding provides evidence to the structure-function relationship of LC depth and posterior eye biomechanics, supporting its potential clinical use as a biomarker for glaucoma progression.