A Significant Advance in the Biomechanical Evaluation of the Optic Nerve Head

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Glaucoma is characterized by damage to the retinal ganglion cell axons and remodeling of the surrounding connective tissues of the lamina cribrosa (LC) in the optic nerve head (ONH). It has been established that intraocular pressure (IOP) plays an important role in the development of glaucomatous neuropathy. Higher IOP is associated with an increased prevalence, while lowering IOP slows the progression of the disease. From a biomechanics perspective, IOP is a mechanical load that generates stress and strain in the tissues of the ONH. The level and state of stress and strain (i.e., shear, tension, compression) depend on the mechanical behavior of the LC and surrounding sclera. In recent years, a number of groups have made significant advances in mechanical characterization of the posterior sclera. However, mechanical characterization of the LC remains elusive, because of its small size and inaccessibility to most in situ imaging techniques. Biomechanics studies of the LC have relied mainly on static histomorphometry, indirect, or tissue-level anatomical measurements.

Sigal and coworkers have developed an innovative method that uses second harmonic generation microscopy and finite element analysis-based digital image correlation to provide the highest resolution and most direct in vitro measurement to date of the LC response to IOP. In their study, unfixed whole human eyes were cannulated and placed in a laser scanning microscope. The optic nerve was cut flush to the sclera to expose the LC, and a volume slightly wider than the scleral canal and 600 µm deep was imaged at two different pressures. Digital image correlation was used to register two-dimensional (2D) anterior–posterior projections of the scans at two different pressures to calculate displacements and strains at the level of the LC beams. The results showed local regions of high in-plane compressive, tensile, and shear strains. Though the 2D projection may have produced artifacts in the strain calculation, it is likely that these regions do exist. Further work is needed to extend the method to 3D deformation analysis, but these and similar emerging developments in imaging and digital image correlation techniques open new opportunities for studying the mechanobiologic effects of IOP, structure-function of the LC, and age- and disease-induced tissue remodeling in the pathophysiology of glaucomatous optic neuropathy.

References