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Towards a poroelastic model for the mechanics of the Lamina Cribrosa

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Abstract

Glaucoma is well known to be a chronic pathology that plays a key role in the global incidence of blindness. Its onset and progression are strictly related to the loss of retinal ganglion cell (RGC) axon bundles, which constitute the optic nerve head (ONH) and transmit visual information from the retina to the brain. Evidence suggests that a major site of damage in glaucoma is the Lamina Cribrosa (LC), a porous structure of collagen beams, blood, and interstitial fluid, where RGC axons converge to form the ONH. Damage to the LC can arise from both biomechanical insults and hemodynamic anomalies. This work, derived from [1], investigates the combined action of biomechanical and hemodynamic effects on LC, an aspect that is largely neglected in the literature. The lamina is modeled as a Reissner–Mindlin poroelastic plate to analyze the influence of intraocular pressure (IOP) variations and the correlation between mechanical response and blood flow changes. The LC is described here as a transversely isotropic cylinder with a central hole and circumferential symmetry. The equilibrium equations of a poroelastic Mindlin plate are derived assuming Biot poroelasticity and a displacement field consistent with the adopted plate kinematics. Closed-form solutions are obtained and specialized to boundary conditions drawn from the literature and biomechanical observations. Mechanically, stresses and strains increase with IOP, with peaks at the LC periphery, where RGC axons are first observed to be damaged. Hemodynamically, the model predicts that increasing IOP induces a monotonic decrease in blood content, potentially leading to tissue malnutrition. The present analysis also allows for estimating the stiffness of the opening for the central retinal vessels, a quantity difficult to measure experimentally, by relating it to the LC deviatoric strain. Furthermore, comparison with an equivalent isotropic model shows that isotropy overestimates shear strain and blood content. The proposed poroelastic framework thus provides a tool to study the coupling between biomechanics and hemodynamics while overcoming limitations of in-vivo blood flow measurements.

Keywords:

Lamina cribrosa Poroelasticity Anisotropy Hemodynamics

References:

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