Finite element modeling of the human sclera: influence on ONH biomechanics and connections with glaucoma

Abstract:
Scleral thickness, especially near the optic nerve head (ONH), is a potential factor of interest in the development of glaucomatous optic neuropathy. Large differences in the dimensions of the sclera, the principal load-bearing tissue of the eye, have been observed between individuals. This study aimed to characterize the effects of these differences on ONH biomechanics. Eleven enucleated human globes (7 normal and 4 ostensibly glaucomatous) were imaged using high-field microMRI and segmented to produce 3-D individual-specific corneoscleral shells. An identical, idealized ONH geometry was inserted into each shell. Finite element modeling predicted the effects of pressurizing the eyes to an IOP of 30 mmHg, with the results used to characterize the effect of inter-individual differences in scleral dimensions on the biomechanics of the ONH. Measurements of the individual-specific corneoscleral shells were used to construct a 2-D axisymmetric idealized model of the corneoscleral shell and ONH. A sensitivity analysis based on this model quantified the relative importance of different geometrical
characteristics of the scleral shell on the biomechanics of the ONH. Significant variations were observed in various measures of strain in the idealized lamina cribrosa (LC) across the seven normal corneoscleral shells, implying large differences in individual biomechanics due to scleral anatomy variations alone. The sensitivity analysis revealed that scleral thickness adjacent to the ONH was responsible for the vast majority of variation. Remarkably, varying peripapillary scleral thickness over the physiologically measured range changed the peak (95th percentile) first principal strain in the LC and radial displacement of the ONH canal by an amount that was equivalent to a change in IOP of 15 mmHg. Inter-individual variations in scleral thickness, particularly peripapillary scleral thickness, can result in vastly different biomechanical responses to IOP. These differences may be significant for understanding the interactions between IOP and scleral biomechanics in the pathogenesis of glaucomatous optic neuropathy. The relationship between scleral thickness and material properties needs to be studied in human eyes.

Stichworte: sclera, glaucoma, biomechanics, optic nerve head, lamina cribrosa, intraocular pressure

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