

Author Response: Peripapillary Suprachoroidal Cavitation, Parapapillary Gamma Zone and Optic Disc Rotation Due to the Biomechanics of the Optic Nerve Dura Mater

We thank Jonas and colleagues¹ for their interest in our recent paper.²

We agree with the assertion from Jonas and colleagues¹ that the biomechanics of the optic nerve dura mater, especially during eye movements, may have strong implications for various structural changes observed in highly myopic eyes.

For instance, our models may be able to provide explanations about the optic disc rotation around the vertical axis (axis along the superior-inferior direction³) observed in highly myopic eyes. Specifically, in adduction, our models predicted posterior displacements of temporal peripapillary tissues and anterior displacement of nasal peripapillary tissues (Fig.), but overall larger stretching of temporal tissues. This displacement direction was reversed in abduction (Fig.). Of note, adduction was shown to induce larger deformations of the optic nerve head tissues than abduction in our models. However, it is not yet known whether rapid, phasic eye movements in adduction (during lateral eye movements) could have a different effect on the optic nerve head than sustained, tonic muscle constriction of the same medial recti muscles. Thus, it may well be possible that sustained constriction of the medial recti in convergence, during prolonged near-reading in myopes, could add to the optic nerve stress. Kim et al.⁴ have demonstrated that a tilted optic disc in high myopia is an acquired feature. A tilted optic disc may be explained by the continuous stretching of the peripapillary region during eye movements, although this concept still needs to be proven.

In highly myopic eyes, peripapillary intrachoroidal cavitations have a prevalence of approximately 17%.⁵ Although our models did not include the choroid layer, they predicted large tensile stresses (first-principal stress) within the scleral flange and the peripapillary sclera during eye movements (Fig. B, E). These stresses may be transmitted to the choroid and cause peripapillary intrachoroidal cavitation, as shown previously.⁵

Jonas et al.⁶ also suggested that the presence of parapapillary regions without Bruch's membrane or parapapillary gamma zones was correlated with high myopia. Bruch's membrane was not included in our models. However, our models predicted large stress around the scleral canal during eye movements (Fig. B, E), which might cause shearing between Bruch's membrane and the peripapillary sclera or even damage of Bruch's membrane itself and thus account for the parapapillary gamma zone.

It is worth noting that, because of eye elongation in high myopia, the distance between the orbital apex and the optic nerve head is shorter in myopic eyes than in normal eyes. Therefore, the optic nerve is likely to have more "slack" in highly myopic eyes than in normal eyes in primary gaze position.⁷ However, for the same amount of eye rotation, the optic nerve head needs to be displaced more in an elongated eye than that in a normal eye, which may easily exhaust the redundancy of "slack" in a myopic eye and cause tethering of the sclera. In other words, because of this change in loading scenario, myopic eyes may be more prone to develop tilted discs and parapapillary gamma zones. It is also interesting to observe that optic nerve head pulling (during eye movements)

may contribute in part to eye elongation in myopia (through tissue remodeling) and to the creation of staphylomas (often acquired around the optic nerve head). However, there is currently no evidence for this hypothesis, and further studies are needed to explore a possible link between eye movements and axial elongation.

It is also worth noting that the peripapillary sclera shows regional variations in stiffness⁸ and thickness.⁹ How these variations would influence the biomechanics of the peripapillary tissues during eye movement has yet to be investigated.

Finally, our models predicted that the stretching of the peripapillary tissues was highly influenced by the stiffness of the dura. However, data for the properties of optic nerve dura are scarce. For example, the mechanical properties of human optic nerve dura were not as well understood as the dura of brain and spinal cord. Raspanti et al.¹⁰ suggested that the microstructures of the optic nerve sheath are different from other brain meninges, thus their mechanical properties should be different. In our paper, we measured the material properties of porcine optic nerve dura through uniaxial tension testing. Recently, Ethier et al.¹¹ also studied the mechanical properties and microstructures of porcine optic nerve sheath.¹¹ Clearly, more studies need to be done in the future for an improved understanding of the optic nerve dura, especially for human samples.

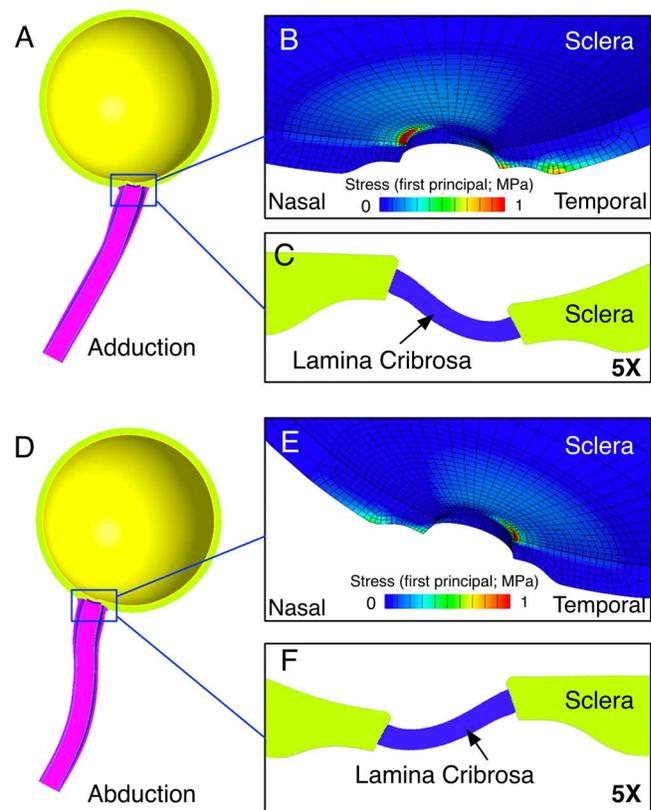


FIGURE. Deformations of the sclera for an eye rotation of 13° in both adduction (A-C) and abduction (D-F). Tensile stresses (first-principal stress) were large within the scleral flange, peripapillary sclera and around the scleral opening. Note that the deformations in C and F were exaggerated five times ($5\times$) for illustration purposes.

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Citation: *Invest Ophthalmol Vis Sci.* 2016;57:4374-4375.
 doi:10.1167/iovs.16-20118