Analysis of IOP and CSF alterations on ocular biomechanics and lamina hemodynamics

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Purpose

Optic neuropathies such as normal-tension glaucoma(NTG) may be caused by pathogenic translaminar pressure difference(TLPd). This mechanistically may lead to an improper perfusion of lamina cribrosa(LC) and alter the natural biomechanics of the eye. LC perfusion parameters are difficult to estimate with non-invasive measurements and the interaction between hemodynamics and biomechanics is affected by many factors that cannot be easily isolated. We employ a mathematical virtual simulator(MVS) to disentangle biomechanical and hemodynamical factors, in particular the system response to intraocular pressure(IOP) and retrolaminar tissue pressure(RLTp) alterations.

Methods

The MVS(Fig. 1b) combines i) a three-dimensional porous-media model for LC perfusion with ii) a circuit-based model for blood flow in retrobulbar and ocular posterior segments and iii) a three-dimensional elastic model to simulate the biomechanics of LC, retina, choroid, sclera and cornea. Systems i), ii) and iii) are solved using advanced computational and visualization methods (*Feel++*, *OpenModelica*). We simulate 5 different virtual situations: baseline(IOP=15,RLTp=7,TLPd=8 [mmHg]), patient1(P1,IOP=11,RLTp=10,TLPd=1 [mmHg]), patient2(P2,IOP=17,RLTp=10,TLPd=7 [mmHg]), patient3(P3,IOP=17,RLTp=3,TLPd=14 [mmHg]) and patient4(P4,IOP=11,RLTp=3,TLPd=8 [mmHg]).

Results

Baseline, P2 and P4 have similar TLPd, however Fig. 1c shows a difference up to 10% in LC perfusion. Fig. 1a displays a 1.4% discrepancy in the blood pressure gradient, whereas Fig. 2 exhibits analogous LC displacements for these three cases. Thus, MVS suggests that this difference may be primarily due to hemodynamical factors. RLTp variations do not seem to have notable effects on the velocity of central retinal artery(CRA) and the central retinal vein(CRV) both pre- and post-lamina(Fig. 1d-e), whereas small fluctuations occur in the CRV velocity due to higher IOP(P2,P3).

Conclusions

In the context of glaucoma, particularly NTG, the proposed MVS multi-scale approach may be employed to single out hemodynamic and/or biomechanical mechanisms involved in the pathophysiology of ocular disease. This innovation may also allow for novel findings in IOP regulation and RLTp effects in central retinal vein occlusion.

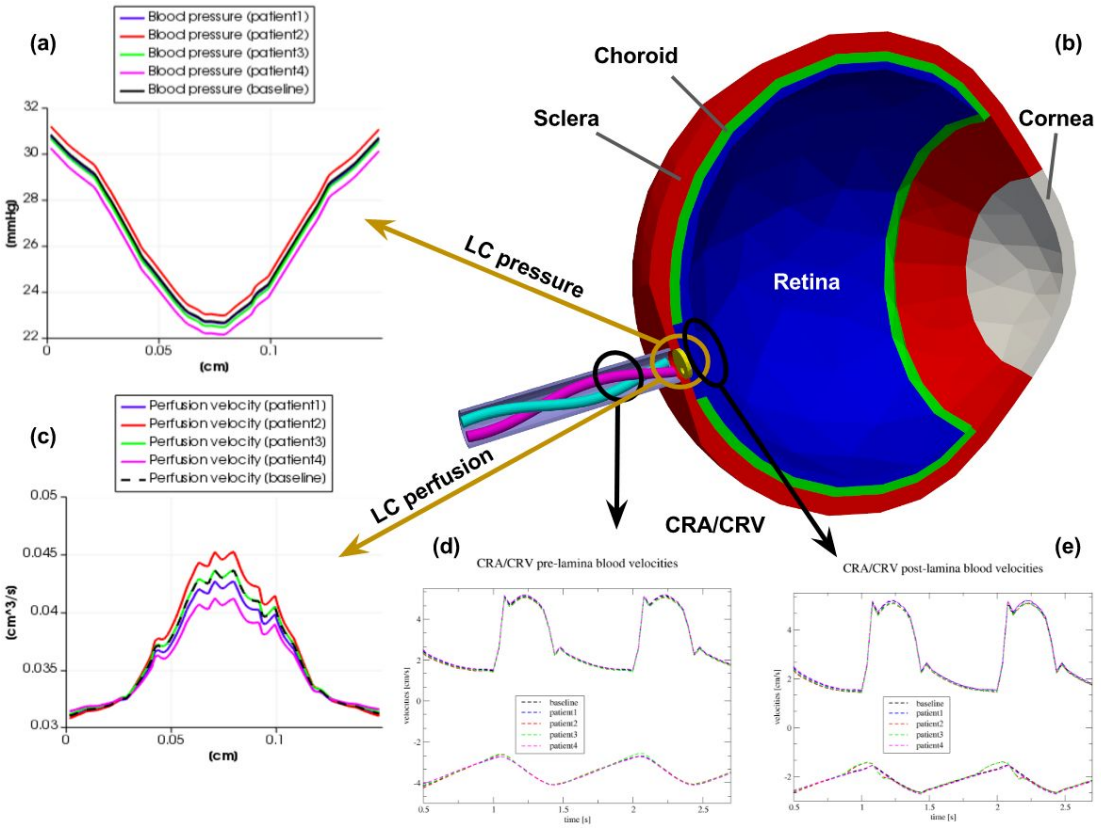

Fig 1: MVS overview and hemodynamics simulated results within LC and CRA/CRV

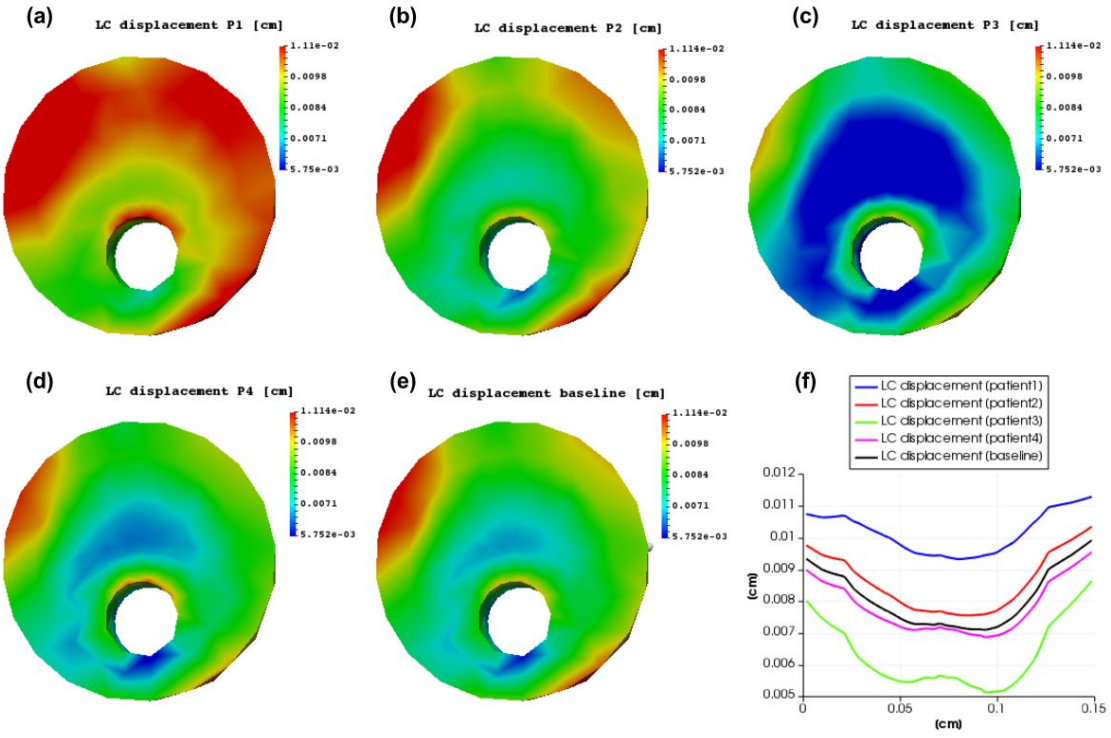

Fig. 2: Zoom on LC displacement simulated via MVS

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LAYMAN ABSTRACT:

Normal tension glaucoma (NTG) is a form of primary open angle glaucoma in which there is no significant elevation of intraocular pressure. Medical studies have not yet been able to identify modifiable risk factors for NTG before vision loss becomes advanced and irreversible.

Starting from clinical measurements (such as blood pressure, intraocular pressure, cerebrospinal fluid pressure), our proposed mathematical virtual model can simulate patient-specific situations and may predict unphysiological behaviors.

Thanks to the hemodynamical and biomechanical three-dimensional virtual images and the computation of key values provided by our simulator, a new set of clinical informations is available to doctors for a more suitable diagnosis.