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Biomechanical modeling of macular hole formation and development

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Abstract

Purpose : A macular hole (MH) is a pathological full thickness retinal defect in the macular region (MR). Interestingly, a MH always possesses a circular shape in the retinal plane. Present assumptions on MH etiology refer to tangential or anterior-posterior tensile forces at the foveal region. Using biomechanical models, we investigated the impact of biomechanical factors in macular region on the MH formation and its circular shape.

Methods : 2D- and 3D-finite-element models of MR were developed based on optical coherence tomography (OCT) volume scans of a healthy eye. The models consist of two elastic layers: the internal limiting membrane (ILM: E=0.147MPa) and the retina (E=0.431MPa). Both materials were modeled as linearly elastic and incompressible. In the ILM in MR a small ellipsoidal slit was constructed as a precursor to a macular hole. In the 3D model, the axial ratio (minor *d* /major axis *b, see Figure*) of the initial constructed slit was determined assuming physiological intraocular pressure (IOP) range. In the 2D model, tangential and anterior-posterior tensile forces were applied to the intact ILM at specific angular vitreal attachments (shearing angle ranged 0°-90°). Maximal principal strains were computed, which are likely candidates of causing failure in the tissue and thus MH formation.

Results : Under physiological IOP-conditions, the 2D model of MR without an initial slit shows high strains exactly in the area, where the MH formation is observed clinically. Using the 3D model further simulations under the same conditions show that an initial slit turns into an oval shape with a tendency to become round. When additional forces were considered in the attachment region of the vitreous it was observed that maximal principal strains in MR become larger with smaller shearing angle under predominant tangential forces. Tangential forces become greater than tensile forces hence being potentially riskier for MH progression.

Conclusions : The IOP as single factor is not alone responsible for the circular formation of a MH from an initial slit. However, forces, especially tangential ones, transferred by the detaching vitreous result in high principal strains in MR. This aspect in combination with weakened tissue might lead to MH formation. Biomechanical modelling can be a useful tool for the investigation of MH etiology as well for the early MH diagnostics and the prediction of its progression.

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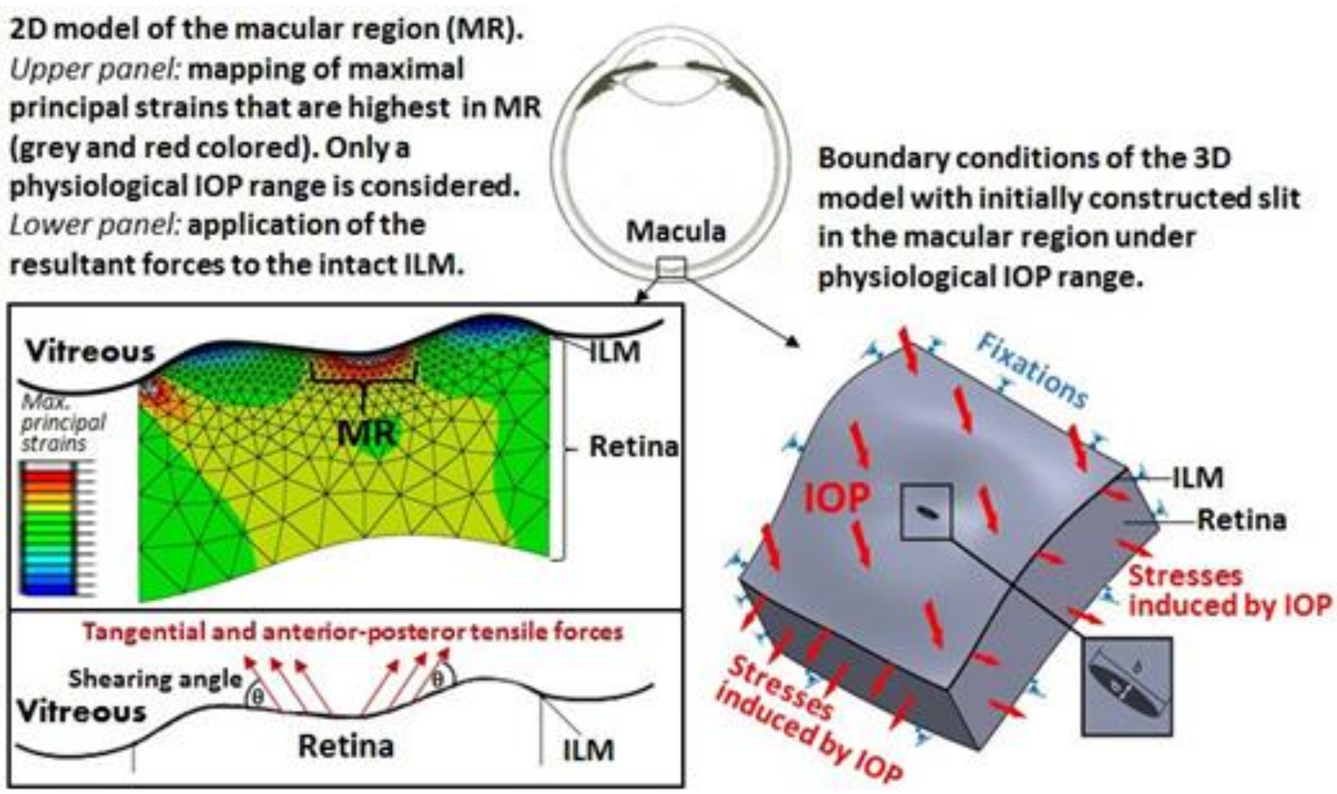

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