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Micromechanical model of the retina to simulate subretinal injection surgery

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Abstract

Hereditary retinal diseases represent a significant cause of blindness among working-age adults (Ben-Yosef, 2022). The optimal treatment option is gene therapy delivered by subretinal injection (Xue et al., 2017). To evaluate the relevance of different aspects of surgery on rupture and detachment of the retina, we developed a finite element model of the retina. Our study adopts an innovative approach for modelling the retina, moving apart from the conventional continuum assumptions. We regard the tissue as the assembly of truss and membrane structural elements, comprising three layers: (i) a membrane discretised into triangular elements, mimicking the retinal pigmented epithelium layer; (ii) an intermediate layer consisting in vertical truss elements, representative of the cells, such as cones, rods and Muller cells, stemming out of the retinal surface; and (iii) a top network of trusses linking the top of the cells, with the function of an internal limiting membrane. We generate the geometrical models of the retina with a Matlab code developed ad hoc, while numerical analyses are conducted with Abaqus. We obtained the elastic parameters of the structural elements from experimental data conducted in our laboratory on porcine retinas: uniaxial tensile test and small punch test. Due to their similarities with human eyes and their high availability. porcine eyes are widely considered the optimal animal model for human ocular

mechanics (McCall et al. 2024). Models of the retina accounting for the microstructure of the tissue have been used to simulate our laboratory tests, demonstrating the ability of the approach to capture mechanical behaviours, difficult to capture with continuum models (Pandolfi et al., 2024). As specific application of the model, in this study we characterize the time-dependent behaviour of the retinal tissue. In the current literature, where the retina is typically modelled as a purely elastic tissue, its time-dependent behaviour has not been yet fully characterized. We describe the calibration of viscoelastic parameters of the microstructural model of the retina, using data from stress-relaxation tests conducted in our lab on a large set of porcine retinas. All structural elements of the retina model are thus described with viscous-elastic constitutive laws. The elastic parts are modelled as Neo-Hookean, while the time-dependent behaviours are modelled through Prony series. The calibrated model will be in the next future used to simulate a subretinal injection surgery, to assess the influence on the retina and the relevance of various surgical parameters such as injection rate, absorption time, and injection volume.

Keywords:

Retina Micromechanical model Subretinal injection