What happens inside the eye: fluid forces under physiologic movements

The vitreous is a gel-like structure that completely fills the posterior part of the eye. Doctors inject drugs directly inside the vitreous to cure sight-threatening diseases like age-related macular degeneration. These are relatively new therapies; few is known on the distribution of the molecules once injected inside the vitreous. In our studies, we used a new approach to understand this behavior. We have set up a computer-based simulation of the eye. We designed a virtual 3D environment that recreates the same condition of a human eye during everyday activities, highlighting particularly the impact of the physiological movements on the peculiar dynamic mechanisms of the vitreous body.

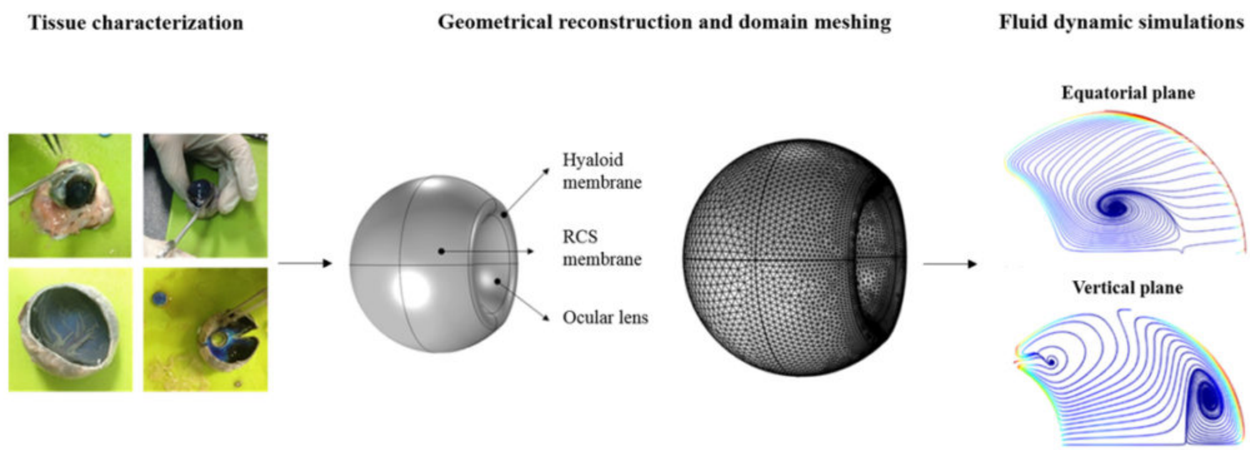

Fig. 1. Outline of the study: tissue characterization (i), development of the computational model based on the finite element method (ii) and fluid dynamic simulations (iii).

The combined modelling method links the outcomes of in-vitro approaches for the evaluation of the behavior of the surrounding ocular tissues to computational fluid dynamics based on the finite element method (Fig. 1). The last element is related to the mathematical implementation of the physiological movements of the eye, called saccades, which are able to completely mix the vitreous in an uncontrollable and involuntary way. The finite element method discretizes the entire vitreous body in very small elements and the velocity of the vitreous is calculated for each of them and then properly summed for all elements of the entire geometry. The in-vitro method is an ad-hoc developed setup that forces fluid flow through ocular tissue samples to be tested in terms of fluid permeation, directly connected to their porous features. Tissue characterization is mandatory for the best modelling implementation, particularly in the new and fascinating world of the eye, which is wrongly considered as a closed chamber despite its highly vascularized network. Because of the difficulty to obtain information about the interaction between the moving fluid and the ocular layers when delivering drug molecules injected inside the eye, we developed a numerical model reproducing our physiological experiences in everyday life.

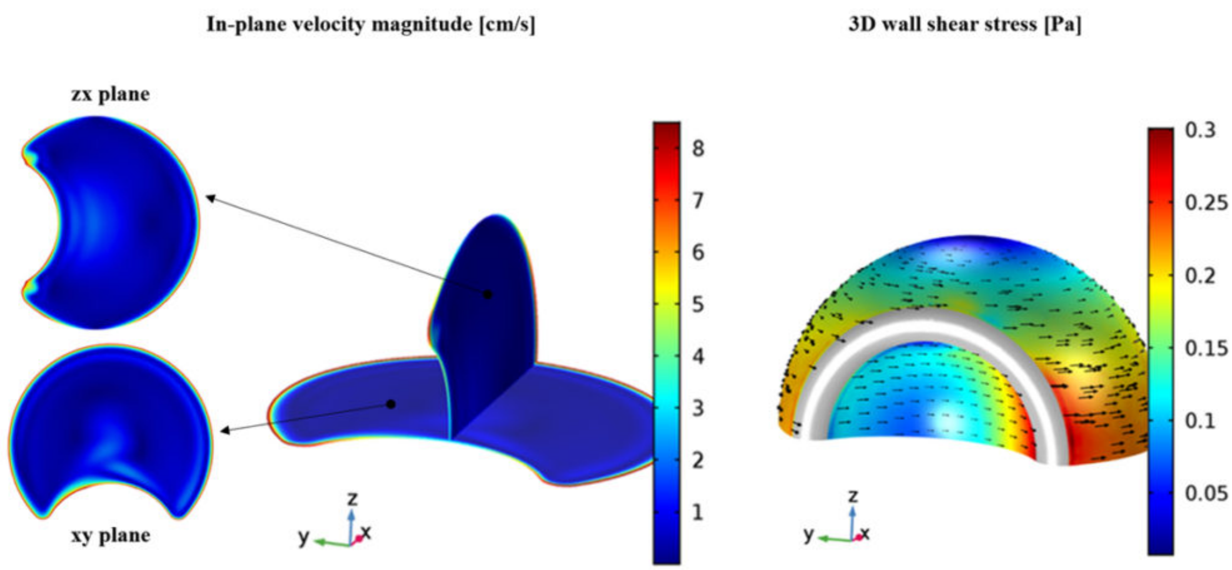

Fig. 2. 3D view of the computational results: in-plane (zx and xy) velocity magnitude (on the left) and fluid forces (wall shear stress) acting on retina and ocular lens (on the right).

The current fluid dynamic model is able to take into consideration the surrounding behavior (e.g., the hydraulic conditions of the anterior chamber, the venous pressure downstream the retinal-choroidal-scleral complex) and the saccadic movements due to the extraocular muscles, simultaneously. We demonstrated the significant role played by the saccades in determining the fluid dynamic mechanisms inside the vitreous chamber of the eye (Fig. 2). The area of higher fluid forces mainly localized nearby the lens was determined by our computational evaluation and it is correlated with the location of retinal breaks found with ultrasound examination. Our combined model clearly represents a powerful tool to investigate vitreous dynamics and its relation to several clinical issues. This is a new method that can clarify how drug molecules move and interact with the tissues in the eye after being injected, and reduce the need of experiments in living subjects, speeding up studies of new therapies for the eye.

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