Modeling the biomechanics of the human cornea

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The human eye is an optical system with the function of refracting the light rays onto the retina. The external spherical transparent portion of the eye (cornea) withstands the physiological intraocular pressure (IOP) exerted by the aqueous humor, a fluid filling the anterior chamber of the eye.

Refractive disorders such as myopia and presbyopia have been traditionally corrected with eyeglasses or contact lenses but, in the last two decades, surgical options that modify the shape of the cornea have been chosen increasingly. With the advanced current technology, refractive surgery has reached high success rates with good levels of customer satisfaction. Nonetheless, expectations of perfection are often unmatched because all eyes are treated in the same way and patient-specific features of the cornea are neglected.

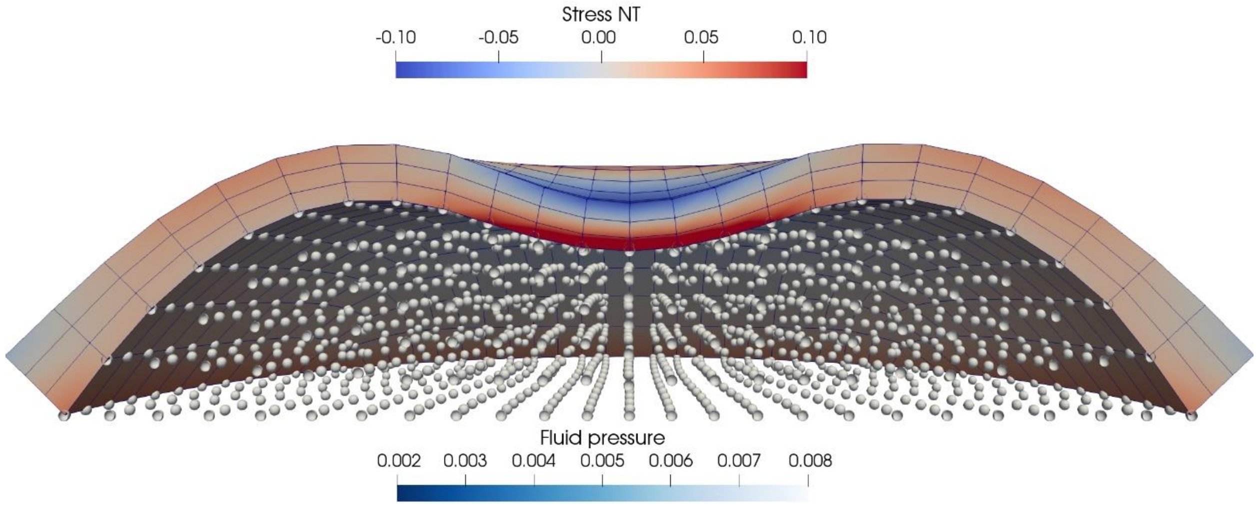
Modern diagnostic instruments for ophthalmology acquire the patent-specific geometry of the whole anterior eye. Yet, basic unknown parameters such as physiological IOP, unstressed geometries, and in-vivo material properties cannot be measured, therefore no predictive patient-specific model of the eye is available. The estimation of all unknowns requires the use of advanced identification procedures, based on the methods of computational mechanics and inverse analysis. The main difficulty is the definition of a diagnostic program that includes a variety of mechanical in-vivo tests sufficiently extended to allow the identification procedures to discern among tissues and material properties.

In this regard, the most promising in-vivo test is the contactless tonometry, commonly referred to as air puff test. The air puff test consists in a rapid air jet pulse applied to the anterior surface of the cornea, causing a fast and local change of the corneal curvature. Clearly, the response of the cornea is governed by the behavior of the solid tissue (cornea) and of the filling fluids, that interact during the test. In the recent literature, numerical analyses of the air puff test disregarded any aqueous-cornea interaction.

As an authentic novelty in computational ophthalmology, we have developed a fully three-dimensional model of the anterior chamber that couples solid and fluid. We discretize the cornea in finite elements, and use a 3D version of the meshfree Modified Finite Particle Method to discretize the aqueous, modelled as a Stokesian fluid. We demonstrate that, in order to calibrate the material properties and create patient-specific model, is fundamental to account for fluid-solid interaction.

Reference

Montanino A., Angelillo M., and Pandolfi A., "A 3D fluid-solid interaction model of the air puff test in the human cornea", J*ournal of the Mechanical Behavior of Biomedical Materials* 94 (2019) 22–31.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