3D FSI SIMULATION OF NON-CONTACT TONOMETRY TEST

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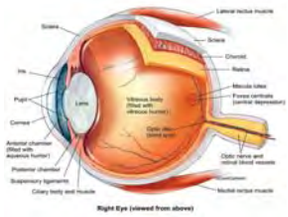
INTRODUCTION

The anatomy of the eye is very complex: it is a multi-layer structure and the mechanical properties are different from layer to layer.

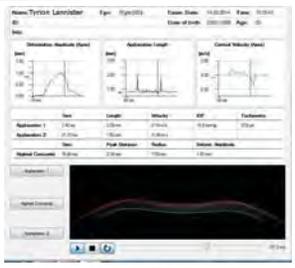


ANATOMY OF THE EYE [1]

Non-contact tonometry (NCT) is a non-invasive ophthalmologic test able to characterize corneal behaviour and intraocular pressure (IOP) in vivo. The test entails a corneal deformation by exerting a short violent air pulse of amplitude 5 to 8 times the physiological IOP in about 30 ms. The tonometer registers a number of dynamic mechanical markers, e.g. deformation amplitude of the cornea apex; markers that are related to the refractive surgery outcomes and to the certain pathologies such as keratoconus and glaucoma onset.

NON-CONTACT TONOMETER [2]

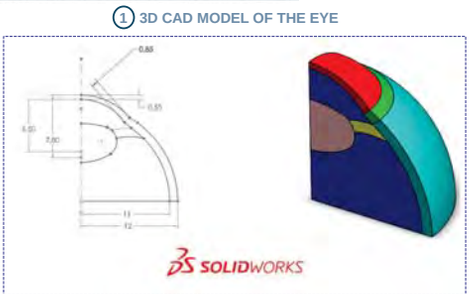
The **aim of this study** is to reproduce the NCT test with a 3D Fluid-Structure Interaction (FSI) simulation.



MECHANICAL MARKERS MEASURED [3]

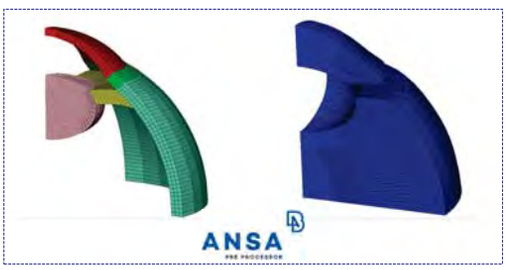
MATERIAL AND METHODS

1 3D CAD MODEL OF THE EYE



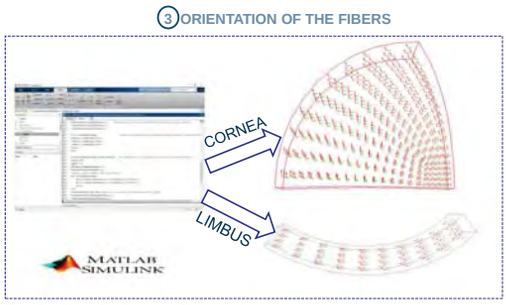
The geometry and the 3D model of an average human eye was built in SOLIDWORS (Dassault System) following the Gullstrand's eye model. The model comprises a non-uniform thickness cornea and a uniform thickness sclera, linked by the limbo. Interior structures are: the ciliary muscle, that smoothly connects the sclera to the lens, the lens and the two humors.

2 SOLID MESH



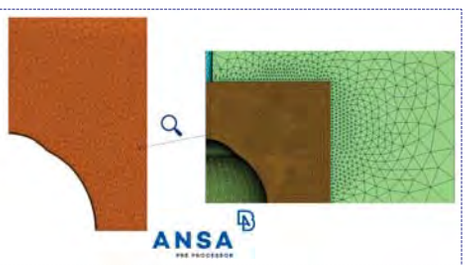
The Hexa-block technique in ANSA (Beta CAE) was used to obtain a high-quality mapped hexahedral mesh for the structure of the eye.

3 ORIENTATION OF THE FIBERS



Two families of orthogonal fibers in the cornea (one along the nasal-temporal direction and one along the superior-inferior direction), and one in the limbus (along the circumferential direction) according to the results reported in [4] were added in the model with a MATLAB (MathWorks) code.

4 AIR DOMAIN



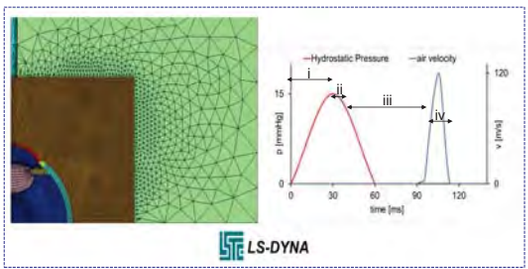
The air domain was discretized with a tetrahedral mesh in ANSA (Beta CAE). An adaptive meshing algorithm implemented within the solver LS-DYNA (LSTC) was used to obtain tetrahedral elements with 5 boundary layers near the interface with the eye.

5 MATERIAL MODEL

Cornea	Hyperelastic matrix with 2 families of fibers in superior-inferior (SI) and the nasal-temporal (NT) meridians [3,5]
Limbo	Hyperelastic matrix with 1 family of fibers in circumferential direction [3,5]
Sclera	Polynomial hyperelastic model (Yeoh) [3]
Ciliary Muscle	Linear Elastic model [3]
Lens	Linear Elastic model [3]
Humors	Newtonian incompressible fluid [3]
Air	Newtonian incompressible fluid [3]

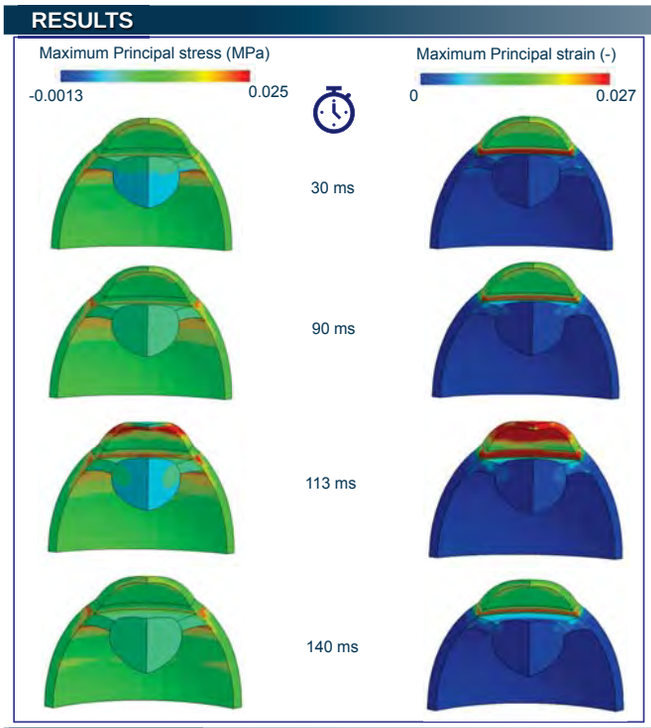
Material parameters of the Ocular Tissues were adopted from [3].

6 FSI SIMULATION

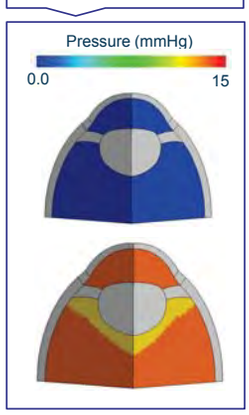


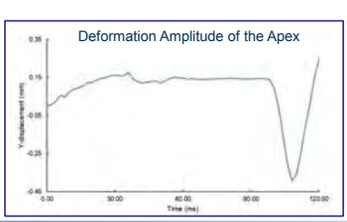
The simulation, implemented in **LS-DYNA** consisted of 4 steps: (i) pressurization of the eyeball to a physiological Intraocular Pressure (IOP) of 15mmHg, (ii) contact between humors and the internal surface of the eye, (iii) stabilization step in which the pressure was transferred to the humors and (iv) impact of the air-jet to the cornea.

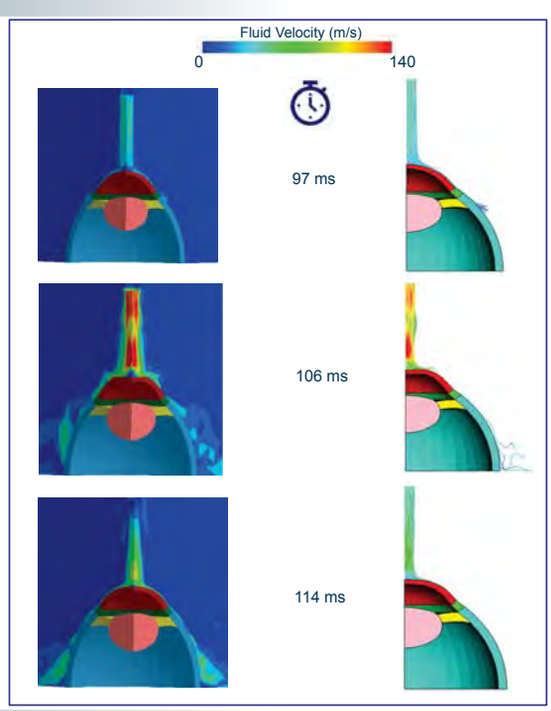
RESULTS



Pressurization step is shown. Starting at 30 ms, equilibrium is reached after 60 ms.







CONCLUSIONS

First full 3D FSI simulation of a NCT test coupling of the structure of the eye, modelled with non-linear material model, with both the air and humors as fluids. Our results indicate the importance of using FSI simulations, including the internal structures, and modeling the humors as pressurized fluids with mass when modeling and NCT test. In this particular, not accounting for the fluid-like behaviour of the humors overestimates the displacement of the apex. Therefore, neglecting the use of FSI simulations when performing material parameter identification based on NCT tests may lead to an overestimated corneal stiffness.

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