# Biomechanics of the Cornea Assessed by the CorVis ST ® Device: a Numerical Approach

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## Abstract

To evaluate by means of finite element modeling the influence of tissue properties of the cornea on its deformation response when an air jet is applied onto its surface and, according to this, to discuss the clinical interpretation of these measurements in terms of corneal biomechanical behaviour.

## Material and methods

A patient-specific finite element model of the eye was developed for our simulations. Corneal geometry data obtained with the PENTACAM ® system from OCULUS in a healthy cornea were used. Specifically, anterior and posterior surface point clouds were used. The model has been built by scripting a fitting algorithm, which uses quadric surfaces for adjusting point clouds. The family of ocular collagen fibres were defined for applying three anisotropic hyperelastic materials[1] of different stiffness, which were simulated afterwards: high, intermediate and low (Figure 1). The material with the lowest stiffness simulated a keratoconus cornea. The influence of intraocular pressure (IOP) was studied by considering three pressure levels: 10, 19 and 28 mmHg. The value of 19 mmHg was the real patient's IOP measured with a Goldmann contact tonometer.

## Results

The deformed configuration of the cornea subjected to an air flow pressure as well as stress and strain fields were computed for each material stiffness and IOP (Figure 2). The maximum displacement of apex, within the physiological range (0.9 – 1.4 mm), showed a linear variation with IOP[2], with the largest apex displacements for the lowest IOP values. In contrast, maximum apex displacement showed a non-linear relation with tissue stiffness (Figure 3). In general, the cornea only affected by IOP is under traction stress (membrane tensional state), but when it is subjected to air-flow pressure, the anterior surface is under compression whereas the posterior surface is under tension, and therefore the cornea experiences bending. This implies that collagen fibres in the anterior surface do not contribute to load bearing.

## Conclusions

Non-contact tonometry devices, such as CorVis ST or Ocular Response Analyzer, mainly evaluates the corneal deformation response (applanation and maximum displacement) as a consequence of the delivery of an air flow pressure over the corneal apex area[3]. This deformation depends on the mechanical properties of corneal tissue, IOP and corneal thickness, and consequently the evaluation separately of the contribution of each factor is not possible. Thus, a cornea with high stiffness and low IOP may show the same deformation response as a cornea with low stiffness and high IOP. In addition, systems based on non-contact tonometry for characterizing corneal biomechanics evaluates the mechanical response of the cornea under bending and, therefore, the membrane behaviour of the cornea is only evaluated, as in a traction or inflation test. These results show that a complete corneal biomechanical characterization would require more than one test for analysing independently the membrane and bending behaviour of the cornea.

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## References

[1]. HOLZAPFEL, G.A., GASSER, T.C. and OGDEN, R.W. A new constitutive framework for arterial wall mechanics and a comparative study of material models. Journal of Elasticity and the Physical Science of Solids. 2000, 61(1-3), 1-48.

[2]. KLING, S. and MARCOS, S. Contributing factors to corenal deformation in air puff measurements. *Investigative Ophthalmology & Visual Science*. 2013, 54(7), 5078-5085.

[3]. HONG, J., XU, J., WEI, A., DENG, S.X., CUI, X., YU, X. and SUN, X. A new tonometer--the CorVis ST tonometer: clinical comparison with noncontact and Goldmann applanation tonometers. *Investigative Ophthalmology & Visual Science*. 2013, 54(1), 659-665.

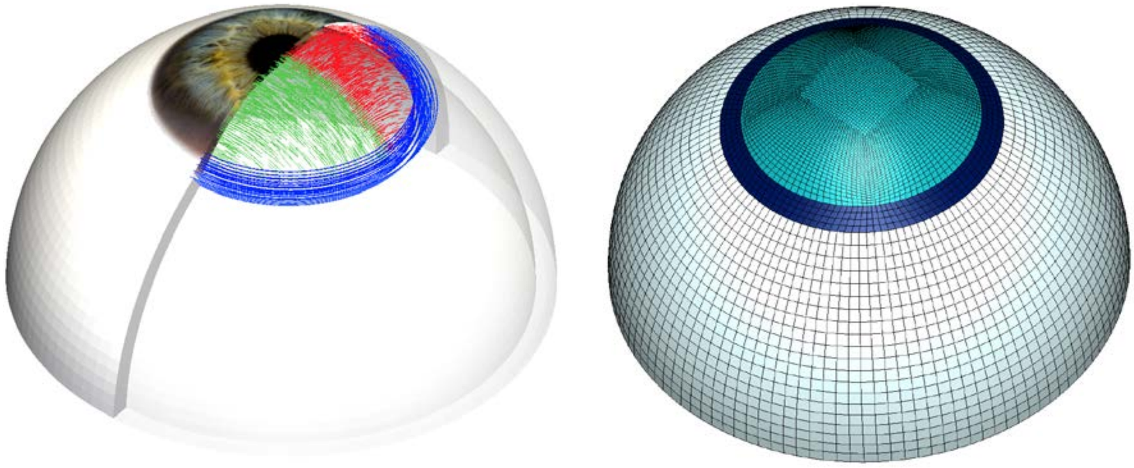

Figure 1. a) Family of collagen fibres definition (Green/Red – Perpendicular cross-linked collagen net of cornea; Blue – Circumferential collagen net of limbus). b) FEM model of eyeball formed by 20-node hexahedron elements (White - Sclera; Dark Blue - Limbus; Light Blue - Cornea)

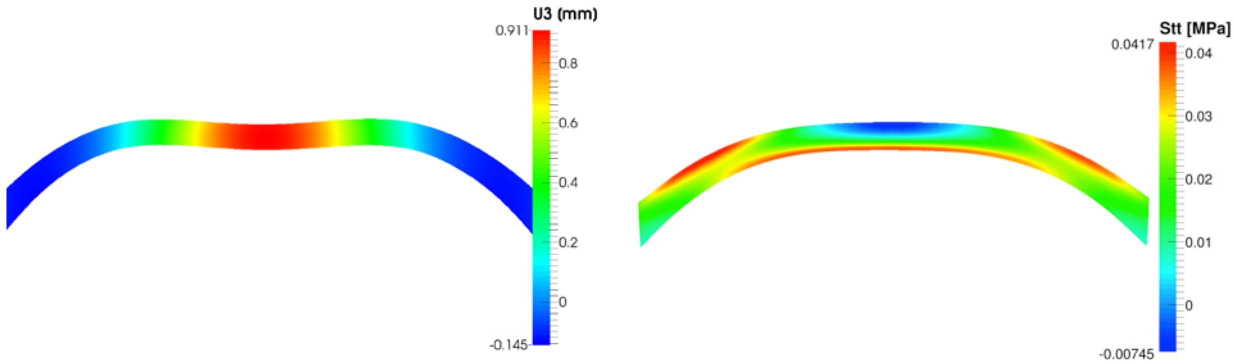


**Figure 2. a) Maximum displacement of corneal apex [mm] at high concavity time. b) Maximum hoop stress [MPa] at High Concavity time. (Note: Both computed for intermediate material and IOP=19 mmHg)**

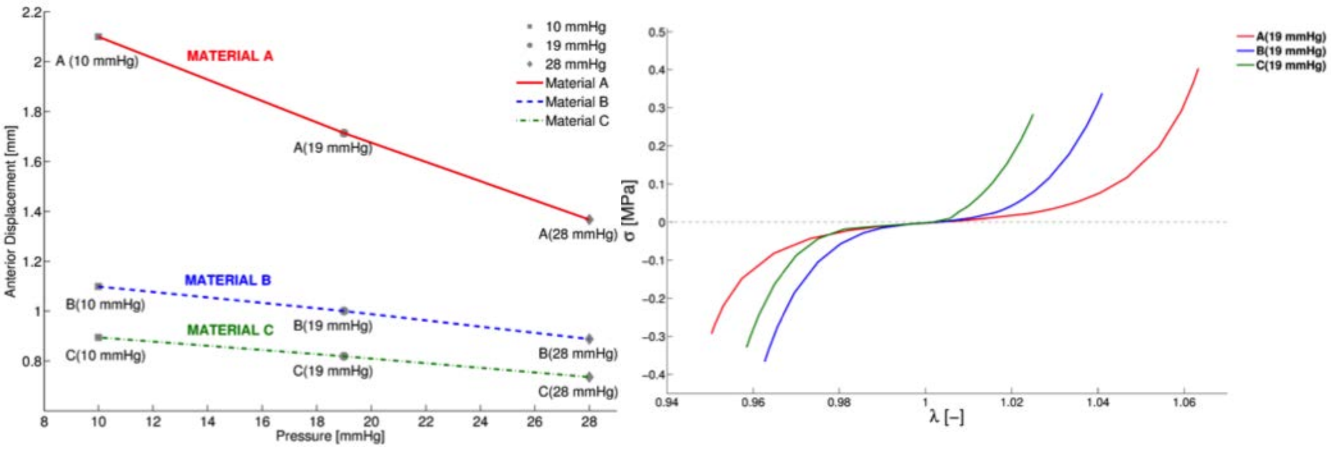


**Figure 3. a) Apex Displacement – Intra Ocular Pressure dependence varying material and IOP parameters. b) Stress-Strain material behaviour depending on tissue stiffness**