SATISFACTORY MODELLING COMPLEXITY FOR PRK IN-SILICO SIMULATION: AN OPTO-MECHANICAL ANALYSIS

Benedetta Fantaci (1), Miguel-Ángel Ariza-Gracia (3), Begoña Calvo (1,2)

1. Aragón Institute of Engineering Research, University of Zaragoza, Spain; 2. CIBER-BBN, Zaragoza, Spain; 3. ARTORG, University of Bern, Switzerland.

Introduction

In the last two decades, corneal laser surgery has become a common procedure to correct medium-low refractive defects. It consists of reshaping the corneal surface by means of a laser in order to correct the present vision error. The action of the laser onto the eye causes a modification of the equilibrium among intra-ocular pressure (IOP) and the corneal tissue mechanics, that could cause a mismatch in the actual dioptric correction and, eventually, post-surgical complications, like ectasia. In this work, we present an in-house developed automatized finite element (FE) methodology to simulate Photorefractive Keratectomy (PRK), analysing the minimal modelling requirements for obtaining a reliable opto-mechanical presurgical evaluation of the surgery outcome.

Methods

A top-down approach was used, by building three corneal models with growing complexity: conic, biconic [1] and patient-specific (PS) models. Our automatized methodology starts by receiving as input patient's topographic data (radius and asphericity values or directly the surfaces point clouds for the PS model), in order to build the geometry point clouds. Due to the lack of peripheral surface data, in PS geometry corneal surface reconstruction is performed by means of Zernike's polynomials [12]. Then, the point clouds are directly meshed with the software ANSA pre-processor by BETA-CAE v22.0.1. A non-linear anisotropic Holzapfel-Gasser-Ogden constitutive model was chosen to model the behavior of corneal tissue, including in-plane and out-of-plane dispersion of the collagen fibers [3]. The effect of three different boundary conditions (BC) was tested: fixed BC at the base of the cornea; symmetric BC at the base of the sclera (only in this case sclera was considered); sliding boundary condition at the base of the cornea, where only radial displacements are allowed. A pre-stretch iterative algorithm was used to compute the stress-free configuration and the patient's IOP of 15 mmHg was applied to the corneal posterior surface. A PRK laser surgery was simulated by removing corneal tissue from the anterior surface. The ablation profile was calculated using conic and biconic equations [4] for the analytical models and wavefront calculation [5] for the PS model, aiming at correcting -4 D, as indicated by the topography of the patient. All mechanical simulations were calculated using ABAQUS. Corneal optics was calculated using an in-house algorithm.

Results

From the mechanical analysis, a concentration of stresses and strains (Figure 1.a - only strains are shown) arises in the optical zone (R = 3 mm), induced by the surgery, where the ablation is performed, in all the models. From an optical point of view, if we look at the pre- and post-surgical sagittal curvature maps (Figure 1.b), it can be noticed how the surgery performs a decrease and a smooth regularization of the surface refractive power, especially in the PS case.

Discussion

Although the PS model is the most representative of patient's real corneal state, simpler model can be used to have an esteem of the opto-mechanical effect of laser surgery onto the structure. While conic model is not able to replicate both myopic and astigmatic defect, the biconic model is a valid approximation to analyze the opto-mechanical changes.

This methodology could become a useful tool for the clinicians to anticipate the surgery outcome, given that it allows to consider the optics and the mechanics of the cornea, both necessary to have a complete evaluation of the clinical state of the patient's eyes. Clinical validation will follow on a larger patients' database.

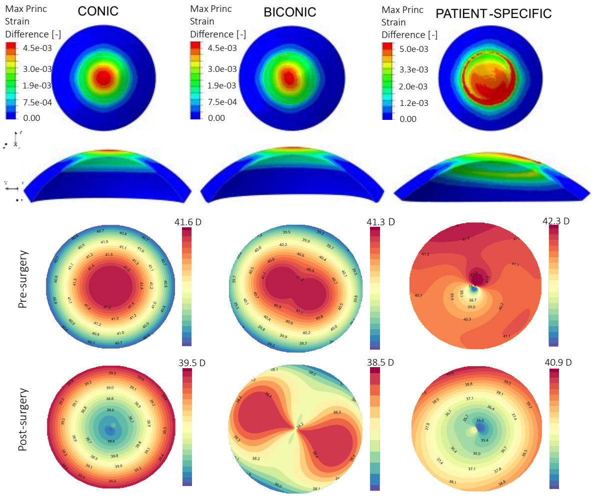

Figure 1.a. Strain Differences caused by the ablation; b. Pre- and post-surgical sagittal curvature maps.

References

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