PATIENT-SPECIFIC OPTO-MECHANICAL MODELLING OF PHOTOREFRACTIVE KERATECTOMY

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

1. Aragón Institute of Engineering Research (i3A), University of Zaragoza, Spain; 2. Bioengineering, Biomaterials and Nanomedicine Networking Biomedical Research Centre (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 propose an automatized finite element (FE) methodology to simulate Photorefractive Keratectomy (PRK) in order to obtain an opto-mechanical presurgical evaluation of the surgery outcome.

Methods

Our automatized methodology starts by receiving as input the point clouds of the anterior and posterior surfaces of the topographic acquisition. Due to the lack of peripheral surface data, corneal surface reconstruction $h(r,\theta)$ (Figure 1.a) is performed by means of Zernike's polynomials: $h(r,\theta) = \sum_{i=0}^{n} c_i \cdot Z(\rho,\vartheta)$, where c_i denotes the Zernike coefficients and Z the polynomials [1]. Then, the reconstructed 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 corneal collagen fibers [2]. Sliding boundary condition, where only radial displacements are allowed, were applied at the base of the cornea. A pre-stretch iterative algorithm [4] was used to compute the stress-free configuration and the patient's IOP of 12 mmHg was applied to the posterior surface of the cornea. A PRK laser surgery was simulated by removing corneal tissue from the anterior surface (Figure 1.b). The ablation profile was calculated using wavefront calculation, as described by [3], 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 (Figure 1.c), we can observe a concentration of stresses and strains in the optical zone (R = 3 mm), induced by the surgery, where the ablation is performed, due to the reduction of the thickness of the cornea. No geometrical abnormality arises from performing the PRK simulation on the FE model. From an optical point of view, if we look at the pre- and post-surgical maps of the mean curvatures, it can be noticed how the surgery performs a smoothing and a regularization of the surface refractive power.

Discussion

No post-surgical geometrical irregularities arose from performing the PRK surgery and a smoothed refractive correction was achieved. 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.

References

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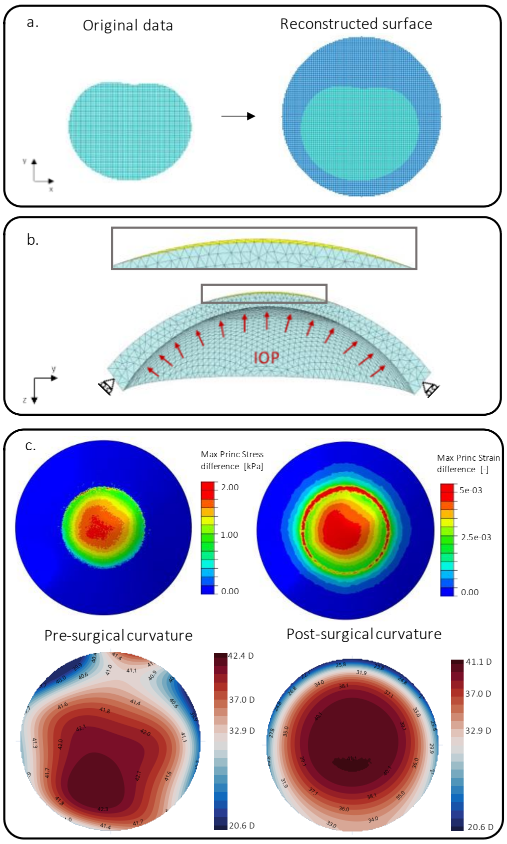

Figure 1. a. Surface reconstruction of patient's topography; b. FE model; c. Opto-mechanical analysis of the surgery