AN ENERGETIC ANALYSIS OF THE NON-CONTACT TONOMETRY: COMBINING NUMERICAL SIMULATIONS AND CLINICAL IMAGES

Elena Redaelli (1), Begoña Calvo (1), Giulia Luraghi (2), Jose F Rodriguez Matas (2), Jorge Grasa (1)

1. Aragón Institute of Engineering Research (I3A), Universidad de Zaragoza, Spain;
2. Dept. of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Italy.

Introduction

The cornea, the outermost layer of the eye, is responsible for transmitting and focusing light onto the retina. Any changes in its mechanical properties can result in visual impairment. Non-Contact Tonometry (NCT) is a clinical tool used to measure the intraocular pressure (IOP) and the mechanical properties of the tissue by deforming the cornea with an air jet and recording the deformation with a Scheimpflug camera [1][2]. The deformation is influenced by four factors: the eye's geometry, the IOP, the pressure of the air jet, and the mechanical properties of the corneal tissue. In silico simulations of NCT can help to separate the effect of each factor. This work focuses on the system's energy balance and the potential for combining numerical simulations with clinical images to diagnose and treat corneal diseases by characterizing the mechanical properties of the corneal tissue.

Methods

A patient-specific corneal model was created using data from the topographer Pentacam (collected at Antwerp University Hospital) and the method outlined in [3]. A Fluid Structure Interaction (FSI) simulation using the settings in [4] was conducted to replicate the action of the air jet of Corvis ST over the deformable patient-specific cornea. The energy balance of the system was analysed. The air pressure over the corneal surface (Fig. 1A) was taken out to calculate the total work of the air puff. The circumferential (Fig. 1B), radial and azimuthal stretch of the structural parts during the air puff were collected to calculate the strain energy of each component. The humors were modelled as incompressible fluids pressurized at 15 mmHg.

For the same patient, the images derived from the tonometer were segmented (Fig. 2A). A Computational Fluid Dynamic (CFD) simulation was run to simulate the air jet against a moving boundary representing the dynamic deformation of the cornea as identified in the clinical images.

Results

During the NCT the work of the air puff is equal to the sum of the internal energy of the structural parts (Fig. 1C). The sclera, being the stiffest part, has the highest internal energy despite having the lowest deformation. As the humors are modelled as incompressible fluids, their pressure increases during the air puff [4] but their volume remains constant. As a result, the total work of the humors is zero.

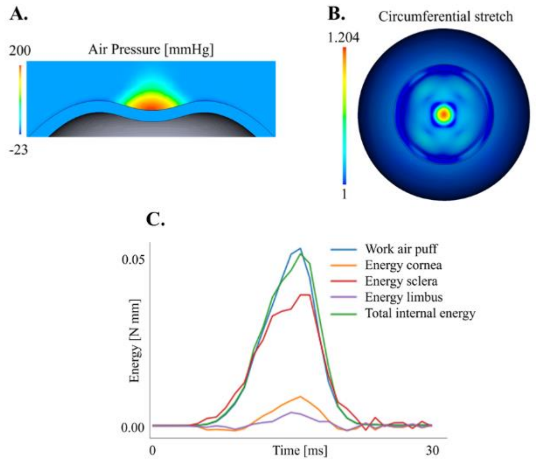

Figure 1:(A) Air pressure and (B) circumferential stretch on the structural parts in the instant of highest concavity. (C) Energy balance of the system.

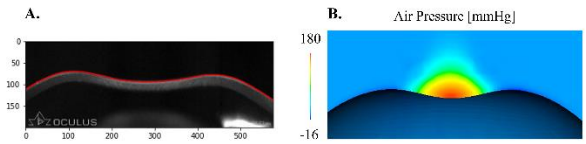

Figure 2:(A) Segmented clinical image (B) air pressure over the moving boundary.

Discussion

The energetic analysis of the NCT enables the isolation of the effect of the mechanical properties of the structural parts, independent of the influence of the IOP. The CFD analysis shown in Fig. 2B was used to calculate the work of the air puff. By measuring the work of the air puff, which is only supported by the structural parts, the proposed methodology can effectively characterize the mechanical properties of the eye tissues.

References

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