MECHANICAL CHARACTERIZATION OF PORCINE CORNEAS THROUGH DIGITAL IMAGE CORRELATION ANALYSIS

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Introduction

Quantification of corneal mechanical properties is crucial for permanent refractive correction using laser ablation or corneal cross-linking (CXL) to accurately predict surgical outcomes. Uniaxial tensile tests have been used for material characterization, but these tests are not representative of the natural 3D loading by the intraocular pressure (IOP). Inflation tests better resemble the physiologic stress distribution, but tracking of the corneal surface displacement is difficult and has been previously limited to a single apical point [1]. In the present study we performed inflation tests under different corneal conditions exploiting digital image correlation (DIC) [2], a non-interferometric optical method for measuring the 3D displacement of the anterior corneal surface.

Methods

Fifteen freshly enucleated porcine eyes were divided into 3 groups and tested within 24 hours: 5 eyes (CXL group) were subjected to the Dresden CXL protocol (3 mW/cm^2 irradiance for 30min), 5 eyes (laser group) had the first 350µm of the anterior stroma removed with a femtosecond laser, and the remaining 5 eyes were de-epithelialized and served as the control group. The experimental setup is shown in Figure 1.A and consists of i) a pressure sensor inserted into the anterior chamber; ii) a pressure pump; iii) two cameras (Imager E-lite 2M, LaVision, Germany) with spatial resolution of 1280×1024 pixels; iv) the eye globe placed in a holder that allowed for corneal expansion. Saline solution was injected into the posterior chamber (0.0833 ml/min), and the IOP was recorded up to 80 mmHg. The 3D displacements of the central corneal region were tracked at a frame rate of 3 fps (Figure 1.B). The resulting point cloud was meshed and the principal in-plane strains were calculated using an in-house Matlab (The MathWorks Inc., Massachusetts) code, which exploits the membrane theory of the finite element method (FEM) [3].

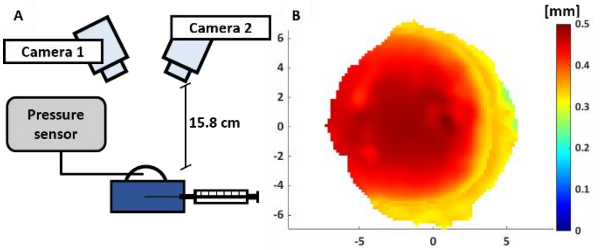

Figure 1: A) experimental setup; B) displacement map

Results

Maximum principal strains (MPS) values were compared for the three groups at ΔIOP values of 20 and 60 mmHg (Figure 2). At 60 mmHg, the laser group showed a statistically significant increase in MPS compared to the control group (7.5±1.2% vs 4.3±1.1%, p=0.008), and to the CXL group (2.7±0.3%, p=0.008). There was a trend (p=0.07) toward a reduction in MPS in the CXL group compared to the controls. Similar differences were observed at 20 mmHg.

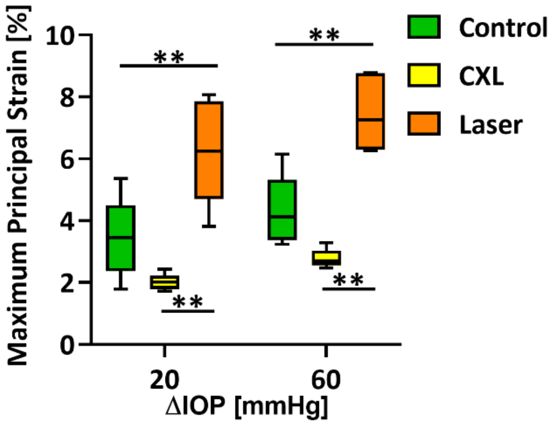

Figure 2: MPS at different IOPs in the three groups.

Discussion

DIC cameras enabled a point-wise registration of the deformation of the central anterior corneal surface during inflation tests. CXL samples were stiffer than controls when subjected to the same IOP, while laser cut samples were significantly softer, possibly indicating a depth dependency of corneal mechanical properties [4]. This experimental data will be exploited to feed inverse FEM algorithms, to determine corneal mechanical properties, either in terms of depth dependence or to quantify the biomechanical alterations induced by CXL.

References

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