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Experimental tests and finite element analysis of healthy, injured and plasma-treated cornea

Maria Vittoria Mascolini[1,*], Ilaria Toniolo[1,2], Simona Neri[3], Antonella Peruffo[4], Anna Perazzi[2,4], Emanuele Luigi Carniel[1,2], Chiara Giulia Fontanella[1,2]

[1]Department of Industrial Engineering, University of Padova, Italy; [2]Centre for Mechanics of Biological Materials, University of Padova, Italy; [3]Department of Animal Medicine, Production and Health, University of Padova, Italy; [4]Department of Comparative Biomedicine and Food Science, University of Padua, Italy

[*]Corresponding authors; e-mail address: mariavittoria.mascolini@phd.unipd.it

Abstract

Background: The cornea plays a significant role in maintaining vision by preserving its shape under varying eye pressure conditions. However, when its structure is damaged due to conditions such as ulcerative melting keratitis, the corneal function in the visual process is compromised [1]. Due to the limited availability of healthy corneas for transplantation, regenerative medicine is exploring alternatives to keratoplasty. A biomechanical investigation is vital to support the development of corneal refractive treatments and surgical procedures by understanding the cornea's complex behaviour.

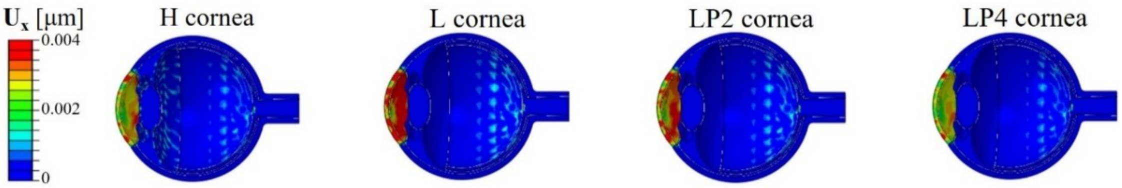
Methods: *Twenty-four cornea samples were used and divided into six healthy samples (H) and eighteen lesioned samples (L) by using NaOH solution (1 N). Two-thirds of the L samples received plasma treatment, six samples for two minutes (LP2) and six for four minutes (LP4). The samples were cut into strips, gripped, and preconditioned by ten loading-unloading cycles (strain 8%, frequency 0.5 Hz). They were then subjected to a progressive strain at a constant rate of 1%/s until failure using the Biomomentum testing machine (Model Mach-1 v500csst). A 3D finite element model of cornea, sclera, lens, retina, anterior and posterior chambers and vitreous body was created and discretized in Abaqus CAE & Standard 2023. A linear elastic model was assumed for all the tissues, using Young's moduli from the literature [2], except for the cornea, for which an Ogden hyperelastic model was used with constitutive parameters evaluated from experimental tests. The intraocular pressure was simulated by applying a fluid cavity pressure of 15 mmHg (within the physiological range of 13-21 mmHg) in the eye chambers and vitreous body.*

Results: *Experimental results confirmed the non-linear behviour of the tissues, Young's moduli in the quasi-linear region and ultimate tensile strength (UTS) were evaluated for each group (mean values, Young's moduli: (H) 4.25 MPa, (L) 3.89 MPa, (LP2) 4.08 MPa, (LP4) 4.35 MPa; UTS: (H) 1.36 MPa, (L) 1.20 MPa, (LP2) 1.12 MPa, (LP4) 1.47 MPa). The contours of displacement along the x-axis were reported (Figure 1), showing that the H and LP4 groups recorded the lowest corneal apical displacement, linked to the highest Young Moduli.*

Conclusions: The findings obtained from the experimental data serve as a basis for the development of advanced computational tools of the whole eye. By bringing together experimental and computational approaches, researchers can gain a better understanding of the impact of illnesses and therapeutic interventions on corneal function, potentially leading to more effective treatment strategies and personalized medical approaches.

Keywords: plasma-treated cornea, mechanical tests, constitutive model.

Figure 1: Displacement contours in the computational eye model by varying the corneal condition (H, L, LP2, LP4).



References

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2. *Basinger et al, Neural Eng, 6:1-9, 2009.*