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Investigation of the corneal frequency response to modulated sound excitation

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Purpose : To investigate the possibility of determining the eye's intraocular pressure (IOP), biomechanical parameters (BM), and geometrical distortion through its frequency response to acoustic excitation as measured by phase-sensitive swept source optical coherence tomography (PhS-ssOCT).

Methods : Experimental (E): Freshly enucleated porcine eyes (<45h) were mounted in front of a PhS-ssOCT at 15mmHg IOP. A loudspeaker was placed 10mm to the corneal apex, and a frequency sweep (0-1000Hz) was applied at sound pressure levels of 0.88Pa. Resonance amplitude and frequency were measured for different corneal treatments: 1) de-epithelized, 2) applied photosensitizer Riboflavin (RF), 3) cross-linked (CXL, Dresden protocol), and different measurement set-ups: a) at/around apex, b) IOP 15 - 30 mmHg, c) eye mounted on artificial orbital fat, mimicked by silicone. Simulations (S): Nonlinear hyperelastic FE models of porcine eyes were built and subjected to a modulated pressure, equal to (E). The frequency response was determined by monitoring the apex displacement over time then using fast Fourier transformation (FFT) analysis to determine the frequency peaks. Resonance frequency and amplitudes were determined across corneal meridians for homogeneous BM and for corneas with local BM variations. For both (E) and (S), resonance frequencies were defined at the positions of peak amplitudes.

Results : (S) and (E) results were in good correspondence and both showed resonance frequencies of 370Hz. An increase of 15 mmHg in IOP resulted in a decrease of the resonance amplitude of up to 1.24±0.61μm (E) and a frequency shift of up to 22.7± 9.3Hz (E). BM changes produced by CXL led to a decrease in amplitude of 2.19±0.78μm, without significant frequency shifts (E). (S) supported these trends, but showed up to 13Hz higher frequency shifts with IOP increase. Additionally, (S) showed that localized BM changes could be detected by examining asymmetries of the resonance amplitude across opposite corneal meridians. Presence of artificial orbital fat resulted in a damping of the resonance amplitude of >50% for (E) and (S).

Conclusions : Sound-coupled OCT measurements made it possible to detect corneal resonance frequencies. IOP and BM could be decoupled, due to differential dependencies of amplitude and resonance frequency on IOP and BM.