Volumic deformation of human cornea under pressure

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Abstract

The cornea is the tissue that forms the outer part of the eye. It plays an essential role in vision, both through its transparency and its shape. This shape is ensured by the cornea's natural curvature and mechanical properties. Previous mechanical experiments have shown that the cornea has a non-linear stress-strain behavior, similar to other collagen-rich tissues. Indeed, it is mainly formed by the stroma (90% of its thickness), which is made up of a stack of collagen fibril lamellae, reminiscent of plywood. However, up-to-now, there has been no study of the volumic deformation of the human cornea during a mechanical assay: most of the studies have focused on the behavior in the tangent direction to the surface of the cornea. In this study, we measured the volume deformation of human corneas during an inflation test. Our observations show a very different behavior in directions tangent to corneal surfaces compared to thickness, with in particular a strong sensitivity to osmotic fluxes in the thickness.

We used 7 corneas for an inflation test. Each intact cornea was placed on an inflation chamber, and liquid was injected while the pressure was recorded. At different pressure levels, the injection was stopped to image a volume near the apex of the cornea with an Optical Coherence Tomograph. Once the pressure has reached a pressure around 20kPa (for a physiological pressure of 1.5kPa), the volume was kept constant. Using the natural contrast of the tissue, we quantified the strain tensor in 3D at the different pressure levels using Digital Volume Correlation.

We were able to measure the strains in all directions. We observe a horizontal strain in the expected range of few percent. It increases with depth, and shows some heterogeneity in the posterior (deeper) region. We didn't observe a significant variation in the shear components.

The most striking deformation is observed in the vertical direction, with a compressive strain which progressively goes down to -20 to -30%, far above the expect value with a compression which starts mainly in the anterior (outer) part of the cornea, and which propagates as the pressure increases. We also note that there is an initial stretch in the center of the cornea, and that, once the pressure is stabilized, the cornea keeps deforming, showing a dynamical aspect in this change of volume. We observe that the strain near the apex is almost homogeneous, apart in some regions in the posterior parts, as expected from the collagen organization. The horizontal strains are around 3%. They increase with depth, contrary to expectations for a spherical cap under pressure. This is in agreement with the deformation

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of a spherical cap under pressure. The vertical strain shows a strong compression, which starts in the 1/3st part of the cornea depth, and which will propagate in the tissue. We associate this effect to a water outlet driven by the mechanical stretch. The initial stretch in the middle part is likely due to an osmotic imbalance, despite the fact that the cornea has been placed in adapted solutions before the experiments. Thus, a proper model of the cornea should include both a vertical heterogeneity of a transverse isotropic medium, but also a poro-osmotic component to describe the vertical water exchanges.