Corneal Stress-Strain Index (SSI) Map

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Purpose: To introduce a novel method to map the mechanical stiffness of healthy and keratoconic corneas.

Methods:

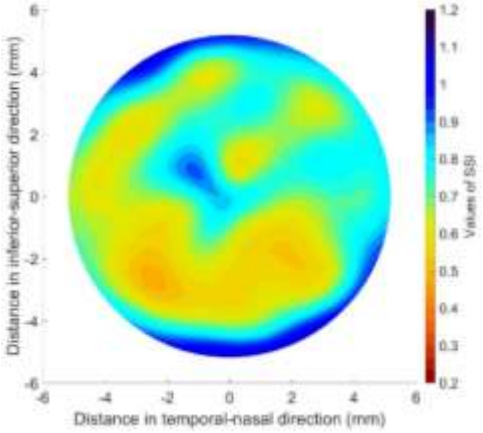
Numerical modelling based on the finite element method was used to carry out inverse analysis of simulated healthy and keratoconic corneas to determine the regional variation of mechanical stiffness across the corneal surface based on established trends in collagen fibril distribution. The Stress-Strain Index (SSI), developed and validated in an earlier study and presented as a parameter that can estimate the overall stress-strain behavior of corneal tissue, was adopted in this research as a measure of corneal stiffness. The regional variation of SSI across the corneal surface was obtained using inverse analysis while referring to the common features of collagen fibrils' distribution obtained from earlier x-ray scattering studies. Additionally, for keratoconic corneas, a method relating keratoconic cone features and cornea's refractive power to the reduction in collagen fibril density inside the cone was implemented in the development of SSI maps.

Results:

SSI values varied slightly across the corneal surface in healthy eyes. In contrast, keratoconic corneas demonstrated substantial reductions in SSI values inside the cone, Figure 1. These SSI reductions depended on the extent of the disease and increased with more considerable simulated losses in fibril density in the cone area. SSI values and their regional variation showed little change with changes in IOP, corneal thickness and curvature.

Conclusion:
SSI maps provide an estimation of the regional variation of biomechanical stiffness across the corneal surface. The maps could be particularly useful in keratoconic corneas, demonstrating the dependence of corneal biomechanical behavior on the tissue's microstructure and offering a tool to fundamentally understand the mechanics of keratoconus progression in individual patients.

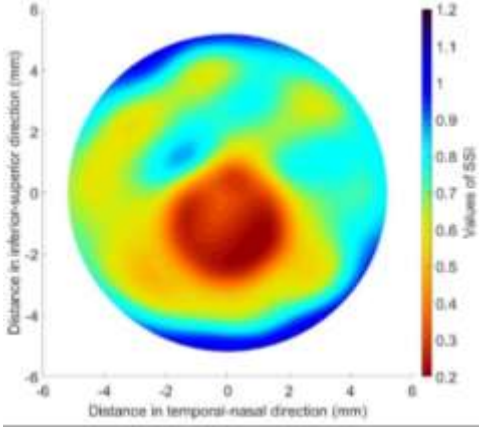
A fibril reduction factor of 0% (Healthy)



(A)

Mean ± standard deviation and range of SSI
0.70 ± 0.12 (0.48 -1.14)

A fibril reduction factor of 60%



(B)

Mean ± standard deviation and range of SSI
0.65 ± 0.19 (0.20 -1.14)

Figure 1 SSI maps for KC corneas with cones experiencing fibril reductions of 0 (A), and 60% (D). The cones had 2.0 mm radius and were located on the vertical central meridian of the cornea. In all cases, the cones' centers were at 1.0 mm away from the corneal apex.

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