Depth-Resolved Corneal Biomechanical Changes Measured via OCE following CXL

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Financial Disclosures

- Matthew W. Ford – patent held by Cleveland Clinic related to OCT elastography (OCE)
- William J. Dupps – patent held by Cleveland Clinic related to OCT elastography (OCE), Consultant (Alcon, Glaukos)

Background

- Underlying biomechanical abnormalities are thought to be a major contributor to development of corneal ectasia – eg, KCN or post-LASIK ectasia
- Current imaging technologies are limited in their ability to evaluate depth-dependent biomechanical properties of the cornea

- Optical coherence elastography (OCE)
    - Employs swept-source OCT to capture images while applying an axial, applanation-like contact with the corneal surface
    - Permits characterization of spatial depth-dependent biomechanical properties

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Background

- Prior study used OCE in live human subjects of both normal and KC eyes
- Demonstrated that patients with KC have a selective weakening of the anterior stroma – finding that may serve as valuable marker for screening

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Article

Depth-Dependent Corneal Biomechanical Properties in Normal and Keratoconic Subjects by Optical Coherence Elastography

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Purpose

To evaluate depth-resolved changes of corneal biomechanical properties in eyes with corneal ectasia after CXL using optical coherence elastography (OCE)

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Methods

- 4 eyes of 4 subjects with prior diagnosis of corneal ectasia were prospectively enrolled
- Data collected prior to CXL and 3 months following CXL in the same eye
- CXL was performed according to Dresden protocol

- Optical Coherence Elastography used to image cornea with low-speed applanation deformation while monitoring applanation force
- Cross-correlation applied to track frame-by-frame 2-dimensional OCT displacements

- Slope of force versus local axial displacement during the deformation used to create a 2-D array of axial stiffness (k)

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Optical Coherence Elastography

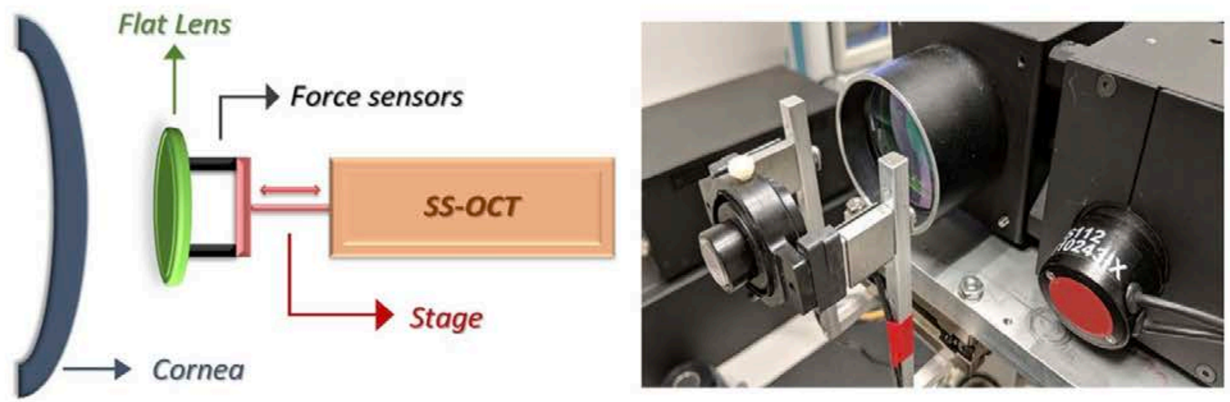

Figure 1. *Left*: schematic representation of the optical coherence elastography system. *Right*: picture of the prototype, with a focus on the transparent flat lens, force sensors, and translational stage. SS-OCT, swept-source optical coherence tomography system.

- k=f/d, where ***f*** is the force generated from progressive contact between the interface and the anterior cornea and ***d*** is the local cumulative displacement of the cornea derived from the OCT speckle pattern tracking
- ***K = defined as slope of a line fit to force/displacement data***

- ***K values are calculated and compared between defined anterior and posterior regions of cornea (Ka = anterior stroma, Kp = posterior stroma)***
- **These values were expressed as a ratio to assess depth-dependent differences in axial stiffness. A ratio (ka /kp) value of 1 = equivalence between the axial stiffness in the anterior and posterior regions**

Subject Characteristics

Subject	Age, years	Diagnosis	Sex (M/F)	Spherical Equivalent MRx (D)	IOP (mmHg)	Km (D)	K_{max} (D)	TPCT (µm)
01	23	KCN	F	+1.88	9.0	51.8	69.5	408
02	26	KCN	M	+2.75	15.0	52.6	63.0	398
03	21	KCN	M	-0.63	16.0	43.5	51.2	495
04	49	Post-LASIK Ectasia	M	-1.75	9.5	43.6	64.3	390

Results

- **Graphs generated for each subject to assess the force/displacement relationship as it evolves across compression sequence**
- **Allows for comparison of displacement values between anterior / posterior regions for any given point in time or force**
- **Permit assessment of depth-dependent differences in the loading behavior of the cornea**

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Results

Subject	Age, years	Eye	K_a/K_p Pre-CXL	K_a/K_p Post-CXL
01	23	OS	0.934	**1.579**
02	26	OD	1.044	**1.235**
03	21	OD	1.051	**1.205**
04	49	OS	1.087	**1.349**

- Results quantitatively support that CXL confers a selective stiffening in the anterior stroma
- Across all 4 subjects – 34% ↑ from baseline the ka/kp value

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Conclusions

- Study has limitations – only 4 subjects
  - Future, larger-scale studies will be valuable and important for confirming the findings post-CXL
- Ex vivo studies have demonstrated these post-CXL changes using destructive and non-destructive methods – first report of in vivo data

- Study provides biomechanical evidence of a selective increase in anterior stromal stiffness properties following CXL

- OCE could be useful for evaluating and comparing biomechanical properties following refractive surgeries, various CXL protocols and improving the safety and predictability of these procedures

Acknowledgments

- Srinidhi Singuri
- William J. Dupps, MD, Phd

- Support: Grant from Research to Prevent Blindness to the Dept. of Ophthalmology of the Cleveland Clinic Lerner College of Medicine of Case Western Reserve University (RPB1508DM)

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