Corneal vs. Ocular Hysteresis?
Implications for Non-Corneal Disease
Interrogation in the Eye

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February 24, 2007
Acknowledgments

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- Cornea, External Disease & Refractive Surgery Fellow

Research support

- Research to Prevent Blindness Challenge Grant (Cole Eye Inst.)
- NIH 8K12 RR023264
- NEI 1L30 EY017803

No financial interests in devices or methods discussed
Objectives

- To review the biomechanical *principles* of corneal hysteresis (CH) measurement

- To investigate the *impact of the posterior segment* on CH measurement

- To discuss *clinical implications* of retrocorneal contributions to CH measurement
Can biomechanical property measurement help us in the cornea?

- The properties of the normal cornea vary from patient to patient
- These differences may influence the response to surgery
Advanced customization

Surgery

Pre-op Measurement

Algorithm

Post-op Measurement

Analyze

Imprecision exists at every step and
Can property measurement help us in the cornea?

- The properties of the normal cornea vary from patient to patient
  - These differences may influence the response to surgery

- Certain diseases and pre-clinical disease states may demonstrate abnormal properties (ectasias)
  - Static imaging (topography, pachymetry) not adequate for refractive surgery risk assessment (Klein, 2006)
The corneal ectasias

- Progressive corneal thinning, distortion, visual loss, hydrops
- Can occur after LASIK (Seiler et al, 1998)
  - Uncommon (19 of 2873 eyes, mean -14.65 D) (Pallikaris 2001)
  - Flaps, high corrections, and retreatment are risk factors
  - Mean onset 16 months, range 1 to 45 (Randleman et al, 2003)
- Risk assessment: topography, thickness measurements and time
Can corneal property measurement discern disease elsewhere in the eye?

- **Glaucoma**
  - A highly prevalent progressive optic neuropathy
  - IOP a major risk factor

- **Discordant conditions**
  - Ocular hypertension
  - Normal tension glaucoma

- **Decoding IOP measurement**

- **Is the glaucoma risk reflected in corneal measurements (OHTS) due solely to IOP underestimation?**
What properties do we measure?

- Resistance to *expansion*
  - Whole-globe ocular rigidity (Friedenwald, Pallikaris)

- Resistance to *extension*
  - Classic axial stress-strain testing

- Resistance to external *bending* force
  - Static or dynamic force
Measuring the elastic modulus

Dupps & Doehring, 2006
Viscoelasticity

- Property of all biological soft tissues
- Viscous domain (fluid property) adds time dependence or “history” to stress response
- Important in ectasia?

![Viscoelastic Relaxation](chart)

![Nonlinear Viscoelastic Material](chart)
A clinical technique for viscoelastic characterization of bending resistance

- Ocular Response Analyzer (ORA) (Luce, 2005)

Image courtesy of Reichert
What does the ORA measure?

- **CH**: viscous damping, *dissipation*, \( P_1 - P_2 \)
- **CRF**: overall resistance, \( f(CCT) \), \( P_1 - k_{CRF} P_2 \)
- **IOP\(_G\)**: Goldmann-correlated IOP, \( \text{ave}(P_1, P_2) \)
- **IOP\(_{cc}\)**: less dependence on corneal properties, \( P_2 - k_{IOP} P_1 \)

Luce, JCRS 2005
Does CH tell the whole story?
What does the ORA measure?

- “the ORA measures what the ORA measures” (David Luce)

- Risk of glaucoma progression?
  - Low CH related to risk of HVF progression* (Congdon et al, AJO 06)
  - Independent of CCT and IOP

- Could abnormal stress dissipation in extracorneal structures contribute to this association?
Purpose

- To investigate the differences in corneal hysteresis (CH) and trans-corneal intraocular pressure measurements between whole human donor globes and sclero-corneal explants procured from the same donor eyes.

- **Hypothesis**: CH measurements are influenced by retro-corneal properties other than IOP.
Methods

- Six phakic eye-bank whole globes debrided, deturgesced with 15% dextran
- Intravitreal IOP (IOP_{IV}) incremented: 10, 15, 20 and 30 mmHg
- ORA replicates (4) at each IOP step
- Repeat on corneal-scleral explants mounted on an artificial AC (same pressures, CCT)
- Differences in CH between same-eye corneas and globes assessed by paired t-test
Experimental setup

- System Diagram
- Digital Pressure Monitor
- Saline Solution
- Pressure Sensor
- Artificial Anterior Chamber Mount
- Barron K20-2125 Pressure Sensor
- OCT Objective Lens
- 1
- 2
- Cornea
- Saline Solution
- System Diagram

Experimental setup
Results

- CCT stable
  - Initial 515 ± 32, final 510 ± 30 µm (p=0.2)

- CH was higher in explants compared to whole globes
  - 10mmHg (15.8 ± 3.2 vs. 14.4 ± 1.9, p=0.02)
  - 15mmHg (15.6 ± 4.1 vs. 12.1 ± 3.0, p=0.002)
  - 20mmHg (18.9 ± 2.7 vs. 12.0 ± 2.3, p<0.001)
  - 30mmHg (19.0 ± 4.0 vs. 10.6 ± 1.8, p<0.001)
Sample ORA waveforms (10mmHg)

Whole globe

![Whole globe waveform diagram]

Cornea and artificial AC

![Cornea and artificial AC waveform diagram]

Delay in P₂

<table>
<thead>
<tr>
<th></th>
<th>IOPcc</th>
<th>IOPg</th>
<th>CH</th>
<th>CRF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Whole globe</strong></td>
<td>16.3 mmHg</td>
<td>14.0 mmHg</td>
<td>8.9 mmHg</td>
<td>8.7 mmHg</td>
</tr>
<tr>
<td><strong>Cornea and artificial AC</strong></td>
<td>3.9 mmHg</td>
<td>9.6 mmHg</td>
<td>17.0 mmHg</td>
<td>14.2 mmHg</td>
</tr>
</tbody>
</table>
Conclusion

- CH values differ in whole globes and in mounted sclero-corneal explants from the same eye (p<0.001)
Discussion

- How do the 2 models differ?
  - CCT and IOP controlled
  - *Only the posterior segment has changed*

- So the differences in CH are due to (and therefore informative of) changes in *posterior segment properties*
  - A corollary: retro-corneal properties impact the cornea even when the corneal substance has not been changed
Comparison of posterior segment states

Native posterior segment
- Greater intraocular volume/AEL (myopia)*
- Greater scleral compliance (?glaucoma)
- => more compliant corneal boundary condition

Artificial anterior chamber
- Reduced intraocular volume/AEL (anti-myopia)*
- Reduced scleral compliance (plastic)
- => stiffer corneal BC
- **Greater capacity for viscous damping**
Implications

- Diseases of the posterior segment may involve a spectrum of abnormal scleral compliance
  - AMD (Pallikaris)
  - Myopic degeneration
  - Glaucoma (Downs, Burgoyne et al)

- A reduction in capacity for dissipating stress may be accessible with CH measurements
Thank you