The effect of corneal wavefront aberrations on corneal pseudo-accommodation

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Background

- The phenomenon so-called “apparent accommodation” long has been recognized*
  - Good near and distance vision with distance correction only in aphakic/pseudophakic pts

*Huber C. J Am Intraocul Implant Soc 1981; 7:244-9
Background

- Apparent accommodation shown to be correlated with:
  - Depth of field
  - Pupillary diameter
  - Corneal multifocality

*Nakazawa and Ohtsuki. IOVS 1984; 25:1458-60;
Fukuyama et al. Ophthalmology 1999; 106:1178-81*
Background

- Apparent accommodation and corneal wavefront aberration in pseudophakic eyes*
  - Coma-like aberration (3\textsuperscript{rd}-order) of the cornea contributes to apparent accommodation (push-up)
  - Did not study individual Zernike terms

*Oshika et al. IOVS 2002; 43:2882-6
Background

- Evidence for delayed presbyopia after myopic corneal refractive surgery reported*
  - Enhanced near acuity
  - Greater measured accommodation

*Nio et al. JCRS 2003; 29:2082-95
Artols et al. Ophthalmology 2006; 113:735-41
Purpose

- To determine the effect of corneal higher-order aberrations on corneal pseudo-accommodation in:
  - Cataract population
  - Eyes following myopic and hyperopic corneal refractive surgery
Patients

- No prior corneal surgery
  - 220 eyes of 137 patients
  - Ages 40 to 80 years

- Prior myopic-PRK 6 months or longer
  - 102 eyes 77 patients
  - Ages 22 to 45 years

- Prior hyperopic-LASIK 3 months or longer
  - 106 eyes of 80 patients
  - Ages from 40 to 59 years
Methods

- Corneal wavefront aberrations:
  - Using the VOL-CT (Sarver and Associates, Carbondale, IL), calculated corneal HOAs (3\textsuperscript{rd} to 6\textsuperscript{th} order, 6 mm pupil) from corneal topographic elevation data (Humphrey Atlas)

- Corneal image quality
  - Using the ZernikeTool program (AMO), calculated polychromatic modulation transfer function (PMTF) with Stiles-Crawford effect
Effect of defocus on image quality

- Effect of defocus on corneal image quality
  - Defocus from -3 D to +3 D in 0.1 D intervals were added to the HOAs of the corneas
  - PMTF at 15 cpd (20/40 object) was evaluated
  - Depth of focus (DOF) was defined by 3 criteria
Depth of focus: Criteria

1) Range over which the PMTF maintains 80% of maximum PMTF value
   - DOF80

2) Range over which the PMTF maintains 50% of maximum PMTF value
   - DOF50

3) Range over which the PMTF ≥0.1
   - DOF0.1
Statistical analysis

- DOF values were compared between groups using t-test with Bonferroni correction.
- Stepwise multiple regression was used to assess the Zernike terms contributing to the DOF.
  - For left eyes, Zernike coefficients with mirror symmetry between both eyes were flipped to match the right eye.
- Correlation analysis was performed to evaluate the correlation between HOAs and DOF.
Corneal aberrations:
No prior corneal surgery
Corneal aberrations:
Prior myopic-PRK

Coefficients (µm)

\[ Z_3^{-3} \quad Z_3^{-1} \quad Z_3^1 \quad Z_3^3 \quad Z_3^4 \quad Z_4^{-4} \quad Z_4^{-2} \quad Z_4^0 \quad Z_4^4 \quad Z_5^{-5} \quad Z_5^{-1} \quad Z_5^5 \quad Z_5^1 \quad Z_5^3 \quad Z_5^5 \quad Z_6^{-6} \quad Z_6^{-2} \quad Z_6^0 \quad Z_6^2 \quad Z_6^4 \quad Z_6^6 \]
Corneal aberrations:
Prior hyperopic-LASIK

Coefficients (µm)

-0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8

Z^3 -3 Z^3 -1 Z^3 1 Z^4 -4 Z^4 0 Z^4 4 Z^5 -5 Z^5 -1 Z^5 1 Z^5 5 Z^6 -6 Z^6 -2 Z^6 0 Z^6 6
DOF curves: No prior corneal surgery
DOF curves: Prior myopic-PRK
DOF curves: Prior hyperopic-LASIK
DOF (D): mean ± SD (range)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Normal corneas (n=220)</th>
<th>Myopic-PRK corneas (n=102)</th>
<th>Hyperopic-LASIK corneas (n=106)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOF80</td>
<td>0.53 ± 0.08 (0.4 to 0.8)</td>
<td>0.57 ± 0.13* (0.4 to 1.3)</td>
<td>0.61 ± 0.20* (0.3 to 1.4)</td>
</tr>
<tr>
<td>DOF50</td>
<td>0.96 ± 0.15 (0.6 to 1.7)</td>
<td>1.04 ± 0.25 (0.6 to 2.4)</td>
<td>1.18 ± 0.43 (0.6 to 2.7)</td>
</tr>
<tr>
<td>DOF0.1</td>
<td>1.21 ± 0.20 (0.2 to 1.9)</td>
<td>1.32 ± 0.23† (0.7 to 2.4)</td>
<td>1.31 ± 0.34† (0.4 to 2.5)</td>
</tr>
</tbody>
</table>

Significant differences between groups except pairs with * and † (all P<0.05 with Bonferroni correction)
Stepwise multiple regression: No prior corneal surgery

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Multiple correlation coefficient R</th>
<th>Zernike terms with significant contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOF80</td>
<td>0.530</td>
<td>6</td>
</tr>
<tr>
<td>DOF50</td>
<td>0.547</td>
<td>6</td>
</tr>
<tr>
<td>DOF0.1</td>
<td>0.465</td>
<td>7</td>
</tr>
</tbody>
</table>
## Stepwise multiple regression: Prior myopic-PRK

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Multiple correlation coefficient $R$</th>
<th>Zernike terms with significant contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOF80</td>
<td>0.521</td>
<td>4</td>
</tr>
<tr>
<td>DOF50</td>
<td>0.401</td>
<td>3</td>
</tr>
<tr>
<td>DOF0.1</td>
<td>0.484</td>
<td>4</td>
</tr>
</tbody>
</table>
### Stepwise multiple regression: Prior hyperopic-LASIK

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Multiple correlation coefficient R</th>
<th>Zernike terms with significant contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOF80</td>
<td>0.469</td>
<td>3</td>
</tr>
<tr>
<td>DOF50</td>
<td>0.561</td>
<td>6</td>
</tr>
<tr>
<td>DOF0.1</td>
<td>0.396</td>
<td>2</td>
</tr>
</tbody>
</table>
DOF ↑ with + or – coefficients of Zernike terms

- Normal corneas:
  - + coefficients of: $Z_{4}^{0}, Z_{4}^{2}, Z_{4}^{-2}, Z_{5}^{-5}, Z_{5}^{3}$,
  - - coefficients of: $Z_{6}^{0}, Z_{6}^{2}, Z_{4}^{-4}, Z_{4}^{0}$,

- Myopic-PRK corneas:
  - + coefficients of: $Z_{3}^{-1}, Z_{4}^{0}, Z_{5}^{1}$,
  - - coefficients of: $Z_{3}^{1}, Z_{3}^{3}, Z_{4}^{4}$,
DOF $\uparrow$ with + or – coefficients of Zernike terms

- **Hyperopic-LASIK corneas:**
  - + coefficients of: $Z_5^{-3}$, $Z_5^3$, $Z_6^{-4}$,
  - - coefficients of: $Z_3^{-1}$, $Z_3^1$, $Z_4^0$, $Z_4^2$, $Z_5^{-5}$,
Summary of stepwise multiple regression results

- **Normal cornea:**
  - DOF ↑ with ↑ 4\textsuperscript{th}-order SA
  - 3\textsuperscript{rd} order vertical coma contributed to DOF50

- **Myopic-PRK corneas:**
  - 3\textsuperscript{rd} order coma significantly contributed to DOF
  - DOF0.1 ↑ with ↑ 4\textsuperscript{th}-order SA

- **Hyperopic-LASIK corneas:**
  - 3\textsuperscript{rd} order coma significantly contributed to DOF
  - DOF ↑ with ↓ negative 4\textsuperscript{th}-order SA
Normal corneas: HOAs vs. DOF

DOF80

\[ R = 0.303, \ P < 0.001 \]

DOF50

\[ R = 0.382, \ P < 0.001 \]

DOF0.1

\[ R = 0.06, \ P = 0.379 \]
Myopic-PRK corneas: HOAs vs. DOF

- DOF80
  \[ R = 0.300, \ P = 0.002 \]

- DOF50
  \[ R = 0.211, \ P = 0.03 \]

- DOF0.1
  \[ R = 0.116, \ P = 0.247 \]
Hyperopic-LASIK corneas: HOAs vs. DOF

- DOF80: $R=0.461, P<0.001$
- DOF50: $R=0.583, P<0.001$
- DOF0.1: $R=0.081, P=0.407$
Summary

- DOF values were greater in post-myopic and post-hyperopic corneas than in normal eyes.
- Corneas with hyperopic-LASIK had greater DOF50 than those with myopic-PRK.
Summary

- Depending on the DOF criterion used, certain Zernike terms significantly contributed to the DOF.

- Those terms were slightly different in normal corneas and corneas following myopic or hyperopic surgeries.
  - Primarily due to the altered wavefront aberration profiles induced by the surgical procedure.
Summary

- Weakly positive correlation between HOAs and DOF in normal corneas and corneas with prior myopic-PRK
- Moderately positive correlation between HOAs and DOF in corneas with prior hyperopic-LASIK
Limitations

- Theoretical study
- Clinical correlation to measurements of DOF in patients is desirable
Conclusion

- Corneal wavefront aberrations play a role in corneal pseudo-accommodation
- Surgical procedures alter the profile of corneal aberrations and effect corneal pseudo-accommodation
Thank you for your attention!

New Cullen Eye Institute Building