Aberration Interaction In Wavefront Guided Custom Ablation

Scott M. MacRae MD
Professor of Ophthalmology
Professor of Visual Science
University of Rochester
Collaborators and Disclosures:

- Manoj Subbaram Venkiteshwar, PhD, Bausch and Lomb
- Geunyoung Yoon, PhD, Consultant Bausch and Lomb
- Dr. MacRae Consultant to Bausch and Lomb, AMO, Starr Surgical
Zyoptix FDA Trial: Results (n=340)

- Mean SE = $+0.17 \pm 0.51$ D
- 91.5% attained UCVA of 20/20 or better
- 75.9% were within $\pm 0.50$ D of target SE

<table>
<thead>
<tr>
<th>Parameter @ 6 months</th>
<th>Postop Myopia (SE $&lt; -0.50$ D)</th>
<th>Postop Hyperopia (SE $&gt; +0.50$ D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidence</td>
<td>14 eyes (4.2%)</td>
<td>74 eyes (21.8%)</td>
</tr>
<tr>
<td>Preop SA (microns)</td>
<td>$0.25 \pm 0.18$</td>
<td>$0.38 \pm 0.18$</td>
</tr>
<tr>
<td>Pre 3\textsuperscript{rd} RMS (microns)</td>
<td>$0.22 \pm 0.14$</td>
<td>$0.35 \pm 0.22$</td>
</tr>
</tbody>
</table>
Aberration Interaction

- Defocus and SA
  - High Preop Sphere treatment causes SA
  - High Preop SA causes Postop Sphere increase

- High Preop SA causes Postop Sphere increase

- V. coma, H. coma, trefoil, secondary astigmatism, spherical aberration, secondary quadrafoil astigmatism

- 2nd Order, 3rd Order, 4th Order
**Positive Spherical aberration = 0.5 µm**

Defocus (µm) =

**Monochromatic light (6mm pupil)**

**Polychromatic light (6mm pupil)**

Defocus:Spherical aberration = 3:1
**Negative Spherical aberration = -0.5 µm**

Defocus (µm) =

**Monochromatic light (6mm pupil)**

**Polychromatic light (6mm pupil)**

Defocus:Spherical aberration = 3:1
Aberration Interaction

- 3rd order and defocus
  - among eyes with cyl

2nd Order
- astigmatism
- defocus
- astigmatism

3rd Order
- trefoil
- V. coma
- H. coma
- trefoil

4th Order
- quadrafoil
- secondary astigmatism
- spherical aberration
- secondary astigmatism
- quadrafoil
Aberration Interaction

- Coma and astigmatism
  - discrepancy in cyl and/or axis between MR and WR

2\textsuperscript{nd} Order
- astigmatism
- defocus
- astigmatism

3\textsuperscript{rd} Order
- trefoil
- coma
- coma
- trefoil

4\textsuperscript{th} Order
- quadrafoil
- secondary astigmatism
- spherical aberration
- secondary quadrafoil astigmatism
When optics centered:
No optical interaction between coma and astigmatism

Vertical coma_z7 = 0.5 μm
astigmatism_z5 (μm) = Astig=0 μm
Decentration

Optics decentered: results in an optical interaction between coma and astigmatism
Eye with Coma: Pupil decentration induces cylinder (defocus+astigmatism).

Decentration

4.0mm pupil

0mm

0.5mm

1.0mm

Defocus

0-180 degree astigmatism

Vertical coma

Zernike coefficient (µm)
Aberration Interaction

- SA and coma
  - decentered SA causes coma

2nd Order
- astigmatism
- defocus
- astigmatism

3rd Order
- trefoil
- coma
- trefoil

4th Order
- quadrafoil
- secondary astigmatism
- spherical aberration
- secondary quadrafoil astigmatism
Aberration Interactions: Hyperopic Overcorrection

1. Aberration interaction between preop $3^{rd}$ & $4^{th}$ order (coma, trefoil & spherical aberration) with postop sphere and cylinder causing postop overcorrection and undercorrection.

2. Aberration Interaction Hyperopic overcorrection noted with $>5$ laser platforms:
   - A. Bausch and Lomb (current studies)
   - B. Alcon: Myopic Retreatment eyes with + spherical aberration tend to get hyperopic overcorrection (Two studies: #1 D. Durrie JRS 2005, #2 G.S. Schwartz JCRS 2005)
   - D. VISX: Hyperopic Overcorrections with Myopic Retreatments D. Hardin, E. Manche
   - E. Wavelight: Hyperopic Overcorrection with high + SA
The Univ. of Rochester Nomogram*
Compensates for Aberration Interaction

Unique Features

- Utilizes the preoperative manifest refraction
  - SE, J0, and J45
  - NOT wavefront sphere

- Compensates for aberration interactions:
  - Accounts for preoperative 3rd and 4th order higher order aberrations effect on postop sphere
  - Optical convolution

- Treatment sphere based on
  - Individual eye parameters
  - NOT a constant surgeon offset

*Patent filed
Clinical Study (508 eyes)

- LASIK (445 eyes)
  - Mean SE: -4.57 ± 1.97 D
  - Mean Cyl: -0.76 ± 0.69 D
  - Mean HORMS: 0.53 ± 0.31 µm

- PRK (63 eyes)
  - Mean SE: -6.65 ± 2.35 D
  - Mean Cyl: -0.81 ± 0.72 D
  - Mean HORMS: 0.52 ± 0.19 µm
The Rochester Nomogram

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LASIK 445 eyes</th>
<th>PRK 63 eyes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-month postop Sphere</td>
<td>+0.04 ± 0.21 D (±1 D)</td>
<td>+0.08 ± 0.29 D (±1 D)</td>
</tr>
<tr>
<td>SE</td>
<td>-0.04 ± 0.21 D (±1 D)</td>
<td>-0.05 ± 0.30 D (±1 D)</td>
</tr>
<tr>
<td>% UCVA ≥ 20/20</td>
<td>94.6%</td>
<td>90.5%</td>
</tr>
<tr>
<td>% SE within ±0.50 D</td>
<td>96.4%</td>
<td>89.9%</td>
</tr>
</tbody>
</table>

% overcorrections (SE > +0.50 D): 1.3% (6/445) (Previous FDA Study 22.8%)
Conclusions: Aberration Interaction and Customized Ablation

- **Aberration interactions (AI)** is important and occurs in multiple laser platforms

- Preop HOA affects postop sphere & cylinder

- Univ. of Rochester nomogram (508 eyes)
  - LASIK eyes with postop UCVA > 20/20: 94.6%
  - PRK eyes with postop UCVA > 20/20: 90.5%
  - SE within ±1 D: 100%

- Compensation of **Aberration Interaction offers better results!**
Aberration Interaction

Secondary astigmatism and astigmatism
- **OPTICAL** relationship
2nd astigmatism_z11 = 0.5 µm

Astigmatism_z3 (µm) = 

1ºAstigmatism: 2nd astigmatism = 3:1

Monochromatic light (6mm pupil)

Polychromatic light (6mm pupil)

Volume MTF under 60c/deg
The Rochester Nomogram for Pharmacologic vs Non Pharmacologic Dilated Zyoptix

Scott M. MacRae MD
Manoj V. Subbaram BS Optom., PhD
Geun Young Yoon PhD
University of Rochester
&
Ian Cox OD PhD
Bausch and Lomb
Rochester Nomogram: Pharmacologic vs Non Pharmacologic Dilated Zyoptix

- 175 eye 2.5% Neosympheine Dilated Zyoptix
- 90 eye Gulden Black Hood: low mesopic Zywaves
- 6.3 mm pupil diameter minimal (60.7% of eyes could be dilated to 6.3mm)
Luminance/Illumination
Photometry Testing

- Tectronics Lumicolor J17 Photometer/Radiometer
- Rural Low Light Night Driving: 0.15 Candellas/meter
- Zywave Maltese Cross: 0.05 Candellas/meter
  (1/3 of night driving illumination)
Results (ROC nomogram)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2.5% Neosynephrine (175 eyes)</th>
<th>No Neosynephrine (90 eyes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preop Sph Eq (D)</td>
<td>-4.89 ± 2.06</td>
<td>-4.39 ± 2.08</td>
</tr>
<tr>
<td>Preop Sphere (D)</td>
<td>-4.52 ± 2.05</td>
<td>-4.11 ± 2.04</td>
</tr>
<tr>
<td>Preop Cyl (D)</td>
<td>-0.81 ± 0.70</td>
<td>-0.56 ± 0.5</td>
</tr>
<tr>
<td>Preop HOA (um)</td>
<td>0.53 ± 0.16</td>
<td>0.53 ± 0.14</td>
</tr>
<tr>
<td>1-month Sph Eq (D)</td>
<td>-0.11 ± 0.34</td>
<td>-0.08 ± 0.23</td>
</tr>
<tr>
<td>Range Sph Eq (D)</td>
<td>-1 to +1 D</td>
<td>-0.63 to +0.50</td>
</tr>
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Standard Deviations of 0.34 or 0.23 D are close to the SD of manifest refraction repeatability: Bullimore 0.2; Nizam 0.33 D; Blackhust 0.28 D
### Zyoptix - Rochester Nomogram

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Zyoptix FDA trial (112 eyes)</th>
<th>Rochester Nomogram</th>
<th>Pharm. dilation (n = 175)</th>
<th>Natural mesopic pupil (n = 90)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preop SE (D)</td>
<td>-3.41 ± 1.44</td>
<td>-4.89 ± 2.06</td>
<td>-4.39 ± 2.08</td>
<td></td>
</tr>
<tr>
<td>Preop HOA (um)</td>
<td>0.45 ± 0.16</td>
<td>0.53 ± 0.16</td>
<td>0.53 ± 0.14</td>
<td></td>
</tr>
<tr>
<td>Postop UCVA &gt; 20/20</td>
<td>89.3%</td>
<td>93.1%</td>
<td>94.6%</td>
<td></td>
</tr>
<tr>
<td>Postop SE (D)</td>
<td>+0.26 ± 0.50 (-1.04 to +1.81)</td>
<td>-0.11 ± 0.34 (-1 to +1)</td>
<td>-0.08 ± 0.23 (-0.63 to +0.50)</td>
<td></td>
</tr>
<tr>
<td>Postop SE +0.50D</td>
<td>≤ 71.4%</td>
<td>91.4%</td>
<td>97.8%</td>
<td></td>
</tr>
</tbody>
</table>

Better postop VA and SE (both pharmacological dilation & natural mesopic pupil)