Custom optimization of intraocular lens asphericity

Li Wang, M.D., Ph.D.
Douglas D. Koch, M.D.
Cullen Eye Institute
Baylor College of Medicine
Houston, TX
Spherical Aberration (SA) in IOLs

- Standard IOLs have (+) SA
  - Add to the + 0.27 \( \mu \)m SA in the cornea

- Aspherical IOLs designed to compensate for the (+) SA of the cornea
## Aspheric IOLs

<table>
<thead>
<tr>
<th>Pupil Size</th>
<th>IOL SA (µm)</th>
<th>Ocular SA (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AcrySof IQ</td>
<td>0.20</td>
<td>~ + 0.1</td>
</tr>
<tr>
<td>Tecnis</td>
<td>0.27</td>
<td>~ 0.00</td>
</tr>
<tr>
<td>SofPort AO</td>
<td>0.00</td>
<td>~ +0.28</td>
</tr>
</tbody>
</table>
What is the optimal amount of SA?

- Other higher-order aberrations (HOAs) exist in human eye
- HOAs vary greatly among subjects*
- Aberrations in different Zernike terms interact to ↑ or ↓ optical performance*

* Wang L, Koch DD. JCRS 2003; 29:1702-08
Purpose

- To investigate the optimal amount of ocular SA to achieve maximum optical quality
- To explore methods predicting the optimal SA based on other HOAs of the cornea
Methods

- Patients:
  - 154 eyes of 94 patients aged 40-80 years
  - Humphrey Atlas maps
  - Corneal wavefront aberrations calculated using VOL-CT (Sarver and Associate)
Methods

- In each eye, we simulated implantation of aspherical IOLs with different amounts of SA
  - To produce residual ocular SA from -0.30 µm to +0.30 µm with interval of 0.01 µm
  - 61 aspherical IOLs for each eye
Methods

- Residual ocular aberrations with implanted aspherical IOLs
  - HOAs only (3rd to 6th order), assuming well-corrected 2nd-order aberrations
  - 4th order SA ranged: -0.30 to +0.30 µm
  - All other HOAs (except 4th order SA) equal to that in the cornea
Methods

- Using Zernike Tool program (AMO-VISX), polychromatic point spread function (PSF) with Stiles-Crawford effect calculated (6-mm pupil)
- 5 parameters used to quantify the optical image quality
5 parameters

- Modulation transfer function volume (MTFV) up to 30 c/d
  - 3-D Volume under the MTF curve
- MTFV up to 15 c/d
- Strehl ratio
  - Ratio of peak focal intensities in aberrated PSF and ideal PSF
- Encircled Energy (EE) at 2 arc minutes
  - EE: fractional energy within a given radius
- EE at 4 arc minutes
Optimal amount of SA for each eye

- Selected the ocular SA at which the maximum quality of image was achieved as “Optimal SA” for that eye.

![Graph showing MTFV up to 30 c/d with SA=-0.13]
Statistical analysis

- Calculated % of eyes that had max. image quality with certain amounts of 4\textsuperscript{th} order SA (0.05 µm interval)
- Performed stepwise multiple regression analysis to assess the predictors for optimal SA of each eye
Results

- Most of eyes did not have best image quality at SA of 0 µm
Results

MTFV up to 30 c/d

% of eyes

Ocular SA (microns)
Results

MTFV up to 15 c/d

% of eyes

Ocular SA (microns)
Results

Strehl ratio

% of eyes

0 10 20 30 40 50 60 70
-0.30 -0.25 -0.20 -0.15 -0.10 -0.05 0.00 0.05 0.10 0.15 0.20 0.25 0.30
Ocular SA (microns)

0.0 3.2 0.6 3.9 7.1 34.4 31.2 12.3 4.5 1.9 0.6 0.0
Results

Encircled Energy (2 arc minutes)

% of eyes

Ocular SA (microns)
Results

Encircled Energy (4 arc minutes)

% of eyes vs. Ocular SA (microns)

0 0.0 0.0 0.6 5.2 45.5 40.9 6.5 1.3 0.0

-0.30 -0.25 -0.20 -0.15 -0.10 -0.05 0.00 0.05 0.10 0.15 0.20 0.25 0.30

Ocular SA (microns)

% of eyes

0 10 20 30 40 50 60 70
Predicting optimal SA: MTFV (30 c/d)

- 8 predictors with $R = 0.794$, $R^2 = 0.630$
  - $C_4^0 = 1.75C_6^0 + 0.51C_6^2 + 0.05C_3^{-1} - 0.1C_4^2 - 0.26C_5^3 + 0.31C_6^4 - 0.07C_3^3 - 0.04C_3^1 - 0.05$
Predicting optimal SA: MTFV (15 c/d)

- 8 predictors with $R = 0.889$, $R^2 = 0.791$
  
$$C_4^0 = 1.48C_6^0 - 0.11C_4^2 - 0.21C_5^3 + 0.29C_6^2 + 0.03C_3^{-1} + 0.22C_6^4 - 0.04C_3^3 - 0.02C_3^{-1} - 0.06$$

[Image of Zernike modes diagram]
Predicting optimal SA: Strehl ratio

- 4 predictors with $R = 0.611$, $R^2 = 0.374$
  - $C_4^0 = -0.41C_4^2 + 0.99C_6^0 + 0.51C_5^1 - 0.06C_3^1 - 0.03$
Predicting optimal SA: Encircled Energy

- **EE 2 arc minutes**
  - 6 predictors with $R = 0.563$, $R^2 = 0.317$
    - $C_4^0 = 1.16C_6^0 + 0.23C_4^2 + 0.09C_3^3 - 0.09C_3^3 - 0.44C_6^{-4} + 0.16C_5^{-5} - 0.03$

- **EE 4 arc minutes**
  - 3 predictors with $R = 0.608$, $R^2 = 0.369$
    - $C_4^0 = 0.86C_6^0 + 0.15C_6^6 - 0.24C_6^{-2} - 0.07$
What about depth of focus with different amounts of residual ocular SA?
IOL “selection” to alter 4th-order SA

Residual ocular SA

- Standard IOL ⇒ +0.45 µm
- IOL with no SA ⇒ +0.27 µm
- IOL with -0.27 SA ⇒ 0 µm
- IOL with -0.47 SA ⇒ -0.20 µm
Perfect cornea except SA: Monochromatic MTF
Average cornea: Poly MTF + Stiles-Crawford effect
Complete correction or reduction of HOAs
Poly MTF + Stiles-Crawford effect

- **Correct all HOAs**
- **Reduce SA to 0**
- **Average cornea with spherical IOL (SA=0.45)**

MTF vs. Defocus (D)
Limitations

- Theoretical data
  - Evaluation in clinical patients desirable
- Assumes 2nd order aberrations (defocus, astig) fully corrected
  - Optimal SA differ with residual defocus / astig
- Assumes perfect centration
- Ignores neuroadaptive response
Perceptual adaptation

- In the following slides, you will see how adaptation affects perception
- 3 pairs of images
  - 1st and 3rd pair are the same

* Webster, Georgeson, and Webster. Nature Neuroscience 2002
Adaptation to Blur

Pre-adapt

stare at the fixation point while adapting
Post-adapt
Conclusion

- Optimal SA producing best image quality varied largely among subjects
- Optimal amount of SA could be predicted based on other HOAs
  - MTFV up to 15 c/d
    - 8 predictors with $R = 0.889$, $R^2 = 0.791$
  - MTFV up to 30 c/d
    - 8 predictors with $R = 0.794$, $R^2 = 0.630$
Conclusion

- Customization of IOL selection should be based on the full spectrum of pre-existing corneal HOAs and not on 4th order SA alone.
Thank you for your attention!

Ski Santa Fe
Results

MTFV up to 30c/d

Optimal SA = -0.03

14.3%
Results

MTFV up to 15 c/d

Optimal SA = -0.06
19.5%
Results

Optimal SA = -0.03

9.7%
Results

Encircled Energy (2 arc minutes)

Optimal SA = -0.03

11.0%
Results

Encircled Energy (4 arc minutes)

Optimal SA = -0.08

16.2%
Neuroadaptation

Artal:

- Eye is adapted to its own HOAs*
  - Rotated version of HOAs ⇒ ↓ quality of vision
- Capable of readapting to new HOAs
  - Magnitude and timing of this response under study