Surgical data reveals that Q-Factor is important for good surgical outcome

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Some history
1st Wavefront Congress, Santa Fe, 2000
Background

Spherical based ablation profiles (hyperopia)
Munnerlyn’s profile

- Pre- and post asphericity are assumed to be equal
  \[ Q_1 = Q_2 = 0 \]
- Valid one for very small optical zones
- Assumes paraxial optics
- Paraxial + small optical zone allows to neglect the pre- and postoperative operative corneal curvature:

\[
a(r) = a_{\text{max}} - \frac{\Delta Dr^2}{2(n - 1)}
\]

**Background**

Ablation profile for sphere based on wavefront theory

- Change in corneal shape equals to wavefront aberrations

\[
a(r) = a_{\text{max}} - \frac{W(r, \phi)}{(n - 1)}
\]

- Wavefront defocus can be represented in diopter

\[
C_4 = \frac{\Delta D r_0^2}{4}
\]

- Ablation profile

\[
a(r) = a_{\text{max}} - \frac{\Delta D r^2}{2(n - 1)}
\]
Background

Change in asphericity due to a defocus correction

- The cornea has an aspherical shape
  \[
  z(x, y) = \frac{-R + \sqrt{R^2 - (1 + Q)(x^2 + y^2)}}{1 + Q}
  \]
- There is a change in the corneal asphericity when using Munnerlyn’s ablation profile
  \[
  dQ \approx -8\Delta DR_1 Q_1
  \]

Q-value and spherical aberration

Preoperative spherical aberration of the cornea

\[ c_{4,\text{pre}}^0 = \frac{\sqrt{5}(Q_{\text{pre}} + 1)}{240r_{\text{pre}}^3} + \frac{\sqrt{5}(Q_{\text{pre}} + 1)^3}{320r_{\text{pre}}^5} + \frac{\sqrt{5}(Q_{\text{pre}} + 1)^5}{448r_{\text{pre}}^7} + \frac{5\sqrt{5}(Q_{\text{pre}} + 1)^7}{3072r_{\text{pre}}^9} + \ldots \]

Postoperative spherical aberration of the cornea

\[ c_{4,\text{post}}^0 = \frac{\sqrt{5}(Q_{\text{post}} + 1)}{240r_{\text{post}}^3} + \frac{\sqrt{5}(Q_{\text{post}} + 1)^3}{320r_{\text{post}}^5} + \frac{\sqrt{5}(Q_{\text{post}} + 1)^5}{448r_{\text{post}}^7} + \frac{5\sqrt{5}(Q_{\text{post}} + 1)^7}{3072r_{\text{post}}^9} + \ldots \]

Induced spherical aberration

\[ \Delta c_4^0 = c_{4,\text{pre}}^0 - c_{4,\text{post}}^0 = 0 \]
Postoperative corneal asphericity that does not induce spherical aberration

SPHERICAL MYOPIA CORRECTION [D]

POST-OP q-VALUE
Distribution of asphericity in a normal population

Mainly negative Q-values

The mean shape of the human cornea
P.M. KIELY, G. SMITH and L.G. CARNEY
OPTICA ACTA, 1982, Vol. 29, No. 8, 1027-1040

PD Dr. Michael Mrochen, 3/7/07
The role of intraocular structures

Corneal aberrations

Wavefront

Total aberrations
Spherical aberration vs. Q-value

Fit Resultate:
$r = 0.55415$
$p < 0.0001$

- Significant correlation
- Extreme large scatter in data set
- Impact of intraocular structures
Ideal Q-value for zero spherical aberration

- Navaro eye model (others were used too)
- Variation of corneal curvatures according to the amount of myopic correction
- Variation of the lens power and lens asphericity according to their typically published ranges
### Data set for Navaro eye model

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Low-power lens</th>
<th>Standard Lens</th>
<th>High-power lens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radii of curvature (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r2</td>
<td>13.78</td>
<td>10</td>
<td>7.66</td>
</tr>
<tr>
<td>r3</td>
<td>-8.27</td>
<td>-6</td>
<td>-4.59</td>
</tr>
<tr>
<td>Axial thickness (d2)</td>
<td>2.9</td>
<td>3.6</td>
<td>4.5</td>
</tr>
<tr>
<td>Surface powers (D)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F2</td>
<td>6</td>
<td>8.27</td>
<td>10.8</td>
</tr>
<tr>
<td>F3</td>
<td>10</td>
<td>13.78</td>
<td>18</td>
</tr>
<tr>
<td>Equivalent power (D)</td>
<td>15.88</td>
<td>21.76</td>
<td>28.18</td>
</tr>
<tr>
<td>Assumed depth of anterior chamber</td>
<td>4.1</td>
<td>3.6</td>
<td>3</td>
</tr>
</tbody>
</table>

- \( Q = -6.1 \)
- \( Q = -3.1 \)
- \( Q = -0.1 \)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Mean value</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corneal radius (mm)</td>
<td>7.86</td>
<td>7.0 to 8.8</td>
</tr>
<tr>
<td>Corneal power (D)</td>
<td>42.74</td>
<td>38 to 48</td>
</tr>
<tr>
<td>Depth of anterior chamber (mm) incl. corneal thickness</td>
<td>3.68</td>
<td>2.8 to 4.6</td>
</tr>
<tr>
<td>Equivalent power of lens (D)</td>
<td>21.3</td>
<td>15 to 29</td>
</tr>
<tr>
<td>Equivalent power of eye (D)</td>
<td>60.1</td>
<td>51 to 70</td>
</tr>
</tbody>
</table>

189 modified eye models
Ideal Q-value for zero spherical aberration

Medium Power Cornea
Highly negative Q of Lens

Medium Power Cornea
Mean Q of Lens

Medium Power Cornea
Q of lens close to zero

- Ideal corneal asphericity Q
- Pre-op refraction [D]

- High Power Lens
- Medium Power Lens
- Low Power Lens

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Ideal Q-value for zero spherical aberration

Lens with highly negative Q

Lens with mean negative Q

Lens with Q close to zero

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The ideal Q-value depends mainly on the optical characteristics of the intraocular structures.

--> Theoretically individual wavefront corrections of higher orders with Q-value based profiles are not possible.
Ideal Q-value for zero spherical aberration – Ray tracing
Ideal Q-value for zero spherical aberration

- Ray tracing algorithm
- Calculated ideal corneal asphericity for zero spherical aberration
- Data set generated
- Pupil size 6.0 mm
Theoretical Results
individual eye models

Theoretical eye models based on "mean values"
do not help to determine the ideal Q-value after corneal laser surgery

-> customized eye model
### Theoretical Results

#### Ray tracing profiles

<table>
<thead>
<tr>
<th>Patient</th>
<th>Eye</th>
<th>Q-value</th>
<th>Spherical Aberration [microns]</th>
<th>Q-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>J.F.</td>
<td>OD</td>
<td>-0.58</td>
<td>0.04</td>
<td>-0.43</td>
</tr>
<tr>
<td>J.F.</td>
<td>OS</td>
<td>-0.43</td>
<td>0.06</td>
<td>-0.22</td>
</tr>
<tr>
<td>S.W.</td>
<td>OD</td>
<td>0.75</td>
<td>-0.29</td>
<td>-0.35</td>
</tr>
<tr>
<td>S.W.</td>
<td>OS</td>
<td>0.79</td>
<td>-0.27</td>
<td>-0.23</td>
</tr>
<tr>
<td>F.E.</td>
<td>OD</td>
<td>-0.60</td>
<td>0.02</td>
<td>-0.51</td>
</tr>
<tr>
<td>D.A.</td>
<td>OD</td>
<td>-0.37</td>
<td>-0.07</td>
<td>-0.65</td>
</tr>
<tr>
<td>D.A.</td>
<td>OS</td>
<td>-0.43</td>
<td>-0.07</td>
<td>-0.71</td>
</tr>
<tr>
<td>E.M.</td>
<td>OD</td>
<td>-0.16</td>
<td>-0.06</td>
<td>-0.40</td>
</tr>
<tr>
<td>B.B.</td>
<td>OD</td>
<td>0.50</td>
<td>-0.22</td>
<td>-0.34</td>
</tr>
<tr>
<td>B.B.</td>
<td>OS</td>
<td>0.84</td>
<td>-0.13</td>
<td>0.36</td>
</tr>
<tr>
<td>W.M.</td>
<td>OD</td>
<td>-0.03</td>
<td>-0.08</td>
<td>-0.34</td>
</tr>
<tr>
<td>B.M.</td>
<td>OS</td>
<td>-0.20</td>
<td>0.01</td>
<td>-0.15</td>
</tr>
</tbody>
</table>

**Refractive range:** +8 D to -12 D
Clinical outcomes study group

N = 35 eye (15 right & 20 left eyes)

RMS < 0.4 μm; 6.0 mm pupil

Tobias Koller et al: Q-factor customized ablation profile for the correction of myopic astigmatism J CATARACT REFRACT SURG - VOL 32, APRIL 2006
Clinical outcomes – study group

<table>
<thead>
<tr>
<th>Table 3. Safety of wavefront-guided versus custom-Q treatment.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VA Type/Group</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>BCVA</td>
</tr>
<tr>
<td>WG</td>
</tr>
<tr>
<td>Custom-Q</td>
</tr>
<tr>
<td>Low contrast VA</td>
</tr>
<tr>
<td>WG</td>
</tr>
<tr>
<td>Custom-Q</td>
</tr>
<tr>
<td>Glare VA</td>
</tr>
<tr>
<td>WG</td>
</tr>
<tr>
<td>Custom-Q</td>
</tr>
</tbody>
</table>

BCVA = best corrected visual acuity; Custom-Q = Q-factor customized treated eyes; VA = visual acuity; WG = wavefront-guided treated eyes

Tobias Koller et al: Q-factor customized ablation profile for the correction of myopic astigmatism J CATARACT RE FRACT SURG - VOL 32, APRIL 2006
Summary

- A prolate shape does not essentially mean a good optical quality; some eyes require an oblate shape.
- Q-value based ablation profiles are able to maintain the preoperative spherical aberration, if patients are preselected.
- Q-value based ablation profiles are not able to correct for preoperative spherical aberration.
- However, there were no clinical difference in Q-value versus wavefront-guided treatments (small study group).
- Ideal correction is only given by combining topography, wavefront and biometry.
Conclusions

Q-value based ablation profiles are a good solution for customized corrections,

if wavefront measurements are not available or

if there are no significant preoperative optical aberration present \((\text{rms} < 0.3 \ \mu\text{m}; \ 6 \ \text{mm pupil})\)
Thank you