Wavefront Analysis and IOLs: What is Lacking?

Karolinne Maia Rocha, MD

Federal University of São Paulo – UNIFESP

BRAZIL

No financial interest
Cornea and Lens HOA
Cornea and Lens HOA

Optical System

Spherical IOLs

Aspheric IOL

Multifocal IOLs

Toric IOLs

Light Adjustable

Young Eyes →

crystalline lens: *Negative* spherical aberration
cornea surface: *Positive* spherical aberration

Aging crystalline lens → towards less negative

The total optical spherical aberration becomes positive.

Spherical aberration X Age

* Wang et al., JCRS 2005; 31:1512-9
### Higher-order aberrations of lenticular opacities

<table>
<thead>
<tr>
<th>Age</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 months</td>
<td><img src="image1" alt="Image" /></td>
</tr>
<tr>
<td>8 years</td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>12 years</td>
<td><img src="image3" alt="Image" /></td>
</tr>
<tr>
<td>15 years</td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>47 years</td>
<td><img src="image5" alt="Image" /></td>
</tr>
<tr>
<td>60 years</td>
<td><img src="image6" alt="Image" /></td>
</tr>
<tr>
<td>70 years</td>
<td><img src="image7" alt="Image" /></td>
</tr>
<tr>
<td>82 years</td>
<td><img src="image8" alt="Image" /></td>
</tr>
<tr>
<td>90 years</td>
<td><img src="image9" alt="Image" /></td>
</tr>
</tbody>
</table>
Nuclear Cataract *

Cornea and Lens HOA
Spherical IOLs
Aspheric IOL
Multifocal IOLs
Toric IOLs
Light Adjustable

What is Lacking
What is Lacking?

The light rays are over-refracted at the periphery of an optical structure.
Spherical IOL

Cornea and Lens HOA

Spherical IOLs

Aspheric IOL

Multifocal IOLs

Toric IOLs

Light Adjustable

What is Lacking?

SA60AT®
Aspheric IOL

Cornea and Lens HOA

Spherical IOLs

Aspheric IOL

Multifocal IOLs

Toric IOLs

Light Adjustable

What is Lacking?
Spherical Aberration & Pupil

Spherical IOLs

Aspheric IOL

Multifocal IOLs

Toric IOLs

Light Adjustable

What is Lacking?
Spherical Aberration & Pupil

- Cornea and Lens HOA
- Spherical IOLs
- Aspheric IOL
- Multifocal IOLs
- Toric IOLs
- Light Adjustable
- What is Lacking?
Aspheric IOL

<table>
<thead>
<tr>
<th>Lens Spherical Aberration (µm)</th>
<th>Overall Spherical Aberration (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0 mm</td>
<td></td>
</tr>
<tr>
<td>Pupil Size</td>
<td></td>
</tr>
<tr>
<td>SofPort AO</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Acrysof IQ</td>
<td>0.20&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tecnis</td>
<td>0.27&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Holladay et al. A new intraocular lens design to reduce spherical aberration of pseudophakic eyes. JCRS 2002; 18:683-691.


What Do We Know?
**Wavefront Analysis**

<table>
<thead>
<tr>
<th>AcrySof® Natural OD</th>
<th>AcrySof®IQ OS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spherical</strong></td>
<td>Aspheric</td>
</tr>
<tr>
<td>Refraction from Wavefront</td>
<td>Aberrations</td>
</tr>
<tr>
<td>Sphere: -0.63 Diopters</td>
<td>Defocus: 1.33</td>
</tr>
<tr>
<td>Cylinder: -0.61 Diopters</td>
<td>Astigmatism: 0.40</td>
</tr>
<tr>
<td>Axis: 168 Degrees</td>
<td>Coma: 0.08</td>
</tr>
<tr>
<td>Match: 63%</td>
<td>Spherical Aberration: 0.24</td>
</tr>
<tr>
<td>Diameter: 1.15 mm</td>
<td></td>
</tr>
</tbody>
</table>

![Wavefront Analysis](image)

**Wavefront Wavefront Analysis**

<table>
<thead>
<tr>
<th>Aspheric Aberration: 0.19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere: 0.31 Diopters</td>
</tr>
<tr>
<td>Cylinder: -1.51 Diopters</td>
</tr>
<tr>
<td>Axis: 0 Degrees</td>
</tr>
<tr>
<td>Match: 77%</td>
</tr>
<tr>
<td>Diameter: 1.15 mm</td>
</tr>
</tbody>
</table>

![Wavefront Analysis](image)
**Results: High Order Aberrations**

3 months

Wavefront Analysis and Contrast Sensitivity of Aspheric and Spherical Intraocular Lenses: A Randomized Prospective Study

KAROLINNE MAIA ROCHA, MD, EDUARDO S. SORIANO, MD, MARIA REGINA CHALITA, MD, ANA CAROLINA YAMADA, MD, KÁTIA BOTTÓS, MD, JULIANA BOTTÓS, MD, LISANGELA MORIMOTO, BS, AND WALTON NOSÉ, MD

<table>
<thead>
<tr>
<th>Aberrations</th>
<th>Defocus</th>
<th>Coma</th>
<th>Spherical Aberration</th>
<th>Astigmatism</th>
<th>Trefoil 6</th>
<th>Trefoil 9</th>
<th>RMS HOA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AcrySof® IQ</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 months</td>
<td>0.57±0.56</td>
<td>0.18±0.14</td>
<td><strong>0.03±0.05</strong></td>
<td>0.57±0.41</td>
<td>-0.10±0.19</td>
<td>0.06±0.11</td>
<td><strong>0.35±0.18</strong></td>
</tr>
<tr>
<td><strong>AcrySof® SN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 months</td>
<td>0.64±0.57</td>
<td>0.19±0.13</td>
<td>0.24±0.04</td>
<td>0.61±0.33</td>
<td>-0.09±0.14</td>
<td>0.09±0.09</td>
<td><strong>0.41±0.09</strong></td>
</tr>
<tr>
<td><strong>Sensar™</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 months</td>
<td>0.74±0.54</td>
<td>0.17±0.11</td>
<td>0.14±0.07</td>
<td>0.63±0.36</td>
<td>-0.07±0.16</td>
<td>0.11±0.16</td>
<td><strong>0.40±0.16</strong></td>
</tr>
</tbody>
</table>
Multicentric study
SofPort AO

- 40 patients
- 20 Eyes Sofport / 20 eyes Soflex

<table>
<thead>
<tr>
<th>Aberrations</th>
<th>Defocus</th>
<th>Coma</th>
<th>Spherical Aberration</th>
<th>Astigmatism</th>
<th>Trefoil 6</th>
<th>Trefoil 9</th>
<th>RMS HOA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SofPort AO</strong></td>
<td>0.82 ± 0.51</td>
<td>0.20 ± 0.17</td>
<td>0.16 ± 0.05*</td>
<td>0.56 ± 0.42</td>
<td>-0.02 ± 0.22</td>
<td>0.10 ± 0.13</td>
<td>0.46 ± 0.19</td>
</tr>
<tr>
<td><strong>Soflex SE</strong></td>
<td>0.98 ± 0.51</td>
<td>0.27 ± 0.17</td>
<td>0.24 ± 0.05</td>
<td>0.49 ± 0.42</td>
<td>-0.07 ± 0.22</td>
<td>0.14 ± 0.13</td>
<td>0.61 ± 0.19</td>
</tr>
</tbody>
</table>

* p < 0.05
Contrast Sensitivity

Cornea and Lens HOA

Spherical IOLs

Aspheric IOL

Multifocal IOLs

Toric IOLs

Light Adjustable

What is Lacking?
Functional Acuity Contrast Testing

Mesopic conditions

(3 cd/m²)
Spherical Aberration and Depth of Focus in Eyes Implanted With Aspheric and Spherical Intraocular Lenses: A Prospective Randomized Study


Distance corrected near visual acuity!

<table>
<thead>
<tr>
<th>Visual Acuity</th>
<th>AcrySof®IQ</th>
<th>AcrySof®SN60</th>
<th>Sensar®AR40</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>0.02 (0.05)</td>
<td>0.03 (0.04)</td>
<td>0.02 (0.05)</td>
<td>$p = 0.888$</td>
</tr>
<tr>
<td>Intermediate</td>
<td>0.43 (0.18)</td>
<td>0.33 (0.15)*</td>
<td>0.42 (0.14)</td>
<td>$p = 0.012^*$</td>
</tr>
<tr>
<td>Near</td>
<td>0.51 (0.20)*</td>
<td>0.39 (0.17)*</td>
<td>0.46 (0.16)</td>
<td>$p = 0.022^*$</td>
</tr>
</tbody>
</table>

* Pupil
* Sph-Cyl
- Other HOA
- Cornea HOA

What is Lacking?

Cornea and Lens HOA
Spherical IOLs
Aspheric IOL
Multifocal IOLs
Toric IOLs
Light Adjustable

Cornea and Lens HOA
Spherical IOLs
Aspheric IOL
Multifocal IOLs
Toric IOLs
Light Adjustable
What is Lacking?
Multifocal IOLs

- ReSTOR®
- ReZoom™
- Array®
- Tecnis™
Multifocal IOLs

How could we measure Quality of Vision??

Halos, Glare, Starburst ...
Chandhrasri S, Knorz MC.  
- Photopic contrast sensitivity decrease was significant in the Array group.  
- HOA with a 4-mm pupil were increased in the Array group only.

Wang JC, Tan AW, Monatosh R, Chew PT.  
- 22.7% reported glare usually at night (80%) as compared with daytime glare (20%). The most common photic phenomena report after surgery was halo.

Mester U, Dillinger P, Anterist N, Kaymak H.  
- Most of the patients described dysphotic phenomena,  
- worse contrast sensitivity

Sen HN, Sarikkola AU, Uusitalo RJ, Laatikainen.  
- Halos were significantly more common at 1 m in the multifocal group (P<.001  
- Contrast sensitivity values were slightly lower with multifocal IOLs
Chiam PJ, Chan JH, Aggarwal RK, Kasaby
- Severe halos and moderate halos occurred in 3.8% and 16.3%.
- Moderate glare was reported by 21.3% in the multifocal group and 7.5% in the monofocal group (P = .008)

- Mild to moderate glare and halos: 40% in the multifocal group.
- Photopic contrast sensitivity was statistically lower (P < .001).

- Glare and halos were reported as severe by only 8.5% and 4.2% of patients, respectively.
**Postoperative Wavefront Analysis and Contrast Sensitivity of a Multifocal Apodized Diffractive IOL (ReSTOR) and Three Monofocal IOLs**

Karinmente Maia Rocha, MD; Maria Regina Chalita, MD; Carlos Eduardo B. Souza, MD; Eduardo S. Soriano, MD; Lincoln L. Freitas, MD; Cristina Muccioli, MD; Rubens Belfort, Jr, MD, PhD

<table>
<thead>
<tr>
<th>IOLs</th>
<th>HOA</th>
<th>Spherical</th>
<th>Coma</th>
</tr>
</thead>
<tbody>
<tr>
<td>ReSTOR n=50</td>
<td>0.35 ±0.15</td>
<td>0.09 ±0.05</td>
<td>0.13 ±0.09</td>
</tr>
<tr>
<td>SA60AT n=20</td>
<td>0.43 ±0.13</td>
<td>0.25 ±0.08</td>
<td>0.15 ±0.07</td>
</tr>
<tr>
<td>MA30AC n=20</td>
<td>0.41 ±0.12</td>
<td>0.23 ±0.08</td>
<td>0.17 ±0.08</td>
</tr>
<tr>
<td>Acqua n=15</td>
<td>0.85 ±0.50</td>
<td>0.37 ±0.04</td>
<td>0.23 ±0.11</td>
</tr>
</tbody>
</table>

5 mm*
Wavefront Analysis

Hartmann Shack

* Multifocal diffractive

ReSTOR®

Cornea and Lens HOA

Spherical IOLs

Aspheric IOL

Multifocal IOls

Toric IOls

Light Adjustable

What is Lacking?

5 mm

Coma = 0.17
Sph = 0.10

ReSTOR®

RMS = 0.23μm

Coma = 0.17
Sph = 0.10

Multifocal IOls

* Multifocal

diffractive
Wavefront Analysis

ReSTOR®

ray Tracing

 WF Summary Display

Coma 0.49
Sph 0.08

WF Exam #4

Date 02-06-2007
Time 14:02
Points Accepted 254
Points Rejected 2
Pupil Diameter 7.62 mm
Scan Diameter 5.00 mm
Fixation Target Position + 1.25 D

Auto Refraction
+0.50 D -1.00 D x 79°
+0.63 D -1.09 D x 72° @ 3.00 mm
-0.48 D -0.88 D x 98° @ 4.50 mm
-0.74 D -1.23 D x 116° @ 5.00 mm

RSF 5.00 mm

Total 2.013 μ
LO Total 0.793 μ
Defocus 0.115 μ
Astigmatism 0.785 μ x 26°
HO Total 1.850 μ
Coma 0.499 μ x 292°
Spherical 0.083 μ
Trefoil 0.769 μ x 57°
Wavefront Analysis

Cornea and Lens HOA

Spherical IOLs

Aspheric IOL

Multifocal IOLs

Toric IOLs

Light Adjustable

What is Lacking?

* Multifocal diffractive

Hartmann Shack

* Multizonal refractive

Tecnis™

ReZoom™

* Multifocal diffractive

* Multizonal refractive
Wavefront Analysis

* Multifocal diffractive

Hartmann Shack

* Multizonal refractive

<table>
<thead>
<tr>
<th>Tecnis™</th>
<th>ReZoom™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refraction from Wavefront</td>
<td>Aberrations</td>
</tr>
<tr>
<td>Sphere</td>
<td>1.11 Diopters</td>
</tr>
<tr>
<td>Cylinder</td>
<td>-0.38 Diopters</td>
</tr>
<tr>
<td>Axis</td>
<td>20 Degrees</td>
</tr>
<tr>
<td>Match</td>
<td>58%</td>
</tr>
<tr>
<td>Diameter</td>
<td>5.00mm</td>
</tr>
</tbody>
</table>

Total Aberrations

High Order Aberrations

Cornea and Lens HOA

Spherical IOLs

Aspheric IOL

Multifocal IOLs

Toric IOLs

Light Adjustable

What is Lacking?

* Multifocal
* Multizonal
* Refractive

ReZoom™

Tecnis™

Spherical IOLs

Aspheric IOL

Multifocal IOLs

Toric IOLs

Light Adjustable

What is Lacking?

* Multifocal
* Multizonal
* Refractive
Wavefront Analysis

* Multifocal diffractive

Hartmann Shack

* Multizonal refractive

**Tecnis™**

<table>
<thead>
<tr>
<th>Aberrations</th>
<th>RMS (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defocus</td>
<td>0.57</td>
</tr>
<tr>
<td>Astigmatism</td>
<td>0.49</td>
</tr>
<tr>
<td>Coma</td>
<td>0.13</td>
</tr>
<tr>
<td>Spherical Aberration</td>
<td>0.15</td>
</tr>
<tr>
<td>Other</td>
<td>0.54</td>
</tr>
</tbody>
</table>

**ReZoom™**

<table>
<thead>
<tr>
<th>Aberrations</th>
<th>RMS (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defocus</td>
<td>1.93</td>
</tr>
<tr>
<td>Astigmatism</td>
<td>0.74</td>
</tr>
<tr>
<td>Coma</td>
<td>0.04</td>
</tr>
<tr>
<td>Spherical Aberration</td>
<td>0.07</td>
</tr>
<tr>
<td>Other</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Cornea and Lens HOA

Spherical IOLs

Aspheric IOL

Multifocal IOLs

Toric IOLs

Light Adjustable IOLs

What is Lacking?

ReZoom™

* Multizonal refractive
Wavefront Analysis

Tecnis™ ray Tracing

WF Summary Display

Coma 0.21
Sph 0.15

WF Exam #18 OS
Date: 12-08-2006
Time: 12:50
Points Accepted: 252
Points Rejected: 4
Pupil Diameter: 8.42 mm
Scan Diameter: 6.00 mm
Fixation Target Position: +3.25 D 5PO

Auto Refraction
+0.12 D -0.07 D x 70°

Refractive Error (vertex distance = 14.0 mm)
-0.07 D -0.81 D x 96° @ 3.00 mm
+0.22 D -0.85 D x 62° @ 4.50 mm
+0.46 D -0.67 D x 11° @ 6.00 mm
+0.46 D -0.67 D x 11° @ 6.00 mm

RMS @ 0.00 mm

Total: 1.800 μ
LO Total: 0.635 μ
Defocus: 0.164 μ
Astigmatism: 0.614 μ x 101°
HO Total: 1.685 μ
Coma: 0.210 μ x 349°
Spherical: 0.222 μ
Toric: 1.327 μ x 95°
Patient’s complaints could be caused by increased light scattering in the eye media which can not be detected by other tests.
Light Scattering

ReSTOR®

Nuijts Rudy.
ESCRS 2006 September 9-13;
London, United Kingdom.

- ReSTOR X Acrysof SA60AT
  straylight meter (Oculus C-Quant, Germany)

- ReSTOR = 1.20 ± 0.17 log units
- Acrysof SA60AT= 1.10 ± 0.19 log units (p=0.19)

Light Scattering degrades the image projected on the retina, thus decreasing the quality of vision.
Wavefront Analysis

Hartmann Shack

AcrySof Toric

Cornea and Lens HOA

Spherical IOLs

Aspheric IOL

Multifocal IOLs

Toric IOLs

Light Adjustable

What is Lacking?

AcrySof Toric SA60T5

IOL plane: 3.0 DC

Corneal: 2.06 DC
Wavefront Analysis

Hartmann Shack

AcrySof Toric

Refraction from Wavefront

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere</td>
<td>0.13 Diopters</td>
</tr>
<tr>
<td>Cylinder</td>
<td>-0.85 Diopters</td>
</tr>
<tr>
<td>Axis</td>
<td>48 Degrees</td>
</tr>
<tr>
<td>Match</td>
<td>60%</td>
</tr>
<tr>
<td>Diameter</td>
<td>5.00mm</td>
</tr>
</tbody>
</table>

Aberrations

<table>
<thead>
<tr>
<th></th>
<th>RMS (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defocus</td>
<td>0.76</td>
</tr>
<tr>
<td>Astigmatism</td>
<td>0.48</td>
</tr>
<tr>
<td>Coma</td>
<td>0.16</td>
</tr>
<tr>
<td>Spherical Aberration</td>
<td>0.25</td>
</tr>
<tr>
<td>Other</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Total Aberrations

High Order Aberrations

Sph 0.25
Wavefront Analysis

Hartmann Shack

AcrySof Toric

<table>
<thead>
<tr>
<th>Refraction from Wavefront</th>
<th>Aberrations</th>
<th>RMS (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere</td>
<td>0.83 Diopters</td>
<td>0.37</td>
</tr>
<tr>
<td>Cylinder</td>
<td>-1.69 Diopters</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Sph 0.20
Wavefront Analysis

ray Tracing

AcrySof Toric

Coma 0.43
Sph 0.15
What else is Lacking?
What else is Lacking ???
An Intraocular Lens Correcting Corneal Coma

J. Tabernero, P. Piers, P. Artal.

ARVO 2006 May;
Fort Lauderdale, USA

- Angle kappa & ocular misalignments
- Corneal coma could be compensated by a mechanism that implies opposite coma for the IOL
Light Adjustable IOL

Dan Schwartz, MD


- LAL (Calhon Vision)
- Silicone matrix
- Photoreactive macromer
- UV 365 nm → silicone polymers
- Light Delivery Device (LDD) / Zeiss Meditec
- Spher. Cyl / Higher order aberrations
Light Adjustable IOL

* Adding Power

* Subtracting Power

Dan Schwartz, MD
What is Lacking??

- Quality of Vision
  - Aspheric X Multifocal
- Image Quality Measurement
  - Sensors reproducibility
- Target Spherical
- Decentration
  - Visual and Pupil Lines
- Customization
  - Highly aberrated eyes
Thank You !!