Wavefront-Guided Contact Lenses: Challenges in Moving from the Laboratory to the Dispensary

Geunyoung Yoon, Ph.D.
Assistant Professor

Department of Ophthalmology
Center for Visual Science
Department of Biomedical Engineering
University of Rochester
Customized Vision Correction Laboratory

http://www.cvs.rochester.edu/yoonlab/
Email: yoon@cvs.rochester.edu

Collaborators: David Williams, Scott MacRae, Krystel Huxlin, Jay Wang; U. of Rochester
Martin Banks; UC Berkeley
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Impact of the wave aberration on retinal image quality

No correction

Conventional correction

+ Higher order aberrations correction
Abnormal eyes have much greater amounts of higher-order aberrations compared to normals.

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### Magnitude of Zernike coefficient (µm)

<table>
<thead>
<tr>
<th>Zernike mode</th>
<th>KC (N = 19)</th>
<th>PK (N = 14)</th>
<th>Normal (N = 378)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$z_3^3$</td>
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<tr>
<td>$z_4^3$</td>
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<tr>
<td>$z_4^4$</td>
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<td>$z_5^6$</td>
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</tbody>
</table>

- **Coma**
- **Spherical aberration**
- **Trefoil**
Higher order aberrations have been successfully corrected using adaptive optics and wavefront-guided refractive surgery.

**Adaptive Optics**

- Distorted wavefront
- Deformable mirror
- Plane wavefront

**Customized refractive surgery**

- Laser Beam
- Cornea
- Lens
- Retina
- Corneal Flap
Customized optics (phase plates) can also correct the higher order aberration.

Low contrast (10%) visual acuity

- Correcting 2nd order only
- Correcting 2nd + higher order

Normal eyes

Keratoconus

1.2 line improvement

3.2 line improvement
Is it feasible to correct the higher order aberration with customized soft contact lenses?

With conventional contact lens

With customized contact lens
Higher order aberrations can be generated by customized contact lens.

CCL for normal eye for a 6 mm pupil

Manufacturing higher order RMS error
= 0.25 μm
Correcting the higher order aberration with customized soft contact lenses

Normal eye for a 6 mm pupil

With conventional lens

HO rms = 0.69 µm

With customized lens

HO rms = 0.49 µm
Correcting the higher order aberration with customized soft contact lenses

**Keratoconic eyes**

6 mm pupil

**With conventional lens**

HO rms = 3.07 µm

**With customized lens**

HO rms = 1.05 µm

Wavefront height (µm)
Improving visual performance with customized contact lenses in keratoconus

High contrast letter (100%)

2.1 lines improved

Subjects

Visual acuity (logMAR)

Conventional lens

Customized lens

6 mm pupil
Improving visual performance with customized contact lenses in keratoconus

Low contrast letter (20%)

2.1 lines improved

Subjects

Visual acuity (logMAR)

Subjects

Conventional lens

Customized lens

6 mm pupil
Challenges to make customized contact lenses correct the higher order aberration better

- Manufacturing error
- Decentration and rotation of lens
- Image quality degradation immediately after blinks
- Tear film uniformity on lens surface
- Temporal changes of the aberration
- .....
Manufacturing error

Normal eye

Abnormal eye

Design  Measurement  Manufacturing error

HO rms = 0.25 µm

HO rms = 0.58 µm
Dynamic movements of soft contact lens after blinks
Horizontal and vertical decentration of soft contact lens after blinks

Advanced keratoconus

Lens decentration (µm)

Time (sec)
Rotation of soft contact lens after blinks

Advanced keratoconus

![Graph showing lens rotation over time for advanced keratoconus](image)
Partial vs Full Customization
Partially vs Fully customized contact lenses: averaged HO aberration in a normal population

6 mm pupil (n=159 normal eyes)

Spherical aberration
Partially vs Fully customized contact lenses: Averaged magnitude of HO aberration in a normal population

<table>
<thead>
<tr>
<th>Zernike Mode</th>
<th>Spherical Aberration</th>
<th>Coma</th>
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<tbody>
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<td>5</td>
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<td>21</td>
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</tbody>
</table>

6 mm pupil (n=159 normal eyes)
Partially vs Fully customized contact lenses

- **Aspherical lens**
  Correcting averaged spherical aberration

- **Customized aspherical lens**
  Correcting individual spherical aberration

- **Customized coma lens**
  Correcting individual coma

- **Customized aspherical + coma lens**
  Correcting individual spherical aberration and coma

- **Fully customized lens**
  Correcting most higher order aberrations
Retinal image quality metric: volume MTF (vMTF) under white light condition

Visual benefit = \( \frac{v\text{MTF}_{\text{HO correction}}}{v\text{MTF}_{\text{conventional}}} \)
Theoretical performance of partially customized contact lenses based on white light volume MTF

Without rotation

6 mm pupil (n=159 normal eyes)
Theoretical performance of partially customized contact lenses based on white light volume MTF

With 5 degree rotation

6 mm pupil (n=159 normal eyes)
Conclusion

Customized soft contact lens has successfully reduced the ocular higher order aberrations by a factor of 3 in keratoconus.

This reduction in the higher order aberration improved both high and low contrast visual acuity by 2.1 lines on average.

Contact lens movements are the most critical factor that decreases visual benefit.

Partially customized contact lenses are less sensitive to the lens movements. However, achievable visual benefit is smaller than fully customized contact lens in the presence of typical amounts of lens movements.
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Research to Prevent Blindness

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