Performance of Customized Contact Lenses on Keratoconic Eyes

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Additional vision improvement can be achieved by correcting higher order aberrations

Eye

Conventional Correction (lower order)

Customized correction (lower & higher orders)
Corneal Topography

Normal cornea

Abnormal cornea

Keratoconus

Penetrating keratoplasty
How many orders do we need to use to fit the aberration in abnormal eyes?
Minimum number of Zernike modes needed to characterize corneal aberrations

Residual higher order rms < 0.1 µm

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of Zernike modes</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>64</td>
<td>81</td>
<td>91</td>
<td>88</td>
</tr>
<tr>
<td>LASIK Complaints</td>
<td>87 eyes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keratoconic</td>
<td>27 eyes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK</td>
<td>8 eyes</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

- ~10th
- ~11th
- ~12th
Limitations of the S-H Wavefront Sensor

- Normal Eye
Limitations of the S-H Wavefront Sensor

- Abnormal Eye

- Incident wavefront

- Centroiding area

- (a) Multiple or over-lapped spots

- (b) Cross-over
Large Dynamic Range Shack-Hartmann Wavefront Sensor

• Concept

- Translatable plate (mask)
- Multiple or overlapped spots
- New centroiding area
- Cross-over

Incident Wavefront
Large Dynamic Range
Shack-Hartmann Wavefront Sensor
Large dynamic range Shack-Hartmann wavefront sensor
We have successfully measured highly aberrated eyes for a large pupil.

Conventional S-H sensor

Not measurable

Large dynamic range S-H sensor

Total rms = 13.33\(\mu\)m
Higher order rms = 3.85\(\mu\)m
Pupil = 6.7mm
Abnormal eyes have much greater amounts of higher-order aberrations compared to normals.
Without customized correction

Blurred image

Wavefront aberration

With customized contact lens

Sharp image

Ideal wavefront Customized contact lens

Prototype customized optics - phase plate -

Optical zone (~ 7 mm in diameter)
Improvement in visual performance in keratoconic eyes

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

**High contrast (100%) letter**

- **Mild KC**
- **Advanced KC**
- **Mean**

- **2.4 line improvement**

**Low contrast (10%) letter**

- **Mild KC**
- **Advanced KC**
- **Mean**

- **3.2 line improvement**
Customized soft contact lenses made with lathe machine

Wavefront sensor measures the aberration of the eye with a blank contact lens on.

Decentration and rotation of contact lens are measured.
Measured aberration of customized contact lens

Design

Measurement

Zernike coefficient ($\mu m$)

Zernike mode
Higher order aberrations were significantly reduced by customized contact lens resulting in improvement in retinal image quality.

6 mm pupil

With conventional CL

With customized CL

HO rms = 3.07 µm

HO rms = 1.28 µm

The subject reported significant vision improvement with CCL compared to RGP lens.
Higher order aberrations were significantly reduced by customized contact lens resulting in improvement in retinal image quality.
Effect of movements of customized contact lens on the eye

Eye’s aberration + Customized contact lens aberration = Residual aberration

Without decentration =

With decentration =
Statistical approximation of contact lens movement
- Gaussian distribution -

Number of events vs Radial decentration (μm)

Number of events vs Rotation (degree)
Visual benefit vs dynamic movement of contact lens

5 mm pupil

$\theta_{\text{rotation}} = 7 \text{ deg}$

Normal eye (n=30)

Abnormal eye (n=15)
Effect of movements of customized contact lens on the eye
Contact lens movements after blink

Decentration (mm) vs Time (sec)

- Decentration (mm) is measured on the y-axis.
- Time (sec) is measured on the x-axis.
- There are three lines indicating different parameters:
  - X-decentration (blue diamonds)
  - Y-decentration (magenta squares)
  - Rotation (cyan triangles)

The graph shows the movement of contact lenses over time after a blink, with each parameter plotted separately.
Effect of dynamic movements of customized contact lens on retinal image quality

Conventional correction

2 sec → blink → 5 sec → 6 sec → 7 sec → 8 sec → 9 sec

Customized correction
Conclusion

Customized optics is another candidate to correct the eye’s higher order aberration and to improve visual performance in abnormal eyes.

It would be the challenge to come closer to perfect correction with customized contact lens when decentration and rotation of the lens exist.
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