Technology Requirements for Customized Ablation

- Scanning Spot Delivery
- Very Fast Eye Tracking
- Accurate Wavefront Device
- Wavefront and Laser Registration
Scanning Spots Size & Latency of Tracking?
### Tracker Latency vs Spot Size

<table>
<thead>
<tr>
<th>D (mm)</th>
<th>d_c (mm)</th>
<th>Profile</th>
<th>0 ms</th>
<th>4 ms</th>
<th>32 ms</th>
<th>96 ms</th>
<th>No eye tracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>0.25</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>250</td>
<td>1.0</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
</tr>
<tr>
<td>1000</td>
<td>0.25</td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
<td><img src="image16.png" alt="Image" /></td>
<td><img src="image17.png" alt="Image" /></td>
<td><img src="image18.png" alt="Image" /></td>
</tr>
<tr>
<td>1000</td>
<td>1.0</td>
<td><img src="image19.png" alt="Image" /></td>
<td><img src="image20.png" alt="Image" /></td>
<td><img src="image21.png" alt="Image" /></td>
<td><img src="image22.png" alt="Image" /></td>
<td><img src="image23.png" alt="Image" /></td>
<td><img src="image24.png" alt="Image" /></td>
</tr>
</tbody>
</table>

- Smaller spot size means more detailed correction of aberrations and the need for shorter tracker latency.
Wavefront Centroid Sampling or Reconstruction Accuracy?
High Density, Dynamic, Adaptive Sampling of Wavefront Errors?
Centration and Registration?

Tracker Centration  Tracker Alignment
When is the Tracker linked to Registration?

- **VIDEO BASED**
  - Eye intrinsically registered
  - Iris crypt registration only recently introduced in selected systems

- **LADAR**
  - Limbal registration intrinsic to tracker
Pupil/Iris Registration

• If not fixed, the centroid shifts with dilation

• Centroid shifts from dim (measurement) to bright (surgery) light conditions – wavefront alignment error introduced

• Iris feature recognition through the flap may be problematic
Pupil Center Offset from Limbus

1. Locate Limbus
2. Locate Pupil
3. Measure Offset
Pupillary Center Shift with Dilation

RMS Error Shift with Pupil Shift

Wavefront Simulated Tracker Criteria
(8-mm Pupil)

Improve 95% of normal eyes to:

<table>
<thead>
<tr>
<th></th>
<th>Diffraction limit</th>
<th>Best 10% of untreated normal population</th>
<th>Duplicated image quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral centration</td>
<td>0.050 mm</td>
<td>0.200 mm</td>
<td>0.400 mm</td>
</tr>
<tr>
<td>Torsional alignment</td>
<td>1 deg</td>
<td>4 deg</td>
<td>10 deg</td>
</tr>
</tbody>
</table>

Courtesy of Michael Mrochen, PhD
Wavefronts Change With Position

Spherical Aberration

- Same diameter
- Same vertical scale
- Same eye
- Center shifted by 500µ

Coma

With this shift, you’d be correcting the eye above with the wavefront to the right!

From Donnenfeld, ASCRS ‘04
Effect of Decentration
(typical patient, 500µ shift)

Higher-order aberrations

Whole eye wavefront
500µ right

Sph 0.24 D
Cyl 0.27 D
Axis 136°
LO RMS 0.33 µm
HO RMS 0.23 µm
TOT RMS 0.40 µm
Pupil 6.50 mm
Wavelength 0.588 µm

Measurable HOAs
Measurable sphere/cyl

ANSI Z80.28
Limbal Registration with Cyclotorsion Compensation
Importance of Axis Alignment

Residual Aberration For Most Axis-Sensitive Term (%)

Zernike Order

Conventional Astigmatism
Ablation pattern correctly oriented – no difference error

“A Perfect Fit”

Ablation pattern misaligned 10 degrees

no longer exists

Ablation pattern misaligned 20 degrees

Waves no longer match

Wavefronts: Change with Rotation
Status Post-LASIK OS – Rotated Wavefront Comparison

10 Degree Shift
- High Residual RMS Error

Made with CTView
Sarver and Associates
Status Post-LASIK OS - LADARWave

Spectacle Plane Refraction (12.5mm)

4.82D / -1.73D x 50
(SE 3.96 Match = 18%)
Status Post-LASIK OS – Calculated Image Quality Difference

20/20 ------

5 Degree Rotation

Made with CTView
Sarver and Associates
Registration: The Math Tells Us

• The more misaligned the correction, the worse the correction
• The effect is higher with higher order aberrations
• This implies a need to:
  • Include precise identification of the position of the wavefront at the time of measurement
  • Accurately match this information (“registration”) at the time of treatment, including cyclorotation effects
Registration Requirements

1. Align the centration & wavefronts during measurement
2. Realign the wavefronts for treatment
3. Control for positional cyclotorsion (sitting up to lying down)
4. Control for intraoperative cyclotorsion (a second order effect, relative to #3)
CustomCornea™ Registration Involves

- Measuring
  - Registering the wavefront to the eye

- Treating
  - Registering the ablation profile to the eye, correcting for cyclotorsion and translation
New LADARWave Software Features

• Auto-centration and Auto-Registration
  – Automatic pupil and limbal ring placement

• one-click surgeon confirmation required
Centration

- Center patient’s pupil in the concentric circles on the video display.
- Use the Z-position indicator to determine the Z direction in and out from the patient.
  - If the white diamond is above the mid-point indicator, the instrument is too close to the patient’s eye.
  - If the white diamond is below the mid-point indicator, the instrument is too far from the patient’s eye.
Centration

Retake for Automatic Alignment or Save

- If the image quality analysis determines that the image cannot be processed for alignment, the Retake for Automatic Alignment or Save message will appear.
- Click the Retake (  ) button and retake the photo (recommended).
  - However, if the operator feels the image is acceptable, click the Save (  ) button.
  - The saved image must be carefully examined and either or both the pupil and limbal rings must be manually aligned.
Centration

"Auto-Centration by Wavefront"
Wavefront Measurement

“Auto-Registration by Wavefront”
Wavefront Measurement

Retake for Automatic Alignment or Save

• If the image quality analysis determines that the image cannot be processed for alignment, the Retake for Automatic Alignment or Save message will appear.

• Click the Retake ( ) button and retake the photo (recommended). ✗
  – However, if the operator feels the image is acceptable, click the Save ( ) button in front of the joystick.
  – The saved image must be carefully examined and the limbal ring must be manually aligned.
Untracked Image/Tracker Line-of-Site

- Tracker Line-of-Site displays the tracking system’s line of site and may be helpful if you are having difficulty aligning a patient’s eye or to monitor patient eye movement during surgery.
LADARVision Alignment

“Auto-Registration under Laser”

Centration Image from LADARWave

Space-stabilized image alignment on LADARVision
Smart Video Imagery for Auto & Scleral Registration

- Automatic identification of pupil and limbus during centration
- Automatic identification of limbus and ink marks during measurement
- Replacement of ink marks with natural scleral features
- Repeatability of natural features means wavefront/exam on different days
X-Y Limbal Registration
(note pupil size changes, quality of **iris** image)
Scleral Registration
(note quality of iris image)

No shear  Shear  No shear  Shear

original  stabilized

Permits registration and cyclotorsion tracking.
Scleral/Limbus Registration

- Possible Limitations of pupil/iris registration are not encountered
- Automatic identification of limbus and vessels during measurement
- Replacement of current ink marks with natural scleral features
- Repeatability of natural features means wavefront measurement and surgery can be performed on different days
Conclusion

• Registration is critical for success of wavefront-guided surgery.
• Registration involves both measurement and treatment
• Auto-centration and registration of the wavefront images should improve consistency and improve results.
• Future advances in auto-registration and scleral vessel at the laser should further improve consistency and results.
Efharisto!
(Thank You)