Imaging of the Cornea

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In the last 30 years we have advanced rapidly in relation to corneal imaging due to Refractive Surgery

• Keratometer 1880-1990 was the ‘Gold standard’.
• Placido topography- qualitative and quantitative
• Slit scanning tomography
• Scheimpflug tomography
• OCT
• Confocal Corneal Microscopy
• High resolution Ultrasound
• UBM
Corneal Optics and Structure

- Curvature of anterior and posterior
  Radius of curvature (mm) or dioptres (D)
- Shape of ant and post surface- microns of elevation relative to a reference surface
- Micro-irregularities in microns relative to surrounding area can significantly degrade the image
- Power of the cornea- shape of the surface and refractive index of the surface
- Thickness and 3D structure (microns) can alter its shape and biomechanics
The keratometer: Gold standard 1880-1990

Limitations

Only four points

Approx 3-4 mm diameter

Single meridian radius of curvature

Major & minor axes @ 90

Assumes spherocylindrical cornea
Evolution

Topography

1974  Qualitative photokeratoscopy
1984  Computerized videokeratography
1988  Computed Anatomy Corneal Modeling System (TMS)
1989  Eyesys videokeratography

Tomography

1995  Orbtek Orbscan slit scanning
2000s  Scheimpflug slit scanning
Placido-based computerized videokeratography (CVK)
Placido-based computerised video-keratography based on 1st Purkinje image

Common Features

Placido mire projection
Requires good quality tear film
Reconstruction algorithms
Range 0.3 - 10.5mm diameter
Up to 8,000 data points analysed
Colour coded topographic maps
High accuracy anterior curvature data

Dingledein & Klyce 1989
Interpretation of topo maps
Orbscan Slit scanning elevation tomography

Non-placido, non-virtual
20 slit images R & L
Reliant on **light scatter**
to triangulate true height
from up to 9600 points
Pentacam: Scheimpflug rotational scanner

1. 3D Anterior Chamber
2. Corneal Pachymetry
3. Corneal Topography
4. Cataract Analyzer
Principle of a Scheimpflug system

- Slit illumination
- Cornea scatter light
- Sectional image is captured by the camera
- Image of illuminated planes from anter to posterior surface is sharp
- Distortion correction
- Reference point calculation
Pentacam
Applying topography

In 1990, it was shown in a study that 58% of randomly selected keratoconics had one parent with at least one abnormal Placido corneal indice.

Application: diagnosing keratoectasia revealing subtle (or not so subtle) differences
Scheimpflug measurement of posterior corneal surface
Comparing Pentacam and Orbscan IIz posterior curvature measurements in keratoconus eyes

Pentacam vs Orbscan IIz

- Determine similar thinnest points
- Determine similar radii of curvature
- However, differ in posterior elevations above best-fit sphere

Comparing pachymetry: Orbscan II, Pentacam, Ultrasound in normal and after laser surgery

Hashemi H, Mehravaran S.
Zeimer Gallilei & CSO Sirius-Scheimpflug and Placido.

To improve quality of anterior curvature data

Combination of both

Gallelei has 2 Scheimpflug cameras

Sirius has 1 Scheimpflug camera
Conclusions

- The pre and post laser pachymetry measurements obtained by **Orbscan II**, **Pentcam**, and **Galilei** tomographers were sufficiently disparate that the three devices could not be considered equivalent.
- All three devices demonstrated a high level of repeatability, although the Galilei exhibited the best repeatability.
- Pentacam and Ultrasound- similar pachymetry measurements
- For consistency use same equipment
- Orbscan- measures lower readings after corneal refractive surgery due to light scatter
Corneal Wavefront Analysis

- Mixture of astronomy, mathematics, optics and ‘headaches’
- Defines optical status of the eye
- Total wavefront analysis- cornea, lens and media
- Corneal wavefront analysis data from elevation/slit based tomographers.
- Cornea has +ve spherical aberrations and lens is –ve but with age lens becomes +ve
Aberrations- measured in RMS value or expressed as Zernike polynomials

- 90% are low order- prism, myopia, hyperopia and astigmatism
- 10% are higher order- spherical, coma and trefoil

  - Spherical aberration increases in low lighting due to large pupils- night myopia
  - Coma- keratoconus, decentered ablations and corneal grafts
  - Trefoil- not as degrading to vision as coma

RMS = Root Mean square
### Zernike Polynomials

<table>
<thead>
<tr>
<th>Zernike Term</th>
<th>Name</th>
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<tbody>
<tr>
<td>$Z_0^0$</td>
<td>Piston</td>
</tr>
<tr>
<td>$Z_1^1, Z_1^{-1}$</td>
<td>Tilt (Prism)</td>
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<tr>
<td>$Z_2^0$</td>
<td>Defocus</td>
</tr>
<tr>
<td>$Z_2^2, Z_2^{-2}$</td>
<td>Astigmatism</td>
</tr>
<tr>
<td>$Z_4^2, Z_4^{-2}$</td>
<td>Secondary Astigmatism</td>
</tr>
<tr>
<td>$Z_4^0$</td>
<td>Spherical Aberration</td>
</tr>
<tr>
<td>$Z_3^1, Z_3^{-1}$</td>
<td>Coma</td>
</tr>
<tr>
<td>$Z_3^3, Z_3^{-3}$</td>
<td>Trefoil</td>
</tr>
<tr>
<td>$Z_4^4, Z_4^{-4}$</td>
<td>Quadrafoil</td>
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Simulation on the effect of aberrations on retinal image

<table>
<thead>
<tr>
<th>Zernike Polynomials</th>
<th>Point Spread Function (PSF)</th>
<th>Retinal Image</th>
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<tbody>
<tr>
<td>Perfect Eye (piston)</td>
<td></td>
<td>E</td>
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<tr>
<td>Coma</td>
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<tr>
<td>Spherical Aberration</td>
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Corneal topography/tomography

- Topographic/tomographic analysis in combination with other technologies now reveals corneal structure and function at the micron level.

- However, data may conflict with accepted wisdom and devices are not inter-changeable in practice.

- Universal gold standards are challenged or yet to be established.