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Corneal Imaging in the Modern Optometric Practice
Loretta Szczotka-Flynn, OD, PhD
Room: Crystal C

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TOPICS FOR TODAY

- Corneal Topography
- Anterior Segment OCT
- Confocal Microscopy

Corneal Topography:
- Is the gold standard in contact lens practices
- Acceptance credited to:
  - lowered prices
  - smaller instruments
  - portable instruments
  - software enhancements

Contact Lens Applications
- Standard map displays
  - Select qualitative designs
    - spherical, toric, aspheric
    - replacement of contact lenses
- Select quantitative parameters
  - BC, PC, OAD, OZ
- Contact lens software modules
- Other software modules
  - KC detection, shape indices, irregularity
  - Monitor CL induced change
  - Pachymetry
  - Wavefront analysis

LIMITATIONS OF THE KERATOMETER

- Power and curvature at visual axis only
- Qualitative assessment of regularity
  - No interpretation or quantitative data
- Measures 4 points 3.6mm apart
  - 5% of the corneal surface (depends on K's)
  - Lacks central & peripheral data
- Assumes spherocylindrical surface
- Assumes orthogonal symmetry

Subjective Keratometry Errors
Mapping the Cornea

- Placido Disc Topography
- Rasterstereography
  - Par Vision Systems: elevation, based on stereo-photography
- Interferometry
  - Euclid System: Elevation topography
- Scanning Slit Topography
  - Orbscan II (includes placido)
- Scheimpflug
  - Pentacam

Reflective and Slit-scan Technologies

- One image, one surface.
- Angle-dependent specular reflection.
- Measures slope (as a function of distance).
- Multiple images, multiple surfaces.
- Omni-directional diffuse backscatter.
- Triangulates elevation.

Placido reflective systems can only measure the anterior tear film. ORBSCAN measures the anterior cornea, posterior cornea, and the anterior lens and iris.

What are the choices?
Placido Disc Systems

- Optikon/Eyequip
  - Keratron; Scout
- Humphrey Instr.
  - Atlas
- Medmont
  - Medmont E300
- Technomed Tech
  - Technomed, colored rings
- Tomey Tech.
  - THS-1, 2, 3
- Topcon
  - infrared Placido unit
- Nidek
  - choroid Placido, spatial refractometer
- Orbscan II
- Others

Placido curvature may be ambiguous.

Reflective devices can suffer other ambiguities. Because of its inherent symmetry, Placido reflective corneal topography can NOT disambiguate a central hill from a central depression. Both appear as a local increase in curvature, that is, as "central islands".

Avoiding Artifacts and Misinterpretation

1) Eyelid position
2) Ring digitization errors
3) Color scales
4) Corneal apex alignment
5) Selecting the correct map

1) Eyelid Position

- Keratron only
  - eyelash breaks ring pattern
  - acquires image when not in focus
2) Ring Digitization

- Long vs Short Working Distance Systems

- Short Working Distance System

View the placido image

3) Decoding Color Scales

- Absolute Scale
  - Standard
- Normalized Scale
  - Color Map
  - Autosize
- Adjustable Scale
  - Customized

Absolute Scale

- Fixed Color Coded Scheme
  - Always assigns same color to a given dioptic interval
  - Forces data to fit within a predetermined range

Saturated scales

- Can saturate extreme ends of scales
  - Tomey 8-100 D
  - Keratron 8-101.5 D
  - EyeSys/Premier 35-52 D
  - Humphrey 39-50 D
Absolute Scale

**Advantages**
- Visually compare eyes or occasions
- Quickly visualize significant corneal changes
- Quick insight for best CL fitting approach

**Disadvantages**
- Large dioptric range
- Large intervals
- Local irregularities may be masked
- Less detail if scale saturates

Normalized Scale

**Advantages**
- Automatic subdivision of each cornea into equal, adjusted, dioptric intervals
- Set number of colors to fill dioptric range
- Color intervals vary between eyes/occasions
- Usually smaller intervals than axial maps
  - Min 0.40 D steps Tomey
  - Min 0.50 D steps EyeSys/Premier
  - Min 0.25 D steps Humphrey

**Disadvantages**
- Can be misleading
- Cannot visually compare maps without referring to associated color scales
Scale selection in Contact Lens Fitting

- **Absolute Scale**
  - Quickly determine fitting approach based on
    - Corneal Astigmatism
    - Average corneal curvature
- **Normalized**
  - May sway the fitting approach if scale not referred to

Relatively normal surfaces can appear complex due to minor variations.

Here are two anterior elevation maps from normal corneas that could be confusing to read. The color changes are presented using a standard scale in 5 micron steps. The problem with large step sizes is that it tends to mask large changes by lumping them into a limited number of color steps categories. Also by changing step sizes and scaling for different cases, one can easily get confused and under or over diagnose pathology.

Elevation Color Scales

The step size of the scale is user selected as is the center point and width of the normal band. For anterior and posterior corneal elevation maps I have chosen a step size of 5 microns. The center point of the normal band is zero deviation from the best fit sphere, and the width of the normal band is 50 microns, or 25 microns more elevated and 25 microns more depressed than the best fit sphere.

Everything in the normal band will be shown as green.
On the left the standard scale for the normal anterior corneal surface is used and on the right the normal band scale is used showing an all green normal surface.

The normal band scale is a screening tool for gross pathology. Using the standard scale, the with-the-rule astigmatic pattern in this patient is obvious but is eliminated by use of the normal band scale.

The normal band scale can also be used with 3-D Orbscan maps. The image on the lower right is the normal band representation of the cornea on the left.

Here, the normal band scale on the lower right clearly demonstrates a posterior cone centrally in the 3-D posterior corneal surface elevation map.

For keratometric curvature maps we've chosen a normal band of from 40 to 48 keratometric diopters. Within this range all values will appear as green on the Normal Band scale.

Editor Note: A keratometric curvature is any anterior surface curvature expressed in keratometric diopters (K). Because of its dioptric evaluation, it has often been referred to as a power, although it is really a scaled surface curvature. That is, it is a geometric property, not an optical one.

It should be emphasized that this scale could be changed for individual needs and as shown here some rather significant changes can be masked so its usefulness with such a wide scale is for screening.
For corneal thickness we are using a normal band from 500 to 600 microns. Obviously, this scale should be changed for post-Lasik or PRK eyes.

Corneal Thickness Color Scales

- Standard Color Scale
- Normal Band Scale

The standard color scale is used for non-surgical eyes, while the normal band scale is used for post-Lasik or PRK eyes.

Corneal Thickness Map

- Standard Scale
- Normal Band Scale

For corneal thickness, we are using a normal band from 500 to 600 microns. Obviously, this scale should be changed for post-Lasik or PRK eyes.

Standard Scale Quad Map

This is a quad map of an untreated eye where the anterior corneal elevation map is shown on the upper left quadrant, the posterior corneal elevation map is on the upper right quadrant, the corneal power map is on the lower left quadrant, and the corneal thickness map is on the lower right quadrant. Determining normal from abnormal features is certainly not obvious.

Posterior Keratoconus: Normal Band Scale

The first appearance of abnormality is on the posterior corneal elevation map on the upper right where an area of central elevation is present with 2 areas of peripheral depression. On the corneal thickness map on the lower right, a central area of corneal thinning below 500 microns is seen. The most likely diagnosis is a posterior cone with mild central corneal thinning.

Posterior Keratoconus: Standard Color Scale

The other eye of this patient underwent Lasik and here is that quad map using the standard scale.

4) Corneal Apex Position

- Classification of Normal Corneal Topography - Bogan et al; Arch Ophthal 1990
- 399 normal corneas, Axial Maps
  - 22.8% round
  - 20.8% oval
  - 17.3% symmetric bow tie
  - 32.1% asymmetric bow tie
  - 7.1% irregular
Primary Gaze

Upgaze

5) Selecting the Correct Display
- Placido Image
- Eye Image Overlay
- Axial
- Tangential
- Elevation
- Refractive
- Distortion/Irregularity

Eye Image Overlay

Understanding the Maps
- Curvature Maps
  - Axial
    - Sagittal
    - Sagittal
  - Tangential
    - True

- Refractive Maps
- Elevation Maps
- - Snell’s Law
- - Power
- - Height
- - 3-D

Axial "radius of curvature"
- Distance along the normal from the corneal surface to the optic axis
- A reference distance, not a true curvature
- Most recognizable display
- Running avg/excludes extreme values
- Spherically biased
- Used in keratometry

Axial Curvature Map displays a kind of radially-averaged curvature. This eye has with-the-rule astigmatism. The steep meridian is aligned with the red-shifted bow-tie. Axial curvature is measured exclusively in meridional planes (radial directions). The bow-tie is actually an axial artifact generated by the central intersection of the meridional planes.
Tangential radius of curvature

- Based on standard mathematical formula for local radius at a point along a curve
- Includes extreme curvature values
- Proportional to local curvature
- Derivative of axial data
- Axis independent
- More detail

Tangential maps for CL fitting

- More accurate corneal shape
  - Correlated to slit lamp observations
  - RGP fluorescein patterns
  - Optical zone selection
- More detail
  - Detect irregular astigmatism
  - CL induced warpage
  - Monitor disease progression

Axial maps for CL fitting

- Larger, diffuse patterns
- Less noise, but less detail
- Global representation of shape
  - More appropriate for spherical RGP curve selection
  - Normal
  - KC
  - Post-LASIK/post-cataract shapes

Clinical Appearance of KC

Axial maps in keratoconus

- Not sensitive enough for localized curvature changes off VK axis; which affects:
  - Apex curvature and position
  - How does the effect RGP fitting
  - KC detection
  - KC progression
Tangential maps in keratoconus

- POSSIBLE APPLICATIONS:
  - KC Progression
  - Early KC detection (for PRK screening)
  - KC Subset classification based on cone shape, size, and position
  - KC Statistical Indices
  - Contact Lens Fitting??

Elevation Maps

- Depict relative height differences from a reference sphere
- Reds: higher than reference sphere
- Blues: lower than reference sphere

Elevation, whether of the earth or the cornea, is measured relative to some reference surface. The terrestrial reference surface is the "mean sea level".
Topographical Elevation is Relative

On a local scale these features are significant.

5.6 mi

Local clinical features (microns high) are a thousand times smaller than the cornea (millimeters in radius). This disparity in scale makes it IMPOSSIBLE to see clinically relevant features, corneal global curvature must first be removed. This is done by measuring elevation relative to some close-fitting reference surface, a process that inevitably introduces distortion.

Elevation Topology: Central Hill

The normal cornea is prolate, meaning that meridional Prolateness of the normal cornea causes it to rise centrally. Immediately surrounding the central hill is an annular sea. In the far periphery, the prolate cornea again rises above the reference surface, producing peripheral highlands.

Elevation Distortion

As an example of distortion, consider the corneal surface following myopic lasik correction. It is centrally flattened by the surgery. To see surface features, elevation must be measured with respect to some reference surface. This relative elevation peak is NOT the highest point on the cornea. This apparent central "concavity" does NOT exist.

Close-Fitting Reference Surfaces

Topographic maps of terrestrial landscapes are displayed in the form of constant-elevation contours, measured from the "mean sea-level" of the earth. Corneal topography differs from terrestrial topography in that the reference surface is movable. For the cornea, a reference surface (typically, a sphere) is constructed by fitting the reference surface as close as possible to the data surface. A best-fit minimizes the square difference (always a positive number) between the two surfaces, but only within a specified region known as the fit-zone.
These elevation maps are the same exam of a normal eye having with-the-rule astigmatism. They look different, because altering the fit-zone changes the size and alignment of the reference sphere.

Both maps contain exactly the same information. The difference between them is the size of the fit-zone used to develop the reference sphere. Both maps contain exactly the same information. They look different, because altering the fit-zone changes the size and alignment of the reference sphere.

**Default settings:**
- shape = sphere
- alignment = floating

**Changing the shape, size, or alignment of the reference surface:**
- The shape is especially useful, because it is the only reference surface that has no unique symmetry axis (i.e., every diameter is a symmetry axis).
- Two parameters define the best-fit sphere: Radius and Center location.
- The default sphere alignment is floating, which means its center location is unconstrained. Other alignments may force the reference sphere to lie on the map axis.

**Reference Sphere Alignments**
- **Float** imposes no additional constraints on the reference sphere. The sphere moves and changes size until it best-fits the data surface within the specified fit-zone.
- **Center (C)** imposes the center constraint, which forces the reference sphere center to lie on the view axis, although it may move up or down the axis.
- **Pin (P)** imposes the pin constraint, which forces the reference sphere surface to intersect the data surface on the view axis. The sphere center may be off-axis.
- **Apex (C+P)** imposes both center and pin constraints. The sphere center lies on the view axis, and the sphere surface intersects the data surface on the view axis.

**Artificial Alignment Maps**
- This is a normal eye with some with-the-rule astigmatism. The two elevation maps differ only by the alignment of the reference sphere.
- Floating alignment (left) shows the ablation pattern to be slightly offset in the pupil centroid direction.
- Axial alignment (right), which forces the reference sphere center onto the map axis, moves the apparent ablation pattern 0.3 mm towards the map axis.
- Neither map is wrong, but floating alignment (no center constraint) allows the reference sphere to follow the natural symmetry of the surface.
- Neither map depression tracks the actual ablation edge, but only the smoothly varying corneal contour as seen from the reference sphere.

**Elevation Maps**
- Colors identical to curvature displays, but represent height only.
- Steep (red) curvature does not always mean high!
- Flat (blue) curvature does not always mean low!
Elevation maps for RGP fitting

Most useful for RGP fluorescein patterns (vs. curvature maps):
- Reds: ALWAYS displace FL
- Blues: ALWAYS pool FL

Irregularity/Distortion Maps

- Describes the visual limitations of the ocular surface
  - Humphrey Irregularity Map
  - EyeSys Holladay Display/Distortion Map

Difference Maps

Specialized software for Keratoconus Detection
**Keratoconus Detection Software**

Yaron Rabinowitz MD

<table>
<thead>
<tr>
<th></th>
<th>Normals</th>
<th>KC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>44.2±1.6</td>
<td>49.9±4.8</td>
</tr>
<tr>
<td>I-S Value</td>
<td>0.12±0.57</td>
<td>3.7±3.81</td>
</tr>
<tr>
<td>R vs L</td>
<td>0.42±0.25</td>
<td>3.66±3.25</td>
</tr>
</tbody>
</table>

**Videokeratography Patterns**

- Round
- Oval
- Superior Slope (SS)
- Inferior Slope (IS)
- Irregular
- Symmetric Bowtie (SB)
- SB/SRAX
- Asymmetric Bowtie AB/IS
- Asymmetric Bowtie AS/SS
- AB/SRAX

**Videokeratographic Indices to Aid in Screening for KC**

- Rabinowitz, Y. 1995
  - Central K > 47.20 D
  - I-S Value > 1.40 D
  - SRAX > 21 degrees
  - Specificity = 98%

**KISA% index**

Rabinowitz Y, Rasheed K, JCRS 1999

\[ \text{KISA\%} = \frac{K \times I-S \times AST \times SRAX \times 100}{300} \]

- Clinically detectable KC
- KISA% 60-100
- Advanced KC
- KISA% > 600

**Methods**

- Quantitative Descriptors:
  - SRI: Surface Regularity Index
  - SAI: Surface Asymmetry Index
  - SimK
  - Central K
  - I-S value
  - C-P value
Defining Controls: Orbscan II

- In non-diseased eyes, the average amount of maximum posterior elevation using Orbscan II default settings compared to the best fit sphere is about 21-28 μm
  - Rao 2002
  - Wei 2006
  - Lim 2007
  - Sonmez 2007

- One study of 140 normal eyes documented the maximum posterior elevation was never greater than 46 μm
  - Wei 2006
- Another study of 50 normal eyes the posterior elevation was never greater than 40 μm
  - Rao 2002

Posterior Elevation on Orbscan II >50 microns indicative of Keratoconus

Defining Controls: Pentacam

- Posterior elevation ranges from -6 μm to + 18 μm in normals
- 15.5-32 μm of elevation on the posterior corneal surface can delineate forme fruste KC from normals
- Feng et al recently published international values of corneal elevation in normals
  - Upper limits of normal for collective international data were 7.5 μm and 13.5 μm at the posterior apex and posterior thinnest point, respectively.
Scheimpflug Cut-points

**Posterior Elevation >30 microns on Pentacam suggests keratoconus**

Anterior Segment OCT

Slides courtesy of Mark Harrod
UH Eye Institute Ophthalmic Photographer

AS-OCT: What is it?

- An OCT with a lens adaptation
- Shows cross-sectional view of anatomy.
  - Cornea
  - Angle
  - Iris
  - Lens
  - Pachymetry
  - Topography
- More detail than AS ultrasound

AS-OCT: What is it?

- **SD-OCT**
  - Scan speeds: up to 26,000 a-scan/sec
  - Axial resolution of 5 microns
  - Scan depth of 2 mm
    - Optovue RTVue with Cornea Adapter Module
    - Heidelberg Spectralis with Anterior Segment Module
    - Bioptgen Envisu
- **TD-OCT**
  - Scan speeds of 2000 a-scan/sec
  - Axial resolution of 18 microns
  - Scan depth up to 6 mm
    - Zeiss Visante Omni
AS-OCT: What is it?

- Comparison of TD-OCT vs SD-OCT

AS OCT: What Are We Looking At?

- Corneal Thickness
  - Normal

AS OCT: What Are We Looking At?

- Corneal Thickness
  - Edema

AS OCT: What Are We Looking At?

- Corneal Thickness
  - LASIK Flap

AS OCT: What Are We Looking At?

- Corneal Thickness
  - Keratoconus: Mild
AS OCT: What Are We Looking At?

- Corneal Thickness
  - Keratoconus: Moderate

AS OCT: What Are We Looking At?

- Corneal Thickness
  - Keratoconus: Severe

AS OCT: What Are We Looking At?

- Corneal Thickness
  - Keratoconus: Severe

AS OCT: What Are We Looking At?

- Corneal Pathology
  - DESEK

AS OCT: What Are We Looking At?

- Corneal Pathology
  - Abrasion

AS OCT: What Are We Looking At?

- Corneal Pathology
  - S/P PK

Image Source: Optovue.
AS OCT: What Are We Looking At?

- Scleral Contact Lens Fitting
AS OCT: What Are We Looking At?

- **Lens and Capsule**
  - Normal

AS OCT: What Are We Looking At?

- **Lens and Capsule**
  - Captured IOL
AS OCT: What Are We Looking At?

- Iris Scans
  - Iris Cyst

AS OCT: What Are We Looking At?

- Iris Scans
  - Iris Cyst

AS OCT: What Are We Looking At?

- Iris Scans
  - Iris Mass

AS OCT: What Are We Looking At?

- Iris Scans
  - Open Angle

AS OCT: What Are We Looking At?

- Iris Scans
  - Narrow Angle

AS OCT: What Are We Looking At?

- Iris Scans
  - Closed Angle
AS OCT: What Are We Looking At?

• Iris Scans
  – Closed Angle

AS OCT: What Are We Looking At?

• Iris Scans
  – Shunt

Confocal Microscopy
What Can it Show Me?

Confocal Microscopy: What is It?

• Light Microscopy
  – Nidek CS4

• SLO
  – Heidelberg HRT with Rostock Camera Module

Confocal Microscopy: What Are We Looking At?

• Normal
  – Z-Scan Showing Reflectance Peaks, Pachymetry
**Confocal Microscopy: What Are We Looking At?**

- Normal
  - Endothelium
  - Posterior Stroma
  - Anterior Stroma
  - Nerve Plexus
  - Basal Epithelium
  - Epithelium

**Corneal Endothelial Image Analysis Parameters**

- Cell density (cells/mm²)
- Cell area (µm²)
- Coefficient of variation
  - polymorphism or variation in cell size
- % Hexagonal cells
  - pleomorphism or variation in cell shape

**Analytic methods:**
- A Fixed-frame analysis
- B Variable-frame analysis
- C Corners analysis
- D Center analysis
- E Center-Flex analysis
- F Automated
Confocal Microscopy: What Are We Looking At?

• Fuchs’ Dystrophy

• Epithelial Staining

• Acanthameoba Keratitis

• Acanthameoba Keratitis

• Fungal Keratitis

• Fusarium Keratitis
Confocal Images of Corneal Superficial Epithelium
Period 1 Day 1  Period 2 Day 35

10011024 L
• photophobia
• corneal thickness increase ≥ 45µm
• corneal staining
• headache

Confocal of Corneal Basal Epithelial Cells
Period 1 Day 1  Period 2 Day 35

10011024 L
• photophobia
• corneal thickness increase ≥ 45µm
• corneal staining
• headache

Confocal of Cornea Mid-Stromal Keratocytes
Period 1 Day 1  Period 2 Day 35

10011024 L
• photophobia
• corneal thickness increase ≥ 45µm
• corneal staining
• headache

Stromal Reflectivity

The screen shots of Navis software

Lower reflective stroma
higher reflective stroma

PHMB solution user grade 2.5 stain

PHMB User NO STAIN

PHMB User: Grade 3 Stain

Immune cells
Thank You.