CORNEAL TOPOGRAPHY

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Refractive power of the eye

- Eye has 3 refractive elements:
  1. Cornea
  2. Lens
  3. Axial length
- Cornea (air/tear film interface) provides
  \( \approx \frac{2}{3} \) of the refractive power of the eye
- Most current methods of topographic analysis
  actually measure the surface of the tear film, not
  surface of the cornea

Keratometry

- Helmholtz supposition:
  optics of the central cornea approximates a
  spherocylindrical sphere
- Takes advantage of the reflective qualities of the front
  corneal surface
- Projects an illuminated target from a fixed distance
  that is determined by focus and alignment
- Uses the distance between 2 fixed points reflected by
  the anterior surface of the cornea along orthogonal
  meridians to describe central corneal shape
Keratometry

• 2 points on paracentral cornea, 3mm apart
• Instrument measures distance between center of mire and point along the steepest and flattest axis: provides radius of curvature of central cornea and amount and axis of astigmatism
• Since only measures the front surface curvature, it uses a fudge factor (a different index of refraction) to obtain the total power of the cornea

Keratometry: positive features

1. Accuracy and reproducibility for measuring regular corneas within normal range of curvatures (40 - 46 D)
2. Good for fitting CL and IOL power calculation
3. Speed
4. Ease of use
5. Low cost
6. Minimal maintenance requirements

Keratometry: limitations

1. Provides limited information: no data on central and peripheral cornea
2. Assumes that the cornea is symmetrical: not accurate in other corneas
3. Loses accuracy when measures very flat or very steep corneas (> 50 D)
4. Not good for refractive procedures
Keratoscopy

• Keratoscope: instrument that projects multiple concentric rings (mires) on the cornea
• Keratoscopy: direct visualization of the rings
• Photokeratoscope: when a camera is added to photograph the mires

⇒ diameter and spacing of the mires are influenced by corneal power

Keratoscopy: normal cornea

• Central mires are:
  – circular
  – concentric
  – uniform spacing

Keratoscopy

• Steep regions
  – mires:
    • small diameter
    • closely spaced
    • narrow mires
• Flat regions
  – mires:
    • large diameter
    • widely spaced
    • broadened
Keratoscopy: regular astigmatism

- Elliptical distortion of the mires
- Short axis of ellipse falling on the steepest meridian (highest power)
- Long axis on the flattest meridian (lowest power)

Keratoscopy: irregular astigmatism

- Irregular spacing between mires
- Tortuosity of the mires

Keratoscopy: keratoconus

- Central mires have smaller-than-normal diameters
- Teardrope shape
- No longer concentric
Keratoscopy: structured exam

1. Check for artefacts:
   - tear film anomalies cause distortion of the mires: caused by epithelial irregularity or strand of mucus
   - exaggerated tear meniscus along upper or lower lid
2. Evidence of nonorthogonal astigmatism? : causes the mires to have an egg-shape
3. Inspect for abrupt changes from center to periphery:
   - if space between adjacent mires ↓ = steepening
   - if ↑ = flattening

Keratoscopy: limitations

1. Qualitative information
2. Good as long as distortions are large: regular astigmatism of < 3D cannot be detected by visual inspection
3. When central cornea is steep, even higher amounts of astigmatism can go undetected
4. Visually debilitating amounts of corneal asphericity can go undetected by visual inspection

Videokeratography: basic concepts

1. The keratoscope image
   - captures the image on a videoscreen
   - collimated images vs large-face keratoscope targets
   - allows instantaneous capture of all points to be captured
2. Digitizing the image
   - cannot begin to determine the shape of the cornea until it determines the position of each point on the mires
   - most systems measure between 256 and 360 points around the circumference of each mire
   - not perfect: spaces between each mire not studied
Videokeratography: basic concepts

3. Measuring the distance between the center of the keratoscopic image and each sample points
   – “power” measurement, although in D, is usually a measure of the corneal shape (axial measurement) or local corneal curvature

4. Calculating a measure of shape
   – the easiest and most direct measure of corneal shape that can be calculated is a measure of corneal slope called axial power
   – try to calculate the axial distance; used to calculate a local measure of slope (axial power)

Videokeratography

• Axial measurements are an accurate reflection of local refractive power only in the paraxial region

• 2 other ways to measure corneal shape:
   – Instantaneous measurement: looks at local curvature independent from any defined axis
   – Positional

Videokeratography

• First topography available: Computed Anatomy TMS-1:
   – collimating cone with 25 (9 mm diameter) or 30 rings (10.5 mm diameter)
   – video camera gather info in 30 msec
   – gives a lot of info: as many as 8000 points
   – smallest mire leaves only a 0.45 mm diameter of central cornea unexplored

• Many new systems available that differ in their focusing methods, Placido disk arrangements, reconstruction algorithms and presentation schemes
Evaluating topographical maps

• Louisiana State University color-coded map:
  – Hot colors (red, orange, yellow) = steep
  – Green = intermediate
  – Cool colors (light and dark blue) = flat

⇒ color map gives qualitative information
⇒ important to check the color scale to see which colors correspond to which dioptric powers, to determine the dioptric interval between color changes and the entire range of powers represented

Evaluating topographical maps

• Absolute scale:
  – designed to make only clinically relevant information obvious
  – preset min and max values and dioptric steps
  – fixed: same color always represents a specific dioptric range

• Adaptive-color scale:
  – expands or contracts its range according to the range of powers present in a given cornea
  – offers great topographic detail, but meaning of colors are lost and some normal corneas look abnormal and vice versa

Quantitative descriptors of topography

• *Simulated keratometry (Sim K)*:
  – provides info analogous to values obtained by a keratometer
  – provides power and location of the steepest meridian and power of the meridian 90° away

• *Min K*:
  – power and axis of the flattest meridian, regardless of the angle between the steepest and flattest meridian
Quantitative descriptors of topography

• **Surface asymmetry index (SAI)**
  - centrally weighted summation of difference in corneal power between corresponding points 180° apart on 128 equally spaced meridians crossing all the mires
  - theoretically = 0 for perfect sphere or spherocylindrical regular astigmatism
  - the higher the index, the more irregular the surface
  - sensitive to paracentral keratoconus

• **Surface regularity index (SRI)**
  - reflects local power fluctuations along each of the 10 central mires of the TMS-1
  - correlates with localized surface regularity within central cornea
  - high correlation with best corrected vision
  - can predict optical performance

Qualitative interpretation of maps

1. Are measurements in axial, instantaneous or refractive power?
2. What is the scale, and is it appropriate for the goal of testing?
3. Is the cornea complex enough to suspect the presence of measurement artefact?
4. How is the map oriented relative to the pupil and the center of the cornea?

Other methods of topography

1. Interferometry:
   - measures corneal shape at higher resolution
   - ± useful in normal corneas: compares small differences between 2 surfaces
2. Rasterstereography
   - projected grid of light to illuminate fluorescein-dyed tears on the ocular surface
   - photographed: topo determined directly by distortion of grid (no reflection)
   - not as sensitive to detect subtle topo changes
3. Slit images (ex. Orbscan Topography-Pachymetry System)
   - can measure the anterior and posterior curvatures of the cornea
Clinical applications of videokeratography

• Normal cornea: 4 distinguishing characteristics:
  1. Flattens from center to the periphery by 2 to 4 D, with nasal hemimeridian more than the temporal hemimeridian
  2. Each cornea has a variation in topographic pattern that are generally unique to the individual
  3. The 2 corneas of one individual normally exhibit nonsuperimposable mirror-image symmetry: enantiomorphism
  4. Exhibits relative smoothness and absence of significant irregular astigmatism

Normal cornea

1. Flattens from center to periphery: nasal > temporal
2. Topographic pattern unique to the individual
3. Enantiomorphism
4. Relative smoothness and absence of significant irregular astigmatism

Normal corneas

• Naturally occurring patterns:
  1. Round: 23%
  2. Oval: 21%
  3. Symmetrical bowtie: 18%
  4. Asymmetrical bowtie: 32%
  5. Irregular: 7%

⇒ although this classification is somewhat arbitrary, it does describe the range of normalcy in which good vision can be obtained
Regular astigmatism

- The most common naturally occurring deviation from normal
- Symmetrical bowtie pattern
- Most often:
  - with-the-rule: steep meridian at 90°

Regular astigmatism

Against-the-rule: steep meridian at 180°

Regular astigmatism

Oblique
**Irregular astigmatism**

- Every deviation from a pure ellipsoidal shape
- Component of the astigmatism that cannot be corrected with glasses
- Common causes: dry eyes, scars, ectatic degenerations, pterygium, CL warpage, trauma, sx

**Keratoconus**

- Most frequent ectatic disorder
- Topography useful to make diagnosis when no other clinical signs
- Important preop tool for refractive sx: ad 6.5% of subclinical keratoconus reported
- But not sufficient to make diagnosis
- 2 types: 1. Peripheral (72%):
  - typically inferior or inferotemporal
  2. Central: with or without a superimposed asymmetric pattern or bowtie astigmatism

**Keratoconus**

3 topographic features:

1. High central power:
   - > 47 D
2. A difference of 3D or more between points 3mm inferior to the center and 3mm superior to the center
3. Asymmetry between central corneal power of fellow eyes in excess of 1D
Penetrating keratoplasty

- Regular astigmatism
- Irregular astigmatism: large amount of broadly based irregular astigmatism:
  - separation of the hemimeridians of highest and lowest power by an angle other than 90°
  - asymmetry of power between the 2 major hemimeridians
  - areas of high power near the wound
- Useful to correct astigmatism post-PKP

Refractive surgery

- Radial keratotomy
  - central flattening
  - reversal of usual pattern of gradual flattening from the center to the periphery
  - 59% exhibit polygonal pattern
  - a degree of nonuniformity in power distribution is typical

Refractive surgery

- PRK and Lasik:
  - uniform central zone of reduced power
  - smooth transition of power from the ablated zone to the peripheral cornea
  - irregular astigmatism possible
Corneal warpage

- Can be seen with both soft and rigid CL
- Spectacle blur
- Distortion of keratometer or keratoscope mires
- Central irregular astigmatism, loss of radial symmetry, frequent reversal of normal pattern of progressive flattening from the center to the periphery
- Changes can correspond with the resting position of the CL: if rests superiorly can → pseudokeratoconus
- Usually regresses in 4 to 6 weeks, but may take months, may even be permanent

Summary displays

- STARS display (Standardized Topographic Analysis of Refractive Surgery): designed specifically to assist in evaluation refractive surgery
  - 5 topo maps: preop, 1-month postop, last exam
  - 2 difference maps:
    1. Surgical effect: difference between preop and 1 month postop
    2. Healing effect: difference between 1 month postop and last exams

Summary displays

- The Holladay diagnostic summary
  - true refractive power of cornea at every point
  - shape of cornea compared to normal at every point: profile difference map
  - optical quality of the cornea at every point: distortion map
  - 15 specific corneal parameters to quantitatively describe the cornea such as Sim K, asphericity, Corneal Uniformity Index...