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To capture the refractive power of the cornea with a single value of \(n\) is a matter of considerable clinical utility. However, the task of assigning a single \(n\) to describe the cornea’s refracting power is complicated by the effect of the cornea-aqueous interface on transmission of incoming light.
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The math is demonstrated on the following slides.
How can you tell if a given interface will act like a plus vs a minus lens?
How can you tell if a given interface will act like a **plus** vs a **minus** lens?

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‘Draw a box around the interface, and darken the side of higher $n$.\"
Anterior chamber (n = 1.34)

Cornea (n = 1.376)

Air (n = 1.0)

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The air-cornea interface looks like a plus lens, which means that convergence will be added at this interface.

**Corneal Optics**

\( \text{Air (n = 1.0)} \)

\( \text{Cornea (n = 1.376)} \)

\( \text{Anterior chamber (n = 1.34)} \)
Anterior chamber \( (n = 1.34) \)

Light rays

Air \( (n = 1.0) \)

Cornea \( (n = 1.376) \)

Corneal Optics

\[
\frac{n' - n}{r} = \frac{1.376 - 1.0}{0.0077\text{m}} = +49\text{D}
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\textit{David Hunter (of Last Minute Optics) suggests the following…}

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The air-cornea interface looks like a **plus lens**, which means that **convergence** will be added at this interface.

Specifically, the effect is that of a **plus lens to the tune of about +49D**.
Corneal Optics

On the other hand, the cornea-aqueous interface looks like a minus lens, meaning divergence will be added at this interface.

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On the other hand, the cornea-aqueous interface looks like a **minus** lens, meaning divergence will be added at **this** interface.

Specifically, the effect is that of a minus lens of about -6D.

\[
\frac{n' - n}{r} = \frac{1.34 - 1.376}{0.006m} = -6D
\]
Anterior chamber ($n = 1.34$)

Air ($n = 1.0$)

Cornea ($n = 1.376$)

Light rays

Corneal Optics

$+49D$  $-6D$

$+43D$

The net result across the cornea is an overall power of about 43D
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The net result across the cornea is an overall power of about 43D.

Note: The BCSC Clinical Optics book uses these numbers. However… The Refractive Surgery book assumes an anterior-corneal power of 48D, which in turn results in an overall corneal power of 42D. So don’t be confused if you see these numbers.
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**Determination of the true corneal power requires measurement of the posterior corneal curvature—a technically difficult and time-consuming task back in the day.**

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\text{Power} = \frac{1.376 - 1.0}{r_{\text{Anterior}}} + \frac{1.34 - 1.376}{r_{\text{Posterior}}}
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Instead, it was decided to select a single $n$ to capture overall corneal power.

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(Who did all this deciding, I have no idea.)

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Thus, assigning the cornea a single $n$ of 1.3375 accounts for both its anterior (plus) and posterior (minus) effects, greatly simplifying calculations of net corneal power. However, 1.3375 does **not** accurately represent the ‘true’ refractive effect that corneal tissue has on light. In short, it is a **convenient fiction**.
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As an aside: Research into IOL calculations has found that using \( n_K = 1.3375 \) results in **overestimation** of true corneal power to the tune of about half a diopter.

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As an aside: Research into IOL calculations has found that using $n_K = 1.3375$ results in overestimation of true corneal power to the tune of about half a diopter. Thus, most IOL calculation formulae now use $n_K = 1.3333$ instead. Plugging this into Snell's reduced law, a cornea with an anterior radius-of-curvature of 7.5mm has a power of 44.44D. So don’t be thrown if you encounter $n = 1.3333$ in an IOL calculation formula.

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As stated previously, introduction of this net corneal index of refraction simplified the process of corneal power calculations. However, one of the things that makes this process possible is the assumption that the relationship between the cornea’s anterior radius-of-curvature and posterior radius-of-curvature is a constant.

Power = \frac{1.376 - 1.0}{1.34 - 1.376} = \frac{n' - n}{r_{\text{Anterior}}} \propto \frac{r_{\text{Posterior}}}{r_{\text{Anterior}}}

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Power = \[
\frac{n' - n}{r}
\]

Radius of curvature of the surface

\[
\text{Power} = 1.376 - 1.0 = 1.34 - 1.376
\]

\[
r_{\text{Anterior}} \propto \frac{1}{r_{\text{Posterior}}}
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Recall also that keratometers determine central corneal power by assessing midperipheral corneal power, and then extrapolating based on an assumed relationship between midperipheral- and central corneal powers.

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**Corneal Optics**

\[
\text{Power} = \frac{n' - n}{r}
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\( n \) – \( n \) = the ray is coming from
\( n' \) – \( n \) = the ray is going

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Recall also that keratometers determine corneal power by estimating the cornea’s anterior curvature and then extrapolating based on the net corneal index of refraction and the assumed constant relationship between anterior and posterior radius-of-curvature. However, s/p keratoablative surgery this relationship no longer holds, and thus the extrapolated corneal power will be way off. This is why post-keratoablative patients who undergo cataract surgery are at risk for a so-called ‘refractive surprise’—their corneal measurements indicate one power, but the actual power is very different.

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What one word best describes the overall shape of the cornea?
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What does prolate indicate about the cornea’s shape?
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What does prolate indicate about the cornea’s shape? That the central cornea is steeper (ie, has a shorter radius of curvature) than the peripheral corneal.
Q

What one word best describes the overall shape of the cornea? Prolate

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If the opposite relationship holds true--ie, if the central cornea is flatter than the peripheral--what word describes that shape?
What one word best describes the overall shape of the cornea? Prolate

What does prolate indicate about the cornea’s shape? That the central cornea is steeper (ie, has a shorter radius of curvature) than the peripheral corneal.

If the opposite relationship holds true--ie, if the central cornea is flatter than the peripheral--what word describes that shape? Oblate
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Under what (quite common) circumstance might one encounter an oblate cornea?
Q/A

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Under what (quite common) circumstance might one encounter an oblate cornea? In an eye that is s/p keratorefractive surgery for myopia
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What if the entire cornea has the same steepness/radius of curvature--what word describes that shape?
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What if the entire cornea has the same steepness/radius of curvature--what word describes that shape?
Spherical
What one word best describes the overall shape of the cornea? Prolate.

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Does the human cornea ever take on a spherical shape?
What one word best describes the overall shape of the cornea? Prolate

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Does the human cornea ever take on a spherical shape? Essentially never
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What if the entire cornea has the same steepness/radius of curvature? Spherical

What term quantifies the degree of difference between the curvature of the central cornea vs that of the corneal periphery? Q factor (aka Q value)

Q factor can be divided into three groups: Q<0, Q=0, and Q>0. What is the significance of these groups? Q<0 means the central cornea is steeper than the peripheral (ie, the cornea is prolate). Q=0 means the central and peripheral cornea have the same steepness/radius of curvature (ie, the cornea’s overall shape is spherical). Q>0 means the central cornea is flatter than the peripheral (ie, the cornea is oblate).
Corneal Optics

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The **Q factor** (aka **Q value**)

Q factor can be divided into three groups: Q<0, Q=0, and Q>0. What is the significance of these groups?

Q<0 means…
The cornea is prolate—that is, the central cornea is steeper than the peripheral cornea.

Q=0 means…
The central and peripheral cornea have the same steepness/radius of curvature—that is, the cornea's overall shape is spherical.

Q>0 means…
The central cornea is flatter than the peripheral cornea—that is, the cornea is oblate.

If the opposite relationship holds true—ie, if the central cornea is flatter than the peripheral—what word describes that shape?
Oblate

What if the entire cornea has the same steepness/radius or curvature—what word describes that shape?
Spherical
What one word best describes the overall shape of the cornea? **Prolate**

What does prolate indicate about the cornea's shape?

That the central cornea is steeper (ie, has a shorter radius of curvature) than the peripheral cornea.

What term quantifies the degree of difference between the curvature of the central cornea vs that of the corneal periphery?

The **Q factor** (aka **Q value**)

The Q factor can be divided into three groups: Q<0, Q=0, and Q>0. What is the significance of these groups?

- Q<0 means...the central cornea is steeper than the peripheral (ie, the cornea is **prolate**)
- Q=0 means...central and peripheral cornea have the same steepness/radius of curvature (ie, the cornea's overall shape is **spherical**)
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What is the unit of measurement for the Q factor? **It has none--it is a dimensionless number**
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What does prolate indicate about the cornea's shape?

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What if the entire cornea has the same steepness/radius or curvature--what word describes that shape? **Spherical**

What is the average Q factor/value for the human cornea? **-0.26**
What one word best describes the overall shape of the cornea? **Prolate**

What does prolate indicate about the cornea's shape?

The term quantifies the degree of difference between the curvature of the central cornea vs that of the corneal periphery. The **Q factor** (aka **Q value**)

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In one word, what property of the cornea does the Q factor quantify?

Corneal asphericity (in fact, it is often referred to as the ‘asphericity Q factor’)

If the opposite relationship holds true—ie, if the central cornea is flatter than the peripheral—what word describes that shape?

Oblate

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What one word best describes the overall shape of the cornea? Prolate

What does prolate indicate about the cornea’s shape? That the central cornea is steeper (ie, has a shorter radius of curvature) than the peripheral corneal.

Is any portion of the cornea spherical?
What one word best describes the overall shape of the cornea? Prolate

What does prolate indicate about the cornea’s shape? That the central cornea is steeper (i.e., has a shorter radius of curvature) than the peripheral corneal

Is any portion of the cornea spherical? Yes, the central ~3mm closely approximates a spherical surface
What one word best describes the overall shape of the cornea? **Prolate**

What does *prolate* indicate about the cornea's shape?

That the central cornea is steeper (ie, has a shorter radius of curvature) than the peripheral corneal curvature.

Is any portion of the cornea spherical? Yes, the central ~3mm closely approximates a spherical surface.

On balance, and with respect to visual acuity, is the prolate nature of the human cornea a good thing? Yes, definitely.
What one word best describes the overall shape of the cornea? Prolate

What does prolate indicate about the cornea’s shape?
That the central cornea is steeper (ie, has a shorter radius of curvature)

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It seems like a spherical cornea would be better. Why is this not the case?

Is any portion of the cornea spherical?

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Because a spherical refracting structure results in more spherical aberration
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It seems like a spherical cornea would be better. Why is this not the case?
Because a spherical refracting structure results in more spherical aberration.

What is spherical aberration?
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Because a spherical refracting structure results in more spherical aberration.

What is spherical aberration?
See slide-set RS6 for a discussion of this important topic.
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Because the central cornea is steeper than the periphery, it has more power. How much more?
What one word best describes the overall shape of the cornea? Prolate

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Is any portion of the cornea spherical? Yes, the central ~3mm closely approximates a spherical surface

Because the central cornea is steeper than the periphery, it has more power. How much more? About 3-4 diopters more
Power differential of central vs peripheral prolate cornea
What are the three categories of technology for determining central corneal power?
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- Keratometry
- Corneal topography
- Corneal tomography
What are the three categories of technology for determining central corneal power?

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How does a keratometer work?

By producing a reflection of an object of known size off the cornea (technically, off the tear film) from a known distance. By comparing the size of the resulting image to the size of the object, an estimate of corneal curvature can be calculated. No. It assesses the rate of curvature at 4 points in the paracentral zone of the cornea; ie, along a circle 3-4 mm in diameter centered on the corneal apex. Then, based on the assumptions discussed earlier in this slide-set, the central power of the cornea is estimated. No
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So it measures central corneal curvature/power directly?
What are the three categories of technology for determining central corneal power?

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Does keratometry measure the curvature of the posterior corneal surface?
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Does keratometry measure the curvature of the posterior corneal surface?
No
Keratometer (B&L type)
Keratometry image (B&L type)
What are the three categories of technology for determining central corneal power?

- Keratometry
- **Corneal topography**
- Corneal tomography

How does a corneal topographer work?

Like keratometry, corneal topography is reflection-based. However, topographers reflect a set of concentric rings (collectively called a *Placido disk*) from the tear film, and a computer analyzes the distances between, and shapes of, the reflected rings. Based on this analysis, the topographer creates a color-coded 'map' depicting the curvature across the entire cornea.

In doing this, does corneal topography directly measure central corneal curvature/power? No. While it measures power closer to the central cornea than does a keratometer, topography still cannot directly measure central corneal curvature/power.

Does topography measure the curvature/power of the posterior corneal surface? Not at all.

Does topography, of itself, provide adequate information to perform keratorefractive surgery? Provided it is interpreted properly, yes.
What are the three categories of technology for determining central corneal power?

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Corneal Placido-disk topography: Device

Corneal Optics
Corneal Placido-disk topography: Normal mires
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Corneal Placido-disk topography: Color map demonstrating…
Corneal Placido-disk topography: Color map demonstrating...with-the-rule astigmatism
**Corneal Optics**

- **What are the three categories of technology for determining central corneal power?**
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*In doing this, does corneal topography directly measure central corneal curvature/power?*
No. While it measures power *closer* to the central cornea than does a keratometer, topography still cannot directly measure central corneal curvature/power.

*Does topography measure the curvature/power of the posterior corneal surface?*
Not at all
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Why this qualifier? How might interpretation be compromised?

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The acquisition of topography data is susceptible to artifacts which can result in inaccurate mapping.

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The acquisition of topography data is susceptible to artifacts which can result in inaccurate mapping.

What sorts of artifacts interfere with interpretation of corneal topography?
--Artifacts secondary to…
--Artifacts due to…

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Why this qualifier? How might interpretation be compromised?
The acquisition of topography data is susceptible to artifacts which can result in inaccurate mapping.

What sorts of artifacts interfere with interpretation of corneal topography?
--Artifacts secondary to…abnormalities/deficiencies of the tear film
--Artifacts due to…alignment of the topographer

Does topography, of itself, provide adequate information to perform keratorefractive surgery?
Provided it is interpreted properly, yes.
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Does corneal topography directly measure central corneal curvature/power?
No. While it measures power closer to the central cornea than does a keratometer, topography still cannot directly measure central corneal curvature/power.

Does topography measure the curvature/power of the posterior corneal surface?
Not at all.

Does topography, of itself, provide adequate information to perform keratorefractive surgery?
Provided it is interpreted properly.

Why this qualifier? How might interpretation be compromised?
The acquisition of topography data is susceptible to artifacts which can result in inaccurate mapping. The tear film deficiencies can mess up topography.

How might tear film deficiencies mess up topography?
It's important to bear in mind that corneal topography results aren't based on measuring reflections off the cornea; rather, they are based on measuring reflections off the tear film. Thus, if the tear film is inadequate, or abnormal in distribution or composition, the image it produces may be distorted, leading to a 'garbage in, garbage out' situation vis a vis the topography results.
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Does topography measure the curvature/power of the posterior corneal surface?

Not at all

Does topography, of itself, provide adequate information to perform keratorefractive surgery?

Provided it is interpreted properly

Why this qualifier? How might interpretation be compromised?

The acquisition of topography data is susceptible to artifacts which can result in inaccurate mapping. What sorts of artifacts interfere with interpretation of corneal topography?

- Artifacts secondary to abnormalities/deficiencies of the tear film
- Artifacts due to alignment of the topographer

How might tear film deficiencies mess up topography?

It’s important to bear in mind that corneal topography results aren’t based on measuring reflections off the cornea; rather, they are based on measuring reflections off the tear film.

Does corneal topography reflect a set of concentric rings?
What are the three categories of technology for determining central corneal power?

- Keratometry
- **Corneal topography**
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How does a corneal topographer work?
Like keratometry, corneal topography is reflection-based. However, topographers reflect a set of concentric rings (collectively called a Placido disk) from the tear film, and a computer analyzes the distances between, and shapes of, the reflected rings. Based on this analysis, the topographer creates a color-coded 'map' depicting the curvature across the entire cornea.

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How might tear film deficiencies mess up topography?
It’s important to bear in mind that corneal topography results aren’t based on measuring reflections off the cornea; rather, they are based on measuring reflections off the tear film. Thus, if the tear film is inadequate, or abnormal in distribution or composition, the image it produces may be distorted, leading to a ‘garbage in, garbage out’ situation vis a vis the topography results.

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Fixation target

Visual axis

Temporal

Nasal

(OD, viewed from above)

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Fixation target

Optical (pupillary) axis

Visual axis

Corneal apex

Temporal

Nasal

Corneal Optics

(OD, viewed from above)
Fixation target

Note: The corneal apex is formally defined as ‘the location of maximal corneal curvature,’ not as ‘the corneal location intersected by the optical axis.’
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How can one readily identify the corneal apex in the clinic?

When you align a light-source with your line of sight, then align the location of the corneal light reflex with the center of the patient’s pupil, that corneal location is the corneal apex.
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What is the name for the corneal location intersected by the visual axis?
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How can one readily identify the corneal vertex in the clinic?
What is the name for the corneal location intersected by the visual axis?
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How can one readily identify the corneal vertex in the clinic?
When you align a light-source with your line of sight, then ask the pt to look at the light, the location of the corneal light reflex is the corneal vertex
Note that an angle obtains between the optical and visual axes. What is the name of this angle?

Angle kappa
Note that an angle obtains between the optical and visual axes. What is the name of this angle? Angle kappa.
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Angle kappa

By locating the corneal vertex, then taking note of its distance from the center of the pupil.
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NEXT Q
Corneal Optics

Fixation target

Temporal

Corneal apex

Nasal

(OD, viewed from above)
Corneal Optics

(OD, viewed from above)

Fixation target

Optical (pupillary) axis

Visual axis

Corneal vertex

Corneal apex

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**Answer:**

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**Why does any of this axis stuff matter?**

Because the topographic results are heavily influenced by the axis at which the measurements are obtained, they are subject to misinterpretation; for example, the overdiagnosis of keratoconus can occur if one assumes the keratometry axis passed through the corneal apex, when in fact it passed through the visual apex.

**What if anything can be done about these potential sources of error?**

A number of techniques have been developed to deal with these issues. But the most important factor is an awareness of the potential errors on the part of the surgeon.
Corneal Optics

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What is the difference between corneal topography and corneal tomography?

Unlike topography, which only provides information about the shape of the corneal surface, corneal tomography provides 3-D modeling of the cornea—including anterior surface shape, posterior surface shape, and corneal thickness.

How does a corneal tomographer work?

There are two basic technologies:

- Scanning-slit
- Scheimpflug imaging

Does corneal tomography measure central corneal curvature/power directly?

Scheimpflug systems do; scanning-slit do not (but they estimate it very accurately)

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Multiple slit-beam images (which reflect off both the anterior and posterior corneal surfaces) are collected, and used to reconstruct the structure of the cornea. (Note: Some scanning-slit systems work by combining this technology with Placido-disk imaging)
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Scanning slit technology

- The scanning slit triangulates the area between the reflected beam and camera axis to determine the edge.
- Overall analysis of reflected beams determines ‘floats’.
- Difference in two edges created by the same beam, adjusting for time delays, determines the depth.
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What is Scheimpflug photography?
A technique that allows one to take 'side on' pics of the cornea as slit-beam illumination passes through it.

How do Scheimpflug-based systems work?
Multiple Scheimpflug images of the cornea are collected and integrated to produce a model of the cornea.
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Pentacam Overview Report. **Upper pane:** the Scheimpflug image is a cross-sectional image showing the cornea, anterior chamber, iris, and lens. **Lower panes:** A 3-D representation of the patient's corneal shape is provided; the anterior corneal surface is shown in red, posterior corneal surface in green, and iris in blue. **A pachymetry map is a color map that indicates corneal thickness; cooler colors are thicker and warmer colors are thinner** (numeric scale on right).
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What is the difference between corneal topography and corneal tomography? Unlike topography, which only provides information about the shape of the corneal surface, corneal tomography provides **3-D modeling** of the cornea—including anterior surface shape, posterior surface shape, and corneal thickness.

How does a corneal tomographer work? There are two basic technologies:
-- Scanning-slit
-- Scheimpflug imaging

Does corneal tomography measure central corneal curvature/power directly? Scheimpflug systems do; scanning-slit do not (but they estimate it very accurately)

Does tomography measure the curvature of the posterior corneal surface? Yes (well, Scheimpflug systems do; again, scanning-slit systems estimate it)
Corneal Optics

- What are the three categories of technology for determining central corneal power?
  - Keratometry
  - Corneal topography
  - Corneal tomography

- What is the main reason to evaluate corneal topography prior to performing K-R surgery?
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What is the main reason to evaluate corneal topography prior to performing K-R surgery? To determine whether a prospective pt suffers from a corneal ectatic disorder.
Q

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- **What are the two main corneal ectatic disorders to be on the lookout for?**
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  - Keratoconus
  - Pellucid marginal degeneration
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For more on ectatic disorders, see slide-set K12

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