What is the refractive index \( (n) \) of the cornea?

- The refractive index of the cornea varies from 1.40 anteriorly to 1.37 posteriorly, and is different for the epithelial and endothelial surfaces. Therefore, the cornea cannot be said to have a single refractive index.
- The value of 1.34 came from the need to capture the refractive power of the cornea with a single value of \( n \), which is of considerable clinical utility.
- The total effect on incoming light is about +43D, combining the addition of convergence at the air-cornea interface (about +49D) and the addition of divergence at the cornea-aqueous interface (about -6D). Thus, a single value for \( n \) must produce ~43D when plugged into Snell's law.
- The value 1.34 is a convenient fiction. The math is demonstrated on the next slide.
What is the refractive index \( (n) \) of the cornea?

This is a much trickier question than it seems. The answer usually given is 1.34 (or 1.3375 by the anal retentives among us). But this is actually incorrect! The \( n \) of the corneal stroma varies from 1.40 anteriorly to 1.37 posteriorly (and \( n \) is different still for the epithelial and endothelial surfaces). Thus the cornea cannot be said to have a single \( n \).
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So where did the value 1.34 come from? And why isn’t \( n \) somewhere between 1.37 and 1.40?
What is the refractive index \((n)\) of the cornea?

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So where did the value 1.34 come from? And why isn’t \(n\) somewhere between 1.37 and 1.40?

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. While the air-cornea interface adds convergence (about +49D) to incoming light, the cornea-aqueous interface actually adds divergence (about -6D), for a net effect of about +43D. Thus a single value for \(n\) must produce ~43D when plugged into Snell’s law.

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?

Corneal Optics

Air (n = 1.0)
Cornea (n = 1.376)
Anterior chamber (n = 1.34)
How can you tell if a given interface will act like a plus vs a minus lens?

David Hunter (of Last Minute Optics) suggests the following…
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‘Draw a box around the interface, and darken the side of higher $n$. 

Corneal Optics

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'Draw a box around the interface, and darken the side of higher $n$. The shape of the darkened area determines the lens effect.'

David Hunter (of Last Minute Optics) suggests the following…

Cornea ($n = 1.376$)

Air ($n = 1.0$)

Light rays

Corneal Optics

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Corneal Optics

Anterior chamber ($n = 1.34$)

$n' - n \over r = \frac{1.376 - 1.0}{0.0077m} = +49D$

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

David Hunter (of Last Minute Optics) suggests the following...

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‘Draw a box around the interface, and darken the side of higher n. The shape of the darkened area determines the lens effect.’

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

\[
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Corneal Optics

Air \((n = 1.0)\)

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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.

Anterior chamber \((n = 1.34)\)

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The net result across the cornea is an overall power of about 43D.
Anterior chamber ($n = 1.34$)

Air ($n = 1.0$)

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Note: The BCSC Clinical Optics book uses these numbers. However…

Refractive Surgery book assumes an anterior-corneal power of $48D$, which in turn produces an overall corneal power of $42D$.

So don't be confused if you see these numbers.

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I used $n_{\text{cornea}} = 1.376$ for those corneal calculations. So why is the cornea said to have an $n$ of 1.3375?
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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$$\text{Power} = \frac{n' - n}{r}$$

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Instead, it was decided to select a single $n$ to capture overall corneal power. Further, it was decided that an anterior radius-of-curvature of 7.5mm (0.0075m) should coincide with a total corneal power of 45D. (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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\[
\text{Power} = \frac{n' - n}{r} = \frac{1.376 - 1.0}{0.0075} = 1.34 - 1.376
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As stated previously, introduction of this \textit{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 \textit{relationship between the cornea’s anterior radius-of-curvature and posterior radius-of-curvature is a constant.}

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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. Both keratoablative and keratoincisional (ie, RK) surgeries decouple this midperipheral power <-> central power relationship. This is another important source of error leading to refractive surprise after cataract surgery.

Corneal tissue has on light. In short, it is a convenient fiction.
What one word best describes the overall shape of the cornea?
What one word best describes the overall shape of the cornea? Prolate
What one word best describes the overall shape of the cornea? **Prolate**

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
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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?
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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? Oblate
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Under what (quite common) circumstance might one encounter an oblate cornea?
Q/A

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Oblate

Under what (quite common) circumstance might one encounter an oblate cornea? In an eye that is s/p keratorefractive surgery for myopia
What one word best describes the overall shape of the cornea? Prolate.

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

Does the human cornea ever take on a spherical shape?
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Does the human cornea ever take on a spherical shape? Essentially never
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What does prolate indicate about the cornea's shape?

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

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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)

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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…
Q=0 means…
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The central cornea is steeper (i.e., has a shorter radius of curvature) than the peripheral corneal curvature.

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- 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…

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

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…

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 of 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?

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What is the unit of measurement for the Q factor?

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

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

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

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Q>0 means…the central cornea is flatter than the peripheral (ie, the cornea is *oblate*).

What is the unit of measurement for the Q factor?

It has none--it is a dimensionless number.
What one word best describes the overall shape of the cornea? **Prolate**

What does prolate indicate about the cornea’s shape?

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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?

- **Prolate**
  - That the central cornea is steeper (i.e., has a shorter radius of curvature) than the peripheral corneal curvature.

If the opposite relationship holds true—i.e., 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 of curvature—what word describes that shape?

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What is the average Q factor/value for the human cornea?

- **-0.26**

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

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

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

- 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 (ie, 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

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

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Q

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

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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’? See the Refractive Surgery slide-set entitled Aberrations for a discussion of this important topic
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?
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? 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?
What are the three categories of technology for determining central corneal power?

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

- Keratometry
- Corneal topography
- Corneal tomography

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.

So it measures central corneal curvature/power directly?

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.

Does keratometry measure the curvature of the posterior corneal surface?

No
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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Keratometer (B&L type)
Keratometry image (B&L type)
What are the three categories of technology for determining central corneal power?

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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 cornea/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.

Does corneal topography measure central corneal curvature/power directly?

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 of the posterior corneal surface?

No

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

Provided it is interpreted properly, yes
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Corneal Optics

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Corneal Placido-disk topography: Device
Corneal Placido-disk topography: Normal mires
Corneal Placido-disk topography: Mires typical of…
Corneal Placido-disk topography: Mires typical of…**keratoconus**
Corneal Placido-disk topography: Color map demonstrating...
Corneal Placido-disk topography: Color map demonstrating...with-the-rule astigmatism
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*Does topography, of itself, provide adequate information to perform keratorefractive surgery?*
Provided it is interpreted properly, yes
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What sorts of problems regarding interpretation are at risk in corneal topography?

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

What sorts of problems regarding interpretation are at risk in corneal topography?
There are several, but chief among them are artifacts due to the alignment of the topographer.
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Provided it is interpreted properly, yes

**What sorts of problems regarding interpretation are at risk in corneal topography?**
There are several, but chief among them are artifacts due to the alignment of the topographer.

**Why is topographer alignment an issue?**
Because there are three different ‘axes’ in play. They are:

- **Optical axis**: The line passing through the corneal apex and the fovea
- **Visual axis**: The line passing through the corneal vertex and the fovea
- **Topographer axis**: The line between the corneal apex and the center of the topographer
**A/Q**

- **What are the three categories of technology for determining central corneal power?**
  - Keratometry
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Does topography measure the curvature of the posterior corneal surface?
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Does No. Why

Does it provide adequate information to perform keratorefractive surgery? Provided it is interpreted properly, yes
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Like keratometry, corneal topography is reflection-based. However, topographers reflect a set of concentric rings (collectively called a *Placido disk*) from the cornea/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.

What sorts of problems regarding interpretation are at risk in corneal topography?
There are several, but chief among them are artifacts due to the alignment of the topographer.

Why is topographer alignment an issue?
Because there are three different ‘axes’ in play. They are defined as:

- The **optical** axis: The line passing through the corneal apex and the fovea
- The **visual** axis: The line passing through the vertex and the fovea
- The **topographer** axis: The line between the corneal apex and the center of the topographer

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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What is the corneal apex?

The 'peak' of the cornea--the point of maximum curvature

What is the corneal vertex?

The point of the cornea through which the pt's 'line of sight' passes

How are these two points related with respect to their locations on the cornea?

The corneal apex is slightly temporal to the corneal vertex

The topography axis incorporates the corneal vertex--why isn't it identical to the visual axis?

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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)
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How do scanning-slit technology work?
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.

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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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?**
What are the three categories of technology for determining central corneal power?

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

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**

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**Corneal Optics**

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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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Does tomography measure the curvature of the posterior corneal surface?

Yes (well, Scheimpflug systems do; again, scanning-slit systems estimate it)
Q

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- **What is the main reason to evaluate corneal topography prior to performing K-R surgery?**
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- Keratoconus
- Pellucid marginal degeneration