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 is different still for the epithelial and endothelial surfaces). Thus the cornea cannot be said to have a single \(n\).

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 to incoming light (about +49D), the cornea-aqueous interface actually adds divergence (about -6D), for a total effect of about +43D. Thus a single value for \(n\) must produce ~43D when plugged into Snell's law. In a sense, the value 1.34 is a convenient fiction. The math is demonstrated on the next slide.
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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?

Cornea
(n = 1.376)

Anterior chamber
(n = 1.34)

Air (n = 1.0)
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 $n$. The shape of the darkened area determines the lens effect.’
Corneal Optics

Air \((n = 1.0)\)

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Light rays

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

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Corneal Optics

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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

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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.
Light rays

Air (n = 1.0)

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Corneal Optics

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Note: The BCSC Clinical Optics book uses these numbers. However...
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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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Instead, it was decided to select a single $n$ to capture overall corneal power.

$$\text{Power} = \frac{n' - n}{r}$$

where $n'$ is the index of refraction where the ray is going, $n$ is the index of refraction where the ray is coming from, $r$ is the radius of curvature of the surface, and $n_{\text{cornea}} = 1.0$.

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$$45\text{D} = \frac{n_{\text{cornea}} - 1.0}{.0075\text{m}}$$

$$n_{\text{cornea}} = 1.3375$$
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. 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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$\text{Power} = \frac{n' - n}{r}$

1.376 – 1.0

1.34 – 1.376

As opposed to:

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

where the ray is going

\[ n' \]

where the ray is coming from

\[ n \]

Radius of curvature of the surface

\[ r_{\text{Anterior}} \]

is proportional to

\[ r_{\text{Posterior}} \]

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

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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.

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

\[ 1.376 - 1.0 = 1.34 - 1.376 \]

Corneal tissue has on light. In short, it is a convenient fiction.
Q

- 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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Under what (quite common) circumstance might one encounter an oblate cornea?
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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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Does the human cornea ever take on a spherical shape?
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If the opposite relationship holds true—i.e., if the central cornea is flatter than the peripheral—what word describes that shape?

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

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) 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 (i.e., the cornea is prolate).

Q=0 means the central and peripheral cornea have the same steepness/radius of curvature (i.e., the cornea's overall shape is spherical).

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Q<0 means…

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

What does prolate indicate about the cornea’s shape?

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

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 (i.e., the cornea is **prolate**)
- $Q=0$ means… the central and peripheral cornea have the same steepness/radius of curvature (i.e., the cornea’s overall shape is **spherical**)
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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.

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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**

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**Corneal Optics**
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What is the average Q factor/value for the human cornea? **-0.26**
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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')
Corneal Optics

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

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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

Is any portion of the cornea spherical? Yes, the central ~3mm closely approximates a spherical surface
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What is ‘spherical aberration’? See the Refractive Surgery slide-set entitled Aberrations 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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- Because the central cornea is steeper than the periphery, it has more power. How much more? About 3-4 diopters more
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
**Corneal Optics**

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

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
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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?

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

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 corneal *vertex* and the fovea
- The **topographer** axis: The line between the corneal apex and the center of the topographer
Corneal Optics

- **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?

Because it is perpendicular to the orientation of the Placido disk, which is not perfectly aligned with the visual axis.

Why does any of this matter?

Because the topographic results are heavily influenced by the axis at which the measurements are obtained, they are subject to misinterpretation; eg, 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.

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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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- 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

*Does corneal tomography measure central corneal curvature/power directly?*
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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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What is the main reason to evaluate corneal topography prior to performing K-R surgery?
Corneal Optics

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  To determine whether a prospective pt suffers from a corneal ectatic disorder
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What are the two main corneal ectatic disorders to be on the lookout for?
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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.

What are the two main corneal ectatic disorders to be on the lookout for?
- Keratoconus
- Pellucid marginal degeneration