Understanding Corneal Topography
By Dianne Anderson

Corneal topography provides us with a detailed description of various curvature and shape characteristics of the cornea. This information is very helpful for the illustration of corneal astigmatism, detection of corneal pathologies and perfection of contact lens fitting.

Becoming familiar with the basics of topography will allow you to choose the appropriate map for any given patient situation as well as understand the data associated with these maps. This article explains the different topography map types, how to classify corneal astigmatism and corneal shapes associated with various pathologies and how to design contact lenses with the information provided. Even though the image presentations may vary between topographers, this information is universal.

Types of Topographers
Topographers can be small-cone or large-cone Placido disc systems or slit-scanning devices. Placido disc systems project a series of concentric rings of light on the anterior corneal surface. The corneal shape or curvature is directly measured in diopters of curvature along thousands of points on the rings. Placido disc topography systems do not actually measure elevation; rather, they derive anterior corneal elevation data by reconstructing actual anterior curvature measurements via sophisticated algorithms. Small-cone Placido disc topographers project more rings on the cornea and have a shorter working distance than large-cone Placido disc topographers. These systems supply a great deal of measurement points and require a steady hand to ensure accurate image acquisition. The Medmont E300 (Medmont), Scout and Keratron (EyeQuip) and Magellan Mapper (Nidek) are examples of small-cone topography systems. Large-cone Placido disc systems use a longer working distance and project fewer rings onto the cornea than small-cone topographers and are more forgiving when measuring patients with very deep set eyes. Examples of large-cone topographers are the ATLAS 995 and 9000 (Carl Zeiss Meditec) and ReSeeVit (Veatch Ophthalmic Instruments). Slit-scanning or elevation devices directly measure the elevation of both the anterior and posterior cornea via time domain or light-based analysis. These devices process elevation data along several points on the anterior and posterior corneal surfaces. This data is then converted into anterior and posterior curvature in diopters as well as corneal thickness or pachymetry in microns. Examples of elevation devices are the Orbscan (Bausch & Lomb), Pentacam (Oculus) and Visante OCT (Carl Zeiss Meditec).
**Color Scale Settings**

Corneal topography maps utilize advanced color scales to identify curvature data. Areas of steeper curvature are displayed in warm colors such as red and orange, whereas areas of flatter curvature are illustrated in cool colors such as green and blue. Topographers display color maps in “absolute” and “normalized” scales. These color scales appear on the left margin of the map with the flattest curvature at the bottom and the steepest curvature at the top. The absolute or standard scale displays a fixed range of curvatures selected in the settings of the topographer regardless of the map selected. The normalized scale displays the range of curvature or power calculated from the specific map(s) you select. This provides an excellent general view of the entire cornea, as the scale shows the flattest to steepest readings.

**Defining the Maps**

**Axial Map**

The axial map is used most often, since axial curvature is directly related to corneal power. This allows you to correlate the anterior surface shape to the patient’s refractive status. The axial map displays steep areas in hot colors (red) and flat areas in cool colors (blue). These colors directly correspond with the curvature data on the scale displayed at the left when viewing the image.!

A simple example is the axial map of a spherical cornea (Figure 1). Note the consistent curvature throughout the pupillary zone (outlined in black) and concentric flattening outward to the limbus. In this case, the **steepest part of the cornea, known as the apex**, is centered on the visual axis. This is a very symmetric cornea. In cases of corneal pathologies such as keratoconus, the corneal apex is decentered off the visual axis. This is quite apparent on the axial map, and allows you to diagnose corneal irregularities and explains why the patient’s vision is subacute.

**Tangential Map**

This map clearly defines small or “instantaneous” curvature changes. It calculates each measured point of data at a 90° “tangent” to its surface. Tangential maps provide a more detailed description of the corneal shape and provide a clearer view of the size and shape of the cone in a keratoconus patient, for instance. The ability to measure the size of the cone is very helpful in determining the ideal lens design and optic zone size. Additionally, tangential maps define the position of the treatment or effect of corneal reshaping and refractive surgery. Specifically note the red ring of paracentral steepening outside the blue central area of flattening in this example of myopic LASIK (Figure 2). Comparing the red ring’s position in relation to the pupil or visual axis clearly defines the position of the effect.
**Refractive Power Map**

This map provides an interpretation of the quality of vision a patient may achieve from the corneal surface throughout the pupillary zone. The more consistent or uniform the refractive power within the margins of the pupil, the better able the anterior surface of the cornea is to refract light properly. Practitioners do not commonly employ the refractive map, as it does not provide information on curvature or size and shape of the corneal surface (for which the axial and tangential maps are more effective). However, this map can be very effective when used to interpret the quality of vision achievable from a patient’s corneal surface. For instance, when comparing pre- vs. post-corneal reshaping results, the refractive map illustrates the extent that corneal surface changes contribute to the patient’s quality of vision and the position of the effect of treatment in relation to the pupil. Thus, the refractive power map can aid you in determining how well the patient sees specifically due to the contribution of the corneal surface to visual acuity. Additionally, following corneal reshaping or refractive surgery, it can show you how well or how poorly the effect is positioned.

**Elevation Map**

The elevation map defines the height of the cornea in reference to “best fit sphere,” or the radius of curvature that best matches the average curvature of the map. Placido disc topography systems do not actually measure elevation; rather, they gather elevation data by reconstructing actual curvature measurements via sophisticated algorithms. Elevation maps measure corneal height in microns and have a somewhat counterintuitive interpretation. Elevation is defined as the difference between the actual corneal surface and the best-fit reference sphere as measured in microns. Corneal elevation above the reference sphere is measured in positive microns and appears as red shading on the map. Conversely, blue shading indicates that the corneal surface is below the reference sphere and is measured in negative microns (Figure 3). But, the corneal curvature can actually be very steep in these blue areas. Classic examples include the periphery of a cornea along the steep meridian in limbal-to-limbal astigmatism and the inferior periphery of a cornea with oval KC. These maps are especially helpful in determining the outcome of contact lens fitting by predicting areas of excessive bearing (red/positive microns) or pooling (blue/negative microns). This information will guide you in designing the ideal RGP lens—spherical, aspheric, toric, keratoconic or reverse geometry.

![Figure 3](image-url)
Slit scanning and OCT devices measure the elevation of the front and back surfaces of the cornea. This is displayed as anterior and posterior float maps. “Float” refers to the fact that the best fit sphere has no fixed center, but rather floats. The distance between cornea and reference body is optimized to be as small as possible and as equal as possible (Figure 4).

Figure 4

**Displays**

The **Single View** display shows a single exam for a selected patient; recommended use is for baseline screening.

The **Difference Display** shows two exams for the same eye and the difference between them. This highly under-utilized map compares two corneal maps from one point in time to another, which can be very helpful when monitoring corneal changes from one exam to the next. For example, the difference map can clearly define the absolute effect of contact lenses, refractive surgery and corneal reshaping on the corneal surface. This function subtracts each measured point from one map to the other. With this map function, both selected maps will appear with a third “difference” plot displayed. Areas of the cornea that are now flatter are displayed in cooler colors (blue), and areas of the cornea that are steeper are represented in warmer colors (red), as with pre- and post-op refractive surgery, orthokeratology, contact lens-induced changes, keratoconus, etc. The result: You can precisely measure corneal changes. This map is indispensable if you practice corneal reshaping. When comparing the overnight changes or monitoring the patient over time, the difference map indicates the absolute results enacted by the lens. Used in combination, the following interpretations provide a clear picture of the effect: Employ the axial interpretation to determine treatment zone position and prescription changes. The tangential map determines the position of the corneal reshaping lens in the closed eye environment. Lastly, use the refractive power map to measure the treatment zone size (Figure 5).
The **OD/OS Compare display** shows two different views of right and left eye exams for the same patient on the same display. His display is recommended for the observation of differences and similarities between a patient's corneal shape; recommended use is for determining the clinical significance of corneal pathology in one eye as compared to the other. The **Overview display** can show four different views, in any combination, of the same exam for the selected patient. This display is a helpful overview for comprehensive evaluation (Figure 6).

The **Trend display** shows different exams of the same eye on different occasions. This display is especially helpful for illustrating corneal changes over time; recommended use is for monitoring corneal normalization prior to cataract or refractive surgery (Figure 7).

**Classifying Corneal Astigmatism**
Axial maps also illustrate the position and type of astigmatism. Normal astigmatism is symmetric and appears as an hourglass shape either within the pupil margin (apical) or extending the entire length of the cornea (limbal-to-limbal). Symmetric or regular astigmatism is classified with-the-rule (WTR), against-the-rule (ATR) or oblique. WTR astigmatism is steeper along the 90 degree meridian, ATR astigmatism is steeper along the 180 degree meridian and oblique astigmatism is steeper along meridians between 30 to 60 degrees and 120 and 150 degrees (Figures 8, 9 & 10). Irregular astigmatism is asymmetric in presentation and occurs in conditions such as keratoconus (KC), pellucid...
marginal degeneration (PMD), corneal scarring and post-penetrating keratoplasty. Axial maps of keratoconus show an area of excessive inferior, mid-peripheral steepening (Figure 11). The area of steepening is red and can be small (nipple), medium (oval) or large (global) in size. Typically, a variation greater than 10.00 diopters between the steepest and flattest curvature is indicative of keratoconus.\textsuperscript{7} The normalized scale on the left of Figure 11 shows a curvature range greater than 20 diopters. Axial maps of PMD show a distinctive pattern of ATR inferior peripheral steepening which resembles “kissing birds”, “crab claws” or “butterfly wings”.\textsuperscript{8} (Figure 12). Corneal scars induce flattening and appear as blue areas on an axial map, whereas tight PKP sutures induce steepening and appear as red areas on the axial map.

Measurements

A. Apical Radius
The apical zone is the area around the corneal apex where the refractive power is MOST constant. The apex does not always correspond to the geographic center or vertex of the cornea. Apical radius (Ro) is defined as the power of the cornea at the apex.

B. Sagittal Height Value
Corneal sagittal height (z-value), which isn’t available on all topographers, is a measurement in millimeters or microns of the distance between the geometric center of the cornea and the intersection of a specified chord length (y-value). Check with your RGP lab to obtain information on the chord length and corresponding sagittal height of a specific lens design. If you send the lab a copy of the topography map, many times they will be able to recommend the initial lens parameters.

Because reverse geometry and scleral lenses—fits based on corneal vault rather than base curve—have a specified chord length and sagittal value, this measurement is very helpful when
fitting either lens on post-surgical or irregular corneas. To effectively fit these difficult corneas, match the sagittal height of the reverse geometry or scleral lens with the sagittal height of the cornea, and add 15 microns, as doing so allows for a sufficient tear layer.

C. Horizontal Visible Iris Diameter (HVID)
Most topographers are capable of measuring the corneal diameter and label this value as the HVID or “white-to-white” measurement. The units are in millimeters and are usually generated automatically; however, some topographers require manual measurement of HVID. This measurement is extremely important in determining the sagittal height or depth of the cornea. Larger diameter corneas will have a greater depth than smaller corneas when measured over a given chord length. This information is vital in determining the optimal base curve and diameter of a contact lens. For example, a cornea with an apical radius of 42D and an HVID of 12mm will have a greater depth than a cornea with an apical radius of 42D and an HVID of 11mm. The 12mm cornea will fit better with a steeper base curve and/or larger diameter lens than the 11mm cornea.

D. Pupil Size
Topographers automatically generate a pupil diameter measurement. However, not all instruments offer both photopic (with light) and scotopic (without light) measurements.

Indices

A. Eccentricity
There are several mathematical interpretations of corneal shape. One of these, eccentricity, measures the rate of corneal flattening from the apex to the periphery along a specific chord and axis. Corneas that flatten at a greater rate from the center outward are assigned high e-values, and those that flatten at a lesser rate have low e-values. Spherical corneas have low e-values as compared to keratoconic corneas, which have a much steeper apex and flatten at a greater rate toward the periphery. The e-value is also an indicator of corneal sagittal height. Corneas with lower e-values are more spherical and have a greater sagittal height, while corneas with higher e-values are more elliptical and have a lower sagittal height.9

B. Shape Factor
Shape factor is a measure of corneal asphericity and a derivative of eccentricity. It is identified as $e^2$ (e squared).2,10 Shape factor differs from eccentricity; it is possible to assign prolate cornea positive values and oblate corneas low positive or negative values.2,10 In a normal cornea, the steepest radius (hottest color) is near the center, while the flattest curvature (coolest color) is toward the limbus. Patients with KC have highly prolate corneas with high shape factor values.

C. I-S Index
The inferior/superior (I-S) index is a measure of the difference between the average inferior power and average superior power on the cornea.11 The ratio difference between these two measurements is the I-S value, expressed in diopters. A positive value is common and signifies that the inferior cornea is steeper. This positive value will be higher in cases of corneal ectasia, and an I-S value over 1.2 is characteristic of KC.11 Negative I-S values are less common and indicate that the superior cornea is steeper than the inferior cornea.
Simulated Fluorescein Patterns
The simulated fluorescein (NaFl) pattern enables you to visualize the effects of the base curve, diameter and edge lift changes on the lens fit (Figure 13). Specifically, it appears over a given topography map, allowing you to evaluate the tear layer clearance beneath a specified RGP on that cornea. As a result, when you use the simulated NaFl pattern as a guide to achieving the optimal tear layer clearance, you have an excellent chance of designing the best RGP for any given cornea. Keep in mind, however, that the simulated NaFl pattern has limitations, as it does not take into consideration the effects of lid tension, corneal tilt and the tendency of a lens to gravitate toward the corneal apex (which may not be at the geometric center of the cornea). Each of these factors can cause a lens to decenter away from the geometric center of the cornea. The bottomline: The simulated fluorescein pattern allows you to more accurately pick the initial trial lens, which you then evaluate on the eye. The trial lens then enables you to consider the effects of lid tension, etc.

Topography and Contact Lens Designs
The following contact lens designs rely on corneal topography to determine the final custom lens parameters:

A. Toric
In order to minimize rotation and ensure stability, toric lenses must be fit with the optimal base curve and diameter. As previously mentioned, corneal diameter and sagittal height are determining factors in base curve selection. Larger corneas require steeper base curves than smaller corneas. A toric lens with too flat a base curve will rotate and result in fluctuating acuity. Steepening the base curve and/or increasing the diameter is the key to fitting success with soft toric lenses that rotate excessively. Compensating for rotation by adjusting the axis will not resolve the instability.

B. Multifocals
It is imperative that multifocal lenses be centered over the patient’s pupil for optimal acuity at distance. Aspheric multifocal lenses have distance correction in the center and near correction in the periphery. Patients with large pupils may experience haloes and glare with this type of multifocal design as the peripheral near addition induces spherical aberration. Multifocals that have a center near addition create simultaneous vision. Patient’s with large pupils will experience less aberration from simultaneous vision lenses as the periphery is all distance correction. A topography map prior to fitting multifocals is helpful in determining the patient’s pupil size. A topography map over the multifocal lens will show you where the lens sits in relation to the patient’s pupil. If the pupils are very small or the lens decenters, the patient will not be capable of experiencing the multifocal properties and should be fit in monovision rather than multifocal lenses.

C. Keratoconus
In keratoconus, the cone apex is decentered inferiorly and may not be measured accurately with standard keratometry. Having a topography map helps you to streamline the fitting process on these irregular corneas by providing you with curvature readings over the entire cornea. The axial map provides an accurate curvature value of the cone, the tangential map provides a clear picture of the location and size of the cone, and the elevation map indicates the height of the
cone. This information enables you to choose a base curve that will result in apical clearance rather than bearing.

D. Reverse Geometry
These lenses have a flatter central base curve with a steeper mid-peripheral curve and are designed for;

1. Orthokeratology
When fitting these designs, corneal topography enables you to monitor the centration and dioptric effect of the treatment zone, regardless of the fitting method and lens design.

2. Post-Refractive Surgery
You can design reverse geometry lenses for post-RK and myopic LASIK patients empirically by sending a copy of the topography map along with the spectacle prescription to your lab. The lab assesses the color differences—an indication of curvature changes—to determine the base curve, paracentral fitting curve and peripheral edge configuration. The topography map allows you to determine the optimal fitting curve which is based on the corneal curvature beyond the central 3mm measured by standard keratometry. These oblate corneas are steeper in the periphery than centrally, so using the central keratometry reading will result in a lens that is much too flat.

3. Advanced Keratoconus
In cases of advanced keratoconus where it is difficult to get an accurate topography map and difficult to fit standard keratoconus lenses, specially designed reverse geometry lenses are needed to cover the cone apex. These lenses are based on corneal height rather than curvature and a diagnostic fitting set must be used to ensure acceptable results. If this is not achievable, a corneal transplant is recommended.

Topography vs. Keratometry
While keratometers measure only the central 3 mm of the cornea, topographers measure out to 9 or 10mm of the cornea. This gives us a picture of the overall shape and identifies areas of asymmetry or irregularity beyond the central cornea.

There is no one “best” map with which to evaluate corneal topography. A thorough evaluation of the cornea depends on your knowledge of all topographic displays—curvature, height and power. When examined together, they provide a more comprehensive picture of the cornea, which allows you to better and more accurately diagnose and care for your patients.
References


3. Mack C, Merchea M. Advanced Corneal Imaging and Interpretation in the Diagnosis and Treatment of Corneal Disease. AAO lecture. 2006; Denver.


“Understanding Corneal Topography”
To receive one hour of continuing education credit, you must be an AOA Associate member and must answer nine of the twelve questions successfully. This exam is comprised of multiple-choice questions designed to quiz your level of understanding of the material covered in the continuing education article, “Understanding Corneal Topography”.

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Select the option that best answers the question.

1. Placido-disc topographers directly measure
   a. Anterior corneal curvature
   b. Posterior corneal curvature
   c. Corneal Elevation
   d. Corneal thickness

2. Slit scanning devices directly measure
   a. Anterior and posterior corneal curvature
   b. Anterior and posterior corneal elevation
   c. Corneal thickness
   d. b and c

3. The normalized color scale setting displays the range of curvature
   a. For normal corneas only
   b. For irregular corneas only
   c. Specific to the map you have selected
   d. In a standard range regardless of the map selected

4. The axial map displays
   a. Steep areas in RED
   b. Flat areas in BLUE
   c. Apical radius
   d. All of the above
5. The elevation map displays
   a. Corneal height in microns
   b. Areas above the reference sphere in RED
   c. Areas below the reference sphere in BLUE
   d. All of the above

6. Difference maps are especially helpful for
   a. Monitoring corneal normalization prior to cataract or refractive surgery
   b. Monitoring corneal changes after refractive surgery and corneal reshaping
   c. Neither a nor b
   d. Both a & b

7. Apical radius is
   a. A measurement of the most constant power of the cornea
   b. Used to determine corneal depth when combined with HVID
   c. A measurement of the corneal power along the visual axis
   d. a & b

8. HVID is an important measurement for determining
   a. The steepest portion of the cornea
   b. The diameter of a contact lens
   c. Central corneal curvature
   d. Corneal thickness

9. In with-the-rule astigmatism, the cornea
   a. Is steeper along the 90 degree meridian
   b. Is steeper along the 180 degree meridian
   c. Is steeper along meridians between 30 to 60 degrees and 120 and 150 degrees
   d. None of the above

10. The difference between keratoconus and pellucid marginal degeneration is
    a. Keratoconus is an asymmetric mid-peripheral steepening of the cornea
    b. Pellucid marginal degeneration is an asymmetric peripheral steepening of the cornea
    c. a & b
    d. There is no difference between keratoconus and pellucid marginal degeneration

11. To minimize rotation and ensure stabilization of a toric lens
    a. You must adjust the axis orientation
    b. You must adjust the cylinder power
    c. You must steepen the base curve and/or increase the lens diameter
    d. All of the above

12. Reverse geometry lenses are designed for
    a. Orthokeratology
    b. Post-RK and myopic LASIK fitting
    c. Advanced keratoconus
    d. All of the above

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