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Instrument Basics, Part III: Corneal Curvature

Featured Article

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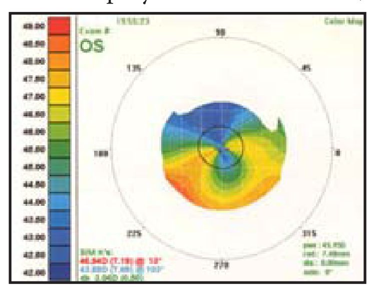
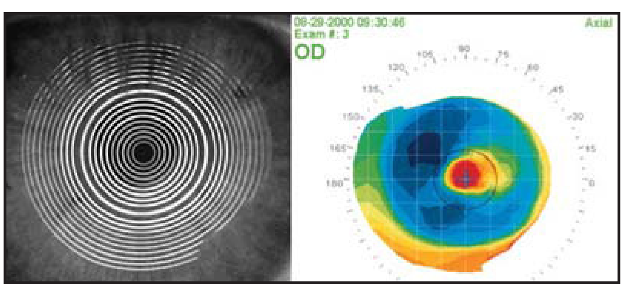
Measurement of corneal curvature/power can be performed with a variety of instruments, most commonly a keratometer, IOLMaster, or corneal topography device. Corneal curvature is usually used for IOL calculations and corneal refractive surgery. It is also helpful for contact lens fitting and detecting irregular astigmatism.

A keratometer measures the size of an image reflected from 2 paracentral points on the cornea. Doubling prisms in the device stabilize the image to enable more accurate focusing. The anterior corneal curvature is then derived from the convex mirror formula and corneal power is estimated empirically based on Snell's law of refraction with simplified optics. The keratometer measures the anterior corneal surface but uses a fudge factor in the index of refraction (1.3375 vs. 1.376) to account for the posterior corneal power and also to allow 45 D to equal 7.5 mm radius of curvature (K (diopters) = 337.5/r). Therefore, a number of limitations exist: the keratometer only measures a small region of the cornea (2 points at the 3-4 mm zone), it measures different regions for corneas of different powers, it does not provide information about the cornea central or peripheral to these points, it assumes the cornea is spherocylindrical and symmetric with a major and minor axis separated by 90 degrees, it ignores spherical aberration, it is susceptible to focusing and misalignment errors, and mire distortion prevents accurate measurement of irregular corneas and cannot be quantified. The IOLMaster also performs keratometry, but is more accurate than a standard keratometer because the corneal curvature data is obtained from 6 points closer to the center of the cornea (2.5 mm zone) and three consecutive readings are averaged.

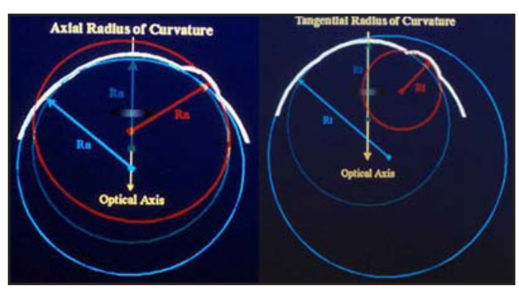
Corneal topography addresses some of the limitations of keratometry, by providing more data, quantitating corneal shape information, and measuring patterns produced by disorders as well as surgery. Various imaging technologies are employed in these devices, such as placido-based (videokeratoscopy), elevation-based (rastersphotogrammetry, scanning slit), and interferometry-based (laser holography, Moiré fringes). Computerized videokeratography (CVK) is the most widely used, and therefore the topic of this discussion.



CVK measures central and peripheral corneal zones and is especially useful for evaluating irregular astigmatism. Applications of CVK include: diagnosis of corneal irregularities (ectasias, dystrophies, surface disease, CL warpage, scars, degenerations), screening refractive surgical candidates, evaluating unexplained visual loss, management of surgical patients (planning and monitoring corneal grafts, refractive procedures, cataracts, pterygia, dermoids), and contact lens fitting.

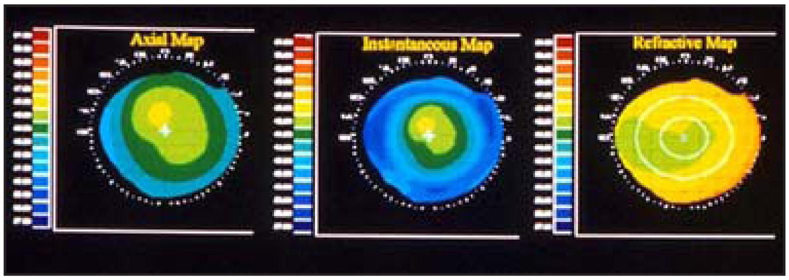


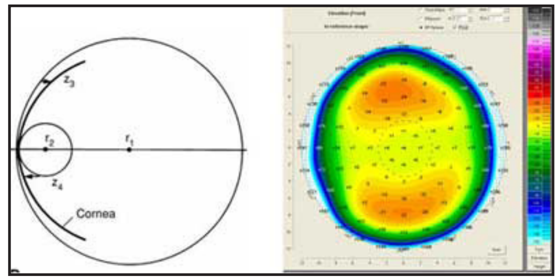
CVK, a placido-based technology, also uses the reflection principle. Multiple rings are projected onto the cornea and the reflected image is captured, digitized, and analyzed. The data is then displayed as various topographic maps: curvature (axial, instantaneous), power (refractive), elevation, difference, or relative. Many devices also contain qualitative classification systems and quantitative indices and algorithms for data interpretation. However, CVK does have limitations: there is a lack of standardization between instruments; it depends on reference axis, alignment, and focus; it is susceptible to artifact (distortion, tear film effect); it is based on simplified optics (only applies to central cornea); and there is a smoothing effect (sampling occurs around the circumference of the mires, there is no measurement between mires).



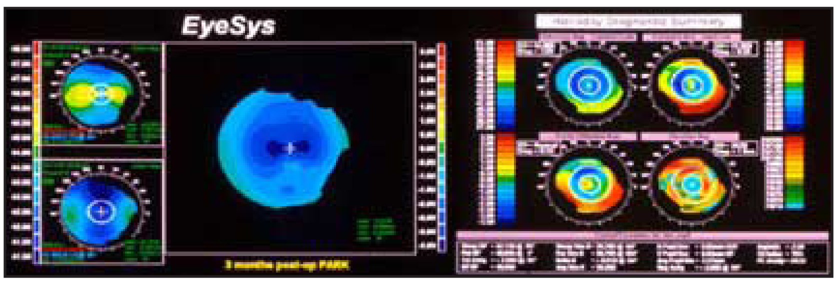
Because clinicians are less familiar with interpreting curvature data, these devices convert this information to power values with the paraxial formula (P = (n-1)/r; where P = corneal power, n = 1.3375 (compensates for negative power of posterior cornea), and r = radius of curvature in meters). This ignores spherical aberration but is a good approximation for the power of the central cornea.

Curvature maps are usually displayed in one of two formats--axial or tangential--depending upon what method is used to calculate the radius of curvature. For the axial map, r = the distance from the corneal surface to the optical (sagittal) axis along the normal. This is similar to a keratometer and assumes that the center of rotation of the best fit sphere lies on the optical axis. It is a good approximation for the paracentral cornea (2 mm zone). The axial (sagittal) map is the most common and provides a good estimate of overall corneal shape, which appears smooth with little noise because it provides an average of adjacent curvature values. This is useful for evaluating corneal optics (i.e., central power of cornea, calculating IOL power, and screening for pathology). On the other hand, for the tangential map, r = the instantaneous radius of curvature at each point on the cornea. This is the true "r", independent of the defined central axis, and is therefore a more accurate measure of curvature. As a result, the tangential (instantaneous) map is noisy because it is more sensitive to local changes and accentuates focal abnormalities. This is useful for evaluating corneal shape (i.e., ectasia, surgically induced changes, and contact lens fitting).



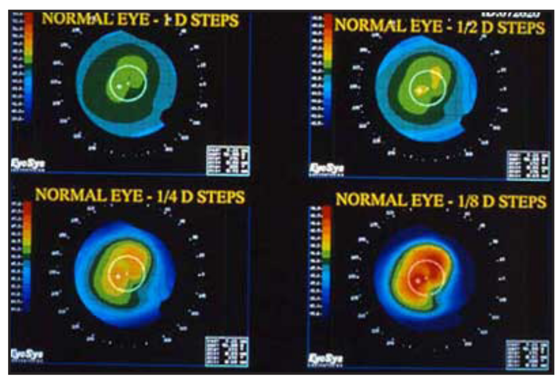


Topographers can display a refractive map by converting radius of curvature data into dioptric power using Snell's law of refraction. This accounts for spherical aberration outside the central zone, and provides information about the imaging power of the cornea. This is helpful for correlating curvature to vision and analyzing surgical effects.

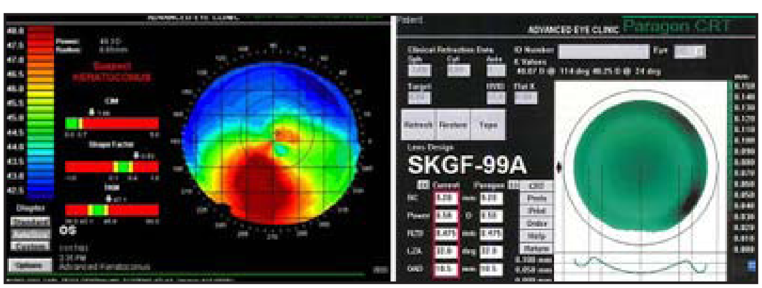


CVK elevation maps estimate the height of corneal regions relative to some reference plane (i.e., best-fit sphere, asphere, or average corneal shape) by using the angle of reflection. True elevation can only be obtained with technology that employs triangulation. Elevation maps can be used for measuring the amount of tissue removed and planning/monitoring surgical procedures.

Other displays include difference maps, relative maps, and data. Difference maps show the change or differences between 2 maps and are used to assess surgical effect or disease progression. Relative maps compare some value to an arbitrary standard such as a sphere, asphere, "normal" cornea, or mathematical model in order to enhance unique features of the cornea and visualize nuances.



In addition to the type of map display, the map scale (dioptric range, step size, number of colors) is also very important because it affects sensitivity. An absolute scale is constant for all exams and is useful for comparisons over time and between patients. A relative or normalized scale adapts to the range of powers on the corneal surface and differs for each cornea. Thus, the power range and step size may be narrow or broad, which magnifies or minifies significant changes.



Sensitivity is also affected by the step size (dioptric range for each map color). The recommended step size is 1.5 D. Small steps increase sensitivity by adding more colors and exaggerate minor or normal changes, which can cause confusion (i.e., pseudokeratoconus) and misdiagnosis. Large steps decrease sensitivity and mask significant changes due to smoothing of points between rings. Inappropriate step size can result in topographic artifact; this can also occur with misalignment, pressure on the globe, and altered tear film.

Most CVK instruments also contain quantitative measures, indices, and algorithms to aid in data evaluation. The most common are keratoconus screening software, simulated keratometry (Sim K; curvatures at the 3 mm zone), surface regularity index (SRI; measures central 4.5 mm, 0 = perfectly smooth surface, correlates highly with visual acuity), surface asymmetry index (SAI; difference in each ring 180° apart, 0 = perfect sphere), potential corneal acuity (PC acuity; predicted vision based on cornea alone). Additional software modules include: Advanced Refractive Diagnostic, VisionPro (VISX Custom CAP), STARS (healing trend), MasterFit (contact lens), and Paragon CRT Lens Selection.