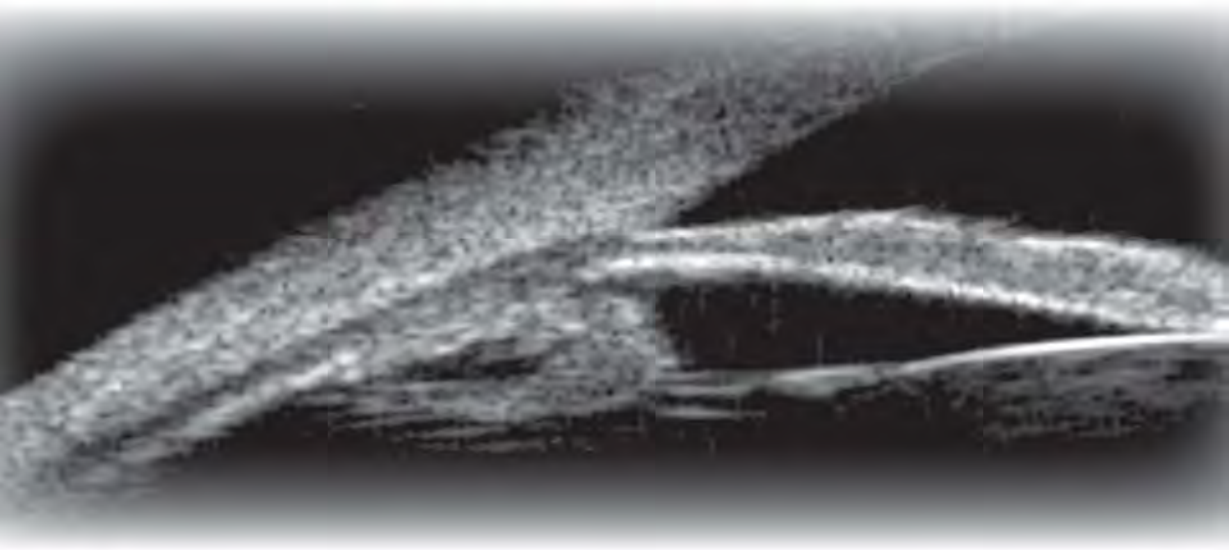
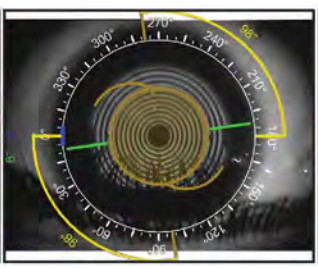
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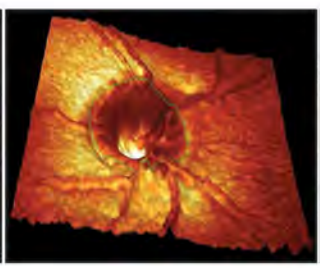
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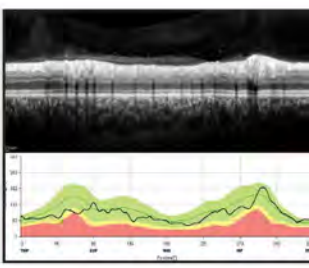
SECOND EDITION











Editors
Tanuj Dada
Neha Midha
Tarun Arora

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3

CHAPTER

Corneal Topography: Newer Horizons

Vijay Sharma, Tarun Arora, Saurabh Verma, Rajesh Sinha

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INTRODUCTION

The cornea is the most important refractive element of the human eye, providing approximately two-thirds of its optical power. Maximum refraction in the eye occurs at the anterior surface of the cornea due to its curvature and large difference between refractive indices of the two media, i.e. air on one side ($\mu = 1$) and cornea on the other side ($\mu = 1.37$). Detailed examination of the corneal curvature is an essential part of the workup before refractive surgery, for fitting of contact lens and for diagnosis and management of ectatic disorders. Keratometry was one of the earliest methods for measuring corneal shape. The keratometry was developed by Helmholtz in the mid-nineteenth which was a milestone in quantifying cornea. Introduction of Placido disk (named after Antonio Plácido da Costa (1848–1915) in 1880 and the computer-assisted videokeratography in 1984 further advanced the corneal evaluation.[1-4] Now various new topographic and tomographic systems are available which are noninvasive, produce reproducible images and are easy to operate and the information obtained from these instruments has become instrumental in furthering the results of refractive surgery, contact lens fitting, monitoring of corneal diseases, corneal transplant surgery and cataract surgery.

CLASSIFICATION

Based on principle, the corneal topography systems are classified as follows:

- Curvature (Placido) based instruments
  - Reflection based, e.g. keratometer
  - Projection based, e.g. computerized videokeratography
- Elevation-based topographers
  - Based on scanning Slit Imaging principle, e.g. Orbscan
  - Based on Scheimpflug imaging principle, e.g. Pentacam

- Mixed/combination of Scheimpflug imaging principle or scanning Slit Imaging, e.g. Sirius topographer, Galilei topographer
- Based on point source color LED topography (CLT), e.g. Cassini Topographer.

PENTACAM

Principle

Theodor Scheimpflug, a cartographer of the Austrian Navy, first introduced the Scheimpflug principle. It describes an optical imaging condition, which allows documentation of an obliquely tilted object with the maximally possible depth of focus and minimal image distortion under given conditions.[5,6] The Scheimpflug principle states that higher depth of focus can be achieved if subject plane, lens plane and image plane are moved in such a way that they cut each other at a point of intersection which is known as Scheimpflug intersection (Fig. 1). Normally, the lens and image (film or sensor) planes of a camera are parallel and the plane of focus (PoF) is parallel to the lens and image planes. If a planar subject is also parallel to the image plane, it can coincide with the PoF, and the entire subject can be rendered sharply. If the subject plane is not parallel to the image plane, it will be in focus only along a line where it intersects the PoF. When an oblique tangent is extended from

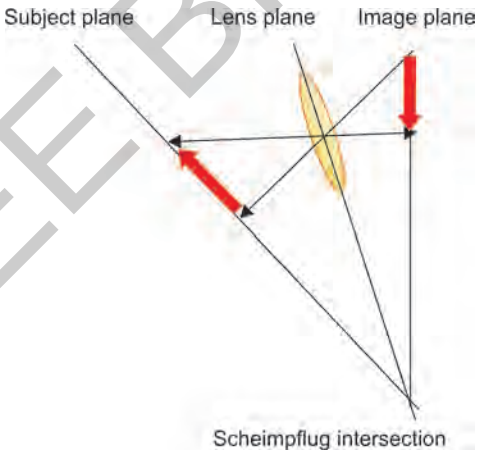


Fig. 1: Scheimpflug principle

the image plane, and another is extended from the lens plane, they meet at a line through which the PoF also passes, referred as Scheimpflug line. With this condition, a planar subject that is not parallel to the image plane can be completely in focus. The Pentacam obtains images of the anterior segment by a rotating Scheimpflug camera measurement (Fig. 2).

The camera is a digital CCD camera with synchronous pixel sampling. The light source consists of UV-free blue light emitting diode (LED's) with a

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Fig. 2: Pentacam

wavelength of 475 nm. The system integrates two cameras. One is located in the center for the purposes of detection of the size and orientation of the pupil and to control fixation. The second is mounted on rotating wheel to capture images from the anterior segment. It gives a complete picture from anterior surface of the cornea to the posterior surface of the lens. This rotating process supplies pictures in three dimensions and also allows the center of the cornea to be measured precisely. The slit images are photographed on an angle form 0 to 180 degrees to avoid shadows from nose. Every picture is a complete image through the cornea at a specific angle, combination of such slit images creates a real 360 degrees image of the anterior segment. The software utilizes a ray tracing algorithm to construct and calculate the anterior segment. It acquires a total of 50 images in approximately two seconds, extracting 2,760 true elevation points from these images which in turn generates 138,000 true elevation points for both the corneal front and back surfaces, from limbus to limbus, including the center of the cornea, a major advantage over keratometers and Placido-based corneal topographers. The measurement process lasts less than two seconds and minute eye movements are captured and corrected simultaneously.

Clinical Interpretation and Uses

Curvature Map/Corneal Power Map

Before interpreting curvature map, it should be kept in mind that there is wide spectrum of normality of human cornea. Curvature map gives information about pattern, symmetry and skewing of axis of anterior surface of cornea. Various pattern seen include

- Pattern 1: Round, where the steepest part of the cornea is round but decentered.
- Pattern 2: Oval, where the steepest part of the cornea is oval and may be centered or decentered.
- Pattern 3: Superior Steep (SS), where the steepest part of the cornea is localized in the upper part of the cornea.

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- Pattern 4: Inferior Steep (IS) where the steepest part of the cornea is localized inferior to the apex of the cornea.
- Pattern 5: Irregular, where the corneal surface takes no particular shape.
- Pattern 6: Symmetric bow-tie (SB). This pattern may be indicative of normal astigmatism or very rarely a symmetrical type of keratoconus (Fig. 3).
- Pattern 7: SB/SRAX: Also called "lazy 8" pattern, i.e. a symmetric bow-tie with angulation (skewing). Angulation is considered clinically significant when it exceeds 21 degrees.
- Pattern 8: Asymmetric bow-tie (AB)/IS: Asymmetric bow-tie, i.e. inferiorly steep.
- Pattern 9: AB/SS: Asymmetric bow-tie that is superiorly steep. This pattern is the reverse of pattern 8. If the difference is more than 2.5D, precaution should be taken when taking the decision.

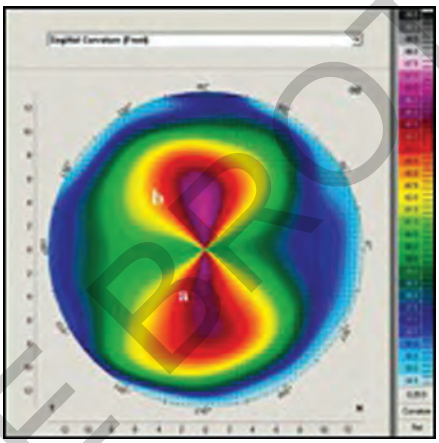


Fig. 3: Symmetric bow-tie (SB) pattern on curvature map

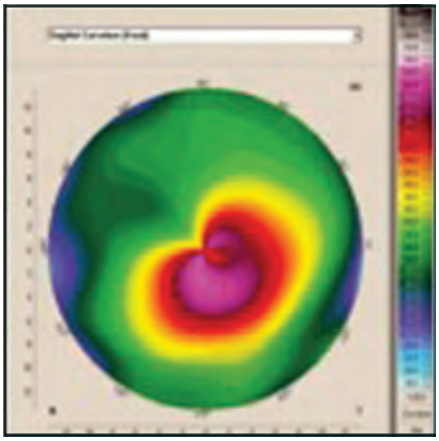


Fig. 4: Asymmetric bow-tie with skewed radial axis (AB/SRAX)

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- Pattern 10: AB/SRAX: That is an asymmetric bow-tie with angulation between the two segments (Fig. 4).
- Pattern 11: Smiling face: This is certainly risky because it often leads to postoperative ectasia, and might be an indicator of keratoconus (Fig. 5).
- Pattern 12: Junctional: It is a circular shape, where the two segments are connected laterally. It is a subject of suspicion (Fig. 6).
- Pattern 13: Vortex pattern: It is also known as the "Nazi Logo" . This is an indicator of corneal instability, and it may precede keratoconus.
- Pattern 14: Claw pattern: It is also known as "kissing birds" and is seen in pellucid marginal degeneration (PMD) (Fig. 7).

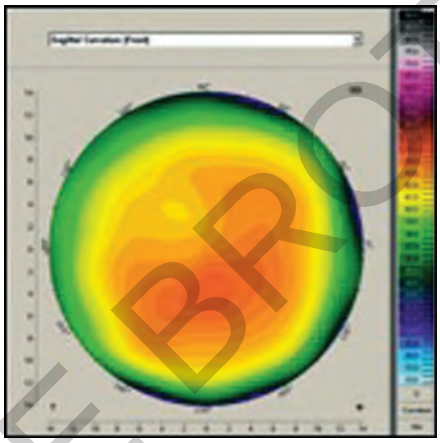


Fig. 5: Smiling face pattern on curvature map

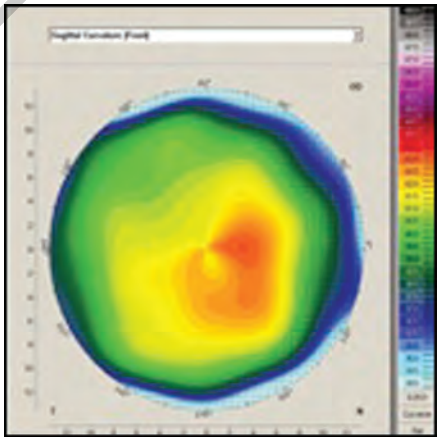


Fig. 6: Junctional pattern on curvature map

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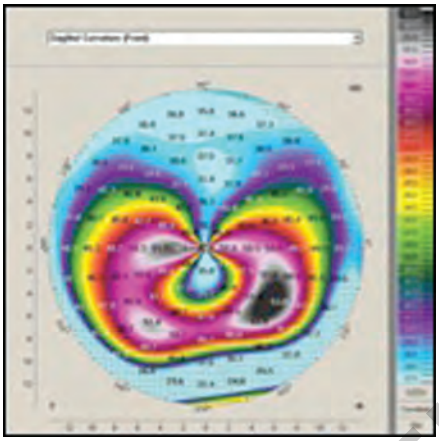


Fig. 7: Claw or "kissing birds" pattern on curvature map

Generally, the two eyes of a person are similar and mirror images of each other, this phenomenon is called enantiomorphism. This is useful to decide wether a cornea is normal or not, by comparing it with contralateral eye.

Elevation Maps

Various points measured on corneal surface are compared against a reference plane and any point higher or elevated than this is presented with warm colors and points lower than reference are represented with cooler colors. Reference plane may be best fit sphere (BFS) or best fit toric ellipsoid (BFTE). BFS is important for

- To see the shape of cornea
- To look for risk factors like isolated island or tongue like extension
- To locate the cone in keratoconus.

BFTE is important for

- To evaluate details of corneal surface
- To evaluate severity of the cone in keratoconus.

Pentacam shows following elevation map (Fig. 8)

- Front elevation map: While interpreting, we look at the values within central 5 mm circle on map displayed in BFTE float mode. Clinical interpretation is as follows:
  - Normal ≤ +12 μ
  - Suspicious +13 μ to +15 μ
  - Risky > +15 μ
- Back elevation map: Clinical interpretation is as follows:
  - Normal ≤ +17 μ
  - Suspicious +18 μ and +20 μ
  - Risky > +20 μ
  - Any isolated island on front or back surface in BFS float mode is suspicious even if values are within normal limits.

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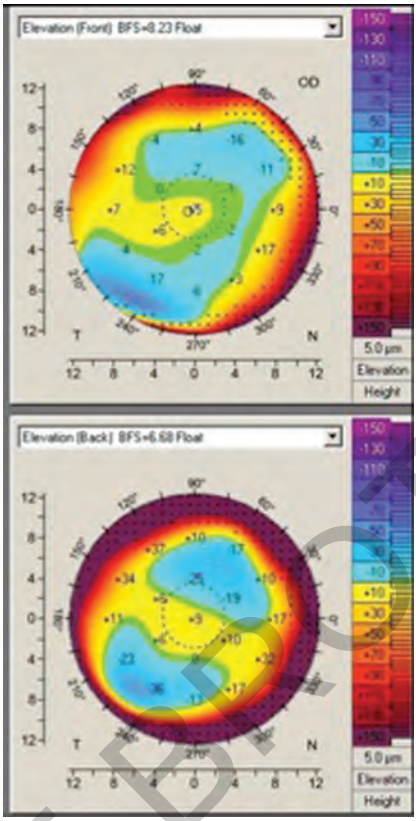


Fig. 8: Front and back elevation maps

Corneal Thickness/Relative Thickness Map

Thickness of cornea at all points is calculated by the difference between front and back surface elevations as calculated by the software on elevation maps. Clinical interpretation of corneal thickness map is as follows:

- S-I ratio- At 5 mm circle, compare symmetric superior and inferior values. Difference >30 µ is suspicious
- Difference of pachy at thinnest location between two eyes should not be >30 µ
- Difference between pachy apex and pachy at thinnest location <10 µ
- If thinnest point is decentered from apex by >–500 µ (0.5 mm), it is suspicious of KC.

Other clinical interpretations for

- Deciding about various procedures like LASIK, INTACs or corneal cross linking
- Diagnosis of corneal ectatic disorders like keratoconus, PMD, iatrogenic ectasia, etc.

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- Observing the progression of ectatic disorders
- Confirming diagnosis of diseases like Fuchs dystrophy.

Asphericity

Asphericity of cornea is shown by Q value. Q value of normal cornea is about –0.26 to 0.35.

- When cornea is steeper in center, Q value is negative (Aspheric **Prolate**)
- When cornea is flatter in center but steeper in periphery, Q value is positive (Aspheric **Oblate**)
- When center equals periphery cornea is spheric.

Keratometry Power Deviation (KPD) Map

This map is calculated by excluding the effect of the anterior curvature power map from the true net power map, i.e. it represents the effect of the back surface of the cornea on the true net power map in every corneal point. The normal value at any point should be <+0.75. Any value falling between +0.75 and +1.5 is doubtful and borderline, but it is not considered significant unless there is a corresponding posterior elevation. Any value more than +1.5 is an abnormal value, especially if it is in the lower part of the map, or if there is a corresponding elevation at the back elevation map.

Progression Index

It is derived from the corneal thickness/location relationship and reflects the rapid change of thickness from the thinnest location to corneal periphery. More the progression higher the progression index and vice versa. Normal value is ≤1.1. High progression index >1.1 is usually seen in ectatic disorders of cornea like keratoconus.

Belin Ambrosio Enhanced Ectasia Display

It is the first screening tool which represents height data of the anterior and posterior corneal surface in combination with a progression analysis of the corneal thickness. It is overall more precise and enables early keratoconus detection.[7,8] The corneal thickness progression analysis is calculated using concentric rings of diameter 2, 4, 6, 8 and 10 mm, starting at the thinnest point and extending to the periphery.

The three black dashed lines show the result of the standard value study. The center line represents the average value of the corneal thickness of all corneas analyzed (Fig. 9). The upper or lower line represents the double standard deviation (95%) of the corneal thickness of all corneas measured. The computer gives red color to the curve of the examined cornea. The red curve should be within the normal range and the course of the red curve should be parallel to the normal range. If the red curve deviates at the 6 mm circle or

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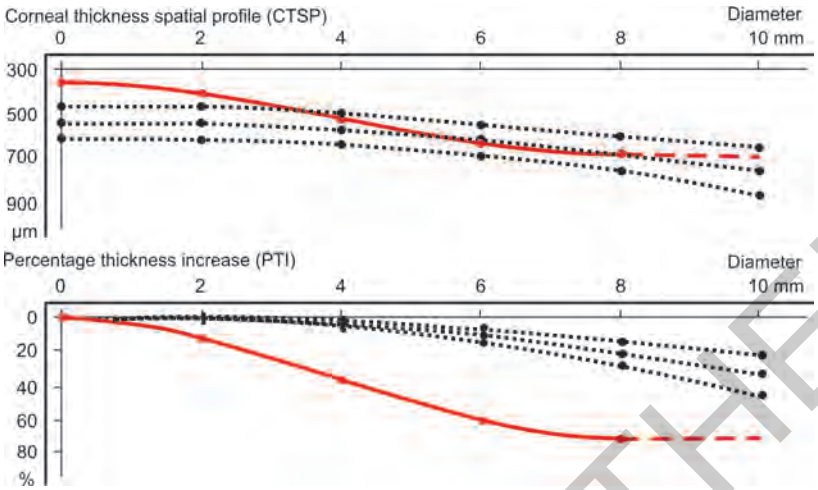


Fig. 9: Abnormal curve in a case of keratoconus

after, it is normal. Otherwise, it is a risk factor because the quick downward deviation means that the corneal center is relatively thinned in relation to the periphery, which proved to be risky either with LASIK, or to some extent with PRK, whether the patient is hyperopic or myopic.

Cornea Volume

Some studies are carried out to realize the relationship between cornea volume and changes, in order to exclude a new indicator for keratoconus.

Chamber Volume

Volume less than 100 mm^3 should alert us to check the patient for angle closure glaucoma.

AC Depth

Central anterior chamber depth, measured from the inner surface of corneal endothelium to the iris plane. It is important for the anterior chamber phakic IOLs. It should not be less than 2.7 mm^3 to keep the corneal endothelium intact. Entering the settings, we can choose external instead of internal to have the depth with the corneal thickness added.

IOP

Click the icon and input the IOP to have the real modified IOP according to corneal thickness. For the same purpose, the nearby square displays the amount that should be added algebraically to IOP to be modified.

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Angle

The average value of anterior chamber volume. An angle less than 25° should alert us to check the patient for angle closure glaucoma.

Pupil Diameter

It is important to measure the pupil diameter neither in high illumination (photopic pupil) nor in the dark (scotopic pupil), but in medium illumination (mesopic pupil).

Lens Thickness and Density (Table 1)

Pupillary dilation is must to take Scheimpflug images of the lens. If the pupil is not dilated enough, the light of the camera may not reach the posterior surface of the lens, so the computer cannot measure its thickness. Scheimpflug images allow for an automatic and objective quantification of the lens density. This is available either by means of a built in lens-density module or the Scheimpflug images can be exported to image analysis software. This is useful both in analyzing opacities due to age like nuclear sclerosis and cases of traumatic cataract. The Scheimpflug map of a cataract may show opacities that scatter light and degrade vision. Thus, the physician can show these maps to the patient and document the changes that are occurring to the patient's crystalline lens in his chart. The Pentacam's densitometry software may help in simplifying cataract grading that provides a reliable, reproducible way of sampling the volume and density of the nuclear cataract and objectively

Table 1: Various models of Pentacam

Pentacam (Basic)	Pentacam (Classic)	Pentacam (HR)
Qualitative analysis of cornea	All features of basic plus Various software package	All features of classic plus Various software package
Glaucoma screening-Pachymetry-based corrected IOP, anterior chamber angle, depth and volume determination	Software package-*Refractive* Calculation of corneal thickness progression for early keratoconus detection	Sharp Scheimpflug images for precise representation of implants, corneal rings, opacities for lens and cornea
Topography-based keratoconus detection and classification	*Software package—Cataract* comprehensive cataract analysis (3D densitometry) and PNS (Pentacam nucleus staging)	Precise imaging for determining positions of pIOLs and IOLs in reference to centering and tilting. Optional 3D pIOL simulation software including aging prediction
Additional software upgrade module can be used to upgrade basic in to classic model	Zernike analysis and corneal Wavefront, e.g. for the selection of aspheric IOLs and determination of higher order aberrations	Belin/Ambrosio Enhanced Ectasia Holladay Report and Holladay EKR (Equivalent Keratometer Readings) for optimized IOL calculation in postrefractive patient eyes
		Contact lens fitting

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classifying it from grade zero up to a grade 5 other than its objectivity in defining congenital cataracts, traumatic ruptures, etc. The Pentacam's new densitometry software is not without limitations. A poorly dilated pupil interferes with the device's sampling technology, and so eyes with pseudoexfoliation, trauma, and intraoperative floppy iris syndrome, for example, are problematic. Also, white cataracts block the system's ability to sample the central nucleus. The grading of lens density through Scheimpflug images has been found to correlate well with the LOCS III grading system for cataracts.

Other Newer Corneal Topographers

Cassini Topographer

Cassini topographer (i-optics, USA) uses multicolored LED point-to-point ray tracing combined with second Purkinje image technology to provide a GPS-like analysis of the cornea along with high-resolution images utilized for surgical guidance (Fig. 10).[9-11] Point source CLT technology projects about 700 red, yellow, and green LED point sources onto the cornea to measure its shape. Each LED is a discrete data point.

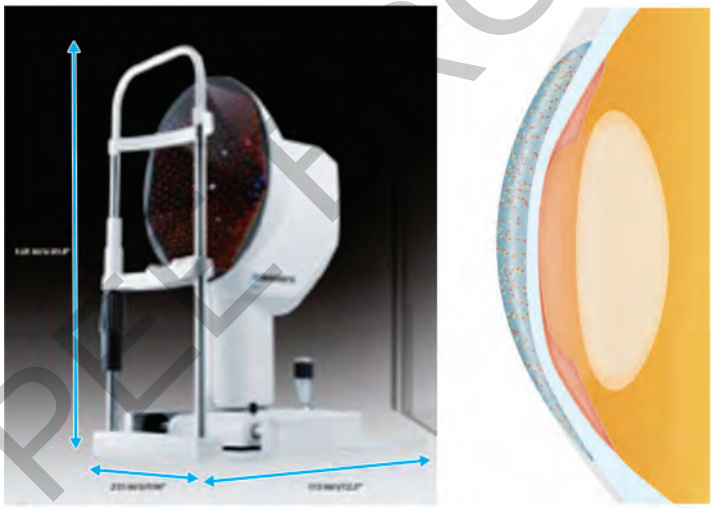


Fig. 10: Cassini topographer

The unique measuring principle enables highly accurate and repeatable measurements of the total corneal astigmatism. It gives submicron accuracy up to <0.8 μ due to color LED triangulation technology. Keratoconus indices like surface regularity index and surface asymmetry index, topographic maps like axial, refractive, tangential, elevation maps, higher order aberrations, shape factor, eccentricity, asphericity, form factor and pupillometry are captured with instantaneous auto capturing technology. As very short time is required for image capture, results are not affected by motion artefacts caused by eye movement. The combination of point sources and distinct colors helps ensure that there is no source-image mismatch. The image processing software

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automatically locates feature points in the reflected images and accounts for smearing and deformation in irregular corneas.

Sirius

Sirius uses a combination of rotating Scheimpflug camera and a Placido disk for tridimensional analysis of both the cornea and the anterior segment (Fig. 11).[12] Merging data from Placido's reconstruction and Scheimpflug images taken by different cameras, accurate measurement of elevations, curvature, power and thickness for the whole cornea can be done. It also has contact lens fitting modules, corneal wavefront and visual quality displays, retroillumination image for densitometry, corneal thickness and anterior chamber depth maps and altimetric maps for various surfaces. Pupillography fully integrated with anterior and posterior corneal topography with measurement available under mesopic, photopic, scotopic and dynamic light conditions. It has high resolution up to one micrometer and analyses more than 100,000 points to detect the smallest of irregularities. Image acquisition is fast as alignment, acquisition and processing takes less than 10 seconds.



Fig. 11: Sirius topographer

Galilei

The GALILEI™ Dual Scheimpflug Analyzer is a high precision optical system for corneal topography and three dimensional analysis of the anterior eye segment, based on a revolving dual channel Scheimpflug Camera and a Placido Disk. It combines the advantages of two technologies: Placido imaging furnishes high accuracy curvature data, while Scheimpflug imaging is optimal for precise elevation data. It gives information about the following:

- High resolution Scheimpflug images
- Pachymetry
- Corneal and lens topography
- 3D anterior chamber analysis
- Crystalline lens thickness

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