Understanding corneal topography

Dr. Rohit Shetty, DNB, FRCS, PhD, Luci Kaweri, MD, Vishal Vohra, MS

Narayana Nethralaya, Bangalore

The cornea is the most important refractive element of the human eye, providing approximately two thirds of its optical power. Corneal topography took birth back in 1600s, when Scheiner compared reflections produced by glass spheres of a known diameter to the reflections produced by the anterior surface of the cornea.[1] Since then, advances such as ophthalmometry (keratometry), Placido disk, keratoscopy and Scheimpflug imaging have increased the accuracy and ability to measure a larger corneal surface area. Present day corneal surgeons are very well aware of different topographers. In this article our main focus is on reading the maps and red flags while interpreting them for beginners.

Basic principles of different topographers:

Computer-assisted videokeratoscopy/placido disc based corneal topography

- Placido rings: 18 superiorly and 22 inferiorly
- 950 nm LED light
- Resolution 0.1mm
- Scotopic and photopic pupillometry
- Measurement range 15-95D

Figure 1: Atlas corneal topography system

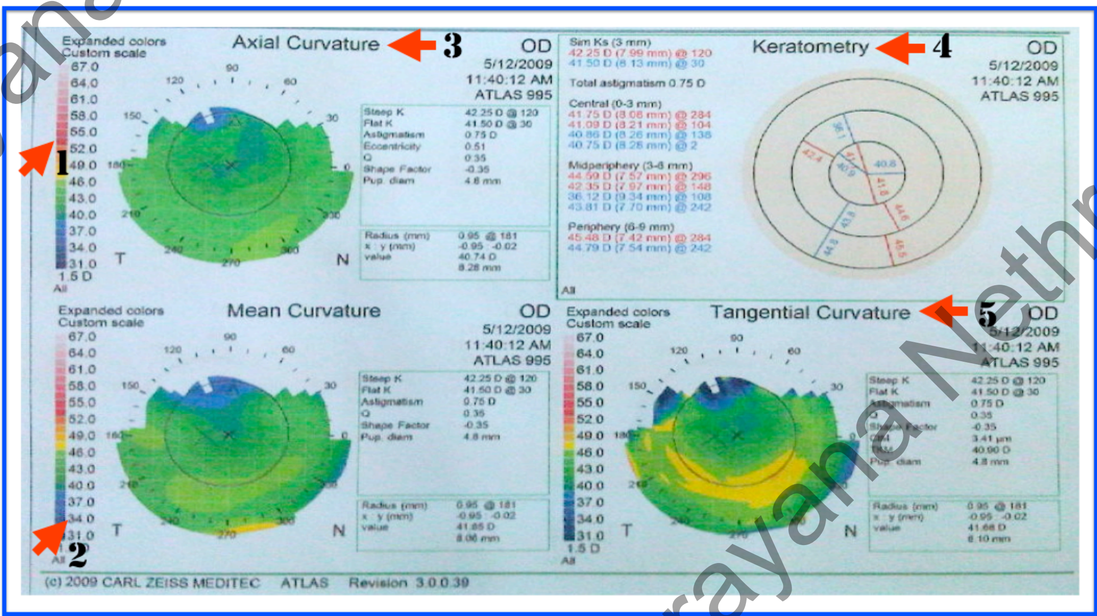


Figure 2: A typical quad map of placido-disc based videokeratography showing 1) Colour coding 2) Standardized scale 3) Axial curvature 4) Keratometry map 5) Tangential curve map

Interpreting the videokeratoscopy map:

1. Before interpreting the data look at the output screen, warmer colours (reds, oranges) on the map represent steeper cornea with higher keratometric dioptric power, the cooler colours (violets and blues) represent flatter cornea with lower dioptric power and greens and yellows represent colours found in normal cornea.

2. Use an absolute or standardized scale for interpretation, having fixed dioptric increment for colour scales. This aids in comparing two maps, but is less sensitive. Normalized maps have different colour scales assigned to each map, based on instrument software which identifies minimal and maximal keratometry. Disadvantage of normalized maps is that two different maps cannot be compared to each other directly.
3. Axial curvature map or sagittal curvature map is the most commonly used map. It is helpful in evaluating the overall shape of the cornea. The biggest advantage of this map is that the pattern diagnosis of a map can be done and a map can be classified into normal or abnormal.(Figure 2)
4. Tangential curvature map or instantaneous map or meridional curvature maps are more sensitive in detecting local curvature change, hence can be useful in detecting early changes, which might have been missed by the axial map. It is more accurate than the axial map in corneal periphery.
5. Classification of various types of topography pattern is done on axial maps.[2]

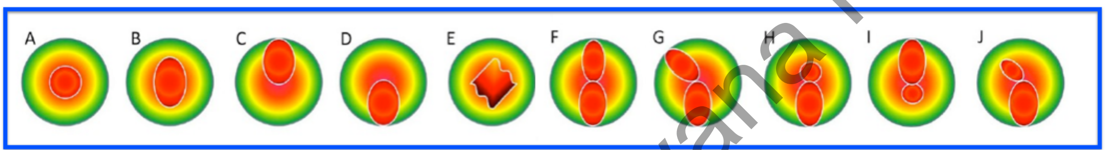


Figure 3: Various topographic patterns A, round; B, oval; C, superior steepening; D, inferior steepening; E, irregular; F, symmetric bow tie; G, symmetric bow tie with skewed radial axes; H, asymmetric bow tie with inferior steepening (AB/IS); I, asymmetric bow tie with superior steepening; J, asymmetric bow tie with skewed radial axes (AB/SRAX)

6. Common indices are as follows:

Simulated keratometry (SimK): Equivalent to keratometry and is calculated at steepest axes and axes 90° to it from the average power at 3 mm zone. Difference is taken as cylinder (Cyl).

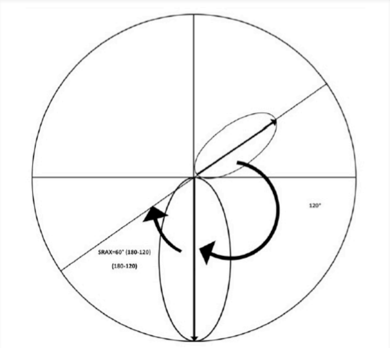
Minimum keratometry (min K): Flat axis.

Surface asymmetry index (SAI): Difference in corneal power between points on the same ring 180° apart, which can quantify the progression of keratoconus etc.

Surface regularity index (SRI): Points in central 4.5 mm are compared with their surrounding points. High values suggest high irregularity in the surface.

Inferior-superior value (I-SV): Calculated from the power difference between five inferior points and five superior points 3 mm form center at 30° intervals.

Many other indices specific for each instrument exist, for example, corneal uniformity index (CUI), predicted corneal acuity (PCA), and point spread function (PSF), etc.



Calculation of SRAX: SRAX is calculated from 180-the angle between two steep axis above and below the horizontal meridian (smaller of the two angles). In this example two steep axis form 120° angle, hence SRAX = 60 (180–120)

Diagnosis of keratoconus can be made by looking at steep keratometry and using the **Rabinowitz/ Mc Donnel diagnostic criteria**[3] (central K-value > 47.20 D and Inferior-Superior asymmetry (I-S value) > 1.4 D) or KISA% described by Rabinowitz/Rasheed[4] as

KISA% = [(K) × (I-S) × (AST) × (SRAX) × 100]/300

K-value here is central keratomertic value in excess of 47.2 D i.e., K- 47.2. If value is less then or 47.2, difference is taken as one. I-S or inferior-superior asymmetry, AST calculated from Sim K1-SimK2, SRAX is calculated from 180-the angle between two steep axes above and below the horizontal meridian (smaller of the two angles). To amplify any abnormality, the value 1 was substituted in the equation whenever a calculated index has a value of less than 1.

Narayana Nethralaya

Slit scanning elevation based topography

- Slit scanning technology combined with an advanced Placido disc system.
- Acquires over 9000 data points in 1.5 seconds.
- 40 slits, 20 from the right and 20 from the left, each 12.50 mm high and 0.30 mm wide, are projected on the cornea at an angle of 45 degrees to the instrument axis.
- Analyzes elevation and curvature measurements on both anterior and posterior surfaces of the cornea
- Capable of detecting and analyzing posterior corneal abnormalities where corneal anomalies first appear.
- Orbscan IIz includes hartman-shack aberrometry

Figure 4: Orbscan IIz topography system

Interpreting the Orbscan map:

1. A typical Orbscan Output is a quad map consisting of
   a) *Anterior Float:* Elevation map of the anterior cornea
   b) *Posterior float:* It is important as Placido based systems cannot pick up early signs of ectasia, which starts from the posterior float,
   c) *Keratometric Map:* Gives the keratometric values for anterior cornea.
   d) *Thickness map*

Orbscan IIzTM is able to measure anterior chamber depth, angle kappa, pupil diameter, simulated keratometry readings (3 and 5 central mm of the cornea), and the thinnest corneal pachymetry reading

One must look for the **Red Flags on Orbscan (Roush criterion)** [5]

2. A thinnest point of < 470 µm on pachymetry.
3. A difference of > 100 µm from the thinnest point to the values of the 7 mm optic zone implies a steep gradient of thinning from mid-periphery to the thinnest point.
4. The thinnest point on the cornea should correspond with the highest point of elevation of the posterior corneal surface. On posterior elevations map a posterior high point > 50 µm above best-fit sphere (BFS). BFS power greater than 55 D on the posterior profile.

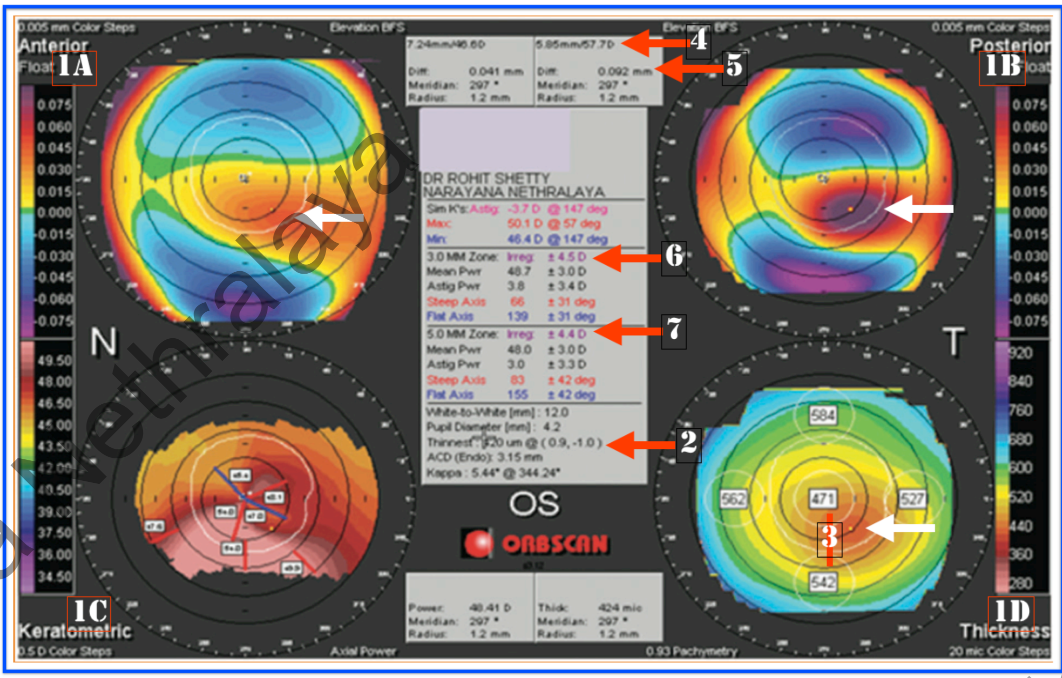


Figure 5: A typical quad map of Orbscan based on slit scanning technology showing 1A) Anterior float 1B) Posterior float 1C) Keratometric map 1D) Thickness map 2) Thinnest pachymetry 3) Difference between centre and 7 mm zone inferiorly 4) Steep keratometry on posterior curvature 5) Difference from best fit sphere 6) Irregularity in 3 mm zone 7) Irregularity in 5 mm zone

5. Relative difference > 100 µm between the highest and lowest point on the posterior elevation map. Keratometric mean power map > 46 D. Bow–Tie pattern or lazy C on the axial power map is suspect when the astigmatism shifts > 20 degree from a straight line.
6. A change within the central 3 mm optic zone of the cornea of more than 3 D from superior to inferior can be correlated to the presence of vertical coma (commonest aberration seen in keratoconus).
7. Composite integrated information which includes highest point on the posterior elevation coincides with the highest point on the anterior elevation, the thinnest point on pachymetry, and the point of steepest curvature on the power map.

In addition to that Efkarpides criteria say that ratio of the radii of the anterior BFS and posterior BFS of the cornea should be more than 1.21.Astigmatic discrepancy of > 1.5 D in the 3 mm zone and a discrepancy of > 2 D in the 5mm zone should be an alert sign.

Scheimpflug imaging

A) Pentacam

- Rotating Scheimpflug camera (180 degrees) to provide a 3-dimensional scan of the anterior segment of the eye.
- A monochromatic slit-light source (diode-emitting bluelight at 475 nm) rotates around the optical axes of the eye.
- Within 2 seconds, 25 slit images of the anterior segment are captured.
- Each slit image possesses 500 true elevation points, and 25,000 points are obtained.
- For each slit image, mathematic software is used to detect edges, including the epithelium and endothelium of the cornea.
- Finally, a 3-dimensional mathematic image of the anterior segment is generated.

Figure 6: The Pentacam, Oculus, Wetzlar Germany

Interpreting the Pentacam maps:

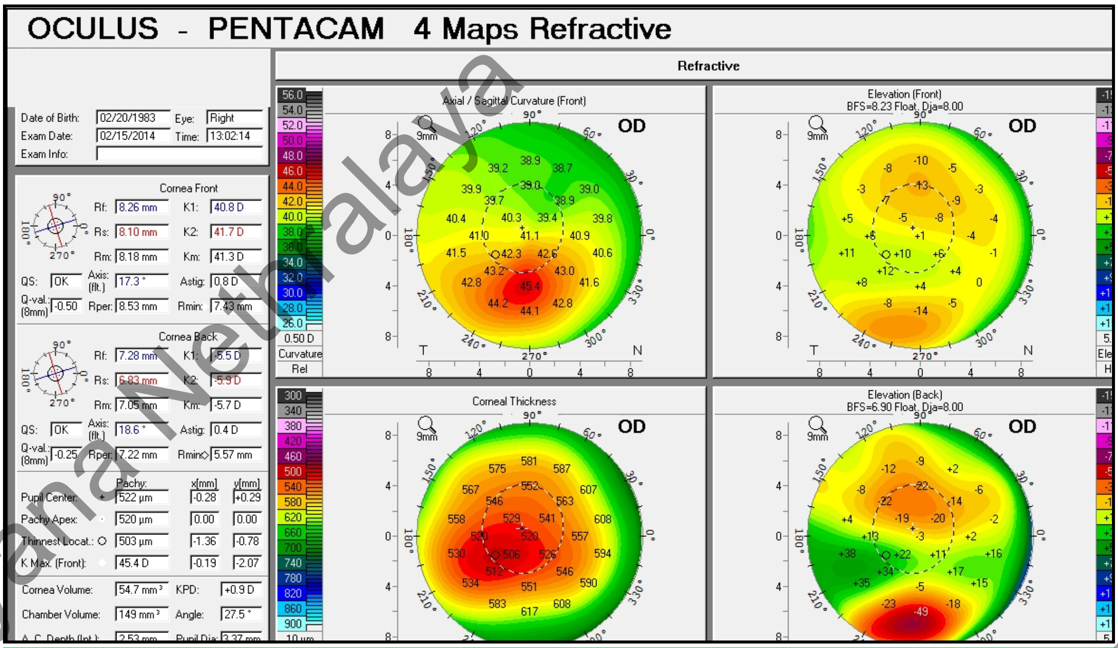
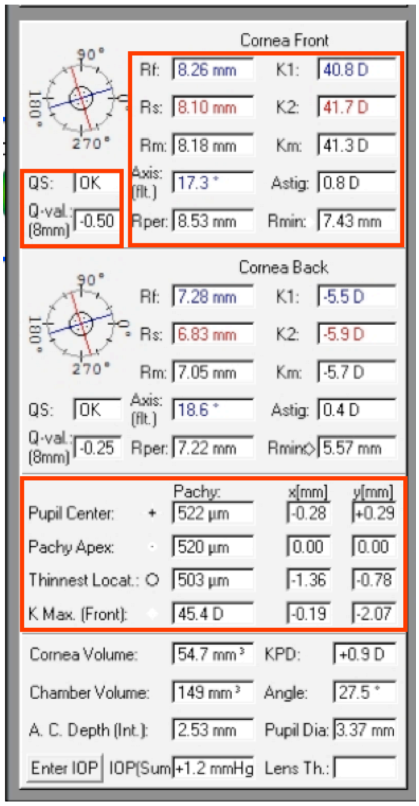


Figure 7: A typical **four maps refractive** of pentacam consists of a) Axial/Sagittal curvature map, b) Elevation (front) map, c) Corneal thickness, d) Elevation (back) map

1. Begin reading a standard pentacam map by looking at the numerical values given on the left hand side of the map.

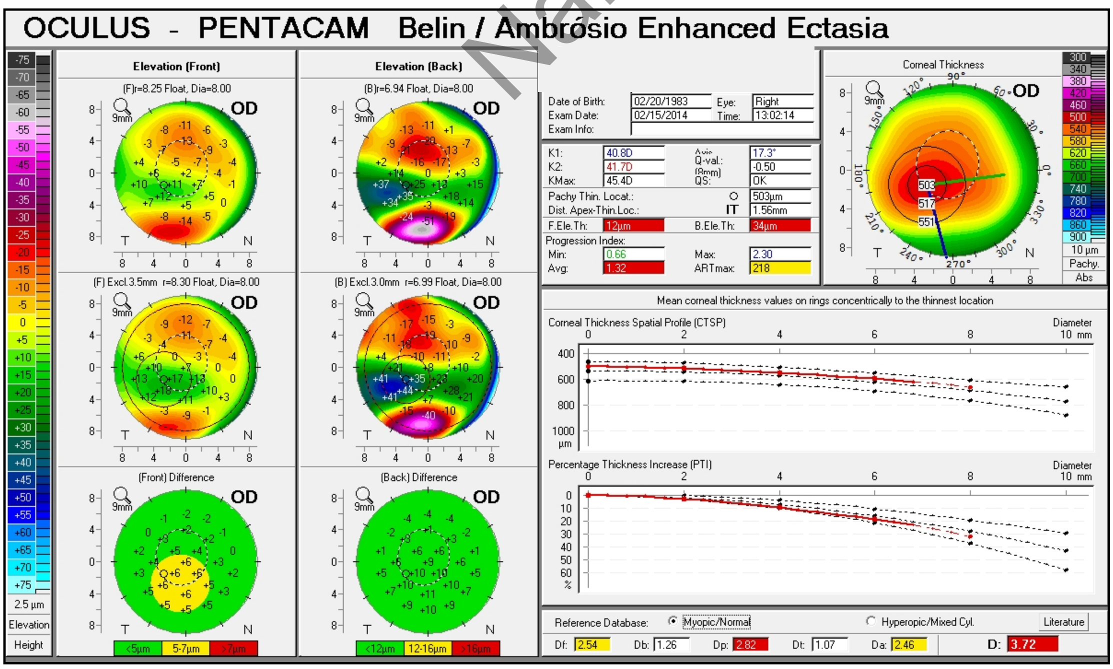


- **Quality specification (QS):** Specifies the quality of the topographic capture and should be displayed "OK". Otherwise the pentacam software tends to extrapolate the missing information leading to false readings.
- **K-readings:** K1- Flat keratometry, K2- Steep keratometry. Consider flat K while treating myopia (should not be less than 34D post-treatment) and steep K while treating hyperopia (should not be more than 48D post treatment).

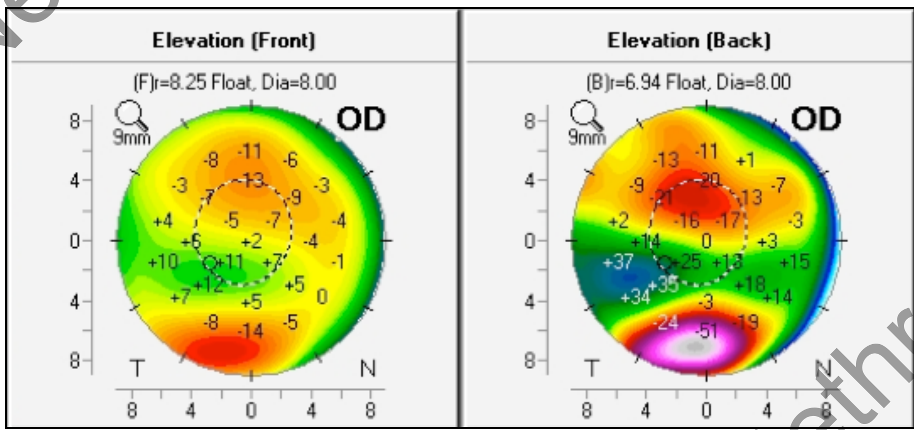
- **Corneal astigmatism:** The total corneal astigmatism after after taking into consideration posterior corneal astigmatism should be compared with the manifest refraction to exclude causes of incongruence, such as lenticular astigmatism, posterior subcapsular cataract, tear film disturbance etc.
- **Q-value:** This value describes the shape of the cornea
- **Thinnest location:** This category gives us an idea about corneal thickness, but we should refer to the thickness map to have full picture about the case. It is very important to study the relationship between the thinnest location and the pachy apex according to the thickness and according to the location.
- **Pupil center location:** It is important when doing decentration of the ablation profile especially when treating hyperopia

2. Start by looking at the maps in following sequence: Anterior elevation first followed by posterior elevation, Pachymetry and thickness distribution; off center distribution of corneal thickness is highly suspicious, the symmetry of both eyes. Look at curvature last.

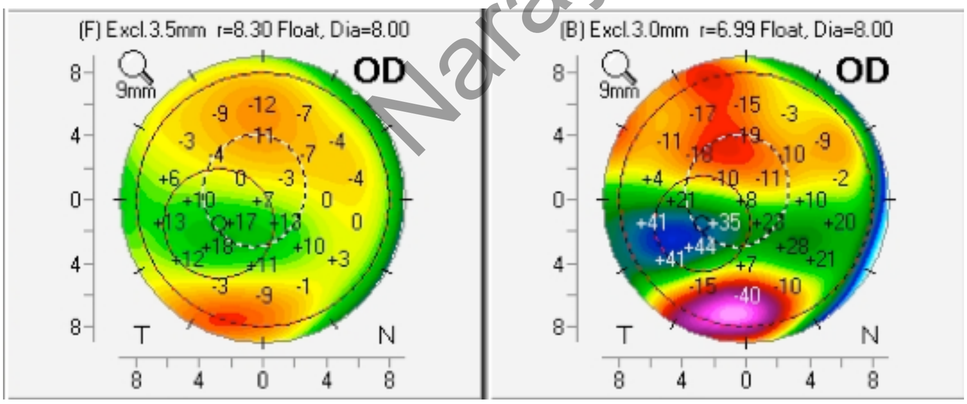
3. **Belin- Ambrosio Enhanced ectasia display (BAD display):** BAD enhance the sensitivity of ectasia detection and is a useful screening tool for refractive surgeons.



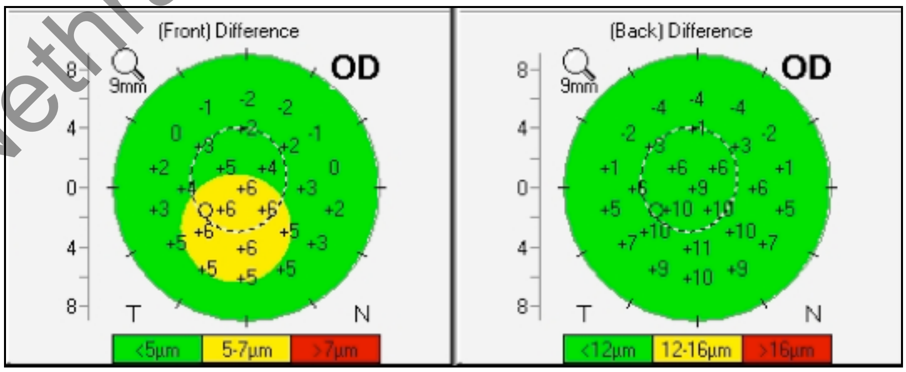
a. On the left half of the BAD display the elevation data is shown. The first two elevation maps (placed side by side) display the baseline relative elevation of the cornea of the best-fit sphere for the front surface (left map) and back surface (right map) of the cornea. The radius of curvature of the best-fit sphere (BFS) in millimeters and the diameter of the zone used to compute the BFS is noted above each map.



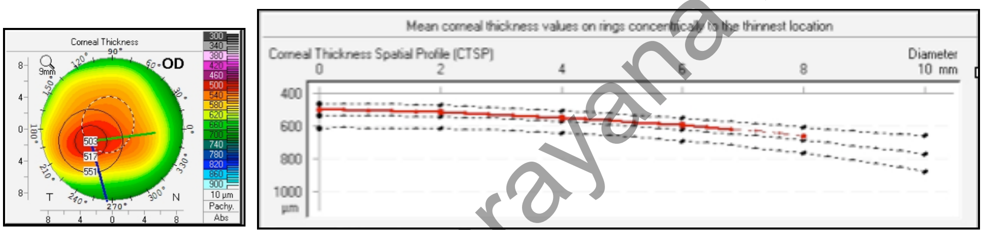
b. Below the standard anterior and posterior elevation maps are the anterior and posterior exclusion maps. In these maps (both anterior and posterior) the best-fit sphere is calculated using all the raw elevation data located outside a 3.5 mm circle centered on the thinnest point of the cornea.



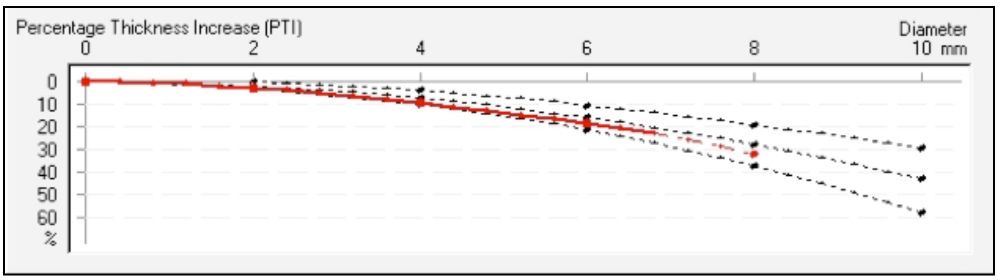
c. The bottom 2 maps are difference maps showing the relative change in elevation from the standard (baseline) elevation map to the exclusion map. The green on the difference map represents a change in elevation (from the baseline to the exclusion map) of less than 6 microns on the front surface and 8 microns on the back surface of the cornea and are typically within the range seen in normal eyes. The yellow areas represent a change between 6 and 12 microns for the front surface and 8 to 20 microns for the back surface. These eyes fall in the suspicious or suspect zone. The red represents areas where the elevation difference between the 2 maps is more than 12 microns anteriorly or >20 microns posteriorly and are the magnitude typically seen in eyes with known Keratoconus.



d. On the right side of the map is a corneal thickness spatial profile (CTSP) graph. It displays the sequence of pachymetric values along concentric circles of increasing diameter, beginning at and centered on the corneal thinnest point (TP).



e. The percentage of thickness increase (PTI) from the corneal thinnest point (TP) is calculated using a simple formula: (CT@x - TP)/TP, where x represents the diameter of the imaginary circle centered on the TP with increasing diameters as provided by the CTSP.

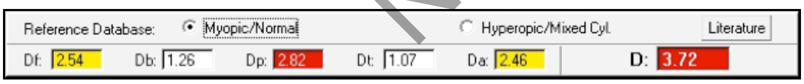


f. The CTSP and PTI graphs present the patient's data in red. The three dark broken lines in the graph represent the upper and lower double standard deviation (95% confidence interval) and the average values from a normal population. The CTSP and PTI graphs provide information, which allows the clinician to differentiate a normal thin cornea from one with early ectatic disease.

g. Center table gives progression index of keratoconus. It is the arithmetic average of thickness on the 1mm, 2mm, 3mm, 4mm and 5mm diameter rings.

Normal progression index is 0.91 ± 0.23mm and in keratoconus is 1.81 ± 1.16mm.

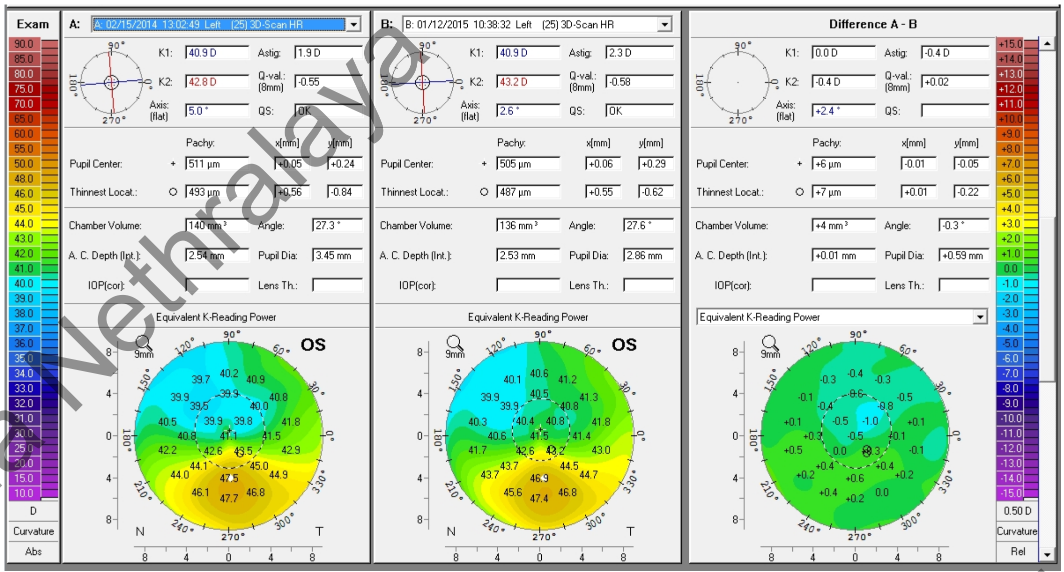
h. Belin-Ambrosio version II reports five new terms (D values for standard deviation from the mean) representing the front surface (Df), back surface (Db), pachymetric progression (Dp), thinnest point (Dt), and thinnest point displacement (Dy). A sixth term (D) is the final overall map reading taking each of the five parameters into account.



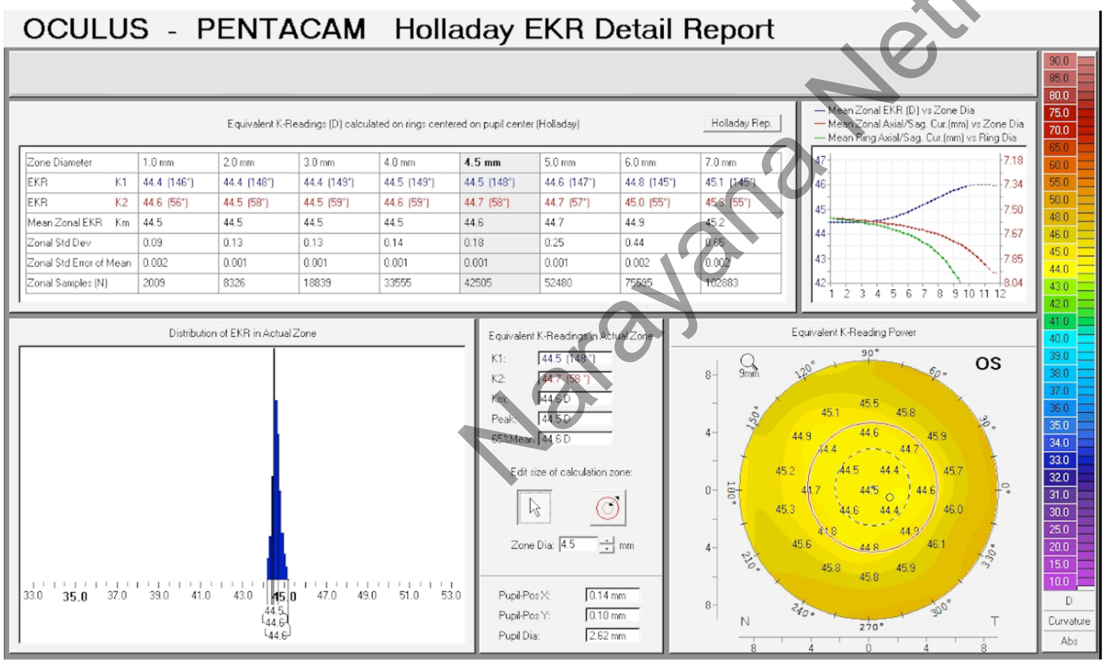
Green colour indicates normal (standard deviation less than 1.6), yellow suspicious (SD: 1.6-2.6) and red abnormal (SD >2.6).

4. **Pentacam comparative maps:**

Comparative maps are available as two maps or four maps display.Most useful in ectatic disorders to look for progression or response to treatment. Before starting the interpretation make sure the fixation point is matched. The difference map at the right corner gives a pictoral representation of change where hot colours represent steeping and cool colours represent flattening as compared to first map.



5. **The EKR map:**



The Equivalent K Reading feature of the Pentacam uses information from both the anterior and the posterior cornea to generate a range of central corneal power values in keratometric diopters. Depending on the EKR zone selected, this value can then be used with the Holladay 2 Formula for IOL power calculations following keratorefractive surgery, or with one of the popular a 3rd generation, 2-variable formulas combined with an Aramberri "Double K" method correction. For both myopic and even hyperopic LASIK, the 4.5 mm EKR zone has been shown to have a high correlation with the central corneal power calculated by the clinical history method.

Upper Left Box:

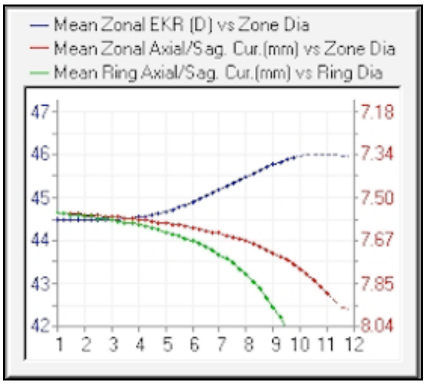
Equivalent K-Readings (D) calculated on rings centered on pupil center (Holladay) — Holladay Rep.

Zone Diameter	1.0 mm	2.0 mm	3.0 mm	4.0 mm	**4.5 mm**	5.0 mm	6.0 mm	7.0 mm
EKR K1	44.4 (146°)	44.4 (148°)	44.4 (149°)	44.5 (149°)	44.5 (148°)	44.6 (147°)	44.8 (145°)	45.1 (145°)
EKR K2	44.6 (56°)	44.5 (58°)	44.5 (59°)	44.6 (59°)	44.7 (58°)	44.7 (57°)	45.0 (55°)	45.3 (55°)
Mean Zonal EKR Km	44.5	44.5	44.5	44.5	44.6	44.7	44.9	45.2
Zonal Std Dev	0.09	0.13	0.13	0.14	0.18	0.25	0.44	0.65
Zonal Std Error of Mean	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.002
Zonal Samples (N)	2009	8326	18839	33555	42505	52480	75595	102883

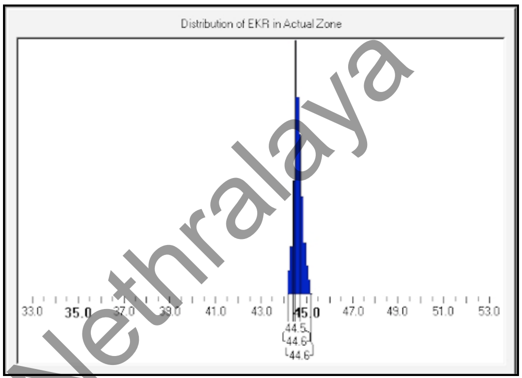
The Table at the Top Left is for the Equivalent K-Readings 65 (D) for various parameters from 1.0 to 7.0 mm pupil diameters. All values are calculated from the pupil center, so that only actual rays contributing to the retinal image are used.

Upper Right Graph:

The Graph shows the Mean Zonal EKR (D) versus Zone Diameter (blue),

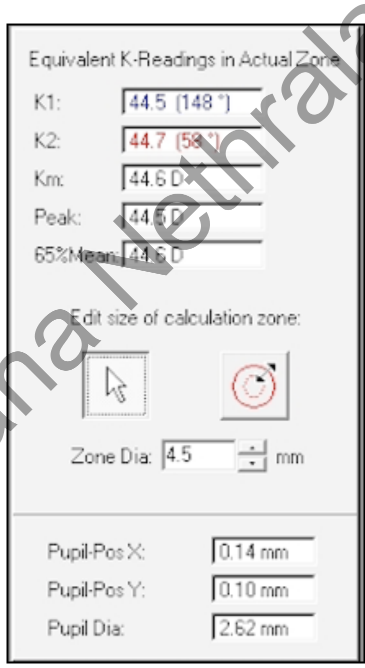


the Mean Zonal Axial Radius of Curvature (mm) versus Zone Diameter (red) and Mean Ring Axial Radius of Curvature (mm) versus zone diameter (Green). The Blue values illustrate the Refractive Power (D) of a zone as one moves from the center of the pupil. The normal increase in power reflects the normal presence of positive spherical aberration in the human cornea (~2 D from center to 8 mm diameter periphery).



Lower Left Graph:

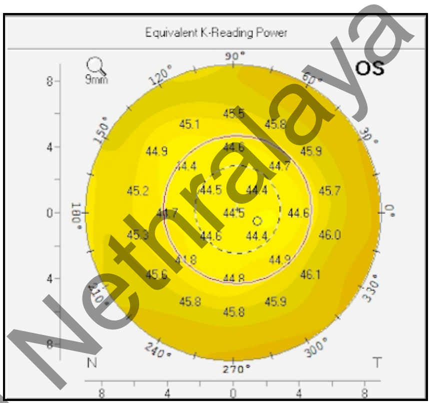
The graph is a histogram showing the relative frequency of EKR Power over the selected zone (default is 4.5 mm zone). The graph is rarely symmetrical and often has multiple peaks with a nominal 2 to 3 D range.



Lower Central Table:

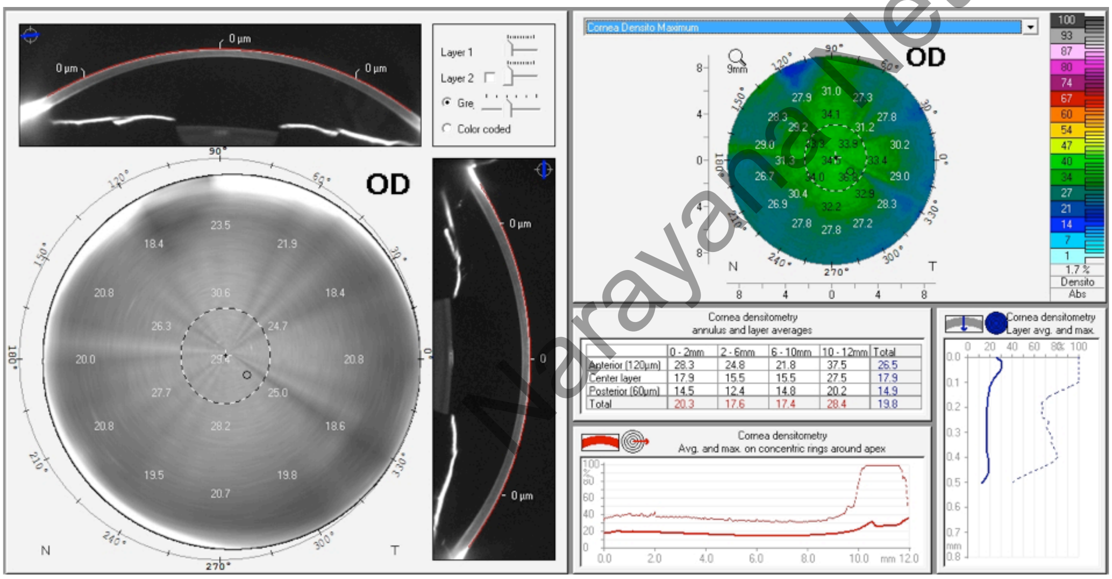
The EKR65 mean, is the weighted mean where 65% of the values are represented using the smallest range of points.

Lower Right Map:



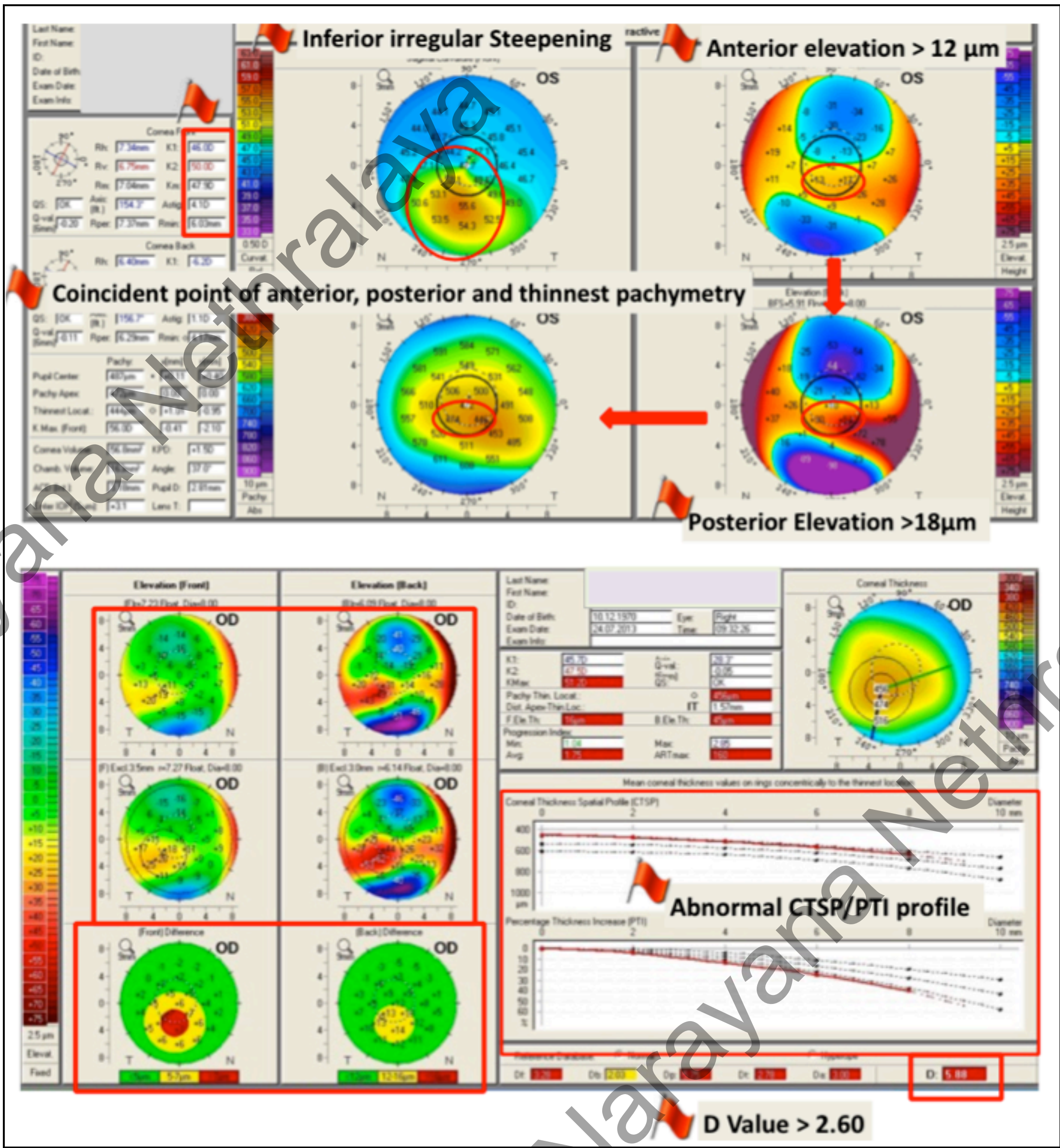
The Equivalent K-reading Power Map uses both front and back power, Snell's law and represents the values that are appropriate for IOL Power Calculations.

6. **Pentacam densitometry maps**.



With the add on software corneal densitometry at different depths and different areas is possible till 12 mm diameter. This helps in grading haze after refractive procedures and corneal dystrophies. Lens densitometry for cataract grading was possible in earlier softwares as well.

One must look for *the Red Flags on Pentacam for ectasia:*



a) The elevation values on the front surface map should not exceed 12 µ. Values between +13 µ and +15 µ are suspicious, and any value > +15 µ is considered a risk factor.

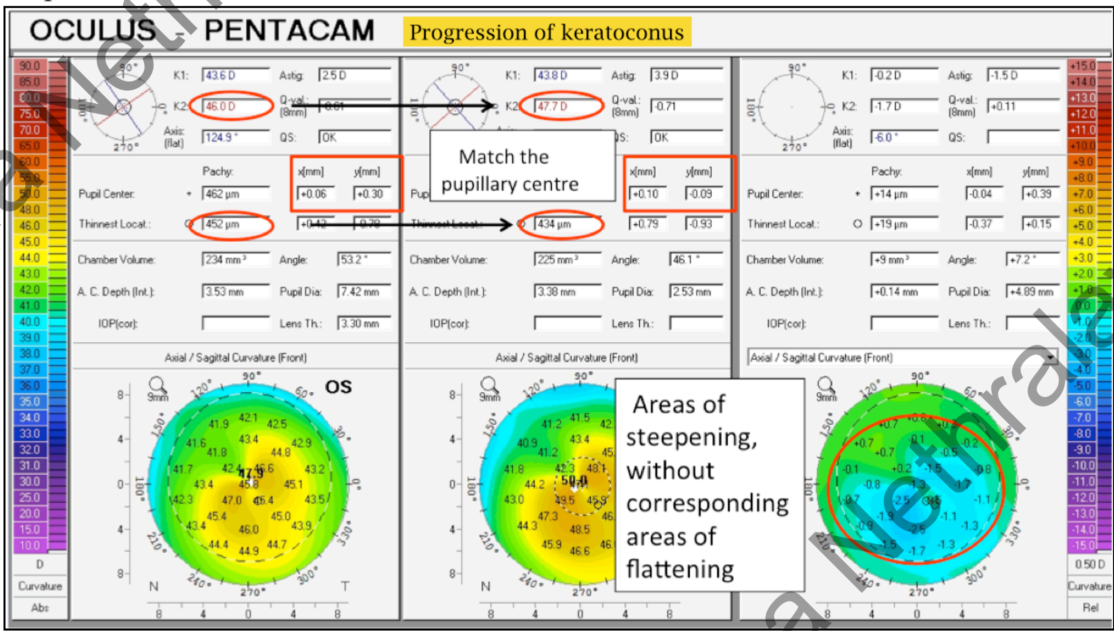
b) The elevation values on the back surface map should not exceed +17 µ. Values between +18 µ and +20 µ are suspicious, and any value >+20 µ is considered a risk factor.

c) The difference between the back and front surfaces (back-front) should not exceed +5 µ at the same point. For example: if the back is +12 µ and the front is +4 µ at the same point, it is suspicious although both values are within the normal limits.

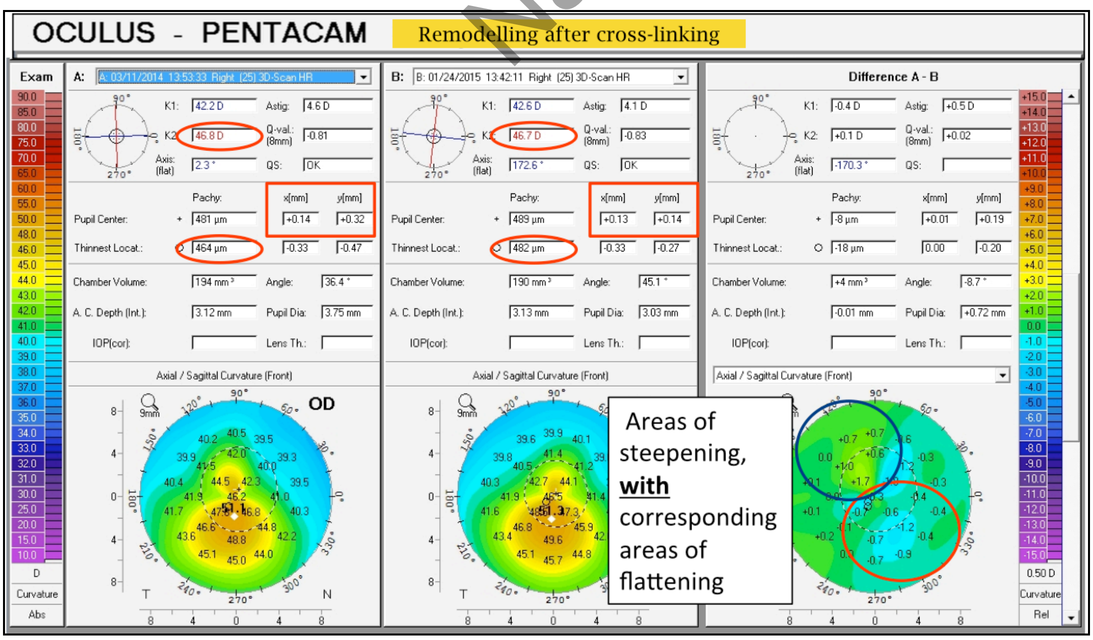
d) If there is any isolated island on either front or back surfaces, it would be suspected, even with values within the normal limits

e) The pattern on the keratometric map, as shown with placido images, any inferior superior asymmetry arouses suspicion

f) Compare the thickness at the apex with the thickness at the thinnest location. The difference more than 10 μ and increasing on follow up is suspicious.[6]



Progression of keratoconus is an increase of 0.5 diopter (D) or more in two or more keratometry values in the steep meridian between two sagittal curve maps or a decrease in corneal thickness of 10% or more at the thinnest point between two pachymetry maps on Pentacam (Oculus, Wetzlar, Germany) in the last 6 months.



g) Inferior-superior difference in the central 4 mm zone of more than 30 μ is abnormal.

h) The difference between the examined cornea and its fellow at the same point should be no more than 30 microns.

B) ***Galilei***

- Uses a monochromatic slit-light source (diode emitting blue light at 470 nm)
- Combines dual Scheimpflug cameras and a Placido disc to measure both anterior and posterior corneal surfaces.
- Obtains more than 122000 points in 1 or 2 seconds.
- Two Scheimpflug slit images are made by the dual camera from opposite sides of the illuminated slit, and the data are averaged.
- The dual camera simultaneously tracks decentration due to eye movements.

Figure 8: The **GALILEI™** Dual Scheimpflug Analyzer

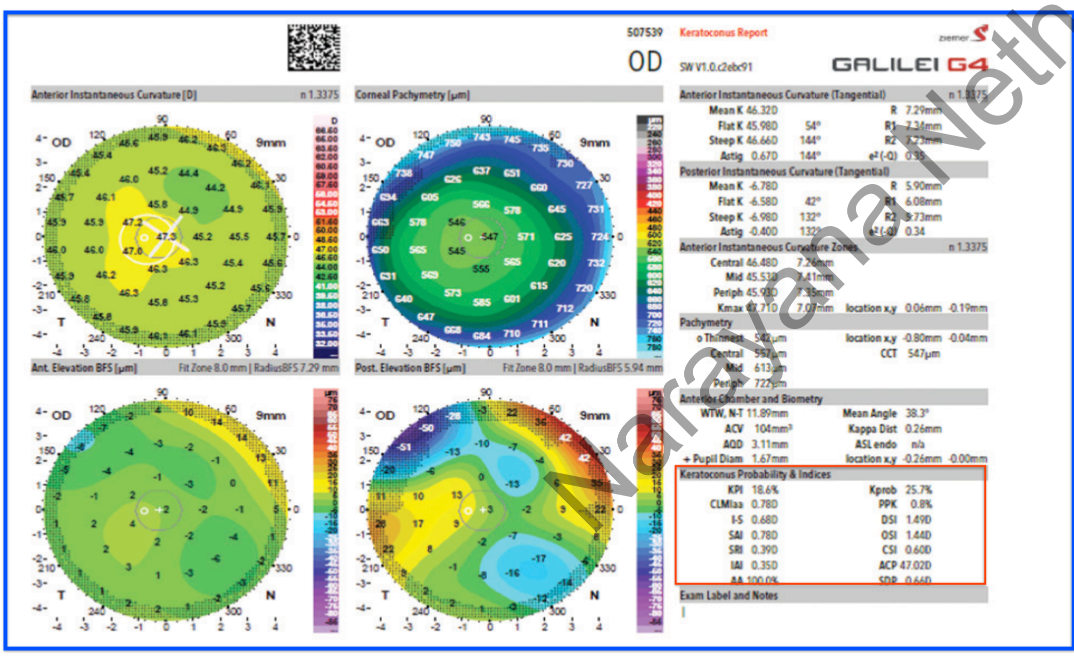


Figure 9: Galilei keratoconus screening output maps showing anterior instantaneous curvature, corneal pachymetry, anterior and posterior elevation.

Interpreting the Galilei maps:

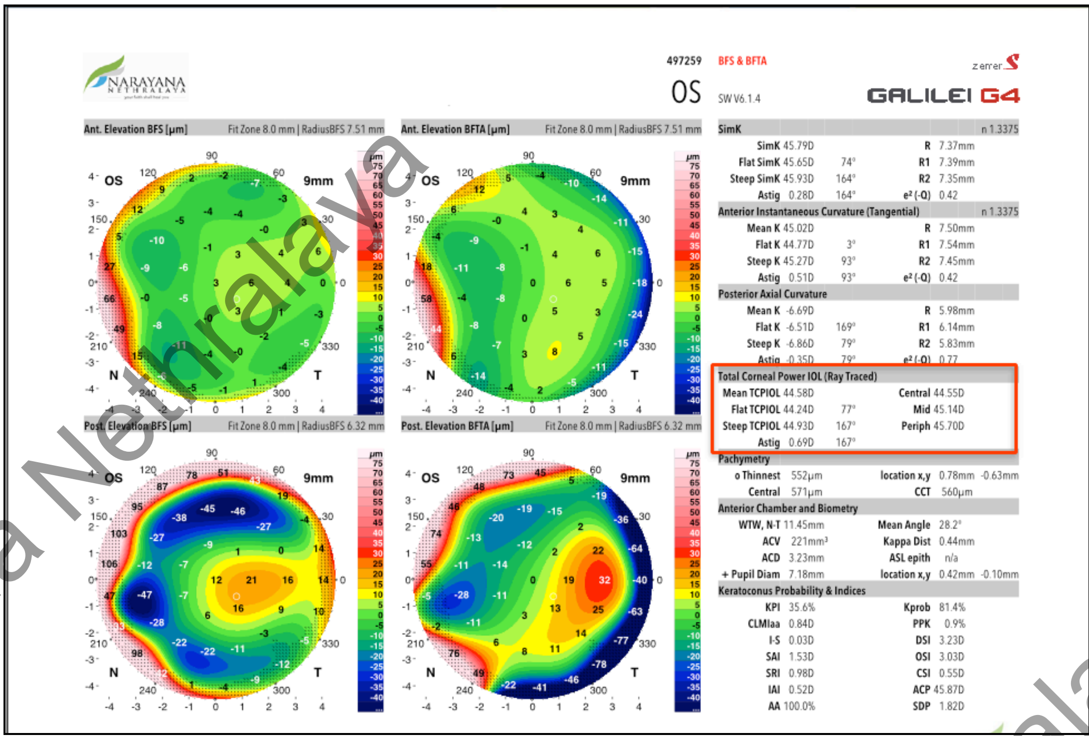
1. A typical refractive map of Galilei gives anterior instantaneous curvature map, pachymetry, anterior (8mm map) and posterior elevation (7.8 mm)

from best-fit sphere maps. In addition, it gives a detailed analysis of anterior chamber measured by double scheimpflug imaging.

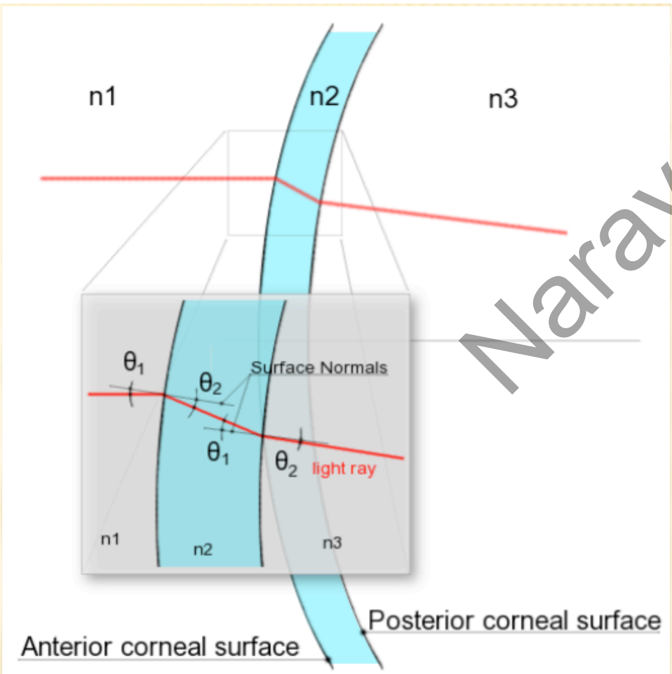
- Keratoconus probability and indices include the inferior-superior asymmetry (I-S), standard deviation of corneal power (SDP), surface regularity index (SRI), differential sector index (DSI), the opposite sector index (OSI), the center/surround index (CSI), the surface asymmetry index (SAI), the irregular asymmetry index (IAI), Average central dioptric power (ACP) and the percentage analysed area (AA). Keratoconus prediction index (KPI), is based on anterior surface measurements and predicts percentage probability of keratoconus.

  KPI 0-10% is normal, 10-20% is borderline to suspicious, 20-30% suspicious to keratoconus, >30% is highly suggestive of keratoconus or pellucid marginal degeneration
- Keratoconus probability value (Kprob) refers to a specificity and sensitivity validation of the reported KPI based on the statistical analysis of a series of normal corneas and corneas with keratoconus.
- Cone location and magnitude index (CLMI) is one of the latest in the development in the field of keratoconus detection based on corneal topography. It can be calculated on any map.
- The percent probablility of keratoconus (PPK) is defined as the optimum probability threshold for the detection of the disease. The suspect range limits are $0.20 < PPK < 0.45$.

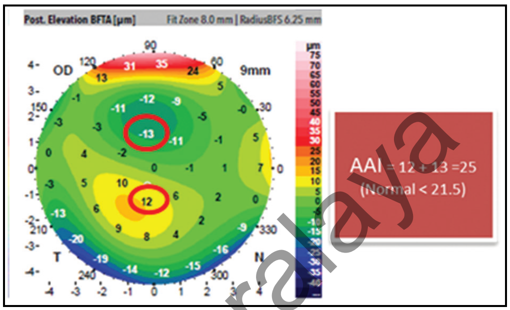
2. In addition to four maps with refractive indices, Galilei utilizes the concept of Best Fit toric and aspheric surface (BFTA) that conforms regularly to the cornea than a Best fit sphere (BFS).[7] BFTA has better ability to screen out Forme-fruste keratoconus because it fits closer to the natural corneal shape by cancelling out its mean asphericity and toricity.



3. **True corneal power** is based on Snell's law and calculated using ray tracing both anterior and posterior corneal powers.



4. **Posterior asphericity asymmetry index (AAI)**



AAI on Galilei is a quantitative indicator of the posterior surface asymmetry.[8] AAI is calculated by absolute summation of maximum elevation and maximum depression in the 6 mm zone on BFTA map. AAI with a cutoff value of 21.5 µm and the corneal volume at 30.8 mm3, are the two most discriminant variables among the parameters incorporated in the analysis for differentiating between normal corneas and those with forme fruste keratoconus

C) ***Sirius***

- Combines a rotating Scheimpflug camera with a Placido disc.
- The extremely high resolution of only one micrometre.
- Blue LED light 475nm
- 21632 (anterior) + 16000 (posterior) points measured.
- Offers detailed descriptions of the morphology as well as the classification of the keratoconus.
- The integrated pupillometry captures the pupil diameter either dynamically or statically according to the defined lighting conditions.
- Provides detailed information on the entire anterior segment of the eye and all necessary information for a pachymetry assisted laser keratoplasty (PALK) thanks to the Scheimpflug camera.

Figure 10: Sirius scheimpflug topographer

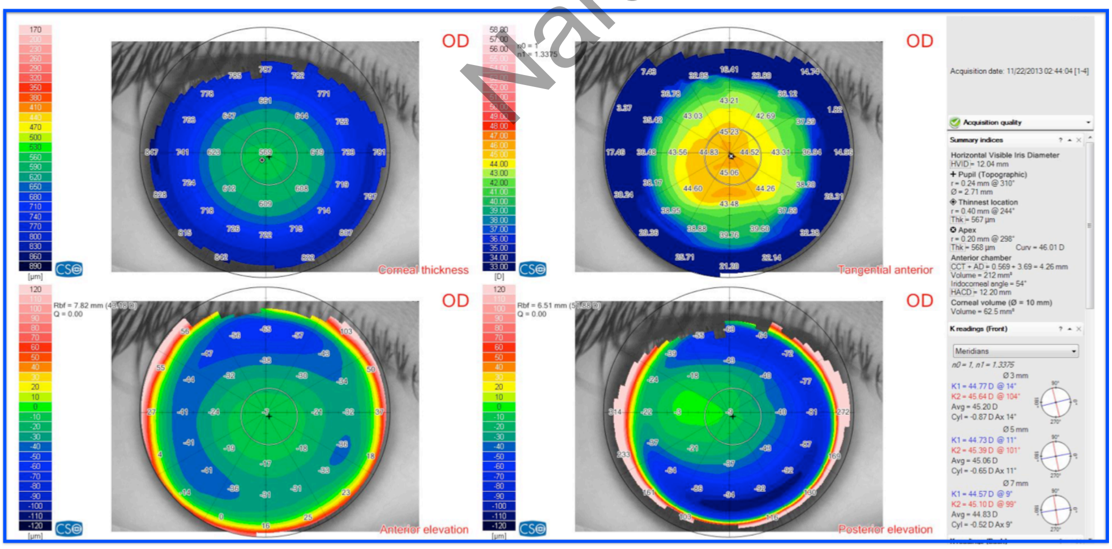


Figure 11: A typical quad map of Sirius topographer showing corneal thickness, tangential curve map, anterior and posterior elevation

Interpreting the Sirius maps:

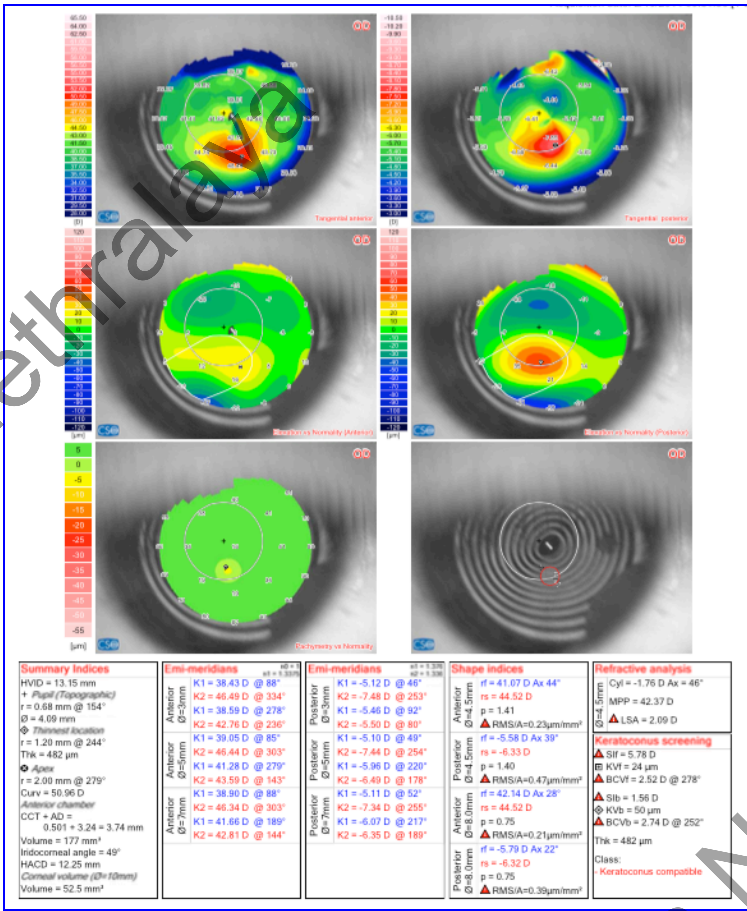


Figure 12: A keratoconus summary map on Sirius

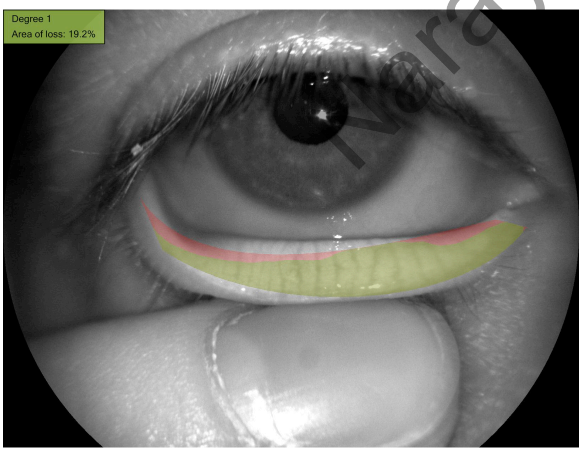
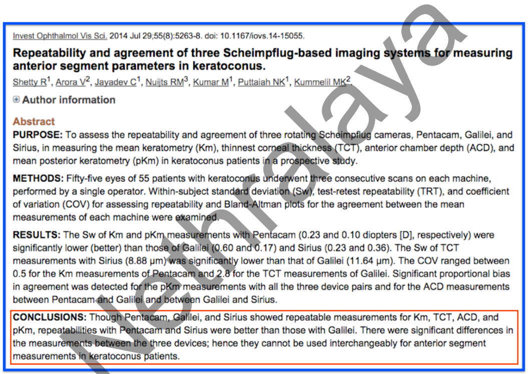


Figure 13: Meibography on Sirius topographer

Interpretation of Sirius maps are same as pentacam scheimpflug imaging. Apart from corneal topography Sirius also gives meibography and tear film analysis. A cataract surgeon may be benefitted by its cataract summary and IOL power calculation using ray tracing especially in post-refractive surgery patients and glaucoma summary for glaucoma surgeons.



Invest Ophthalmol Vis Sci. 2014 Jul 29;55(8):5263-8. doi: 10.1167/iovs.14-15055.

Repeatability and agreement of three Scheimpflug-based imaging systems for measuring anterior segment parameters in keratoconus.

Shetty R[1], Arora V[2], Jayadev C[1], Nuijts RM[3], Kumar M[1], Puttaiah NK[1], Kummelil MK[2].

Author information

Abstract

PURPOSE: To assess the repeatability and agreement of three rotating Scheimpflug cameras, Pentacam, Galilei, and Sirius, in measuring the mean keratometry (Km), thinnest corneal thickness (TCT), anterior chamber depth (ACD), and mean posterior keratometry (pKm) in keratoconus patients in a prospective study.

METHODS: Fifty-five eyes of 55 patients with keratoconus underwent three consecutive scans on each machine, performed by a single operator. Within-subject standard deviation (Sw), test-retest repeatability (TRT), and coefficient of variation (COV) for assessing repeatability and Bland-Altman plots for the agreement between the mean measurements of each machine were examined.

RESULTS: The Sw of Km and pKm measurements with Pentacam (0.23 and 0.10 diopters [D], respectively) were significantly lower (better) than those of Galilei (0.60 and 0.17) and Sirius (0.23 and 0.36). The Sw of TCT measurements with Sirius (8.88 μm) was significantly lower than that of Galilei (11.64 μm). The COV ranged between 0.5 for the Km measurements of Pentacam and 2.8 for the TCT measurements of Galilei. Significant proportional bias in agreement was detected for the pKm measurements with all the three device pairs and for the ACD measurements between Pentacam and Galilei and between Galilei and Sirius.

CONCLUSIONS: Though Pentacam, Galilei, and Sirius showed repeatable measurements for Km, TCT, ACD, and pKm, repeatabilities with Pentacam and Sirius were better than those with Galilei. There were significant differences in the measurements between the three devices; hence they cannot be used interchangeably for anterior segment measurements in keratoconus patients.

A comparision of above three scheimpflug imaging showed that these three machines cannot be used interchangeably. Pentacam has the best repeatability for imaging all parameters except thinnest corneal thickness where Sirius stood out to be the best.[9]

Hybrid topographers:

A) Itrace system:

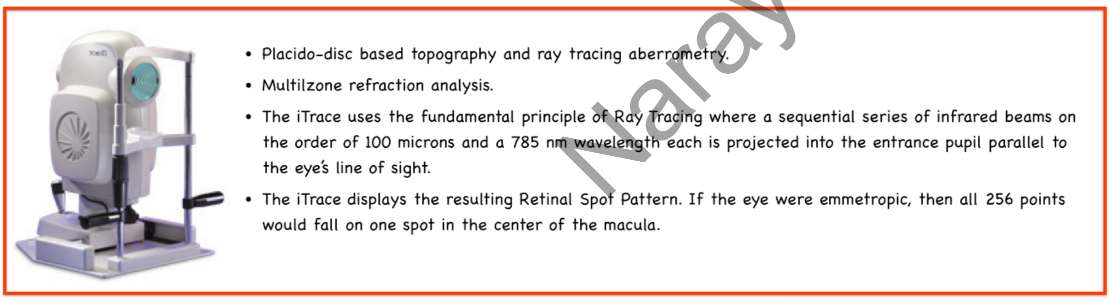


Figure 14: iTrace, Tracey Technology

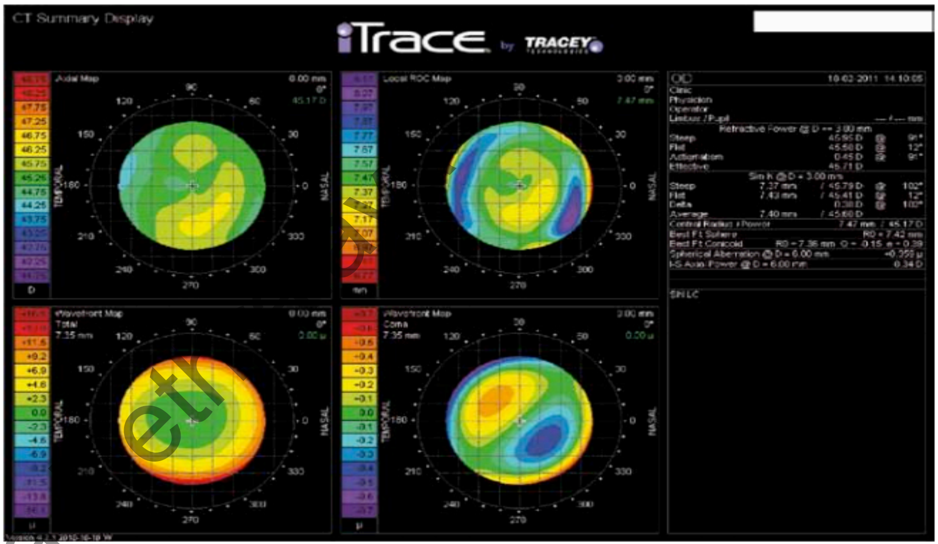


Figure 15: A typical topography display of Itrace showing axial map, tangential curve map, refractive map and wavefront map**.**

Interpreting Itrace topography map:

A typical **topographic map** taken with Itrace system consists of

a) ***Standard axial map:*** Shows the curvature in a specific point of the corneal surface in the axial direction relative to the centre

b) ***Local or tangential curvature map:*** Measures the curvature in a specific point of the surface of the cornea

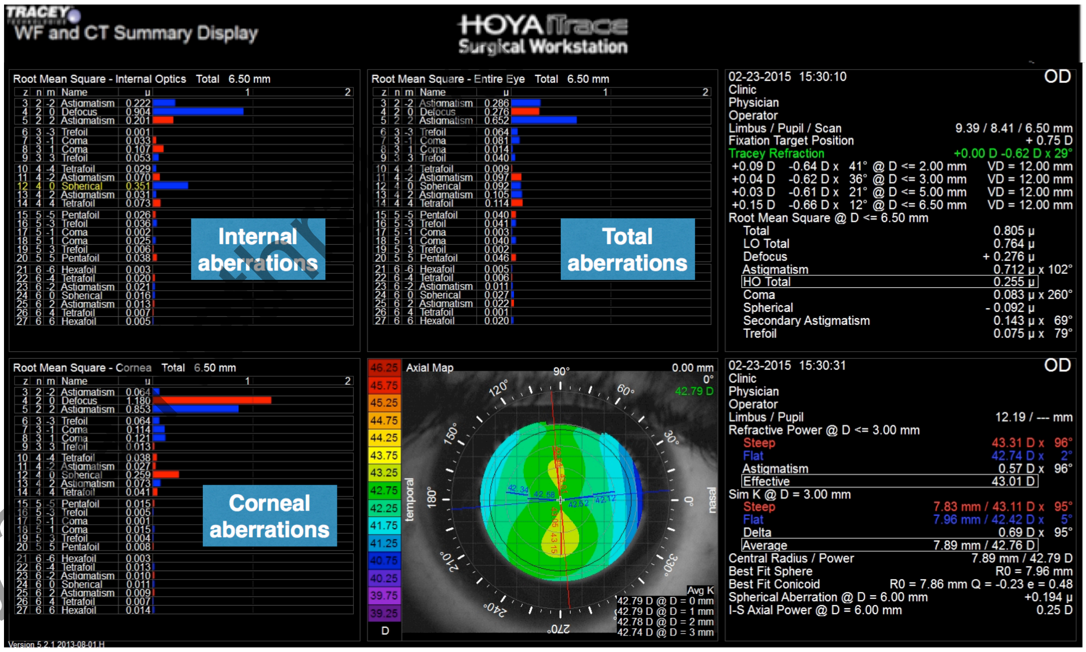
c) ***Refractive map****:* Based on Snellen's law. It gives us the refractive power in dioptric power. Emmetropia will show in green, myopia in warm colours and cool colours will indicate hypermetropia.

d) ***Elevation map****:* Shows the difference in elevation between a point on the corneal surface and a point on the surface of the reference sphere. Different reference morphologies can be chosen.

e) ***Corneal wavefront map***: It shows both the total aberrations map and the different Zernike polynomials map. The coma map is very useful to plan intracorneal ring surgery

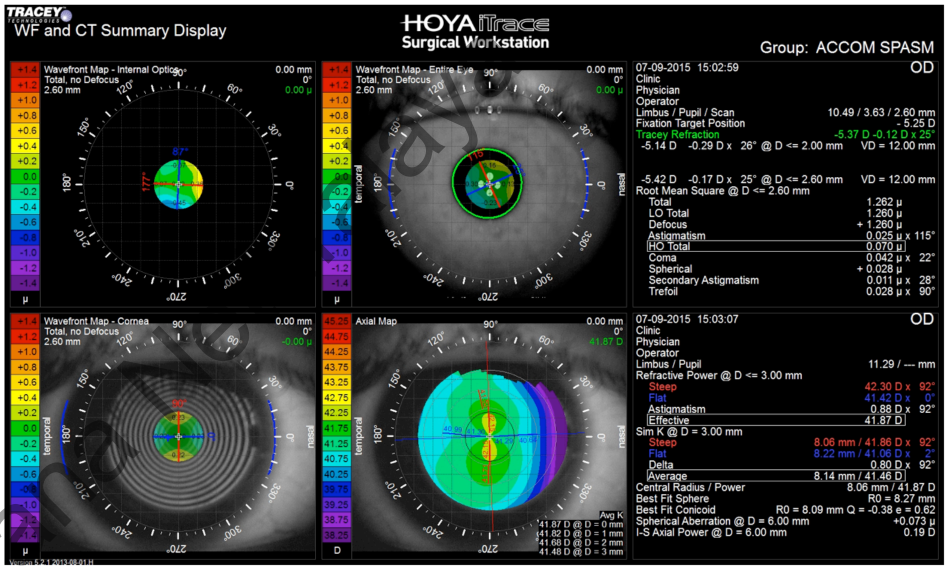
It's also a multizone autorefractometer.

Wavefront map:



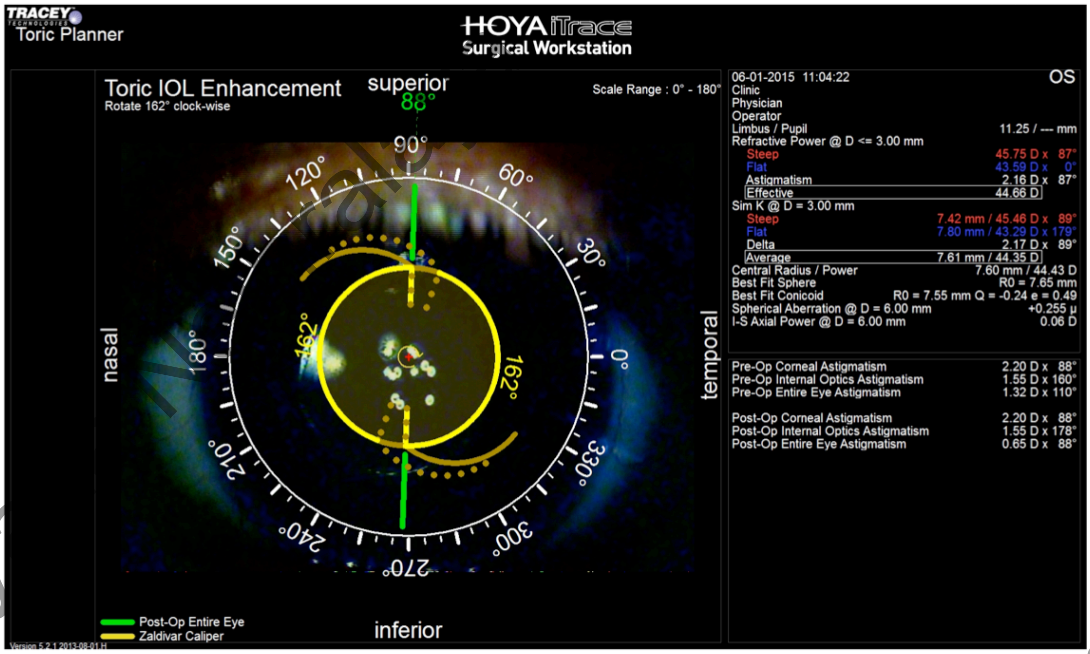
These maps show colour-coded wavefront aberrations of the eye measured in microns of error. The error can be positive or negative. Measurements are taken from the entrance pupil. Warm colours indicate that the wavefront is in front of the reference plane and blue colours indicate that the wavefront is retarded in relation to this plane. Map can be displayed as Zernike polynomials, Snellen's letters for total and higher order aberrations, point spread function, root mean square.

Combined topography and wavefront map:



This map is unique to Itrace system.Through corneal topography the corneal aberrations map can be mathematically generated and these aberrations can be adequately subtracted from the total aberrations of the entire eye. The resulting difference obtained by subtracting the corneal aberrations from the total aberrations mainly represents the aberrations of the internal optics; in this way aberrations from the cornea can be separated from those from the interior of the eye. Most of the aberrations of the internal optics are induced by the crystalline lens. The decision on treating the lens or cornea can be concluded based on these maps.

Toric planning and axis confirmation:



The iTrace offers unique tools to increase toric IOL precision. Its integrated toric calculator, surgically induced astigmatism analysis and the Zaldivar Toric Caliper, improve the precision of toric power selection and placement. The integrated toric calculator presents with several toric power options and predicted results so that the best toric power can be selected. Once you select the lens, you can adjust the incision site "on the fly" to see how it might fine tune the residual astigmatism. Then, precisely determine the location of the placement axis in relation to actual landmarks or surgical ink marks. Assess Treatment Success Finally, using a post-op iTrace exam the patient's visual performance can be revised and analyzed using the Chang Analysis display.

B) Nidek OPD III scan:

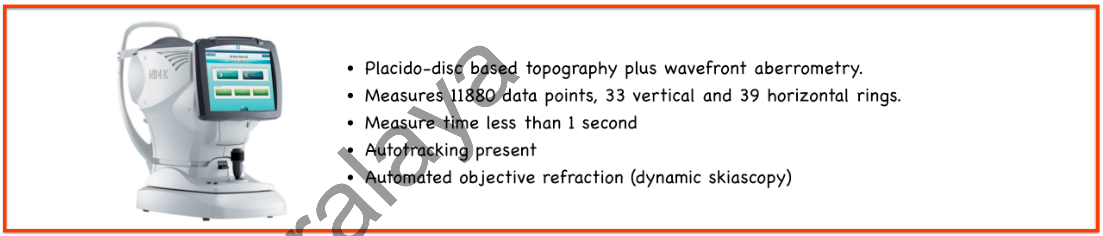


Figure 16: Nidek OPD Scan III wavefront aberrometer

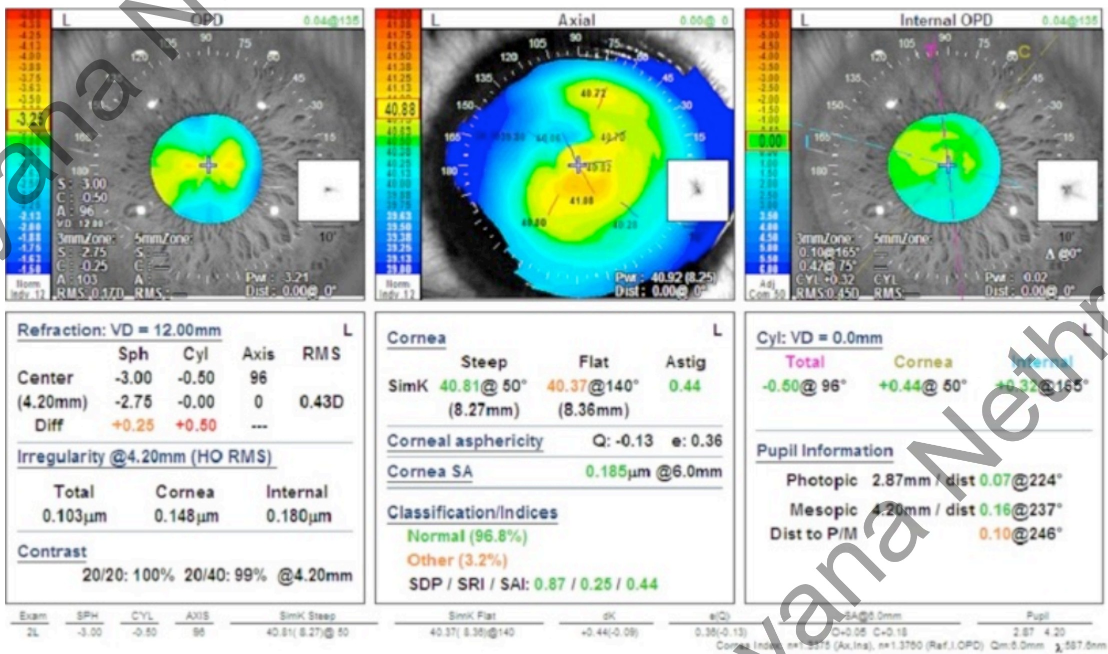


Figure 17: A typical ouput of Nidek OPD III scan showing overview summary

Interpreting NIDEK output map:

1. Gives an overview summary, which provides refractive data, and incorporates corneal disease analysis software and data for cataract and refractive surgery.
2. Gives information about corneal spherical aberration, corneal indices, astigmatism and pupil information.
3. Gives information about pupil size, optical quality indices, higher order point spread function, cornea summary, toric IOL planning, wavefront summary and the Holladay summary.

Various parts of the overview summary are:

a) **Irregularity** helps determine the best strategy for vision correction. Separation into Total, Corneal and Internal components allows determination of the source of the optical pathology.

b) **PSF images** of OPD, Axial, and Internal OPD map simulate objective retinal visual quality from each component of the eye for easy clinical assessment and patient education.

c) **Corneal Spherical Aberration** aids in the selection of aspheric IOLs and contact lenses.

d) Color coded **Classification Indices** help identify post-LASIK corneas and Keratoconus.

e) The **Astigmatism index** aids the implantation of toric IOLs such as incision placement and lens alignment.

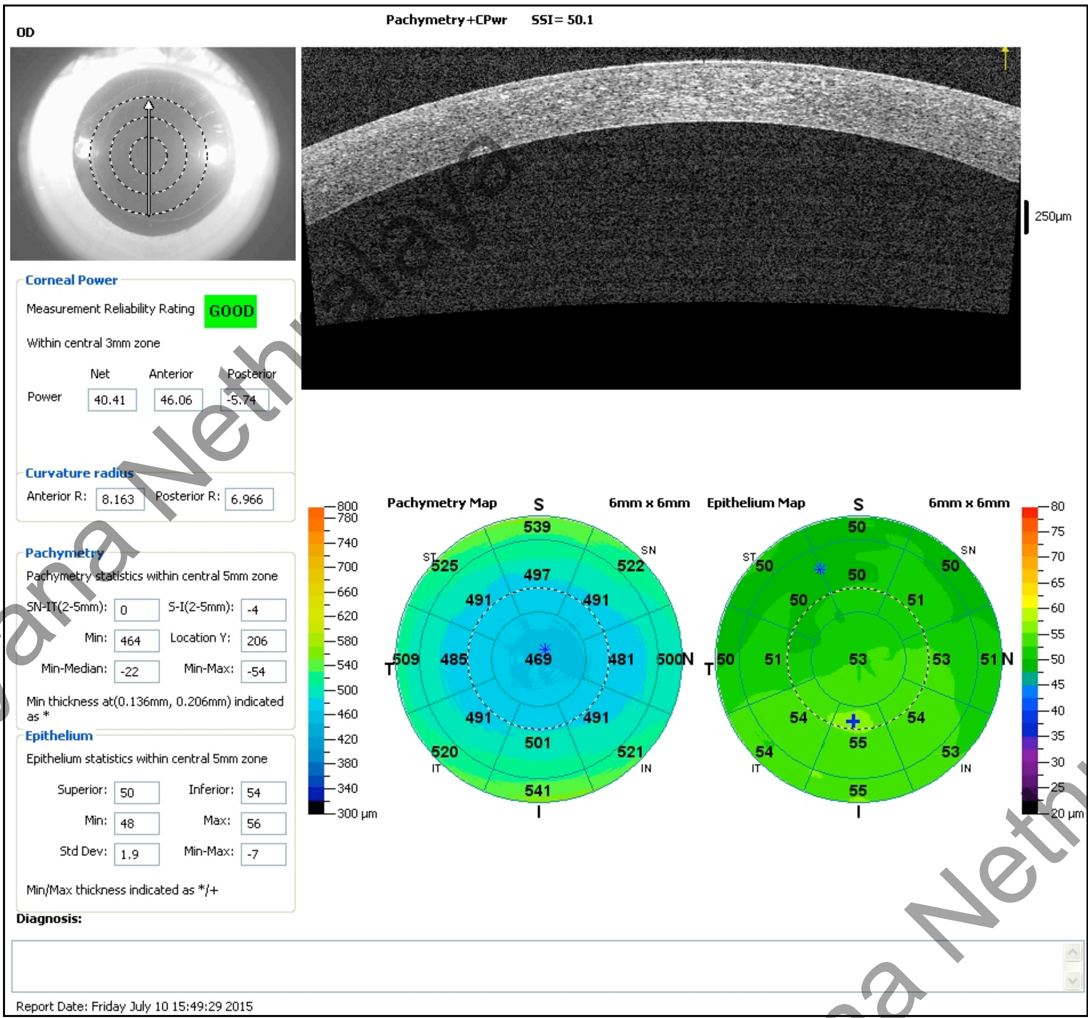
f) A **retroillumination** image of cataracts captured during the OPD exam allows better understanding of pupillary effects on vision and in patient education.

OCT based topographers:

Optovue:

- Spectral domain OCT, uses wavelength of 830nm
- Has corneal adaptor module (CAM) which can take scan width of 4-6 mm with transverse resolution of 10-15 microns
- It consists of 8 high-definition meridional scans (1024 axial scans) acquired in only 0.31 seconds.
- Both anterior and posterior corneal curvatures and power can be measured.

Figure 18: Optovue Rtvue spectral domain OCTs



Interpreting Optovue output map:

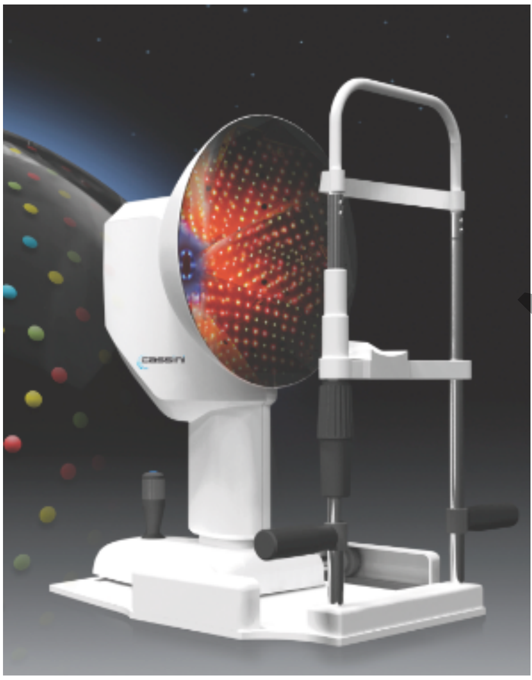
Parameters listed in the RTVue OCT pachymetry map printout:

- **SN - IT**: The average thickness of the superonasal (SN) octant minus the average thickness of the inferotemporal (IT) octant;
- **S - I**: The average thickness of the superior (S) octant minus the average thickness of the inferior (I) octant;
- **Minimum**: The thinnest corneal thickness;
- **Minimum – Maximum**: The thinnest corneal thickness minus the thickest corneal thickness. Keratoconus diagnosing criteria:

- Asymmetric parameters **SN - IT** or **S - I** values greater than 45 µm;
- **Minimum** corneal thickness less than 470 µm;
- Focal thinning parameter **Minimum – Maximum** value less than -100 µm.

The future:

The "Cassini" (i-Optics, The Hague, the Netherlands) system is a novel topographer utilizing a multicolor (red, yellow, and green) spot pattern consisting of hundreds of light-emitting diode (LED) spots on the cornea. The system projects approximately 700 LED point-sources onto the cornea and evaluates their reflection pattern, extending to up to 8.5 mm of the corneal diameter area as raw data.[10] These spots are grouped in seven "septima" segments with a specific Cartesian array arrangement within each segment. The system consequently provides anterior-surface topography results, including axial and tangential



curvature, refractive power, and elevation maps. The system calculates flat and steep keratometry (diopters [D]), axis orientation (°), and related astigmatism (D), and identifies the location of the corneal apex. Four topographic indices relating to surface asphericity, and three keratoconus indices – form factor, the surface regularity index (SRI), and the surface asymmetry index (SAI) are also provided.

Corneal Biomechanics:

Understanding corneal biomechanics is of utmost importance for a refractive surgeon. At present Ocular response analyser and Corvis ST are two commonly used devices used for assessing corneal biomechanics.

Ocular response analyser:

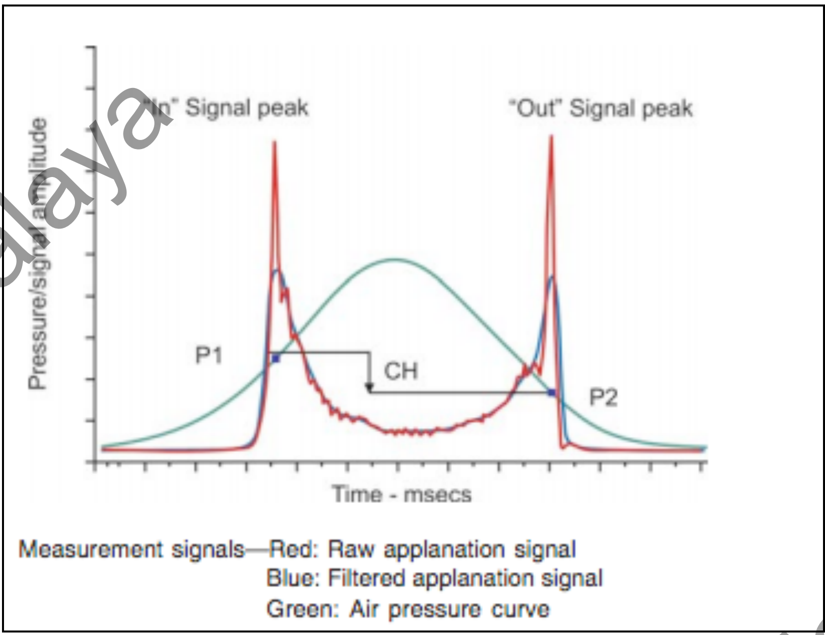
The ORA utilizes a dynamic, bidirectional applanation process for measuring IOP. A rapid air impulse is used to apply force to the cornea. The deformation of the cornea is monitored using an advanced electro-optical system. The precisely metered, collimated air pulse causes the cornea to move inwards causing applanation, similar to conventional noncontact tonometers. However, in the ORA, the air impulse continues to deform the cornea past applanation into slight concavity. Then, the air pump shuts off and, as the pressure decreases, the cornea begins to return to its normal configuration. During this process, it once again passes through an applanated state. The entire process takes only 20 milliseconds, a time sufficiently short to ensure that ocular pulse effects or eye position does not change

The ORA provides these measurement parameters:

IOPg: A Goldmann-correlated IOP value.

CH: (Corneal hysteresis) A measure of viscous damping in the cornea. Normal value: 10.8 mm Hg ± 1.5 mmHg

IOPcc (Corneal-Compensated Intraocular Pressure): An intraocular pressure measurement that is less affected by corneal properties.



CRF (Corneal Resistance Factor): An indicator of the overall "resistance" of the cornea. CRF is derived from the formula P1 – kP2, where k is a constant, derived from the relationship between changes in P1 and P2, with change in IOP. Normal value 11.0 mm Hg ± 1.6 mm Hg

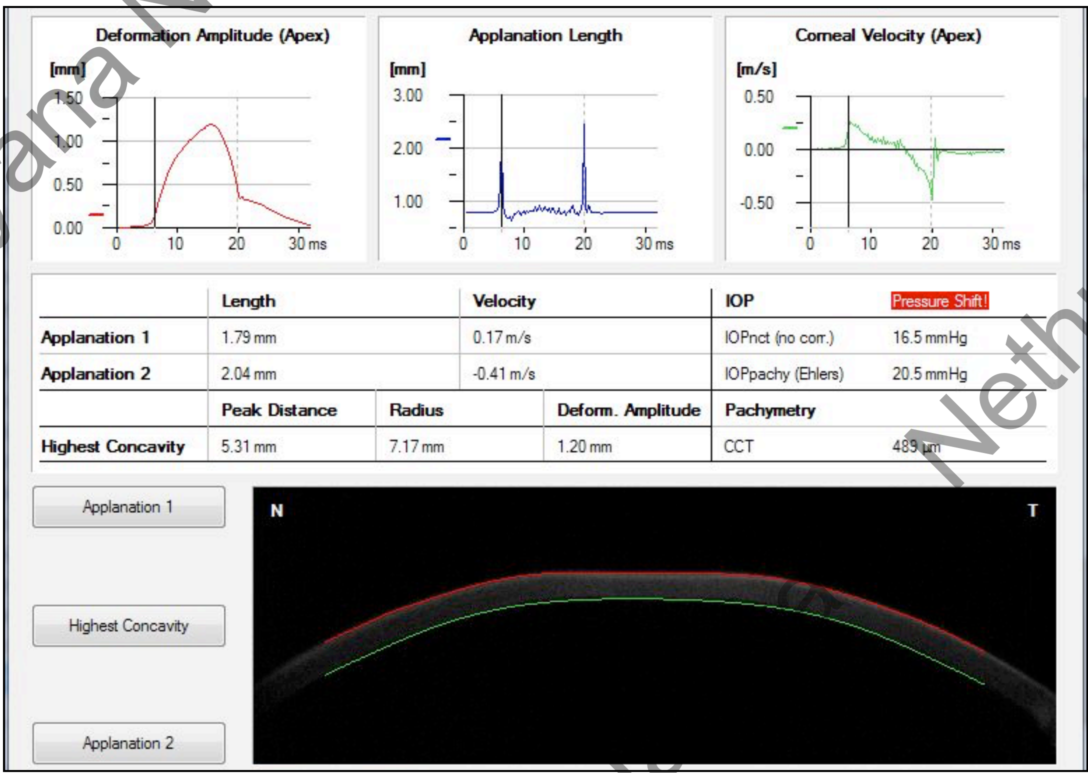
CCT - Central corneal thickness.

Corvis ST:

The Corvis ST (CST) is a novel noncontact tonometer that allows investigation of

the dynamic reaction of the cornea to an air impulse. The CST gathers 4330 frames per second within a 100 ms period, therefore recording dynamic deformation of the cornea to calculate the IOP value. Its measurement range is from 1 to 60 mm Hg. It also measures deformation amplitude, applanation length, corneal velocity,IOP-measurement, Corneal thickness, Scheimpflug images of applanation moments. Uses for a refractive surgeon:

- Determine the true IOP with the Corvis® ST
- Screening for corneal ectasia with the Corvis® ST
- Visualizing the effect of corneal crosslinking with the Corvis® ST



Time of Applanation 1 (AT1): time from the start until an air puff causes the corneal flattening (first applanation)

Length of Applanation 1 (AL1): length of the flattened cornea in the first applanation

Velocity of Applanation 1 (AV1): velocity of corneal deformation during the first applanation

Time of Applanation 2 (AT2): time from the highest concavity until cornea restores its standard curvature,

Length of Applanation 2 (AL2): length of the flattened cornea in the second applanation

Velocity of Applanation 2 (AV2): velocity of corneal deformation during the second applanation

Deformation Amplitude at the Highest Concavity (HCDA): maximum deformation amplitude (from the start to the highest concavity) at the corneal apex. Normal value 1.05 ± 0.11 mm and in keratoconic eyes 1.37 ± 0.21 mm[11]

Conclusion:

Topography is an excellent tool to screen out potentially borderline cases in refractive practice. Placido disc based devices are very useful tool; however they do not show any changes on the posterior surface of the cornea. Newer, diagnostic devices like elevation based topographers, single and dual scheimpflug imaging, and LED technology can help us to visualize the posterior surface of cornea and can also give an accurate idea about the pachymetry of entire cornea. These newer modalities can help us diagnose ectatic disease in preclinical stage, thus allowing an early treatment.

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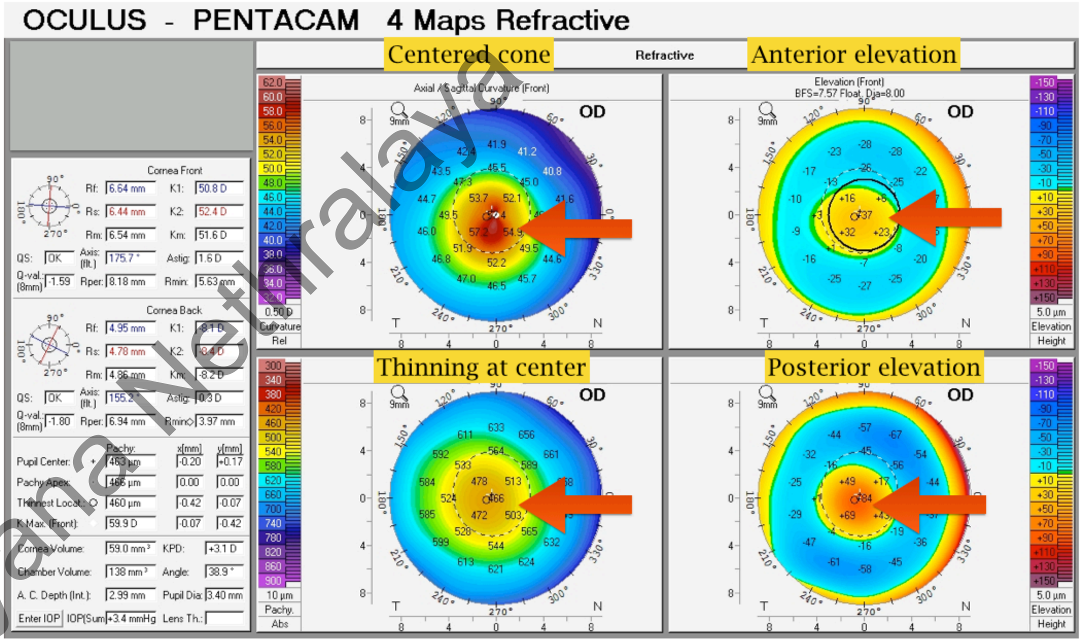
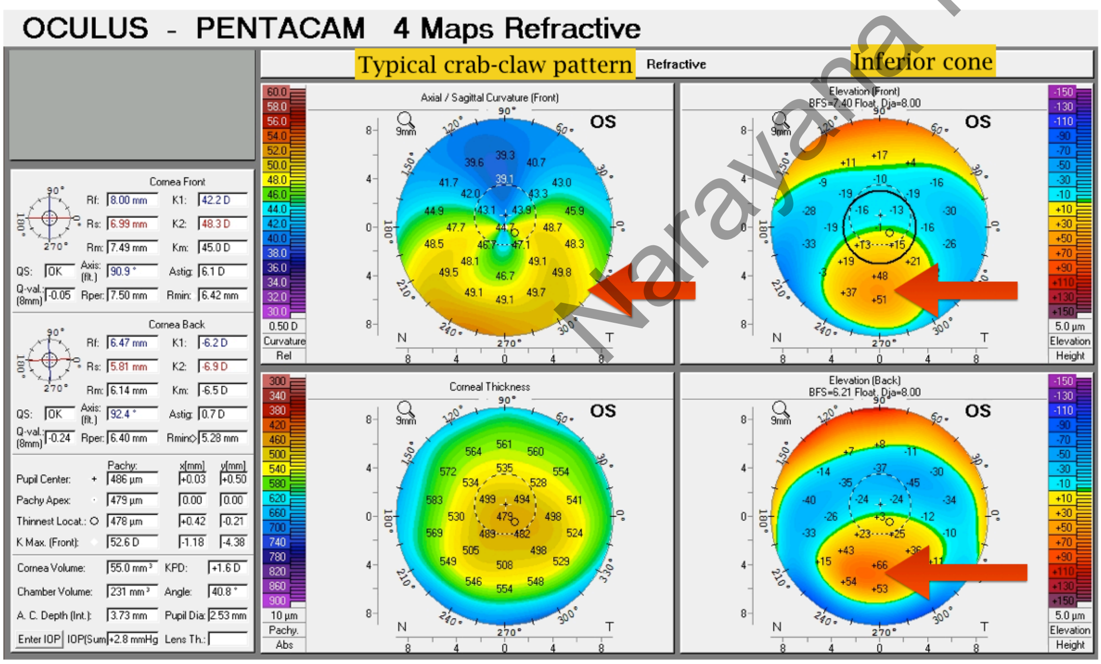
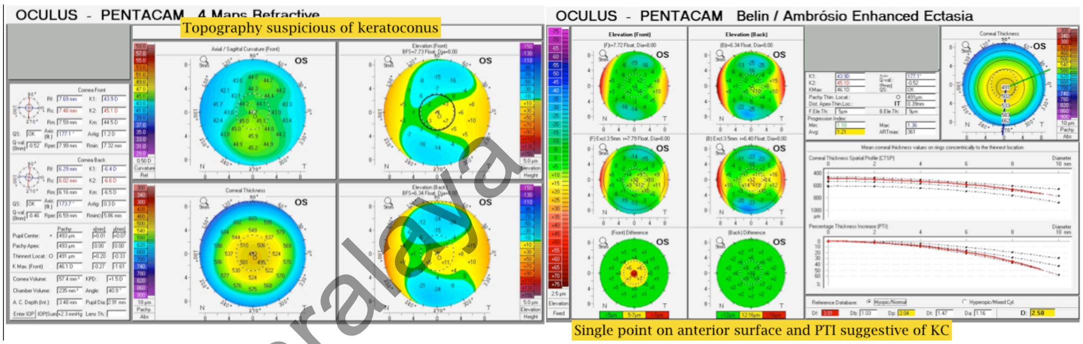
Case examples:



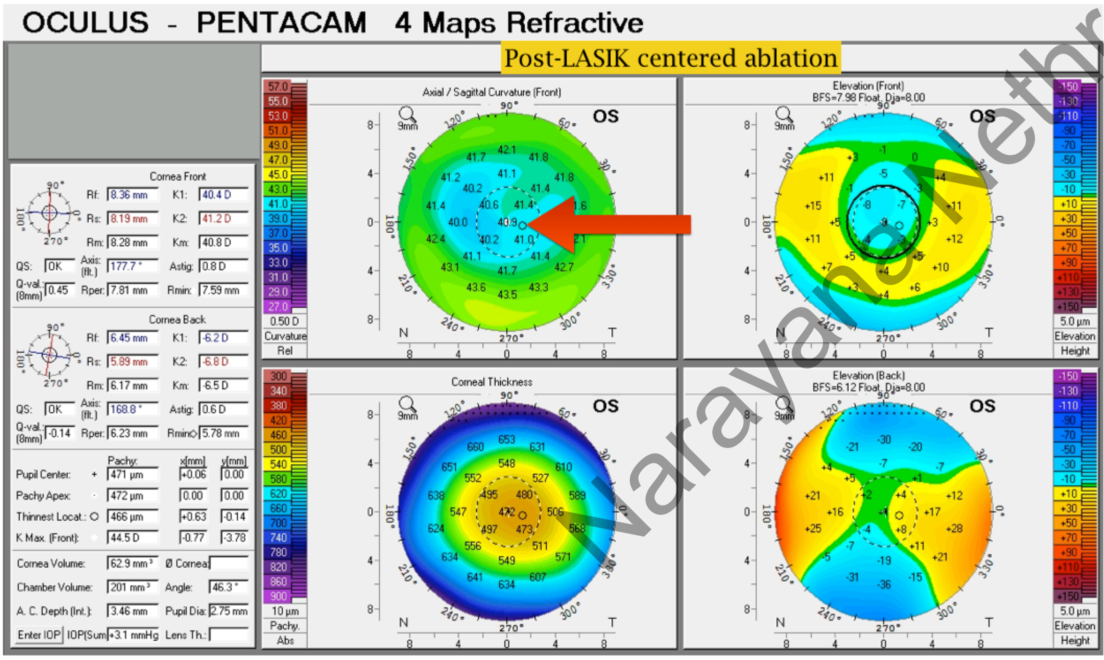
Case1: A typical case of Keratoconus on pentacam



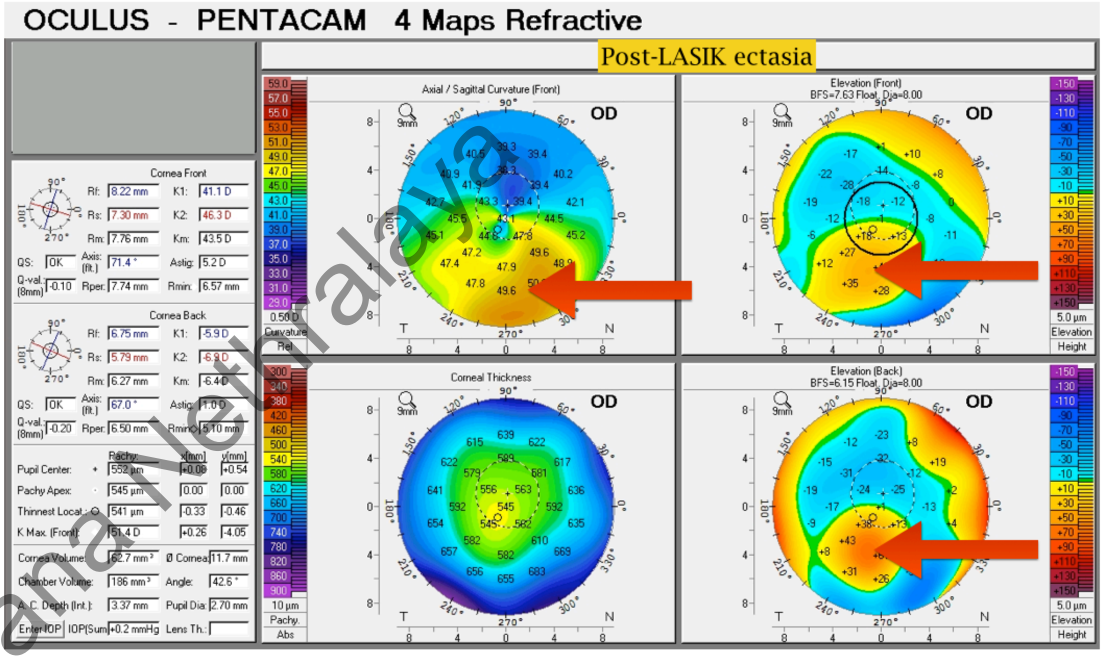
Case 2: A typical topography suggestive of pellucid marginal degeneration (PMD)



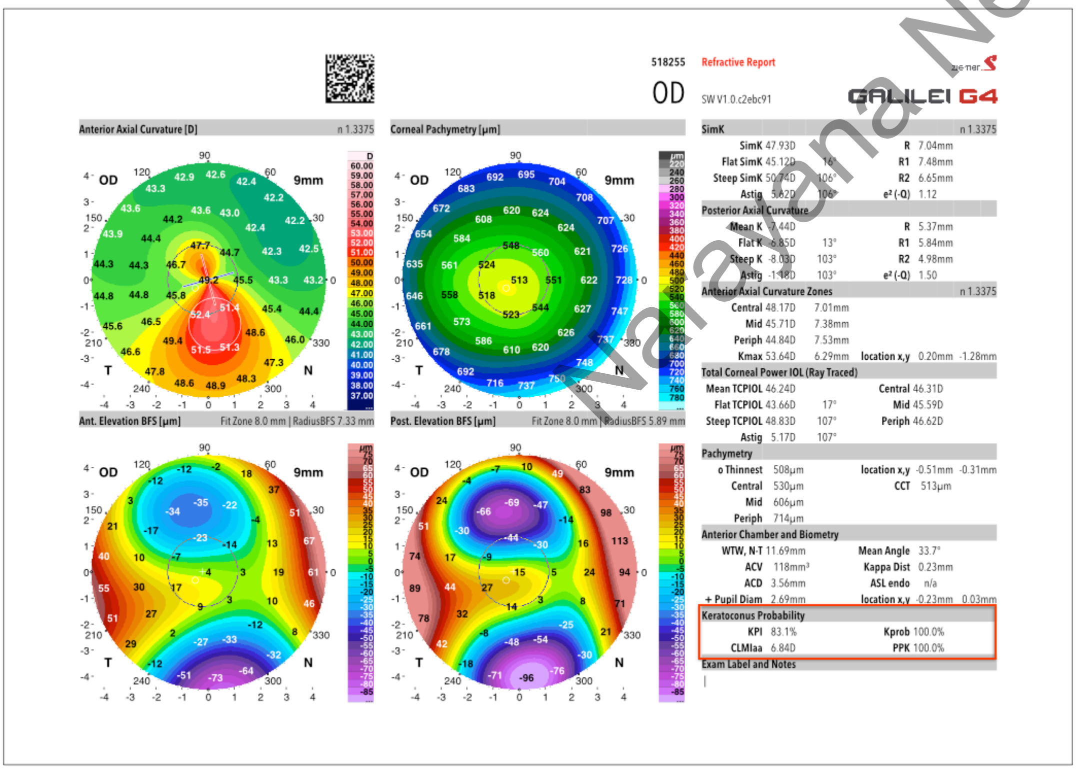
Case 3: Forme-fruste keratoconus



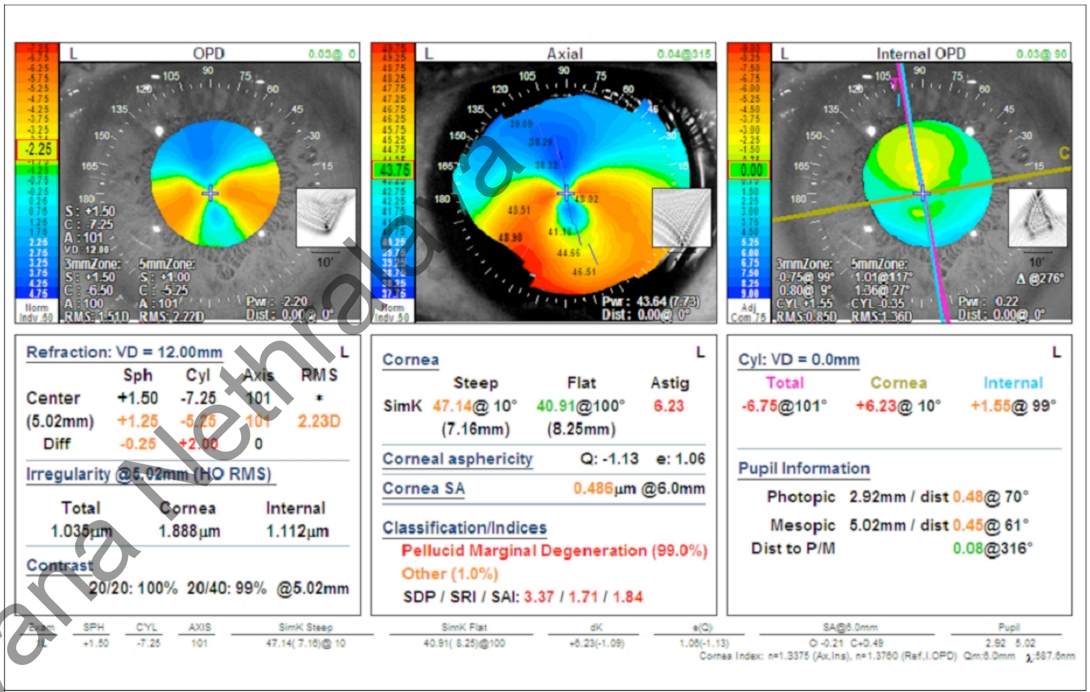
Case 4: Topography suggestive of post-LASIK cornea



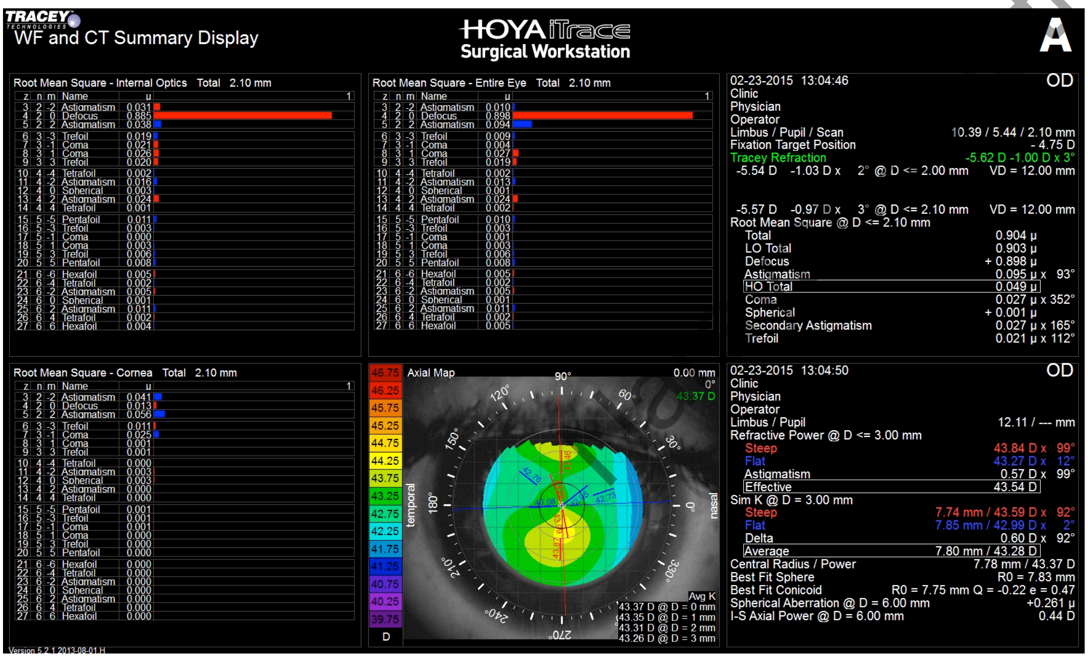
Case 5: Topography suggestive of post-LASIK ectasia

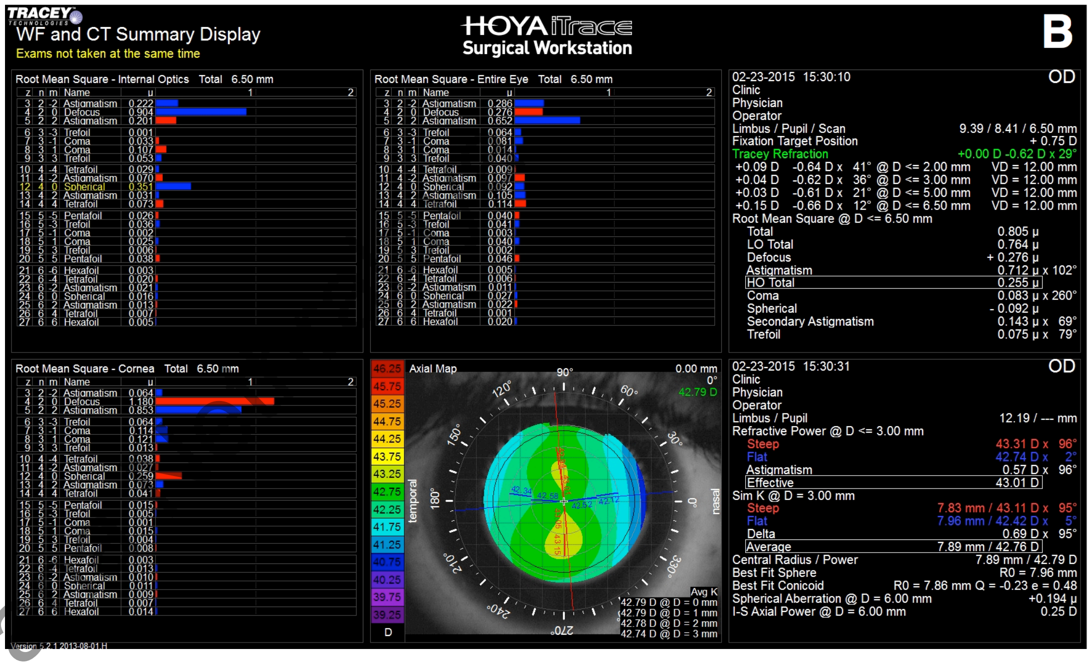


Case 6: Keratoconus diagnosis on Galilei

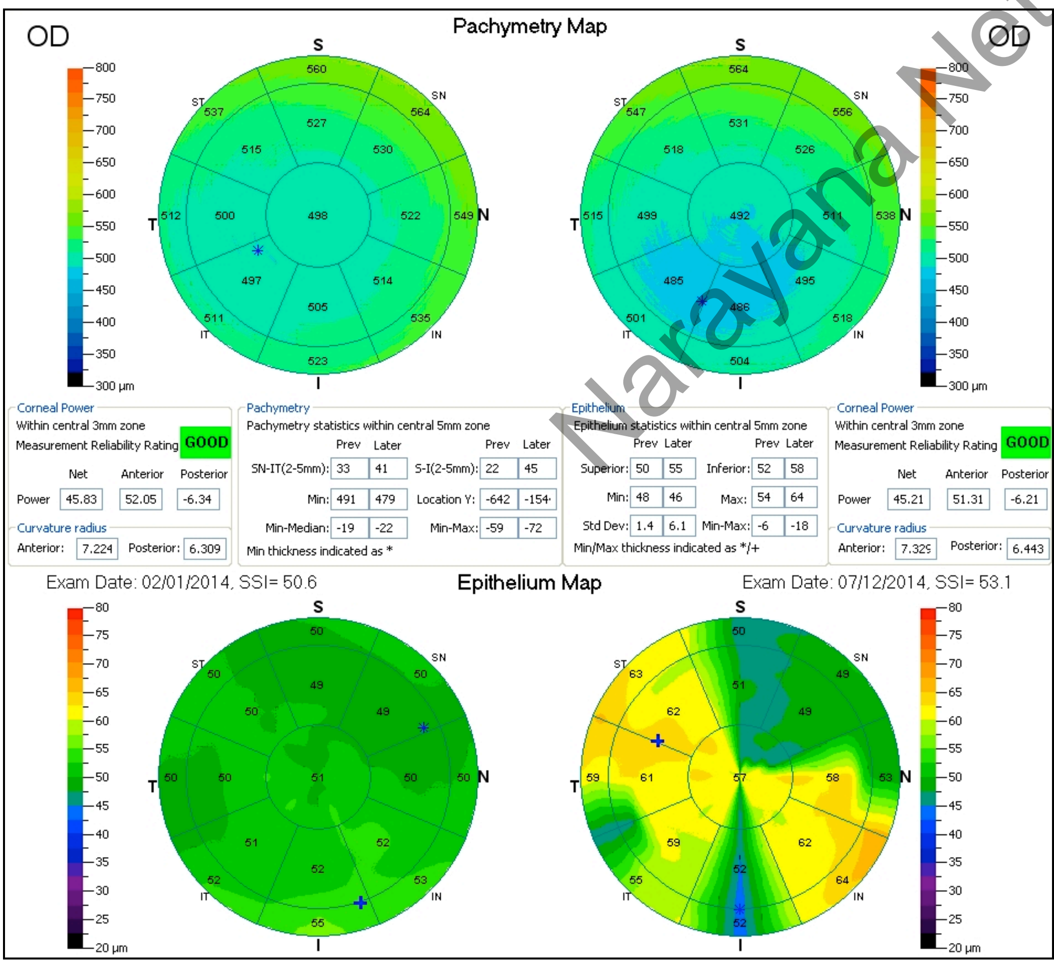


Case 7: Pellucid marginal degeneration on Nidek OPD III





Case 8: Change in internal defocus on Itrace pre (A) and post (B) cycloplegia suggestive of a case of pseudomyopia.



Case 9: Epithelial map on optovue showing contact lens warpage