Corneal topography – recent advances

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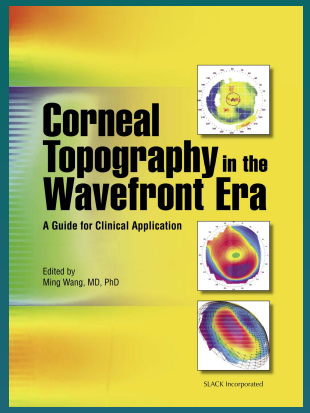
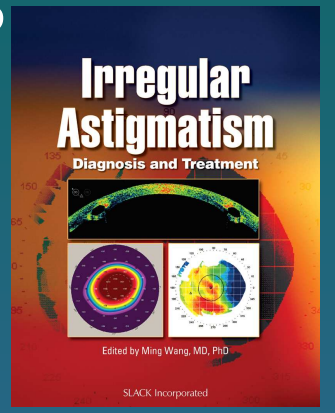


Why do we still need to keep updated on topo in the wavefront era?



- Cornea is the main refractive structure;
- Cornea is what we alter surgically mainly;
- New topo technology offers new capabilities:
  1. **Posterior and pachy** – topography (anterior/posterior) and FFKC;
  2. **Elevation** – excimer laser REMOVES tissue; elevation map is important in treating decentered treatment;
- Wavefront does have limitations (no infor outside the pupil, no infor about axial location of aberration, changes with accommodation);
- Combined topo-wavefront approach to treat problem at where it occurs (topo-linked to treat corneal problems): *not all aberrations at all axial locations are created equal.*

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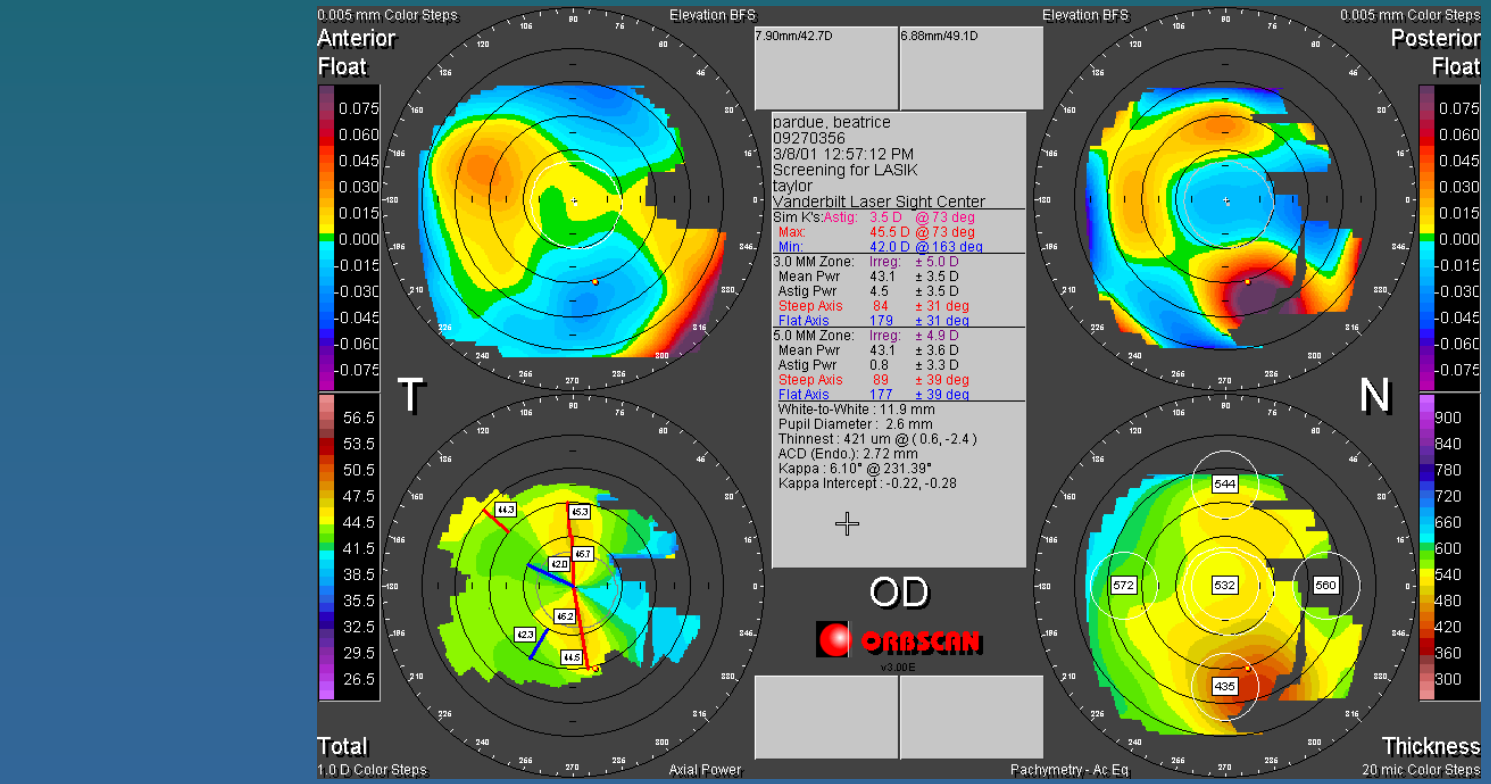
Examination of posterior cornea reveals earliest sign of ectasia: A case of posterior KC (“ominous purple”) in a virgin eye, with normal anterior. Don’t touch it!



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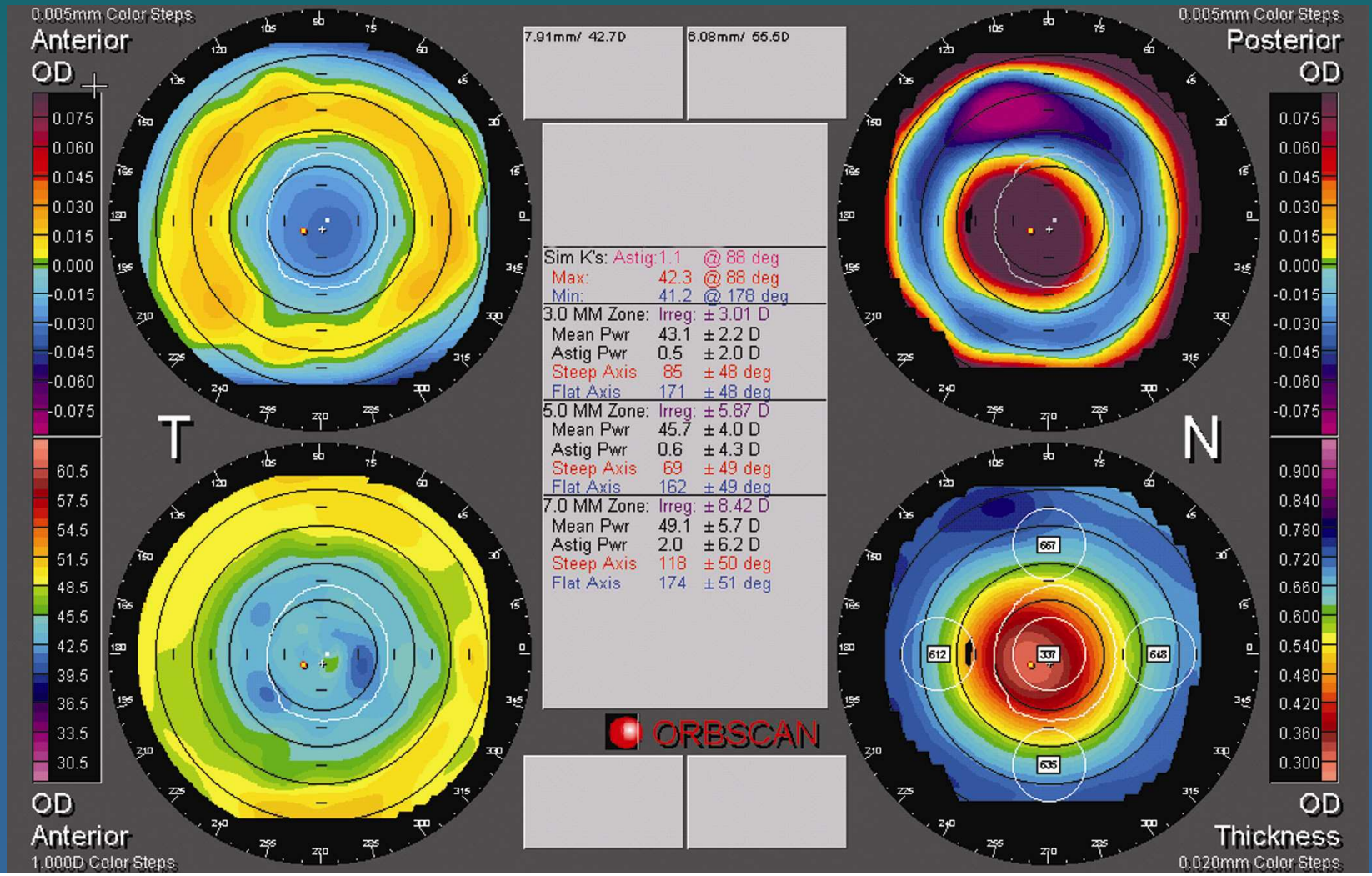
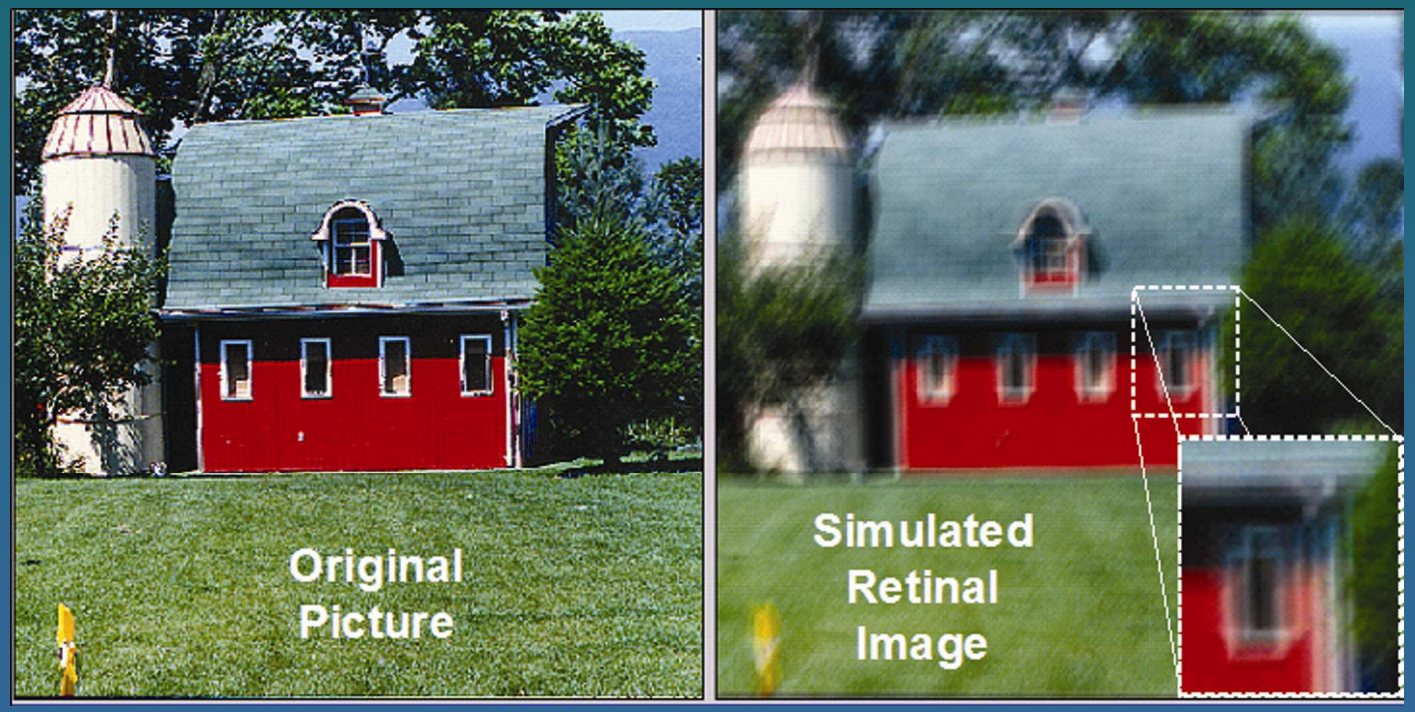
Posterior ectasia s/p LASIK
Don’t enhance it!



Posterior corneal surface changes effect on visual quality



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Current and future topo technolologies

- Placido disk (e.g., Humphrey);
- Scanning slit (e.g., Orbscan);
- 3-D topo (e.g., AstraMax);
- Scheimpflug imaging (e.g., Pentacam);
- Ultrasound (e.g., Artemis);
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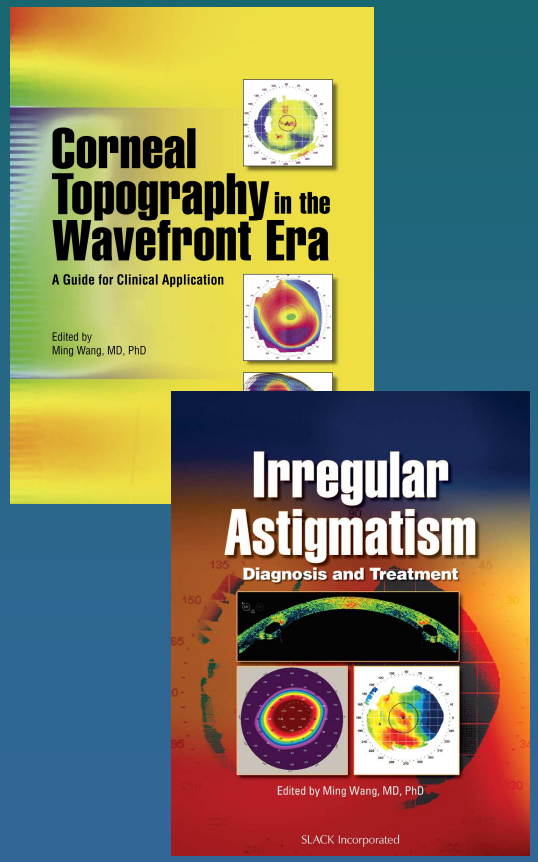

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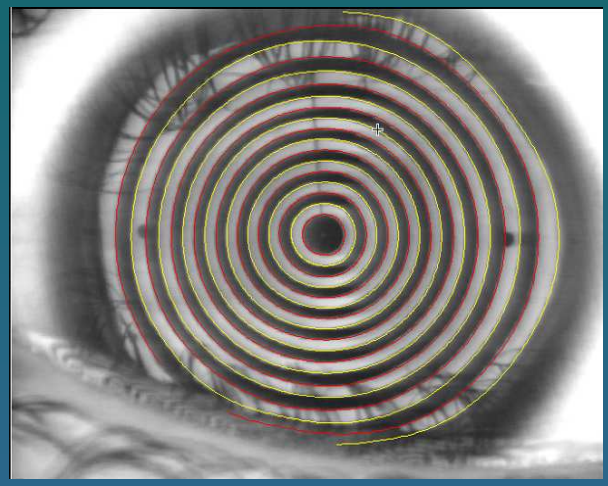
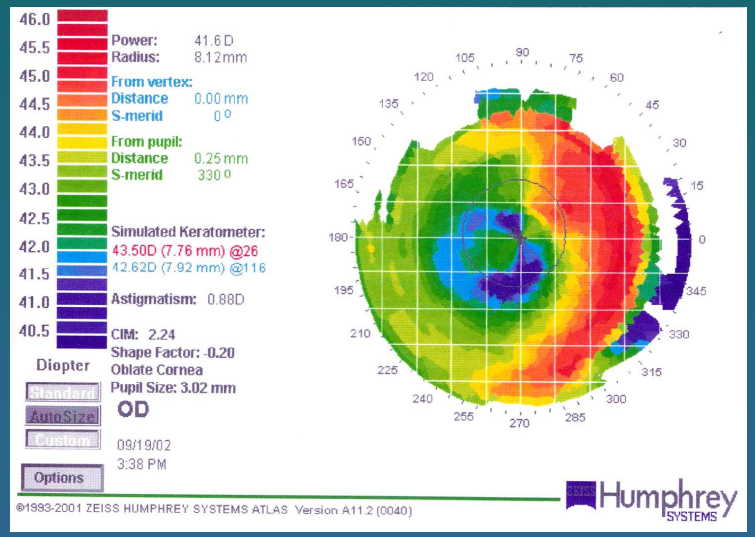
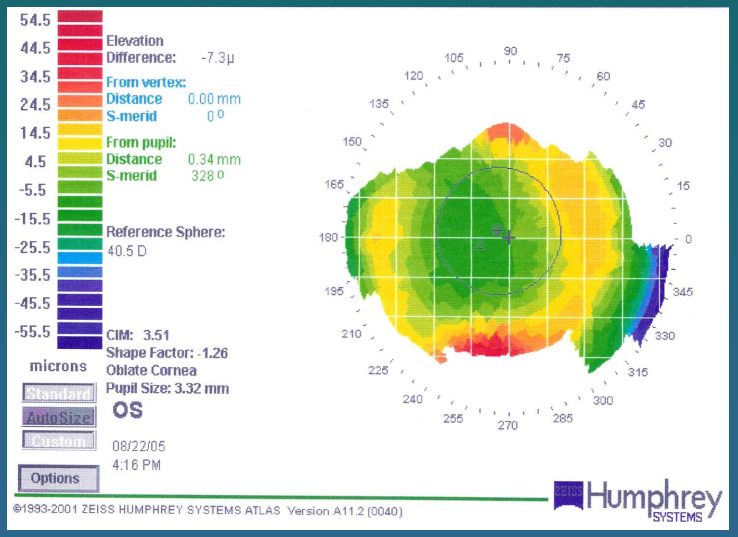
Placido

1. Reliable, long track record, less expensive;
2. Primary data = curvature (accurate);
3. Derived data = elevation (less accurate);
4. No posterior and pachy data;
5. Humphrey Atlas, Tomey, Topcon, Magellan, Keratron, Orbscan, AstraMax.



Placido:
axial vs. elevation maps





Curvature (D) map (*primary* data, accurate)

Elevation (um) map (*Derived* from curvature, not as accurate)

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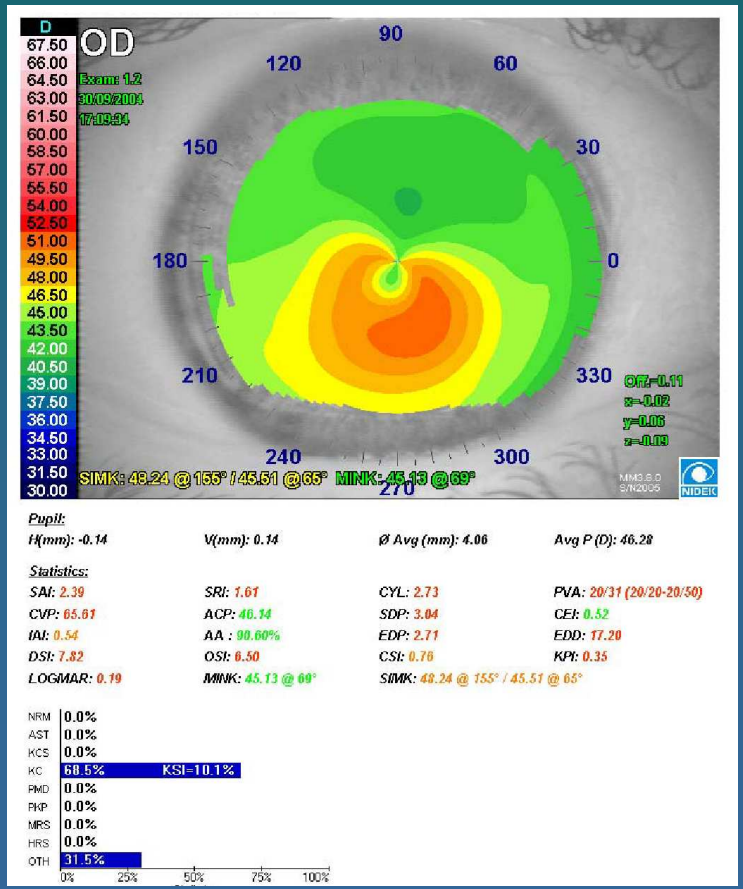
Placido: Magellen Eye Mapper



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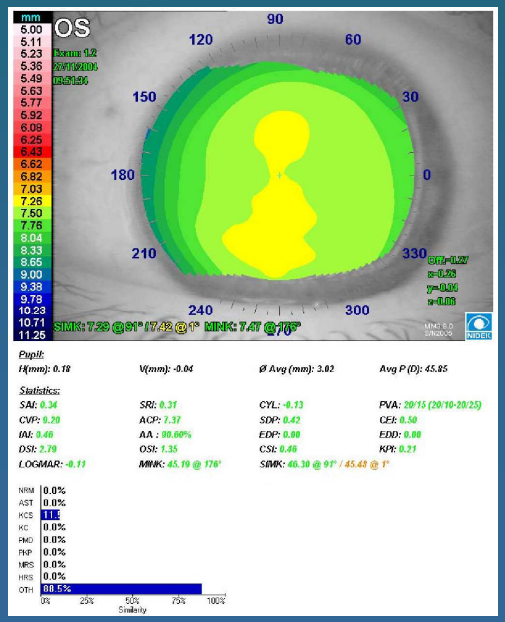
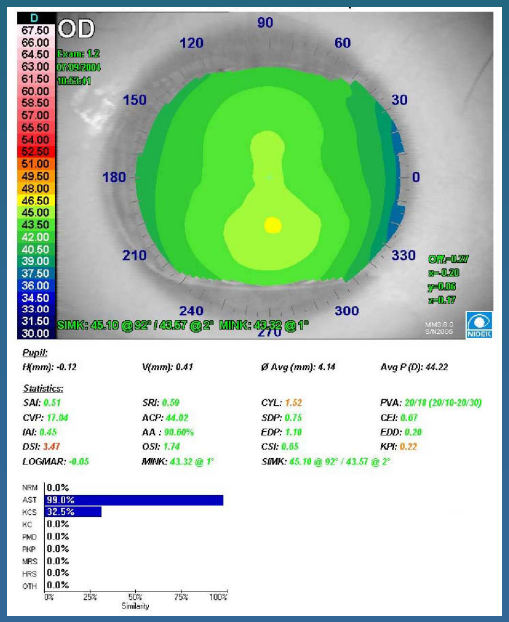
Placido: Magellan

- Neural network for KC detection;
- 30-ring, dual-edge (60 rings of data): 21,600 data points, high resolution.





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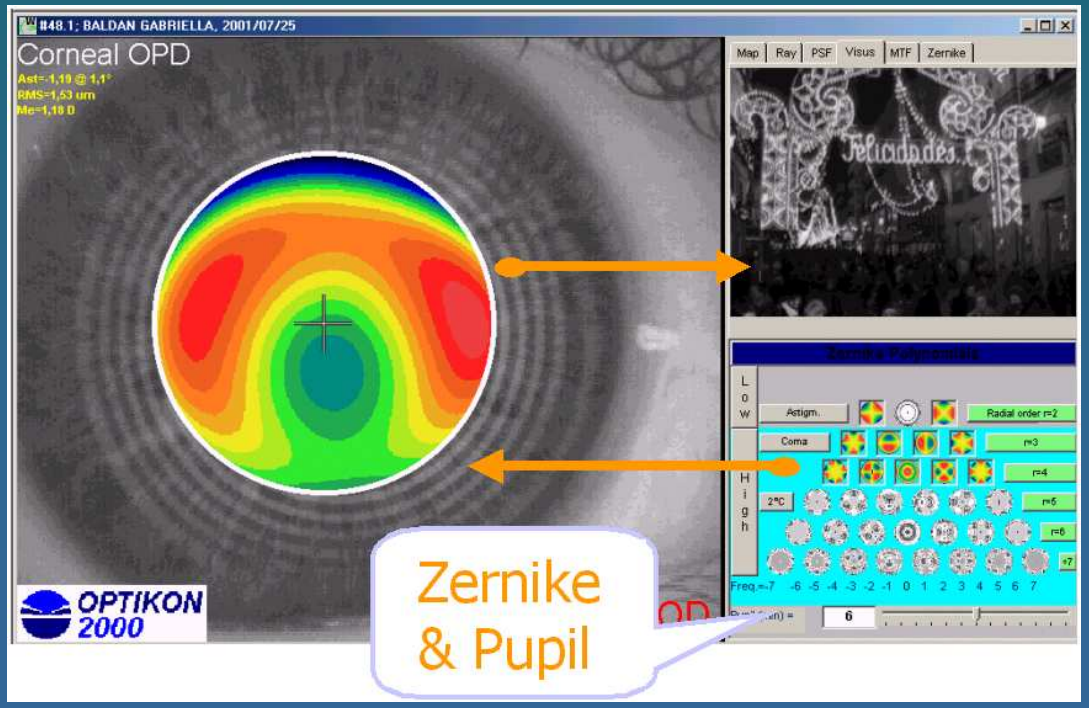
Placido: Opticon Keratron

- Keratron and Keratron Scout (portable);
- Non-spherically biased.



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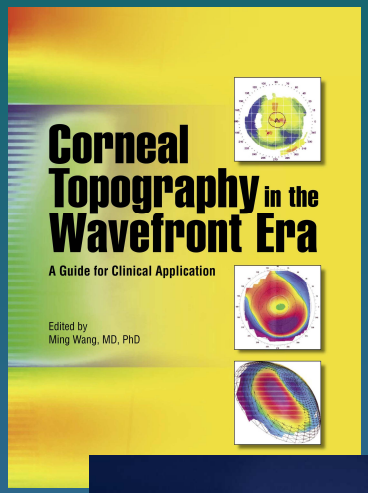
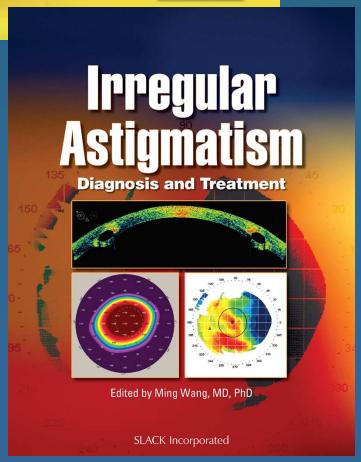
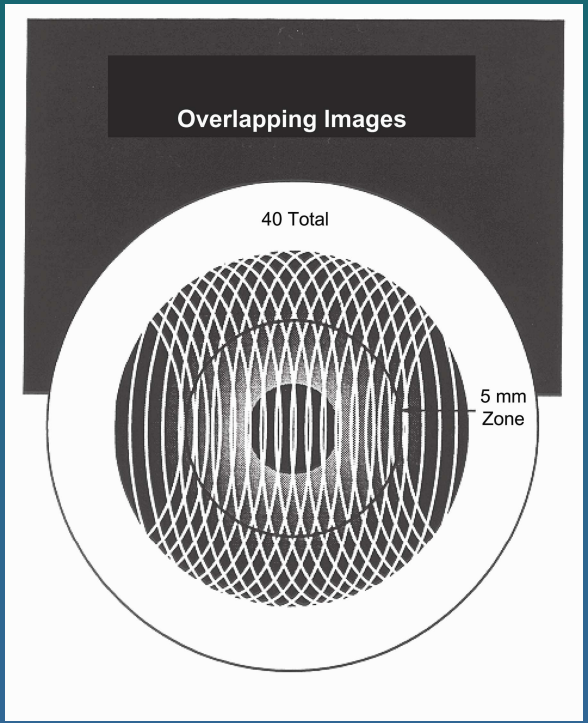


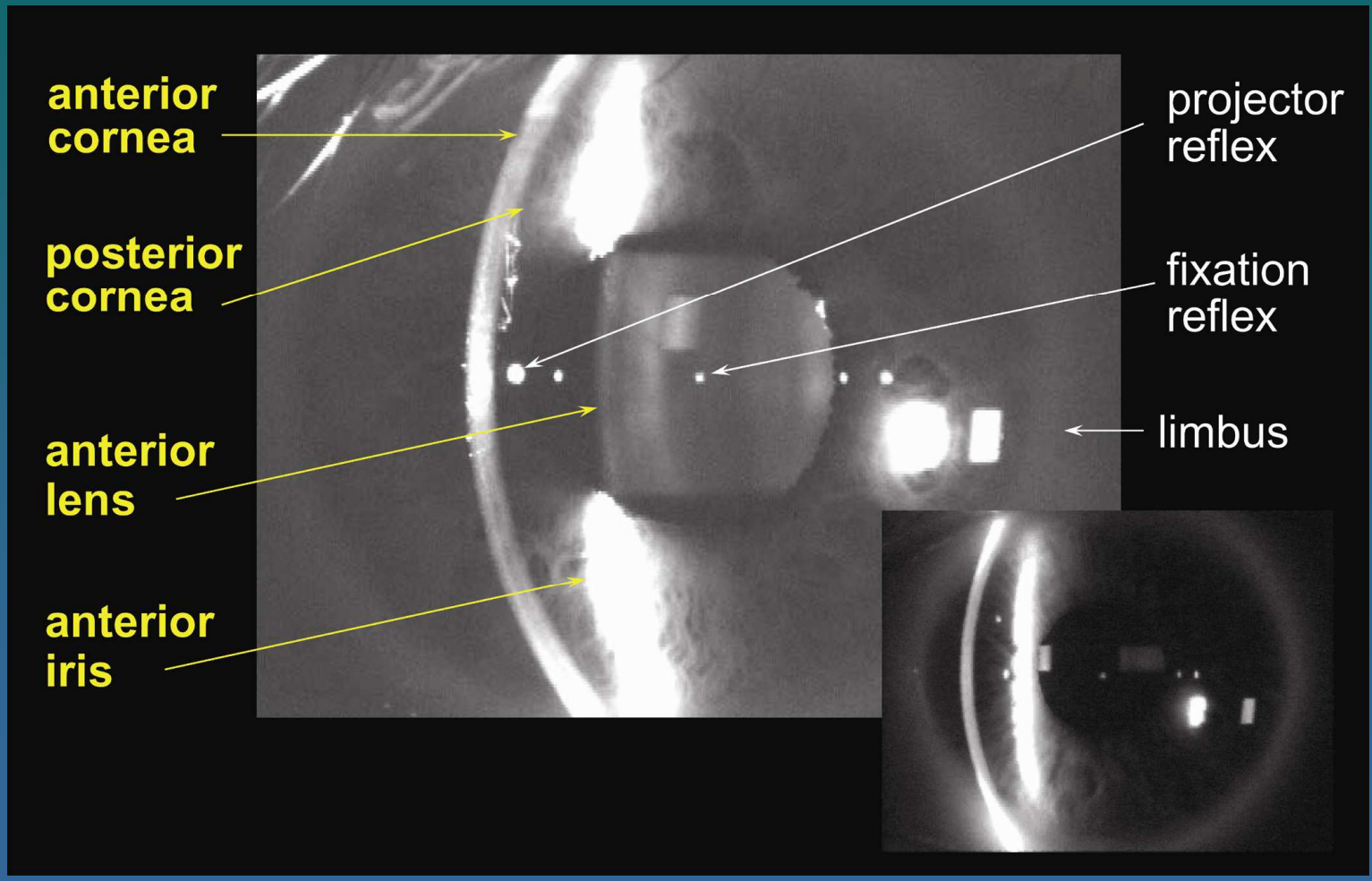


Scanning slit: Orbscan IIz

- 20 slits from each side;
- Primary data: height/elevation of anterior corneal surface, posterior corneal surface, and pachymetry;
- Derived data: curvature (D);
- A placido is added, in Orbscan IIz, for primary curavature data.



Scanning slit: Orbscan



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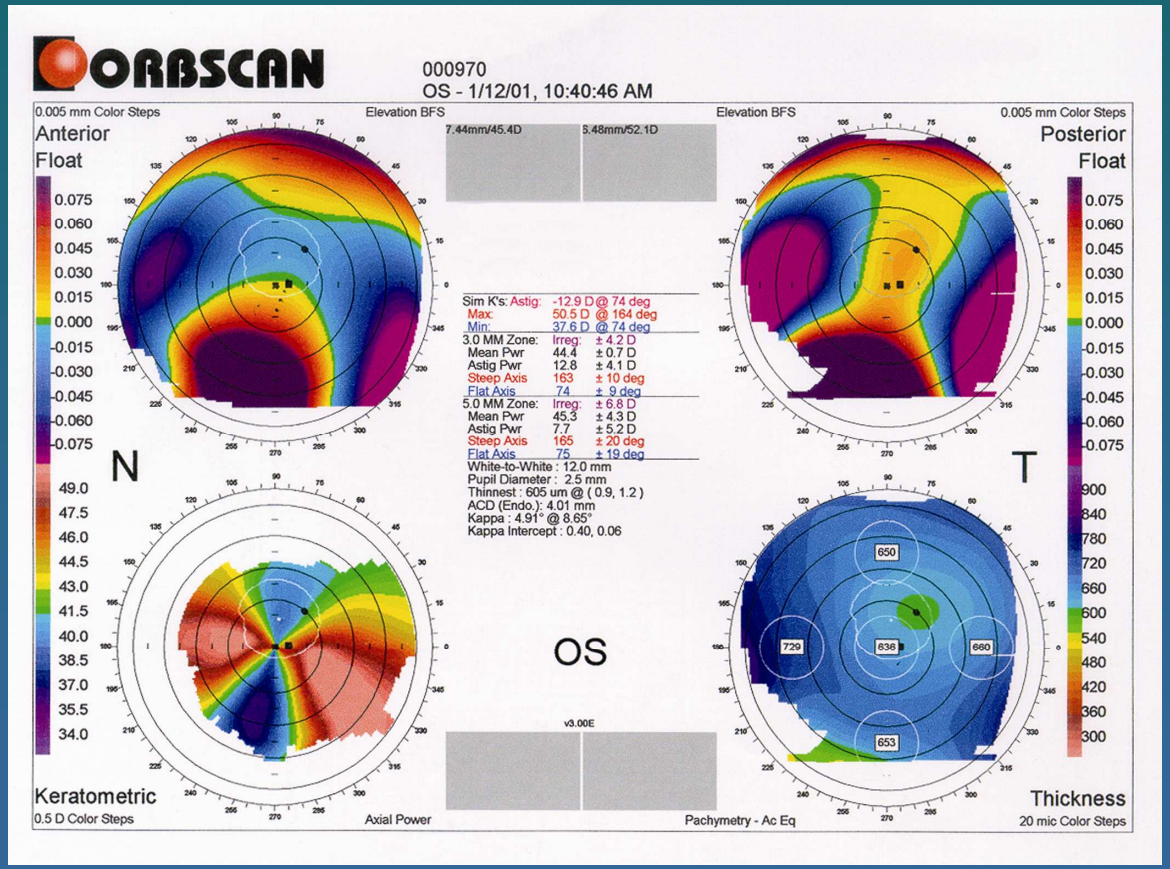
Scanning slit: Orbscan IIz quad map

Elevation



Posterior

Curvature (D)

Placido added!

Pachy

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Primary vs derived data

- Elevation to curvature: first derivative (loss of initial absolute height/position infor);
- Curvature to elevation: integration (generating an arbitrary constant (height))

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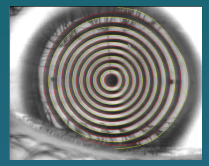
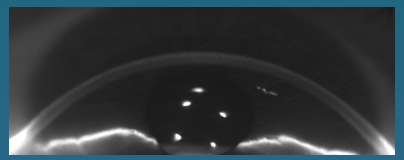
Primary vs. derived data

- **Primary data:** ***directly*** **measured by the device, more accurate, e.g.:**



  - **Curvature data in placido disc systems (Humphrey);**
  - **Elevation data in scanning slit systems (Pentacam);**



- **Secondary data:** ***derived*** **from primary data, less accurate, e.g., the reverse of the above, e.g.:**
  - **Elevational data from Humphrey;**
  - **Curvature (D) data scanning slit system such as Pentacam.**

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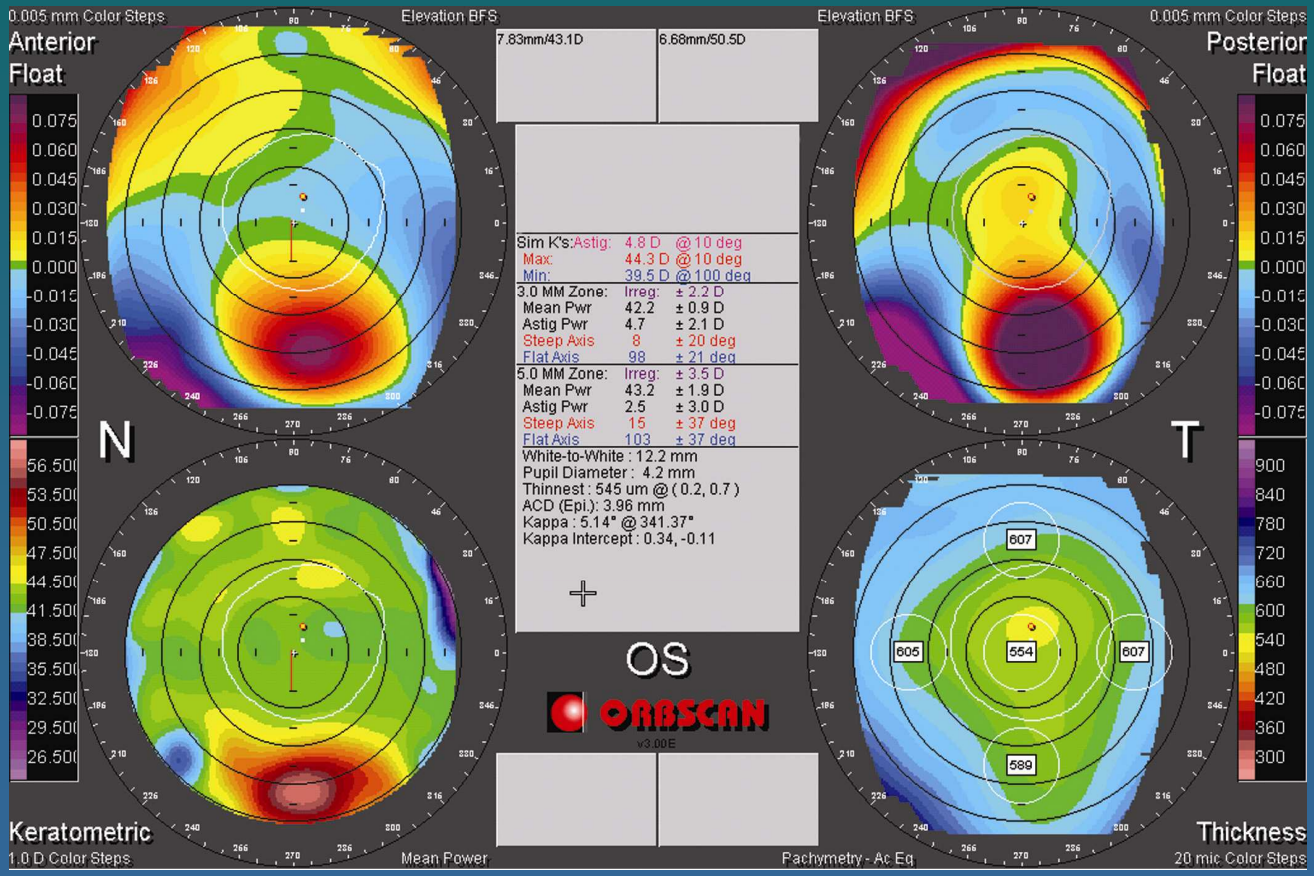
Keratoconus



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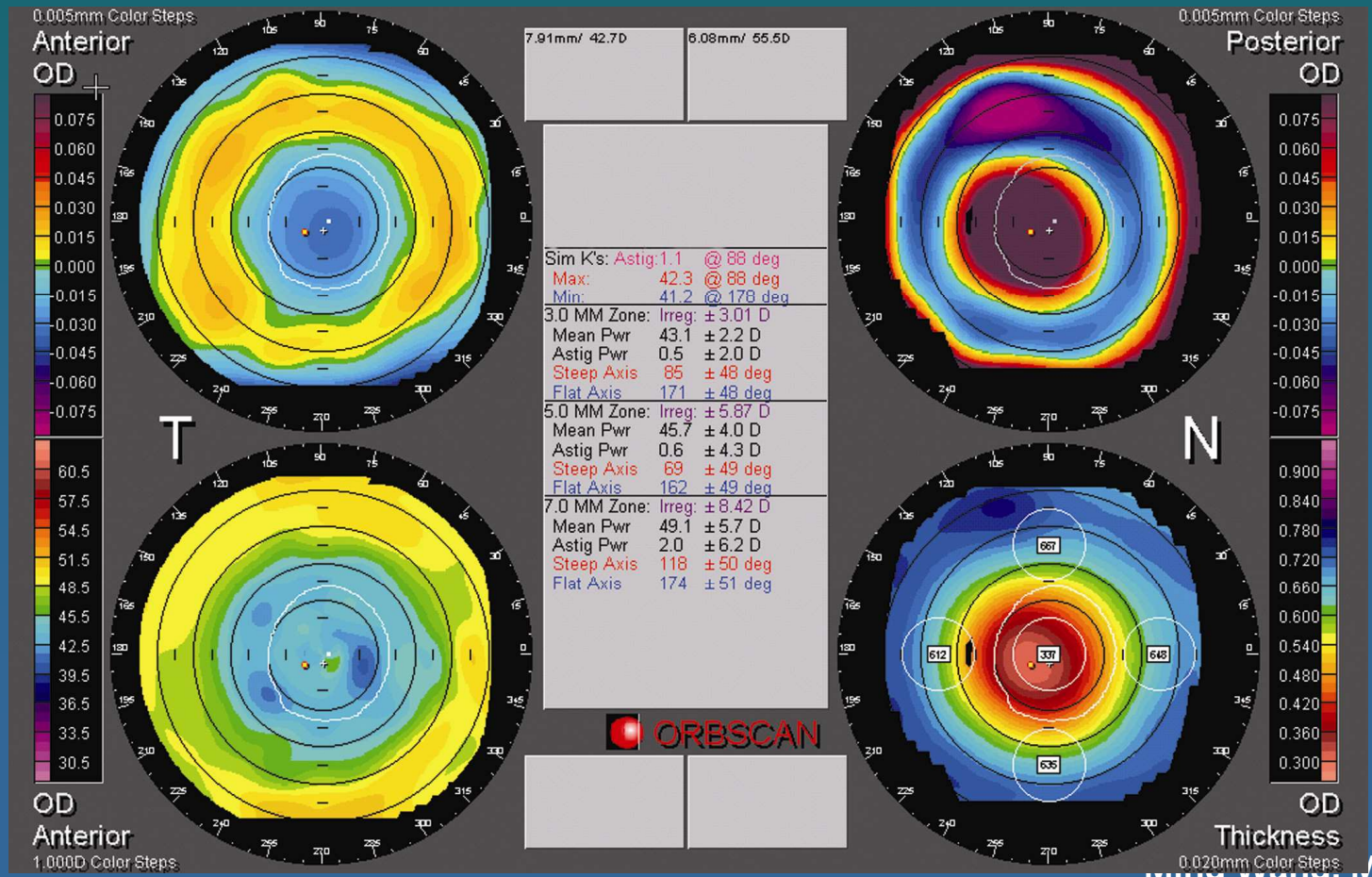
Posterior ectasia S/P LASIK (do NOT enhance (removal of more tissue!))



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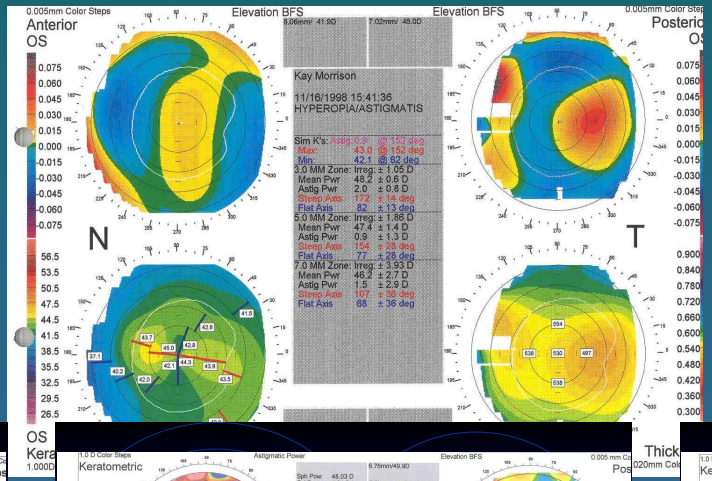
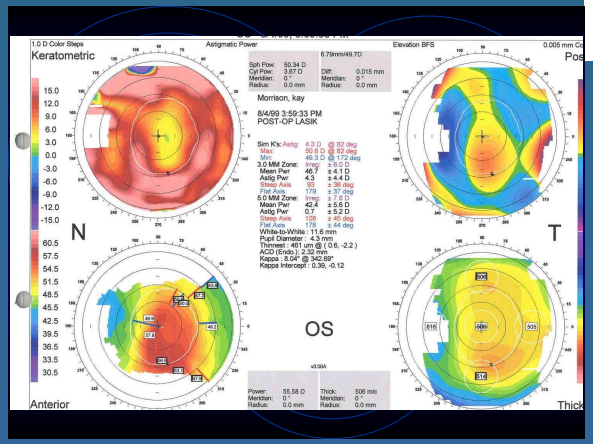
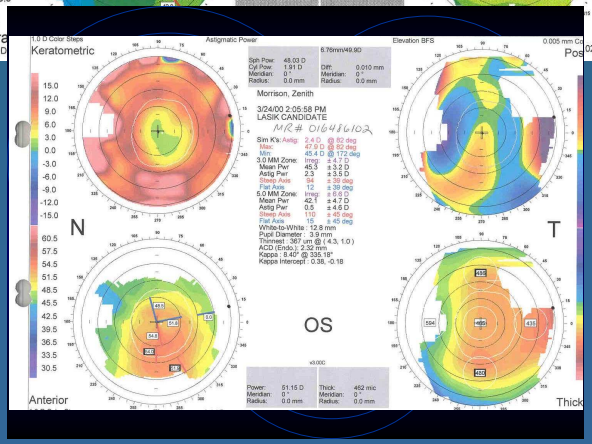
Examination of posterior cornea helps identify the cause of resistance to enhancment: a case of s/p H-L, resistant to enh, why? Preop existing posterior decentered apex!!!

Preop

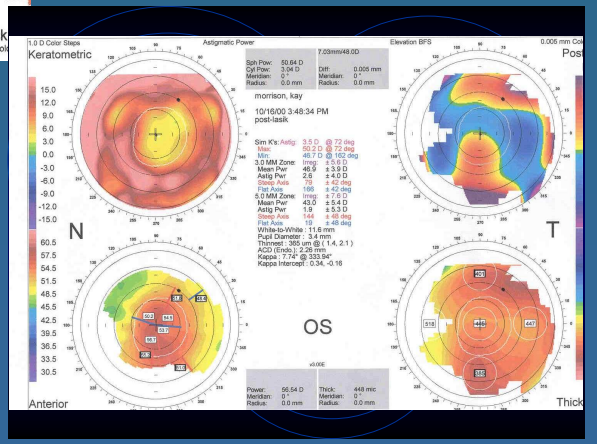




After +4 D H-L

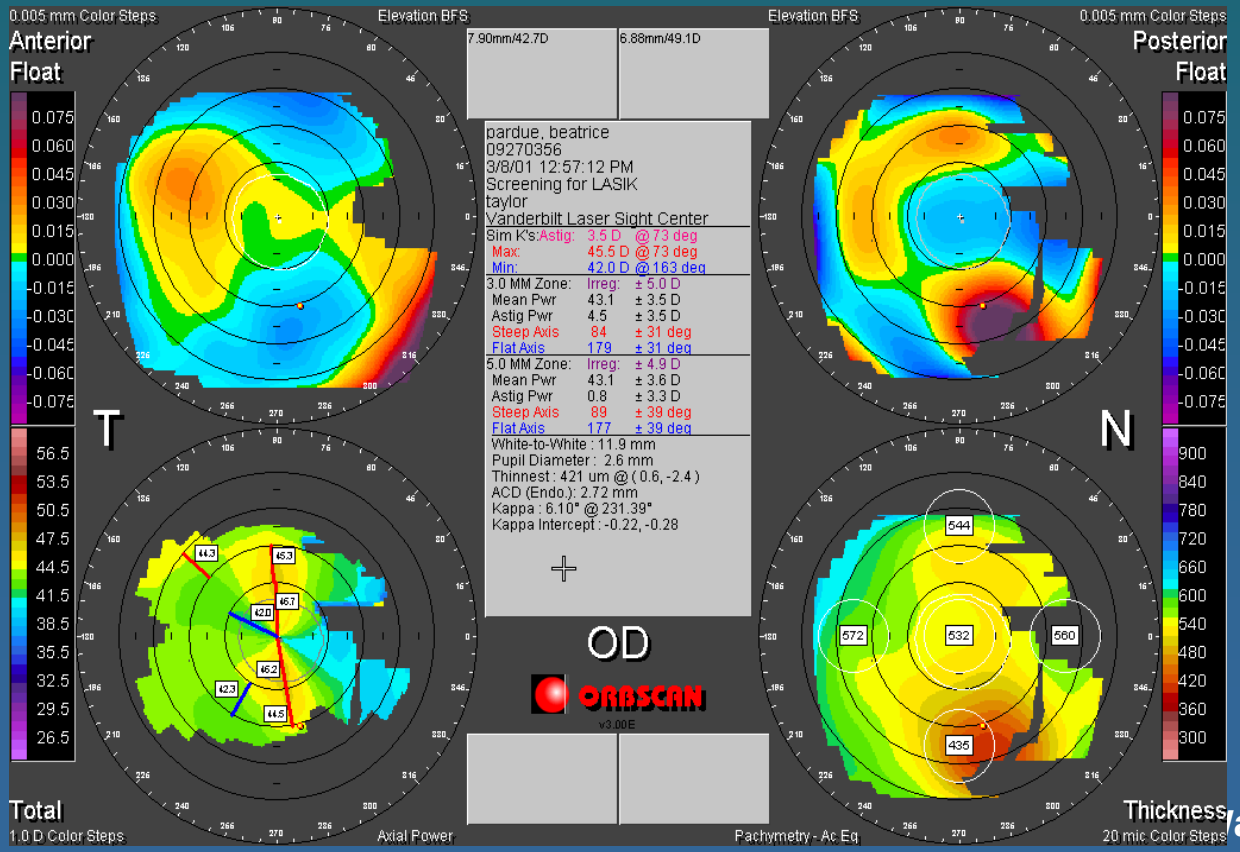


Regressed to +3, after enh



Again reg to +2, after enh

Examination of posterior cornea reveals earliest sign of ectasia: A case of posterior KC (“ominous purple”), with normal anterior. Don’t touch it!



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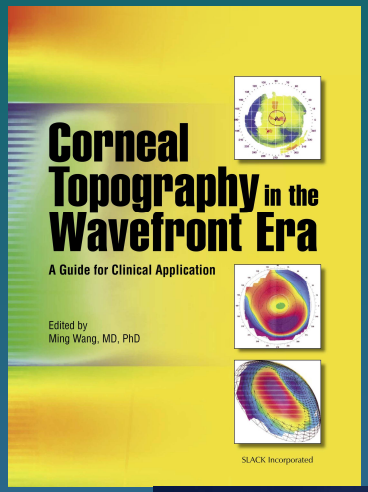

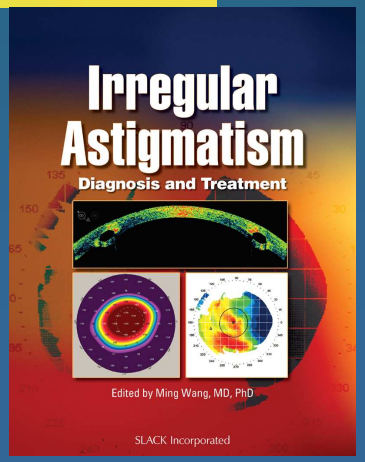

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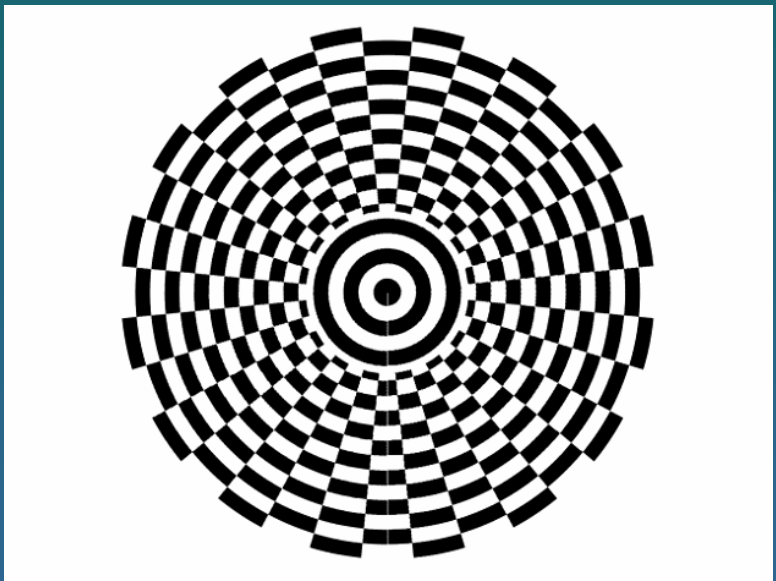
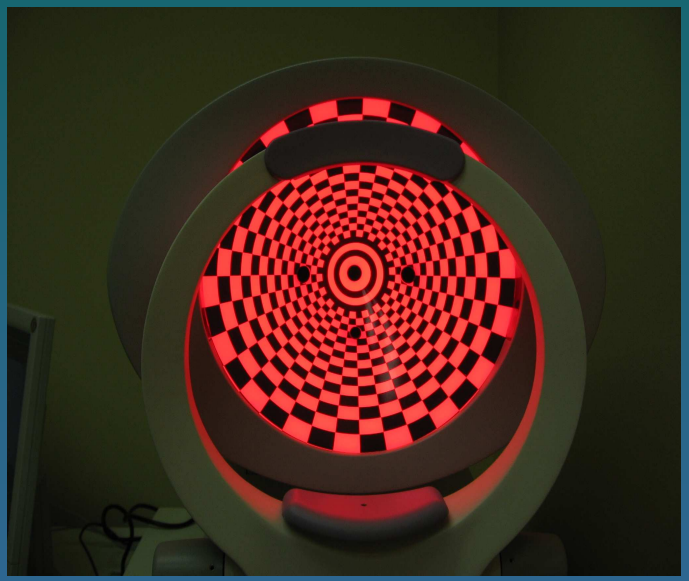
AstraMax (placido + slit)

- 3-camera stereo imaging;
- 2-D checker board placido;
- Rotating scanning slit (but only 4 slits, while Orsbcan has 40);
- Primary data: Both curvature (D) and elevation

2-D checker board placido





<u>Polar coordinate (checker board):</u> angle + radius;
<u>Standard placido:</u> has only half of the polar coordinate's data (just radius data).

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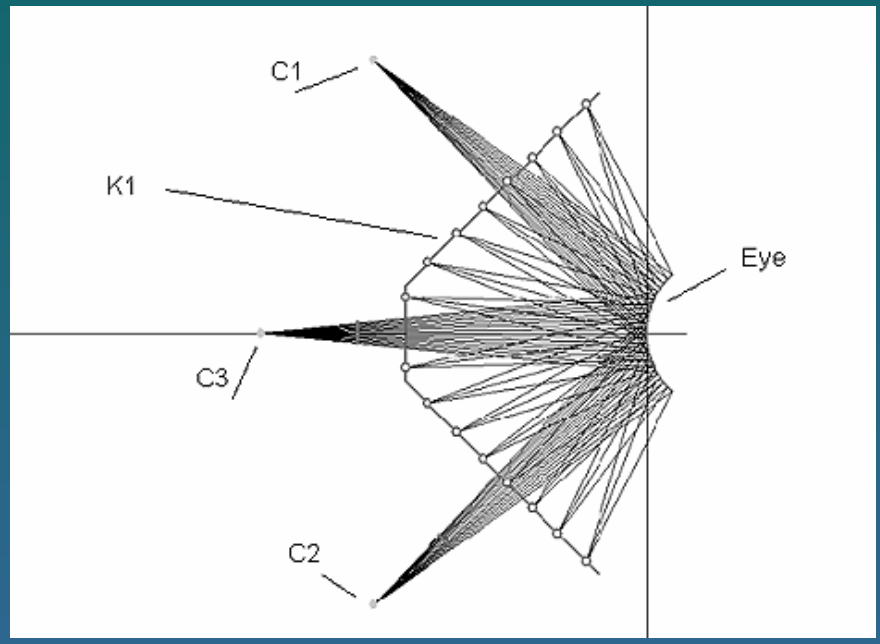
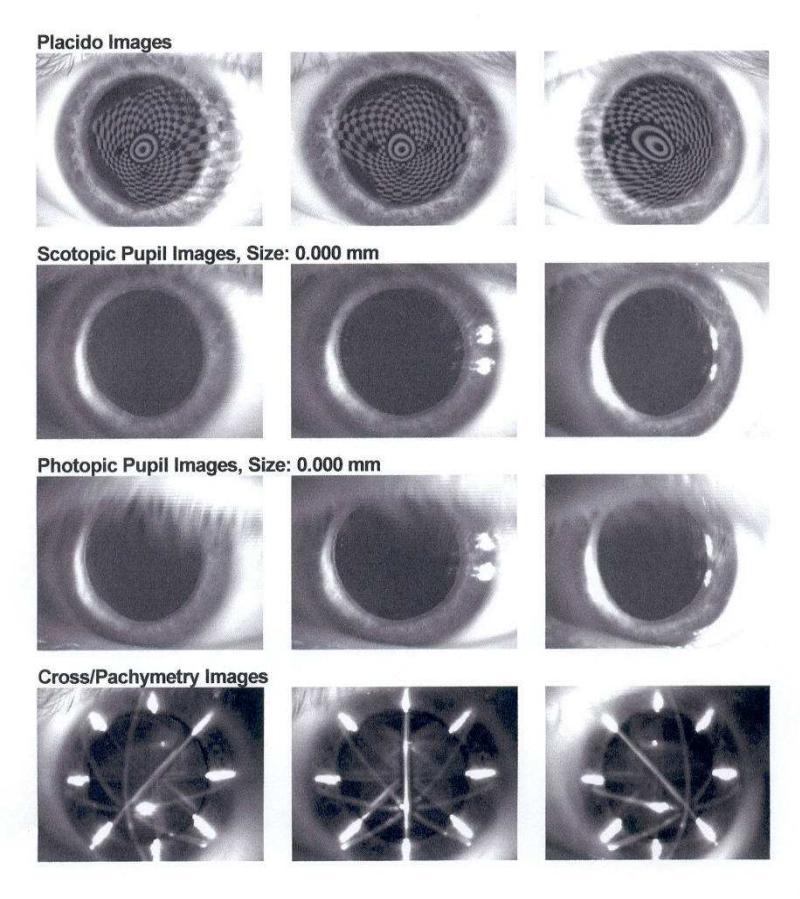
3-D topo: 3 camera stereo imaging



1. Lesser prone to artifactual reading such as from scar or dry eye surface;
2. More data from direct measurements (lesser dependence on intrapolation) and more data degeneracy: enhanced sensitivity of detection

3-D topo: rotating slit (AstraMax)



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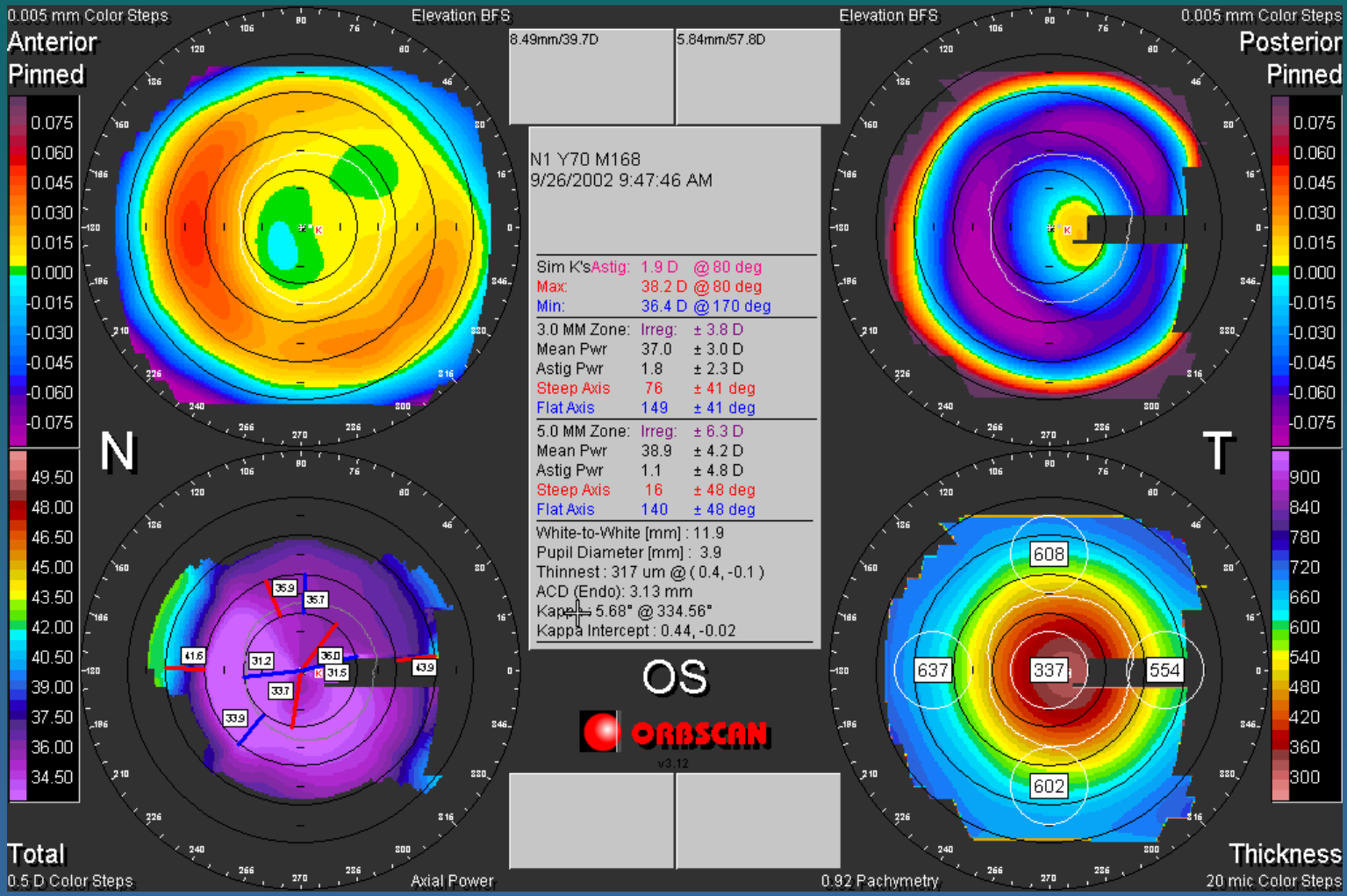
1-D vs 3-D: post myopic LASIK diplopia (1-D)



Featureless flat cornea

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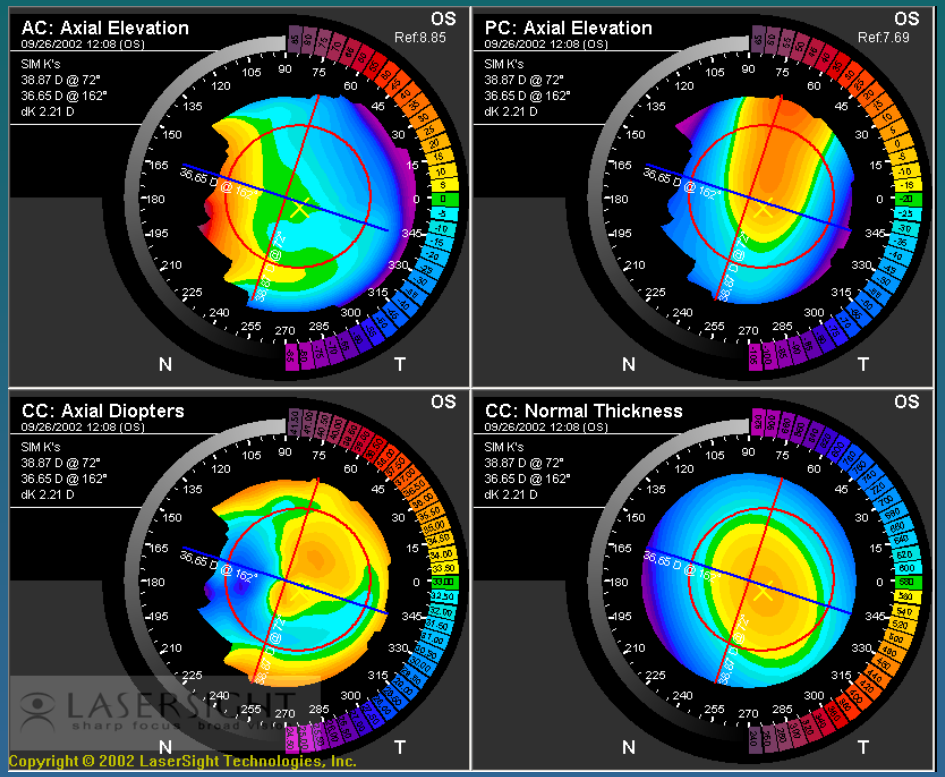
1-D vs 3-D: same cornea, post myopic LASIK diplopia (3-D)



1. 3-D stereo: central irregularity;
2. 3-D stereo and 2-D checker board has enhanced **sensitivity** of detection.

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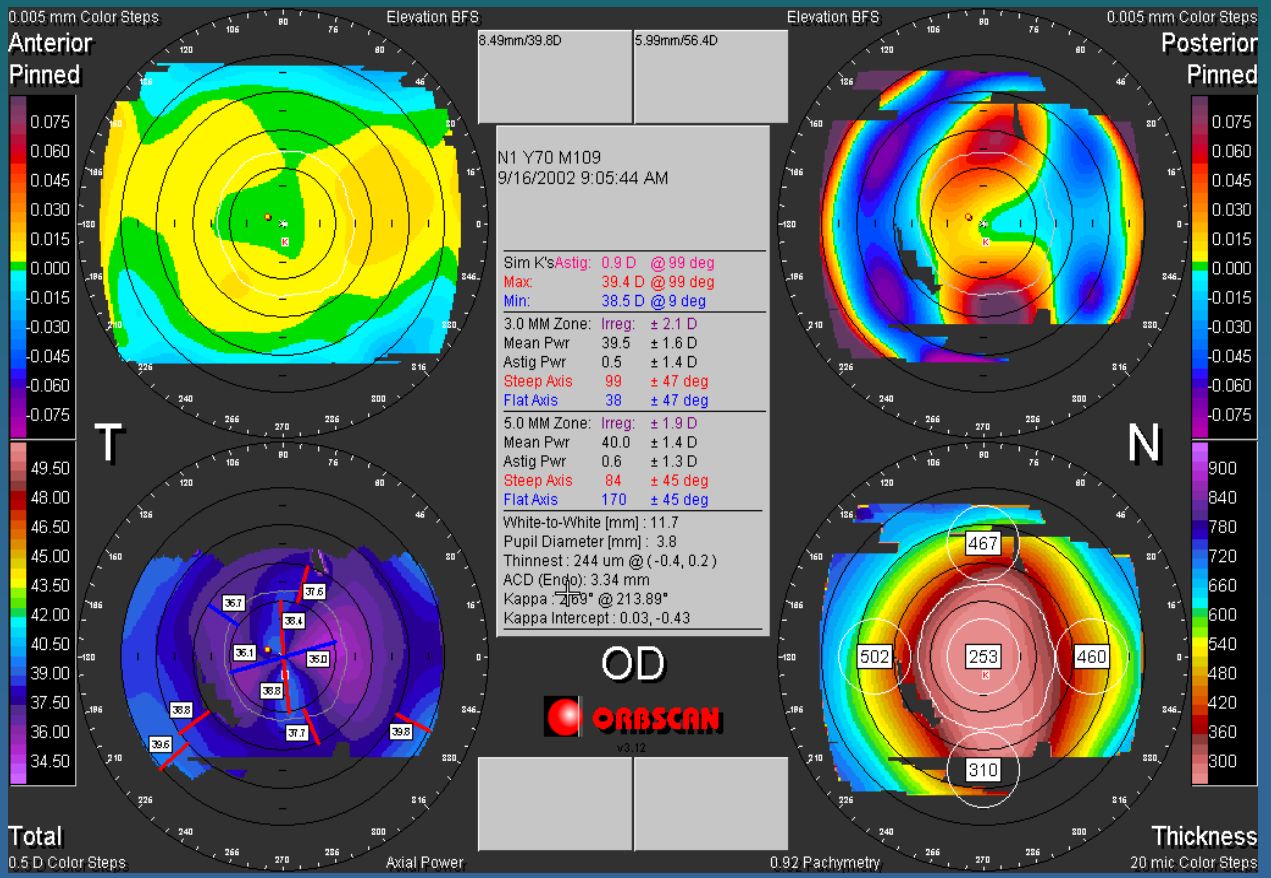
1-D vs 3-D: post high myopic LASIK, artifactual pachy reading of 253um (1-D)??



Ultrasound = 480 um.

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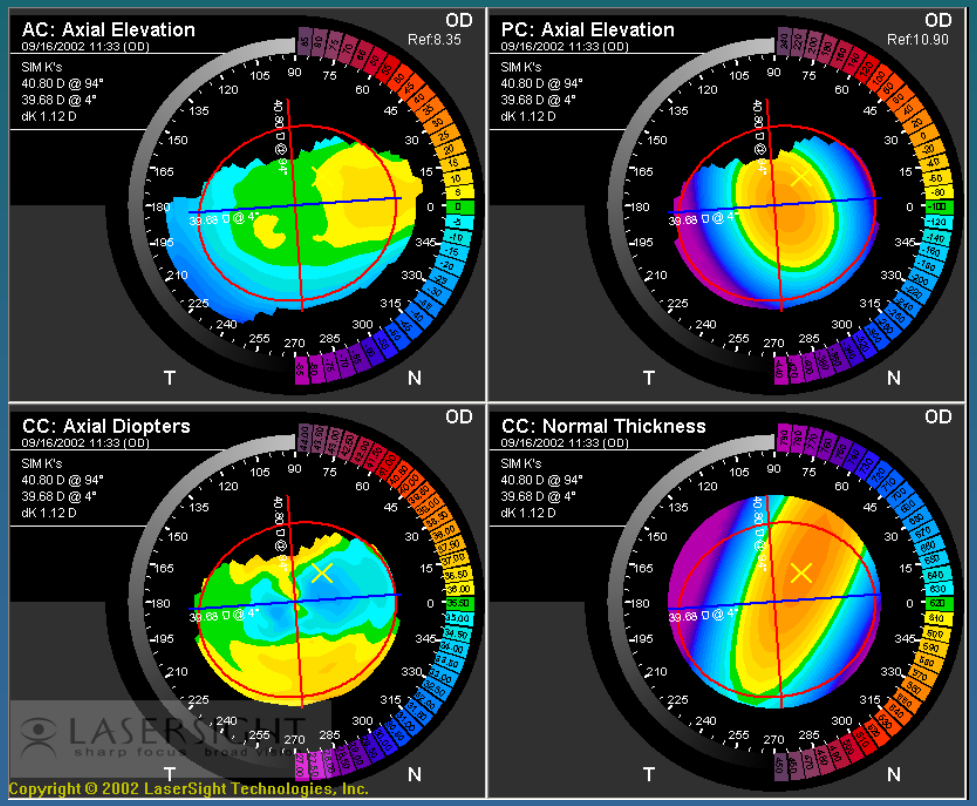
1-D vs 3-D: same cornea, s/p high myopic LASIK, reduced breakdown in extreme Ks or hazy cornea (3-D)



3-D: showing normal topo pachy;
3-D topo (with more data points) does not break down in extreme Ks or hazy cornea.

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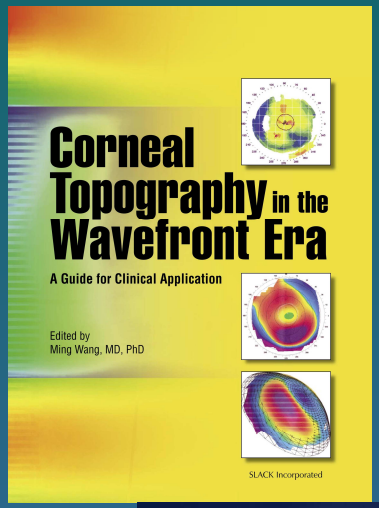

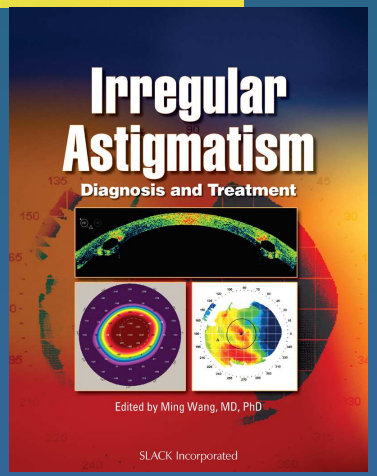

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Theodor Scheimpflug, 1888

1. Austrian, invented a photographic apparatus in 1904, for military for accurate imaging over a wide focal range (e.g., architectural documentation of sekyscaprer facades);
2. 1970, Prof Hockwin, Germany, a cataract researcher, adapted Scheimpflug for sagittal plane imaging of anterior segment of the eye.

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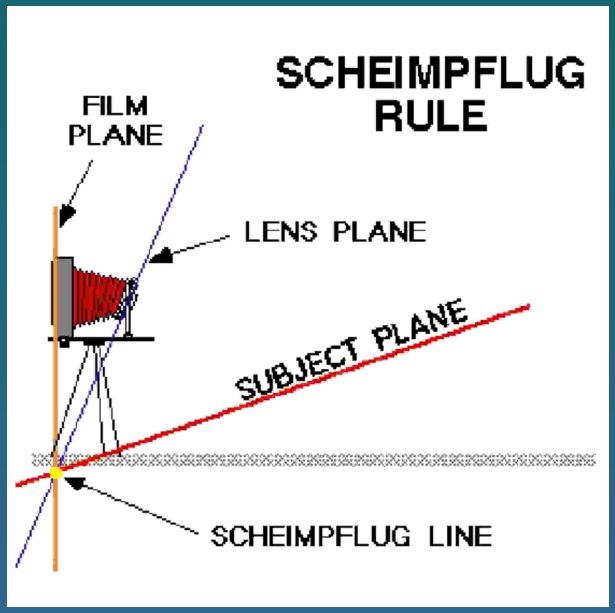
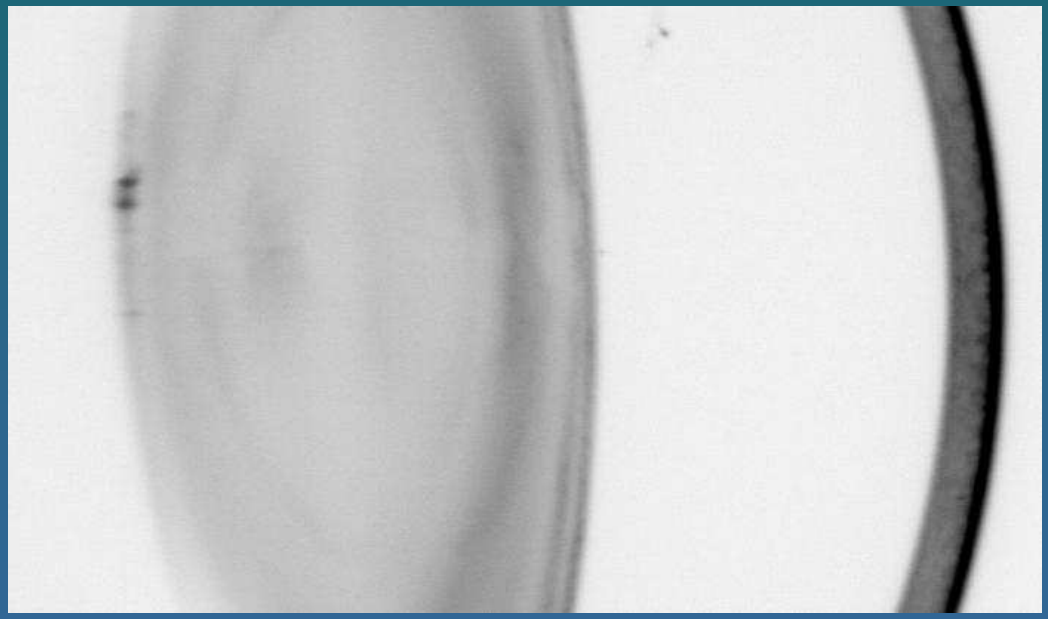
Scheimpflug Rule

- In conventional cameras, object (film) plane, lens plane and subject plane are parallel to each other;
- In Scheimpflug cameras, these planes are not parallel but intersect in a straight line. When film plane and subject plane intersect forming a 90-degree angle, halved by the lens plane, a 1:1 image to subject ratio is achieved;
- Advantage of Scheimpflug: images along the optical axis of the eye can be assessed*.
- * Harold Merklinger: Scheimpflug's patent. Photo Techniques, Nov/Dec, 1996.



Scheimpflug image



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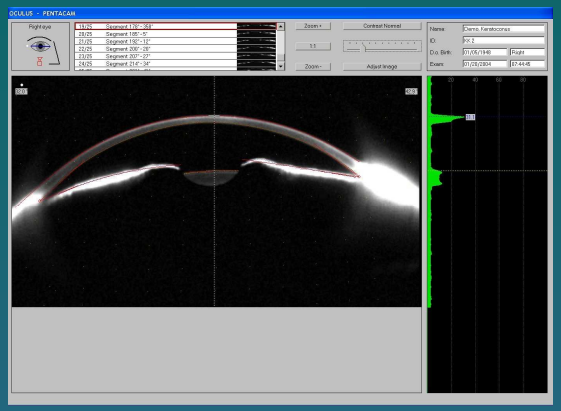
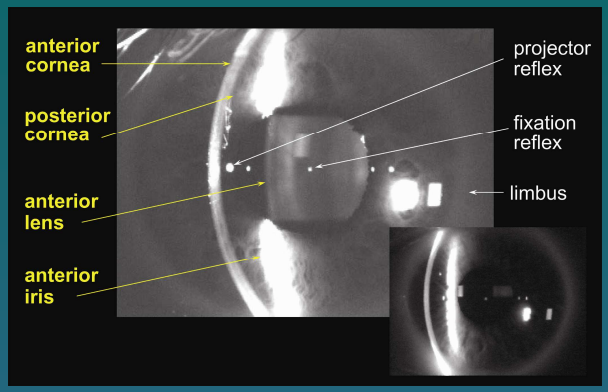
Scheimpflug vs Orbscan vs placido



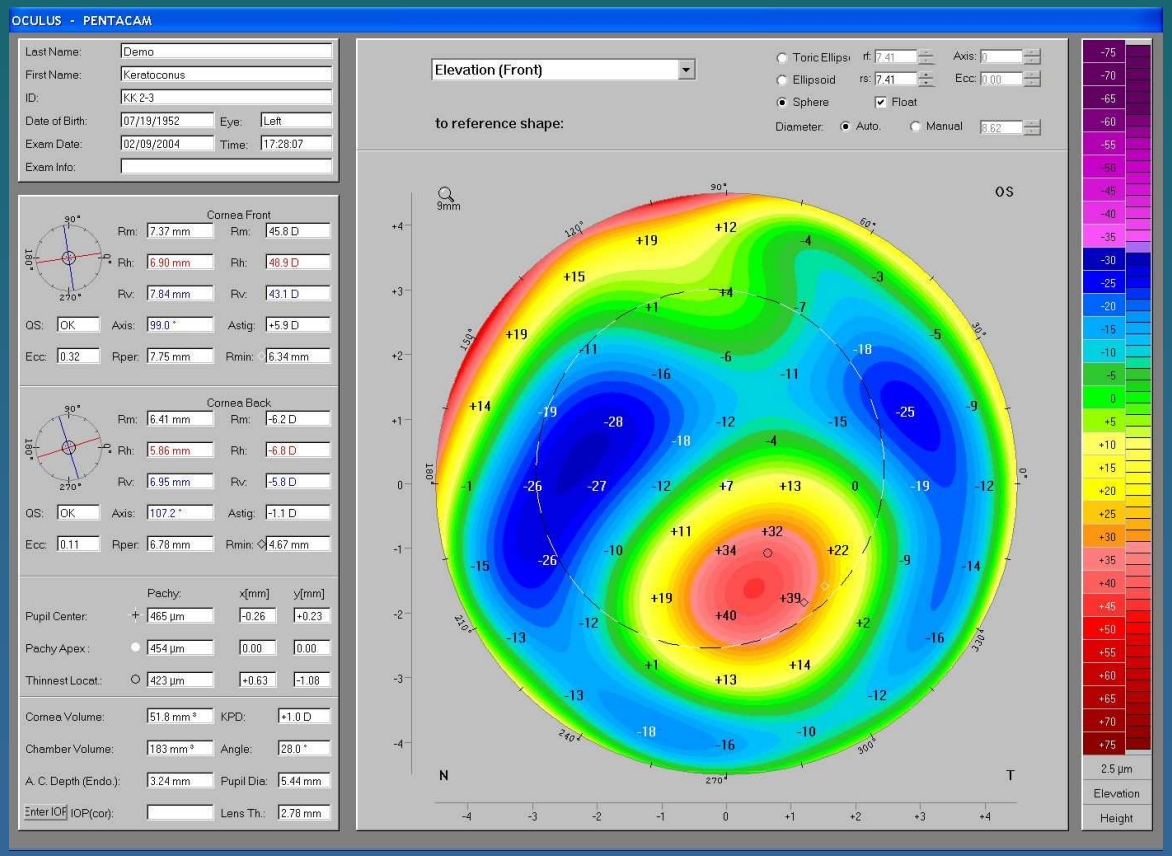


Advantage of Scheimpflug rotating slit over scanning slit:

1. Angle between image and camera is always 90 degree (maximal cross sectional area spread – high sensitivity);
2. Common reference point hinged in the middle (reliability, This is absent in scanning slit). It is particularly important for posterior surface (since it has less intense illumination than anterior surface to begin with (hence lower s/n ratio);

Disadvantage: curvature is derived data (less accurate). Orbscan compensated this by adding a placido (curvature)

Scheimpflug imaging: Pentacam elevation map



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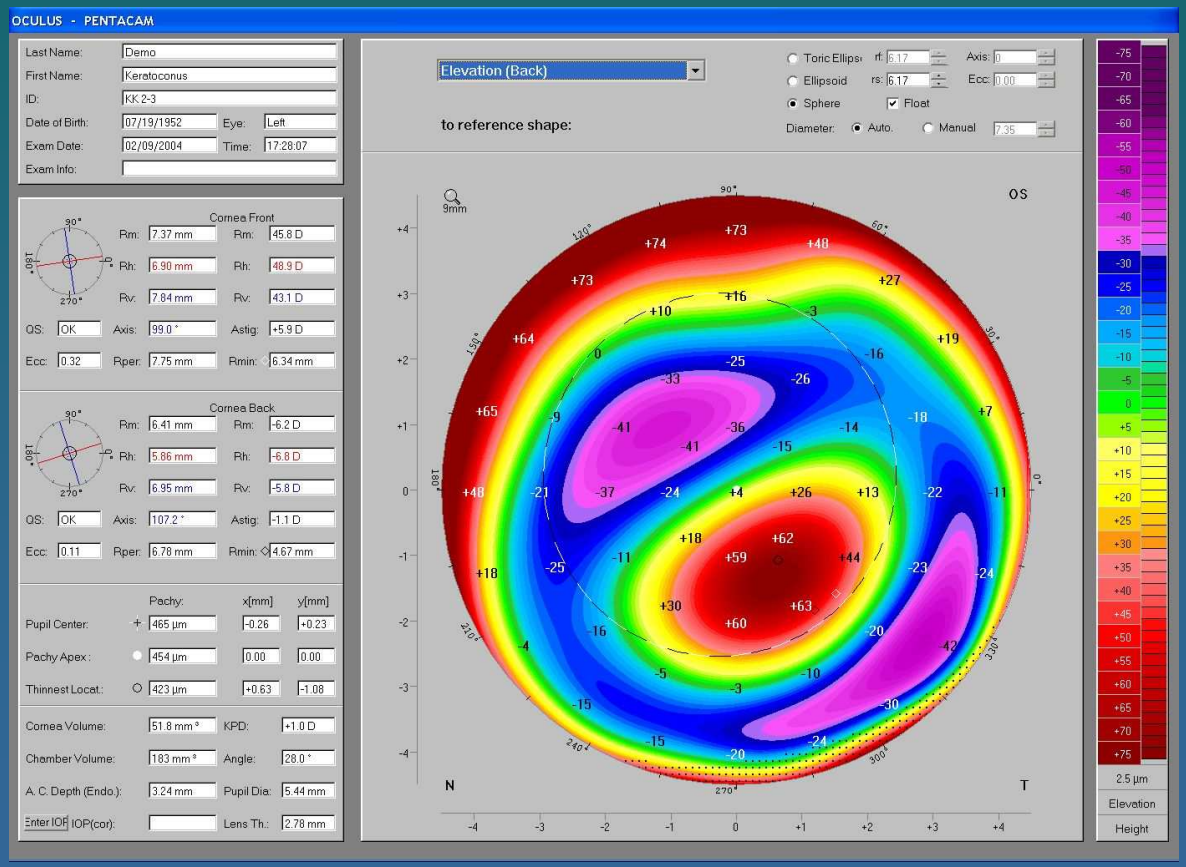
Scheimpflug imaging: Pentacam posterior elevation



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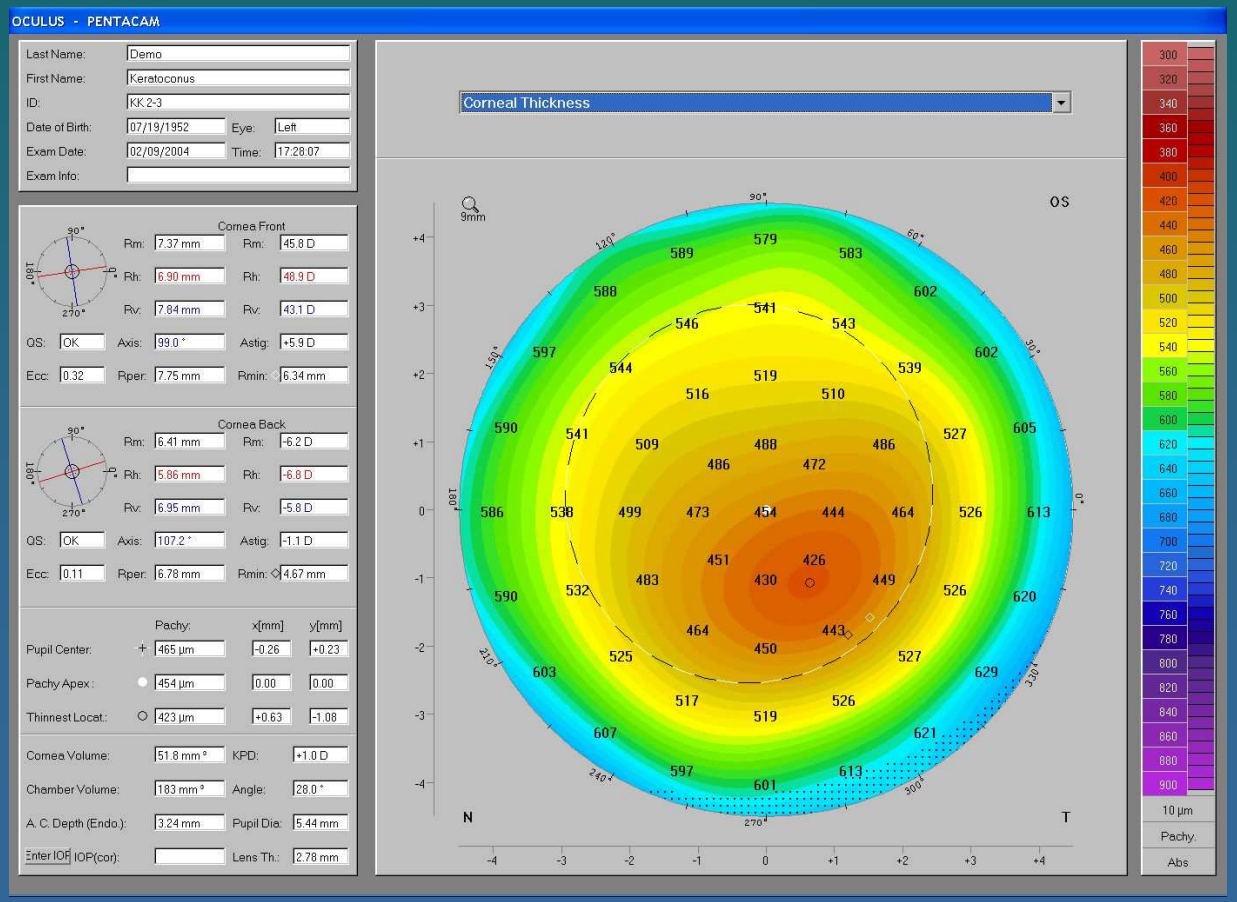
Scheimpflug imaging: Pentacam pachymetry



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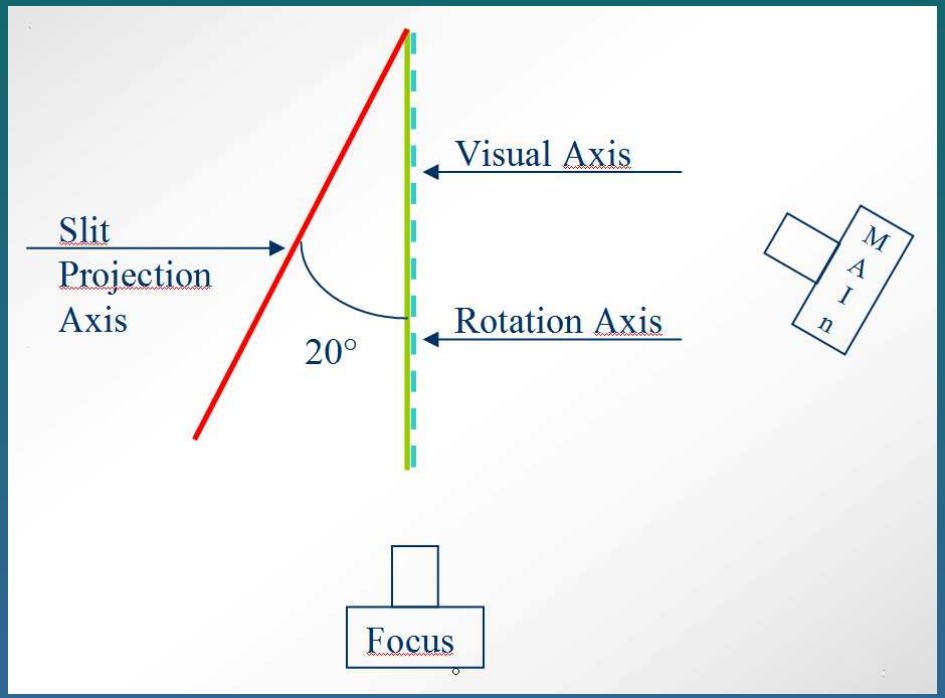
Improved Scheimpflug: Precisio



Precisio improved from previous Scheimpflug products in that Precisio uses off-axis (20 degree) projection through the center of the cornea to eliminate data loss caused by reflection off the center.

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Improved Scheimpflug: Precisio

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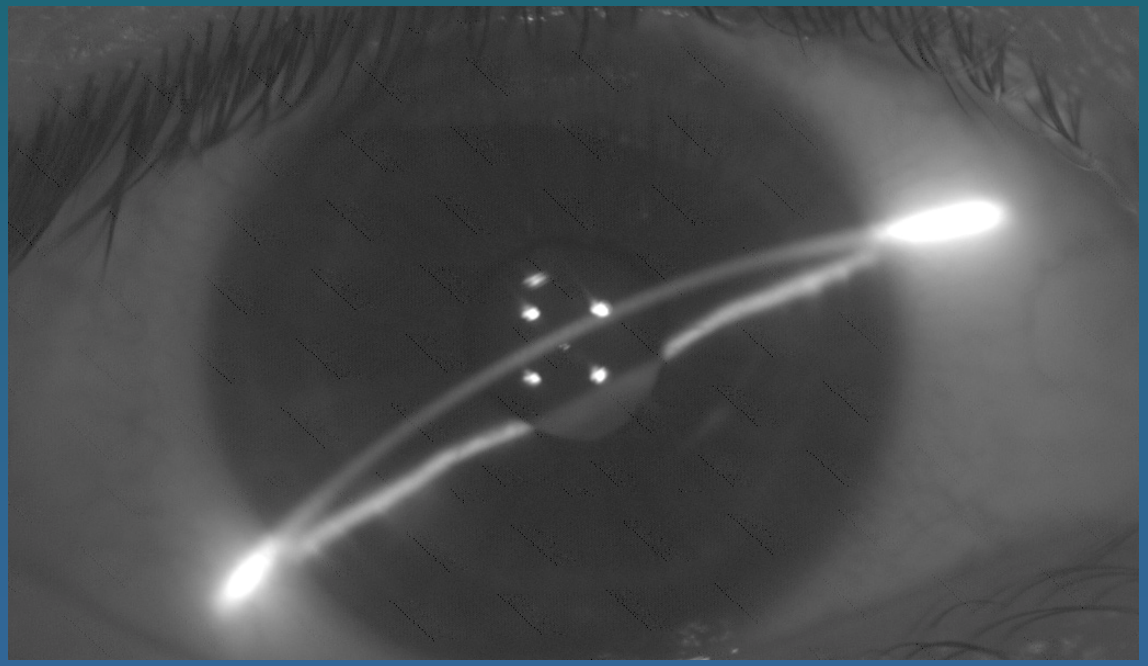
Improved Scheimpflug: Precisio limbal vessel position



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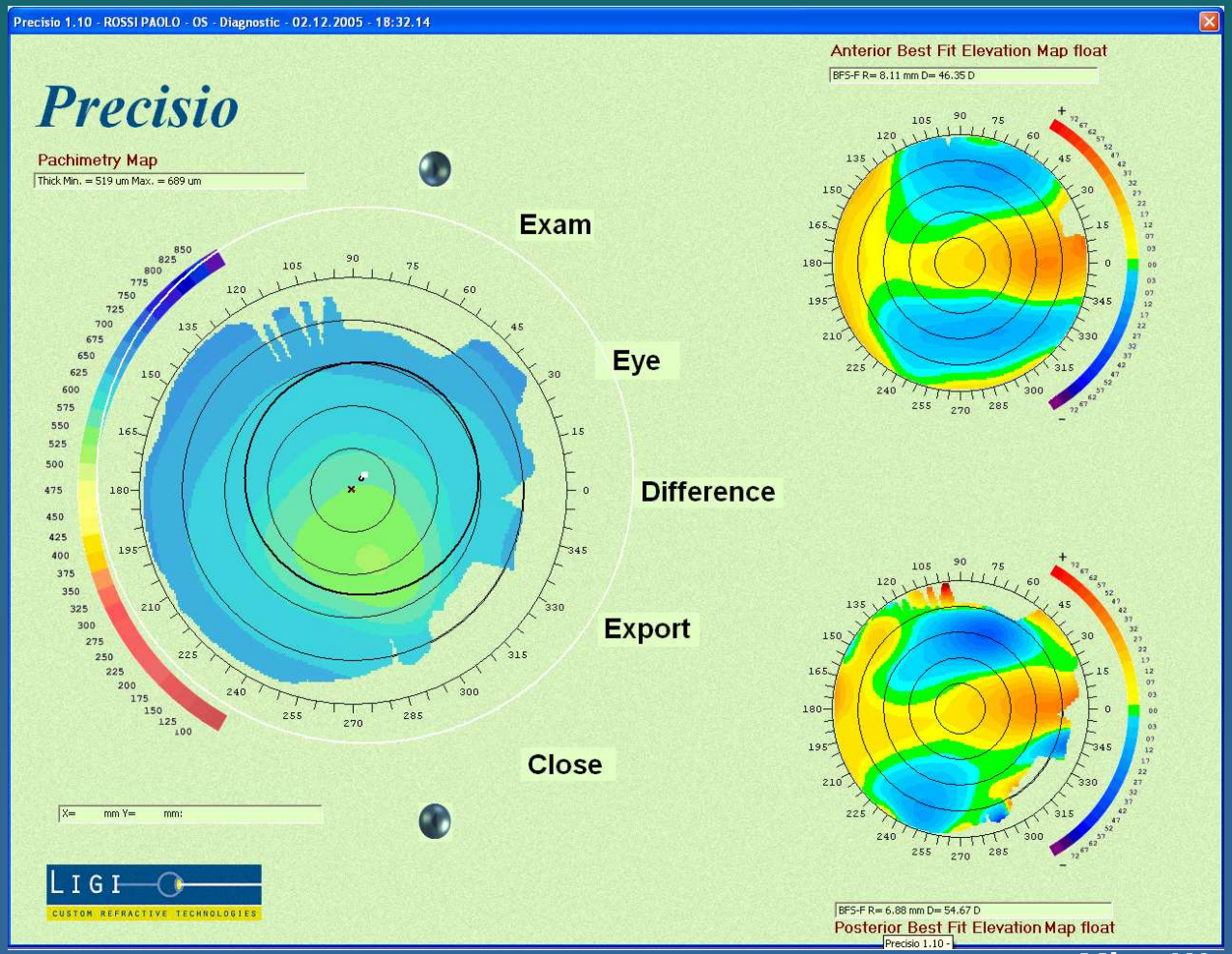
Improved Scheimpflug: Precisio pachymetry



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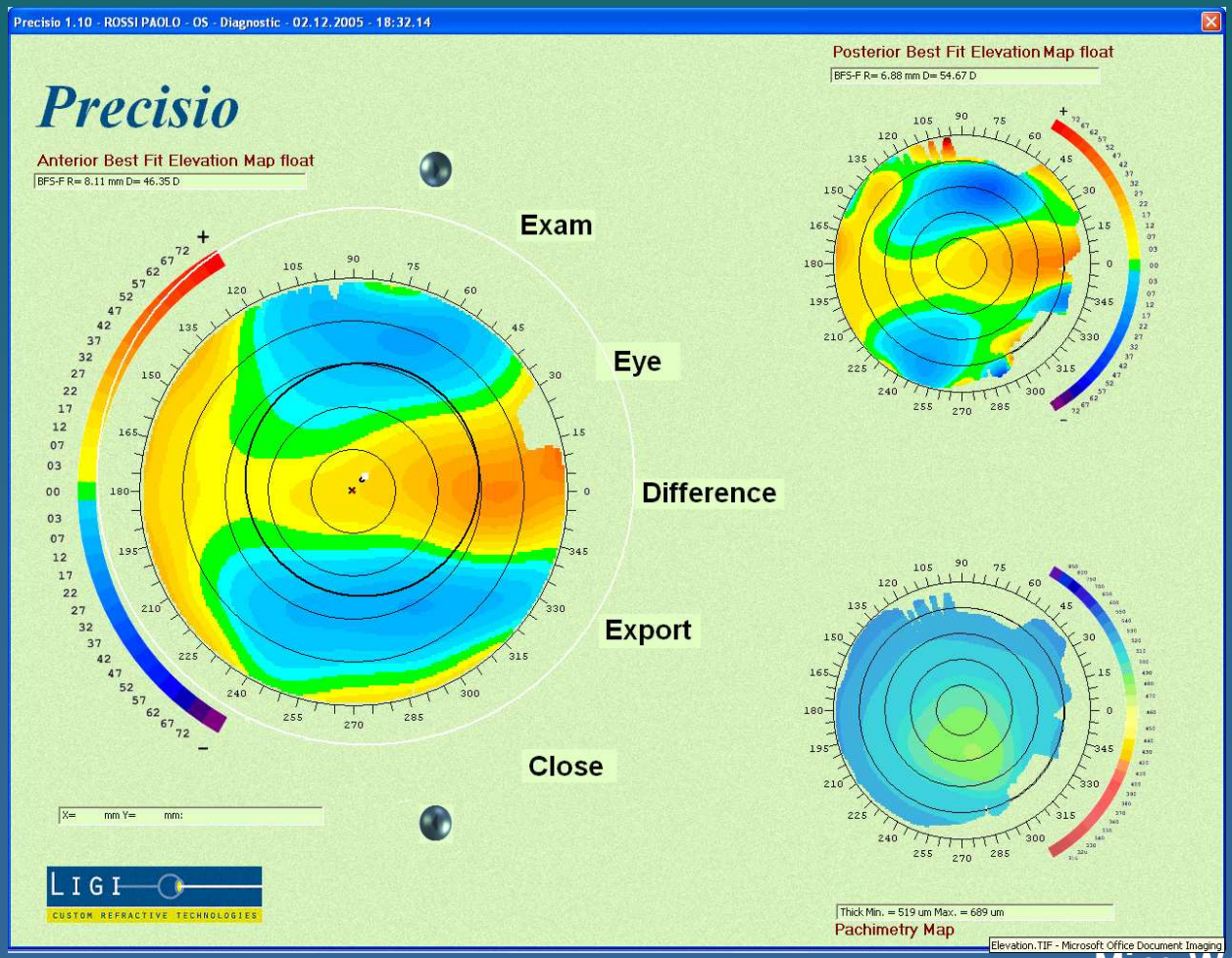
Improved Scheimpflug: Precisio elevation mapping



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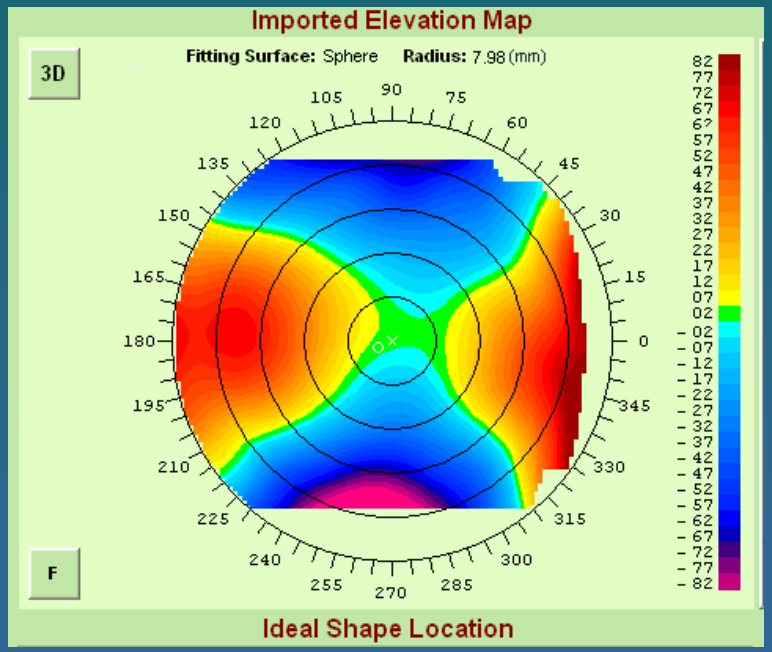
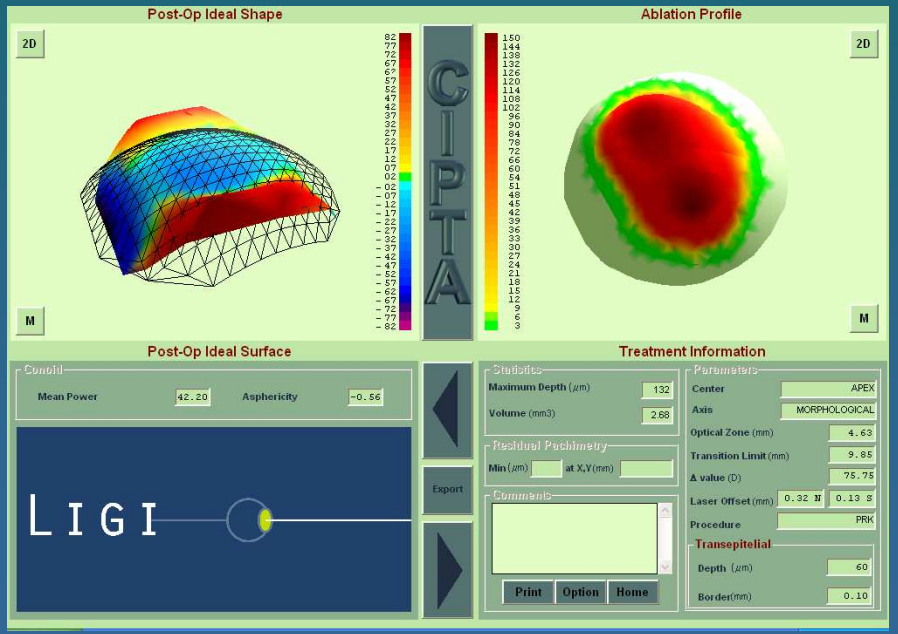
Improved Scheimpflug: Precisio used in CIPTA treatment for complex eyes (10D astigmatism due to misprogramming)



Preop

CIPTA treatment plan



New FDA clinical trial on complex eyes with Cipta (e.g. decentered treatment)

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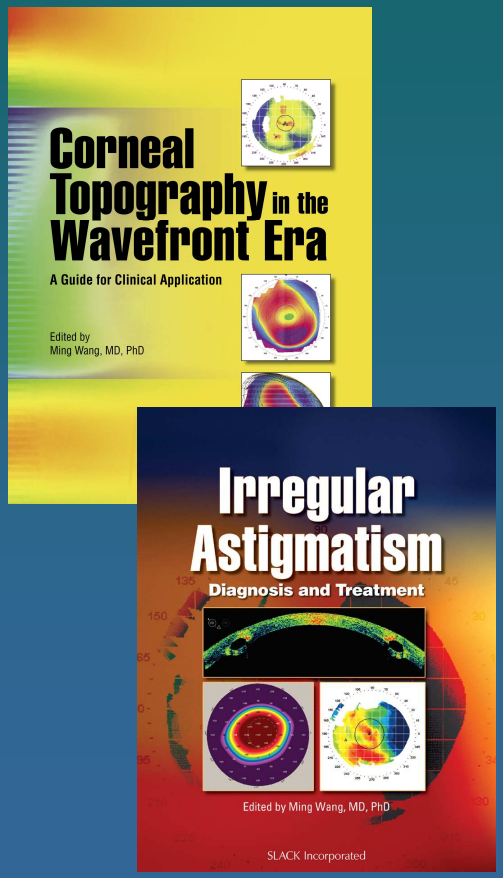
Current and future topo technologies

- Placido disk (e.g., Humphrey);
- Scanning slit (e.g., Orbscan);
- 3-D topo (e.g., AstraMax);
- Scheimpflug imaging (e.g., Pentacam);
- Ultrasound topo (e.g., Artemis);
- Topo-wavefront combined
- (e.g., Tracey, OPD, Orbscan-Zyopitix, Meil-80/CRS Master, Allegro analyzer/topolyzer T-CAT, Waveprint/Humphrey);
- Anterior segment OCT.



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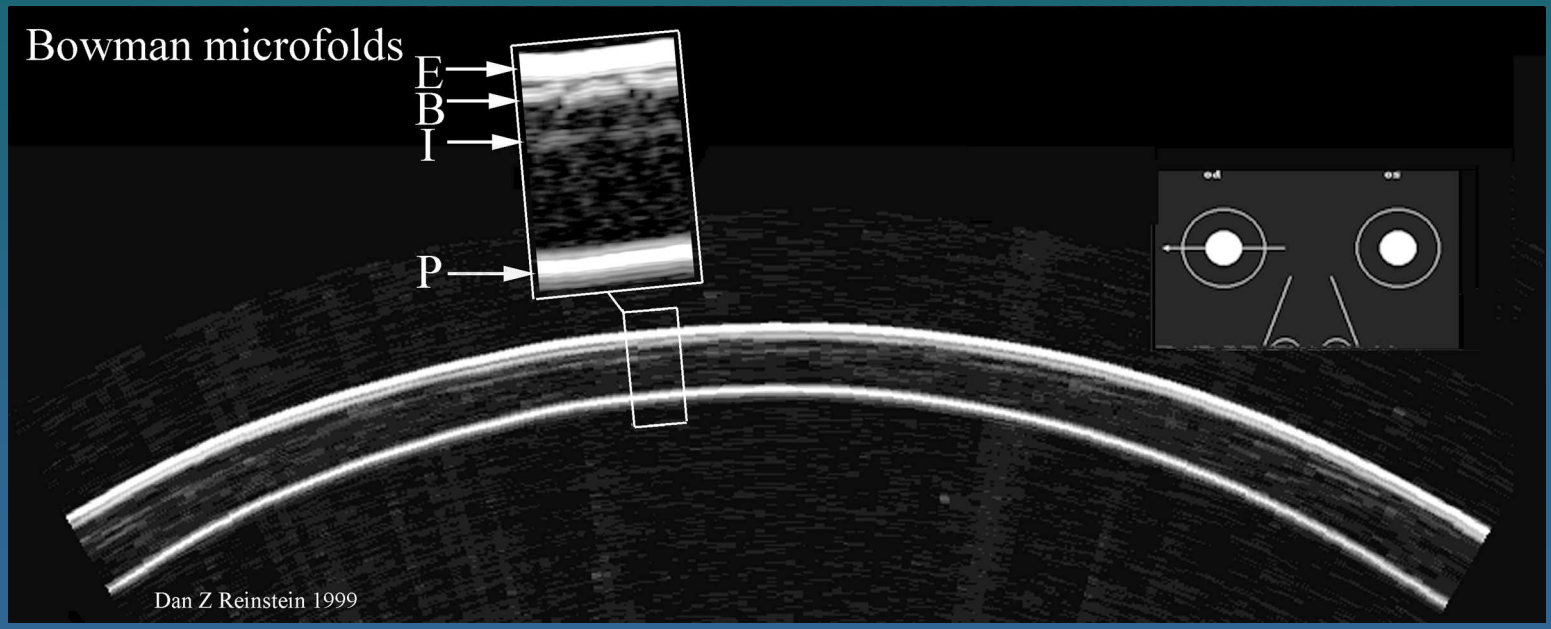
Ultrasound topo imaging: microfolds



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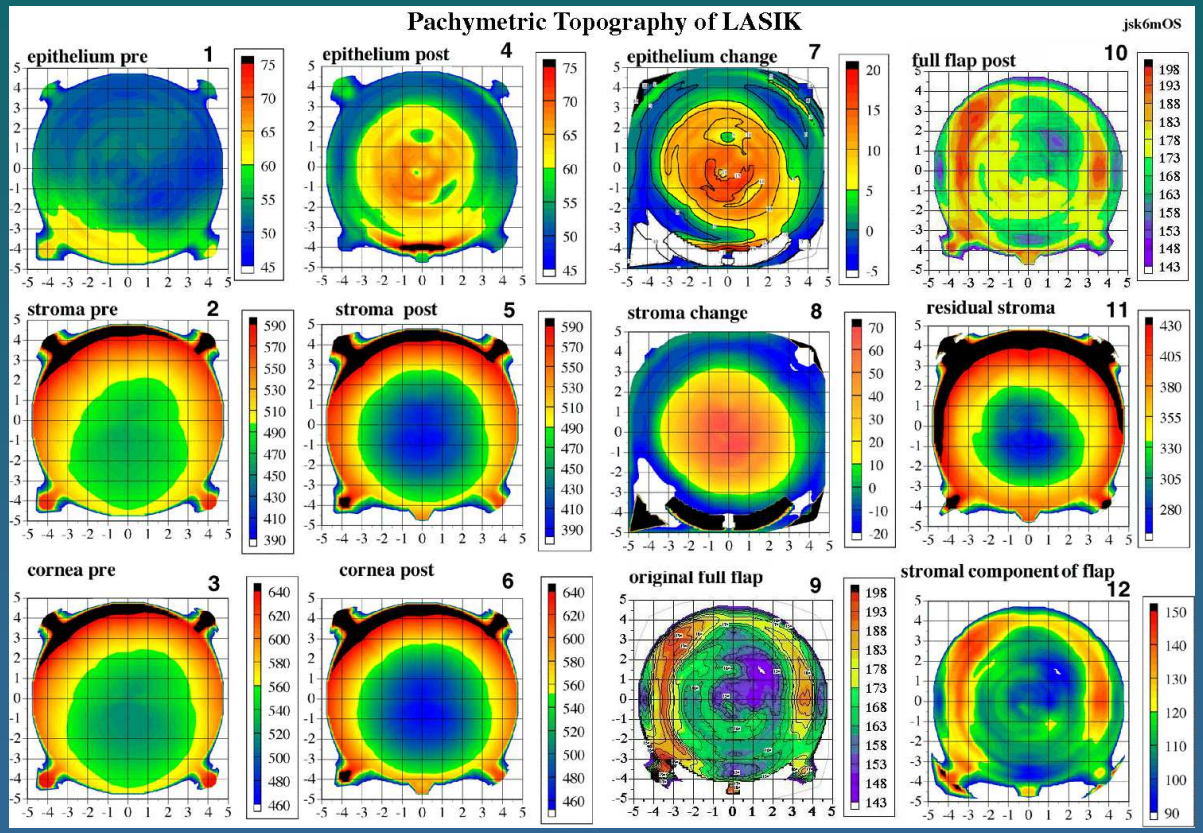
Ultrasound topo imaging: epithelial topo



Advantage: layer by layer topography.

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Current and future topo technologies

- Placido disk (e.g., Humphrey);
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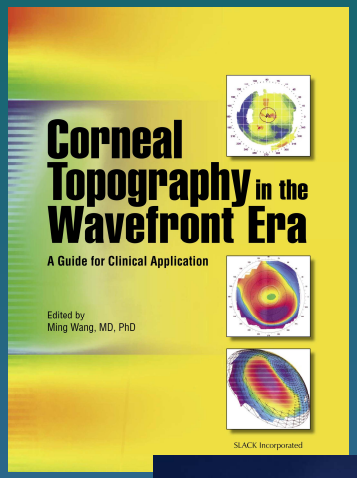

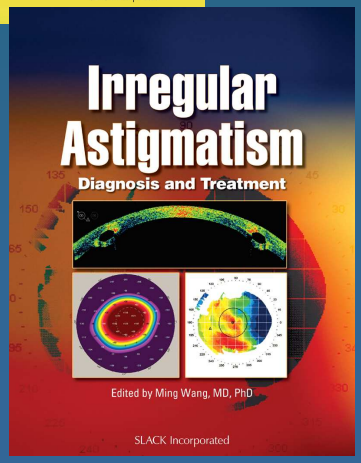

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Why do we need topo-wf combined? Treating problem at its source

- A fundamental assumption of wavefront-based surgery: aberrations, no matter where along the visual axis they arise (ie, from cornea or lens) can be adequately represented by an "end-on collapsed" shot (wavefront map, which contains no infor about axial location of aberration) and adequately treated at any axial location (plane) (e.g., cornea);
- *Do all aberrations at different axial locations created equal?*
- Will treating problems at where it is located (ie., treating corneal problems at cornea, etc) improve the outcome?
- Should we NOT do LASIK if significant aberration is located on the lens?
- A case in point: why the predictability of astigmatic treatment (magnitude and axis) so much lesser than sphere?

Ming Wang, MD,PhD

A study: comparison of LASIK treating anterior cornea versus non-anterior corneal astigmatism

	Group I [(R-K)/R < 1.000]	Group II [(R-K) > 1.000]	P-values
Age	43.71	45.867	0.29
Pre-operative Spherical Equivalent	-5.419	-5.775	0.66
Pre-operative Cylinder (R)	1.355	0.742	0.0001

Table 2

Averages

	Group I [(R-K)/R < 1.000]	Group II [(R-K)/R > 1.000]	P-values
Fraction of Residual Cylinder (R'/R)	0.239	0.502	0.036

For Text:

95% Confidence Interval

	Group I [(R-K)/R < 1.000]	Group II [(R-K)/R > 1.000]
Age	40.473 to 46.947	43.628 to 48.106
Pre-operative Spherical Equivalent	-4.157 to -6.681	-4.839 to -6.705
Pre-operative Cylinder (R)	1.115 to 1.595	.585 to .899

Age, SE comparable, though magnitude of total preop astigmatism is higher in the low lenticular astigmatism group.

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<u>Result:</u> residual untreated astigmatism after LASIK is twice as high in eyes with preop predominantly lenticular astigmatism

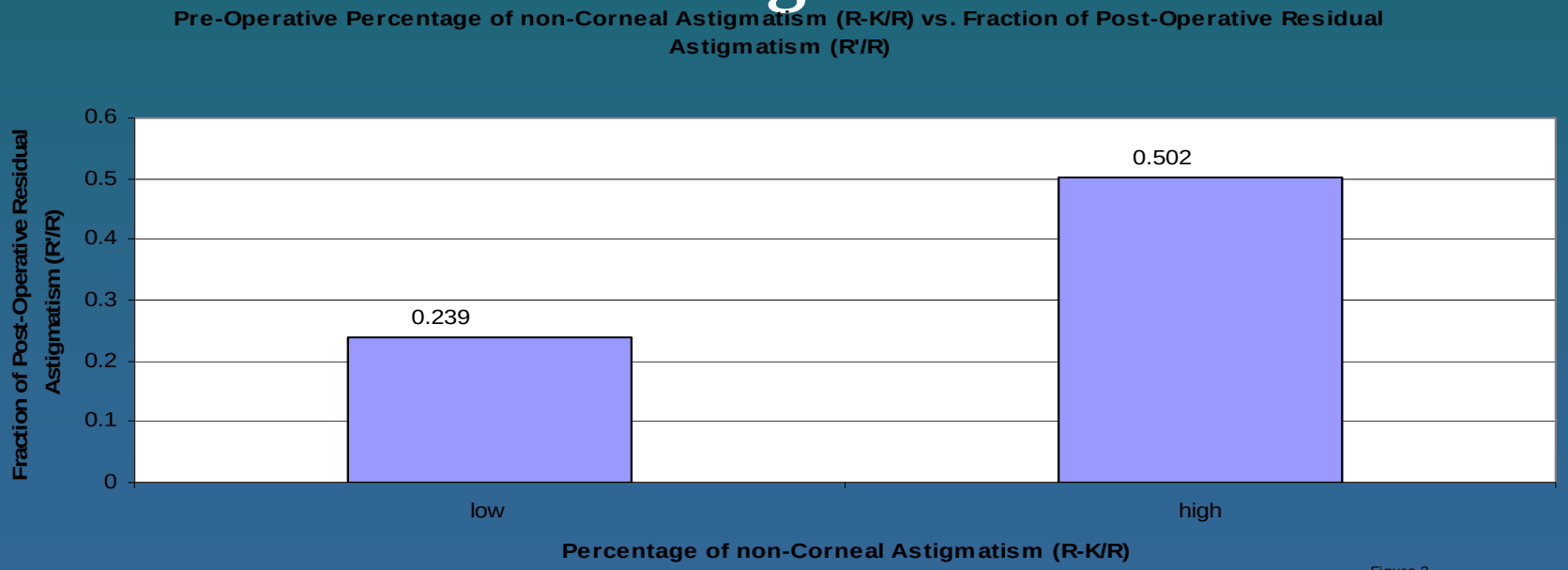

Figure 3

P < 0.05.

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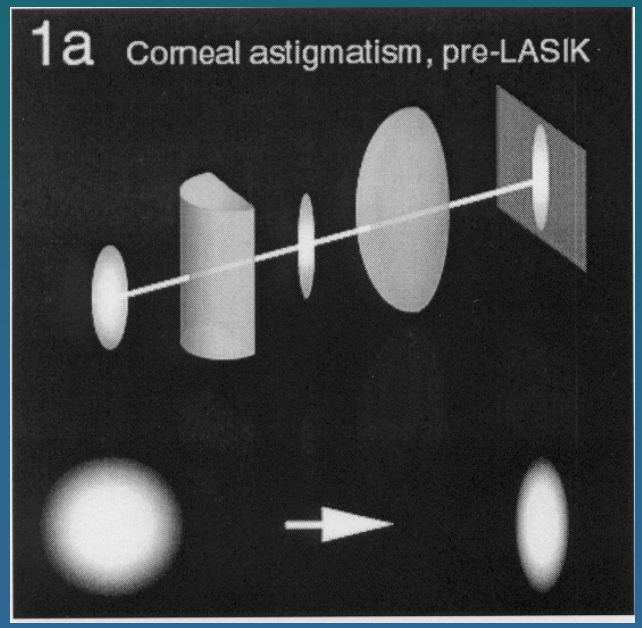
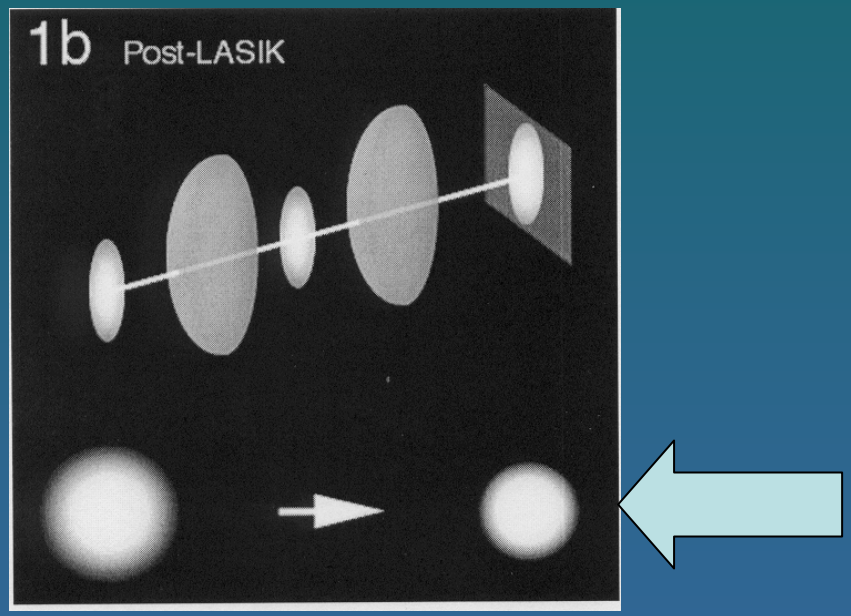
LASIK treating corneal vs lenticular astigmatism

1) LASIK treating corneal astigmatism: Excellent result (less residual astigmatism).



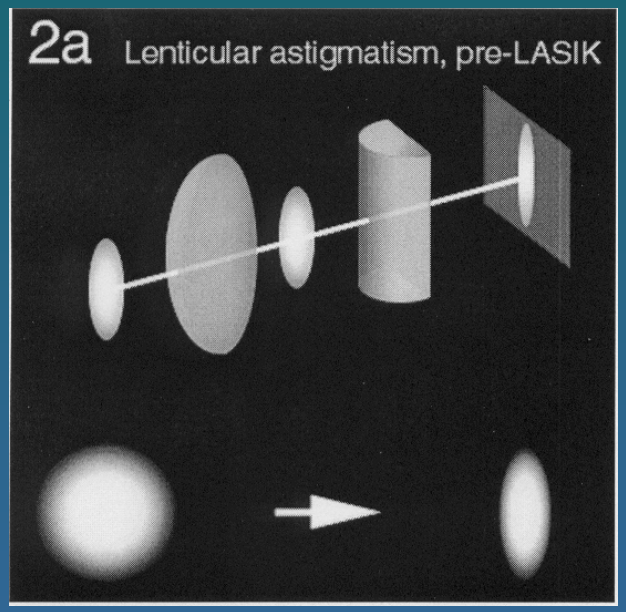


Circular incoming light.

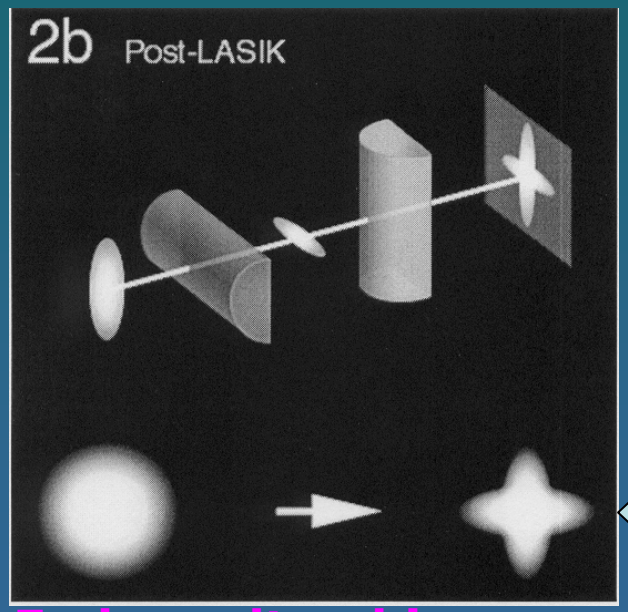
End result: a nice circular image on retina, minimal residual uncorrected cylinder.

LASIK treating corneal vs lenticular astigmatism

2) LASIK treating lenticular astigmatism: Not good result (twice the amount of untreated astigmatism is left).



Circular incoming light.



End result: a bizarre imperfect image on retina, higher amount of residual *uncorrected* cylinder.

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Conclusion of LASIK treating corneal vs lenticular astigmatism study

- **Axial distance between the plane of aberration and plane of treatment does matter;**
- **Treating problem at its source yields better clinical result;**
- **The underlying assumption of the current wavefront-driven treatment today, ie., aberrations, no matter where they arise axially, can be adequately represented by an end-on collapsed shot (wavefront map) and adequately treated anywhere along the visual axis (e.g., cornea), may not be valid; hence, this may present a fundamental limit of resolution of treatment efficacy of wavefront-based treatment;**
- **Also, lens is more dynamically changing, while cornea stays stationary, removing of lens, later, in such post-LASIK eyes with high lenticular aberration may worsen the vision!**
- **Topo-wavefront combined approach is needed, so we can identify the axial location of aberrations, and treat them at where they occur.**

Advantages of topo-WF combination

- Ability to discern source of aberrations as primarily corneal or lenticular (internal ocular sources)
- Improve selection of most appropriate refractive correction procedure
- Enhance custom correction of either cornea (custom LASIK) or lens (custom IOL) for improved visual outcome

Challenges of topo-WF combination

- Registration between corneal topography and aberrometry/wavefront measurements
- Algorithmic accuracy of Zernike calculation from corneal topography
- Appropriate subtraction techniques for measured internal ocular aberrations

Topo-WF combined: Tracey

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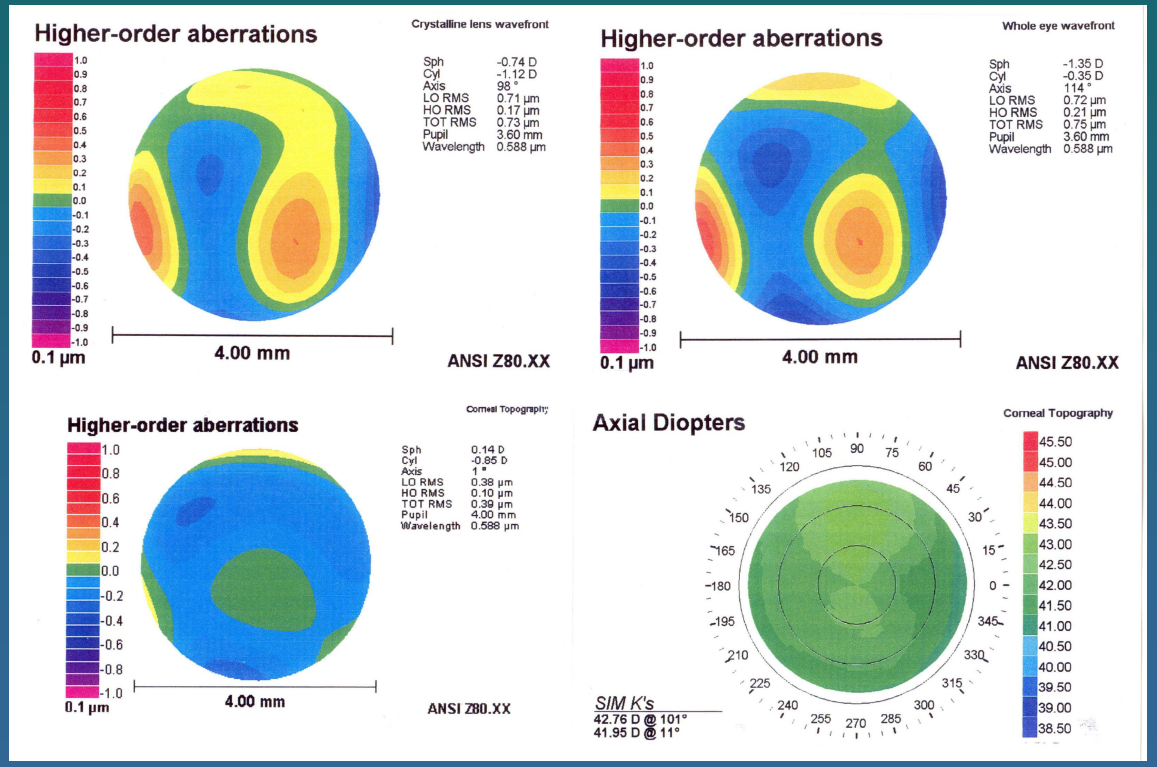
Topo-WF combined: Tracey

Horizontal Coma in Lens w/ Spherical Cornea



Since aberration is largely in the lens, should we NOT touch this cornea with LASIK?

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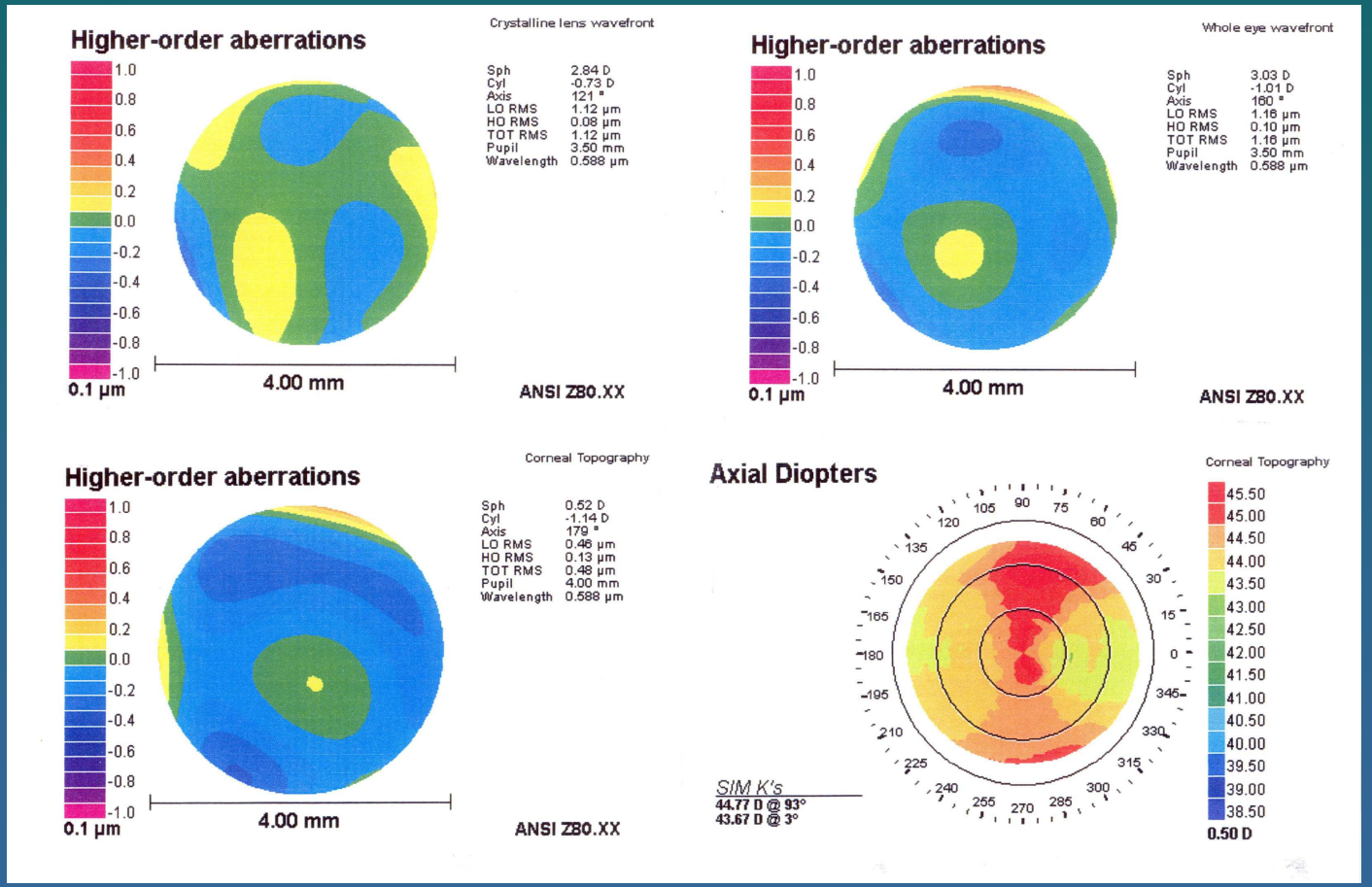
Topo-WF combined: Tracey

Corneal HOA causes WF HOA



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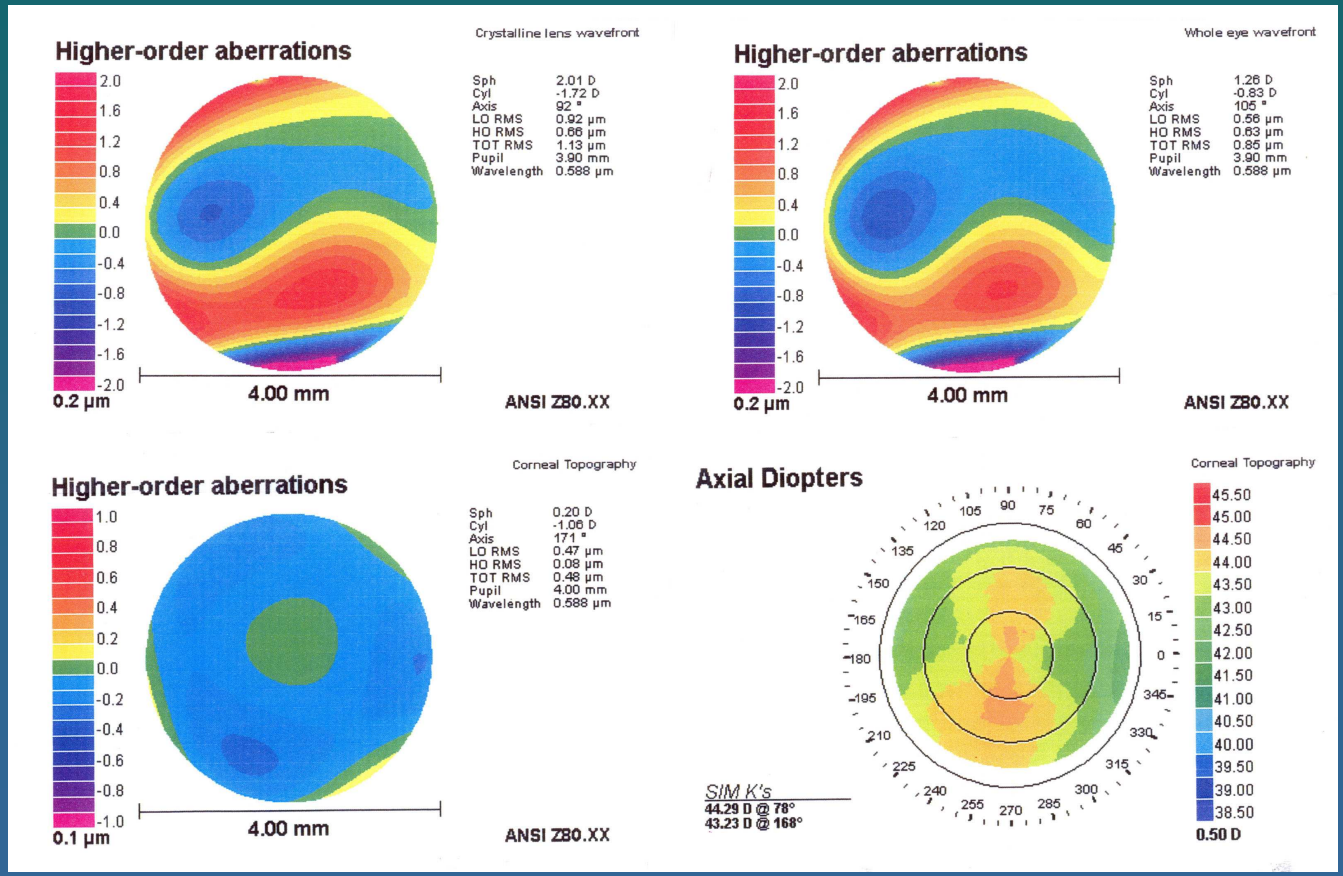
Topo-WF combined: Tracey

Lenticular HOA is responsible for total WF HOA



Don't do LASIK, and create reverse aberration on the "innocent" cornea,
And, later, when you remove the lens, pt's vision might get worse!

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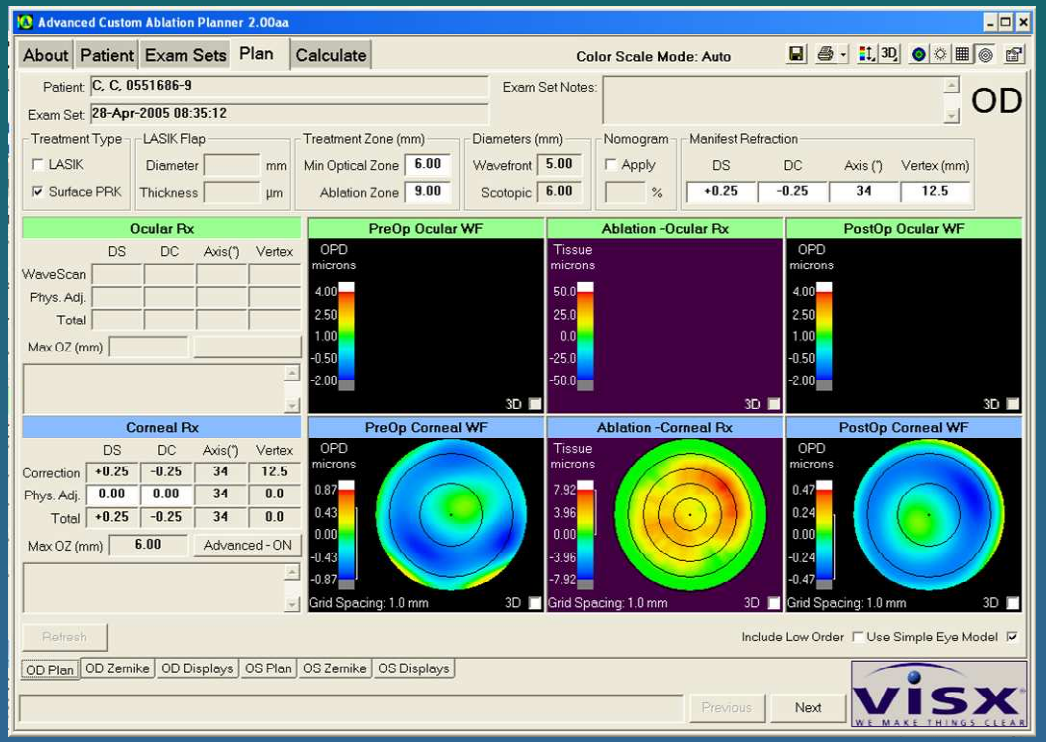
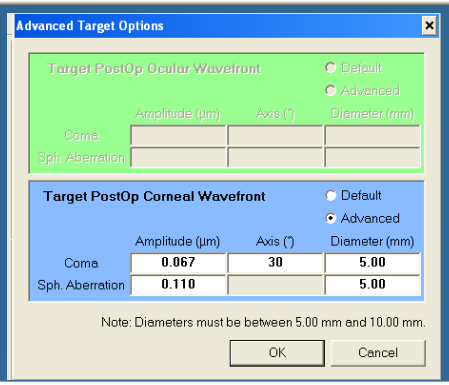
Topo-WF combined: VISX WP-Humphrey





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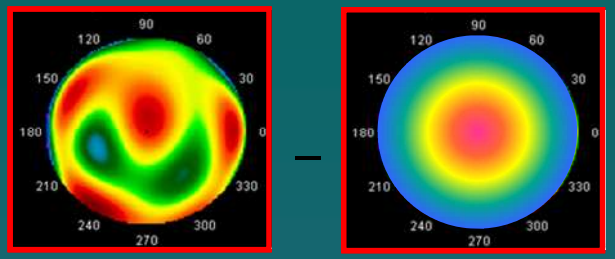
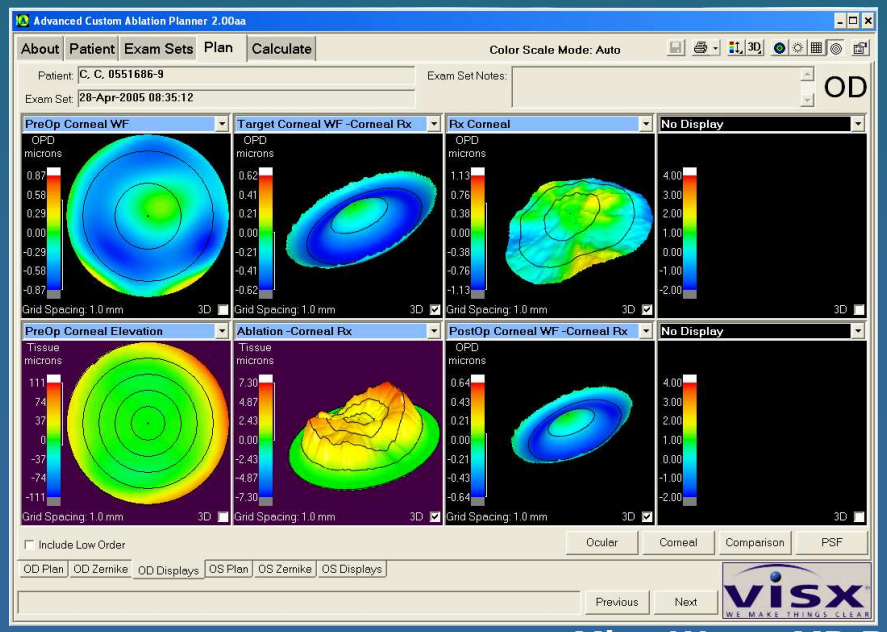
Topo-WF combined:

VISX approach ACAP



VISX Ablation Profile Calculation as in WaveScan

Treatment table for VISX laser



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Summary of new topo technologies

New topo technologies offer new capabilities:

1. **Posterior and pachy – topography (anterior/posterior) FFKC;**
2. **Elevation – treating decentered treatment and central island;**
3. **New tomography topos Schemflug and anterior segment OCT.**

- **Wavefront does have limitations (no infor outside the pupil, no infor about axial location of aberration, changes with accommodation);**
- **Combined topo-wavefront approach to treat problem at where it occurs (topo-linked to treat corneal problems): *not all aberrations at all axial locations are created equal.***

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Topo FFKC criteria 2008

2 D rule:
- > 2D difference in superior and inferior k readings outside the central 3mm;
- > 2D difference in the corresponding inferior corneal locations between two eyes;
- Absolute value of K very high (over 50D) in one eye;

3-point touch:
- Coinciding of location of pathology of ant & post elevation, pachymetry & ant curvature;
- Displaced apex in all maps;

Anterior & posterior float:
- “Ominous purple” in the posterior surface;
- Anterior 15-20 um;
- Posterior 20-25um (post-LASIK: 40-50um);

Pachymetry:
- Bed 250-300um;
- Normal: 535um, SD=35um. No LASIK below 1D(500um), no PRK below 2d (465um);
- KC: 430um, SD=70um;
- Thinnest area is more than 15um thinner than center;
- The difference between thinnest areas between 2 eyes is greater than 15-20um;
- Abrupt & more rapid “out-of-zone” pachy increase from thinnest point radially out;

IA orientation, amount, pattern
- > 3D or more dioptic curvature change,,in central 3-mm circle;
- In central 3-mm circle, not regular (bow-tie) pattern; across the pupil 180 degrees,
- change of astigmatism orientation and amount;
- Against-the-rule astig plus inferior steepening, the "C" pattern, suggesting PMD;

Topo-based FFKC detectors:
- Tomey: positive KC score with either the KCI or KCS index;
- EyeSys: I-S > 1.3;
- Pentacam: ISV, IVA, KI, CKI, /Rmi, IHA, IHD and ABR
- Humphrey Atlas: Path-finder, in red zone.

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Visual quality – the new frontier of refractive surgery in 21st century

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Visual quality – corneal topo is still our bread and butter and indispensable

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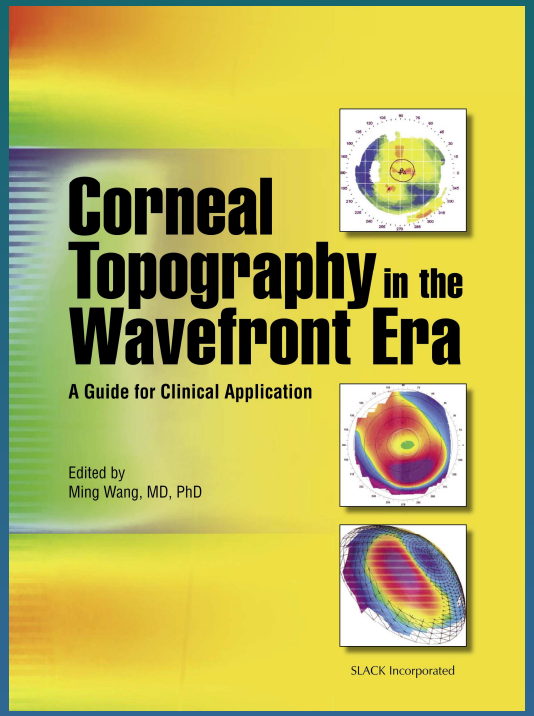

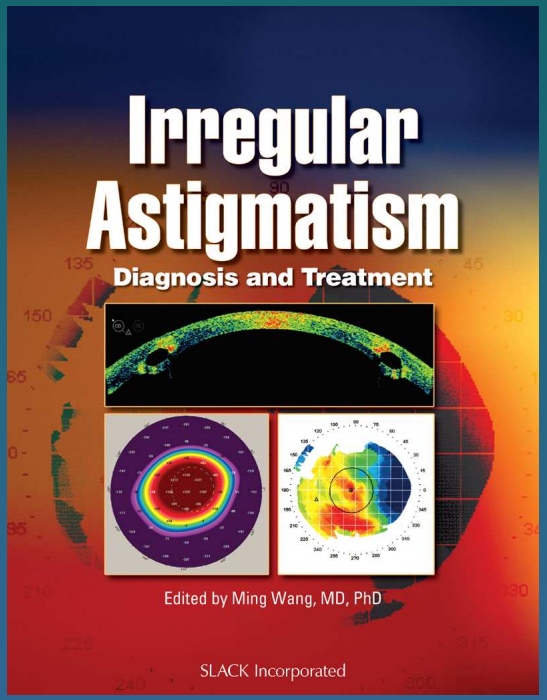

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