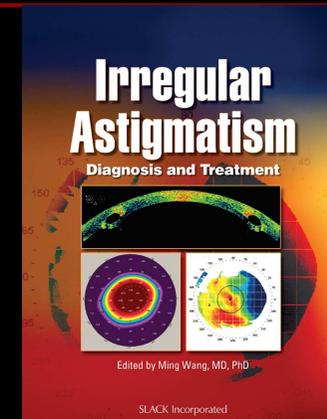
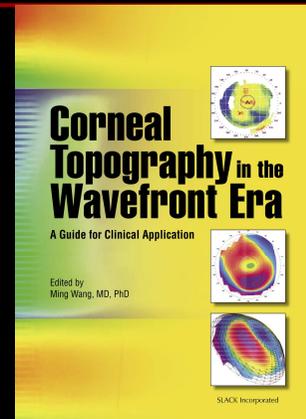


Irregular astigmatism: definition, classification, topographic and clinical presentation

Ming X. Wang, MD, PhD

Clinical Associate Professor of
Ophthalmology of University of
Tennessee

Director, Wang Vision Institute
Nashville, TN, USA



Coworkers

- Tracey Swartz, O.D., MS;
- Shawna Hill, O.D.;
- Helen Boerman, O.D.;
- Lav Panchal, M.D.;
- Yangzi Jiang, M.D., O.D.;

- No financial interest.

Irregular astigmatism

- Definition and classification;
- Statistical indices and KC risk indices;
- Clinical causes;
- Other visually significant corneal changes;
- Topo-WF correlates of irregular astigmatism;
- Treatment.

Definition and classification

Irregular astigmatism, defined as astigmatism where the principle meridians are **not 90 degrees apart** and associated with **loss of vision**, represents one of the most serious and frequent complications of corneal refractive surgery.

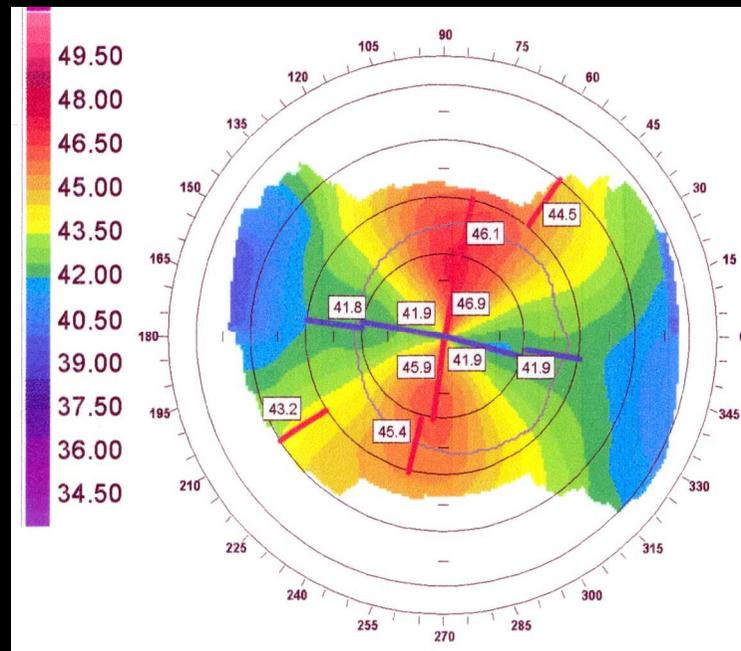
Regular vs irregular astigmatism

- Regular astigmatism is correctable using a cylindrical spectacle lens;
- Irregular astigmatism occurs when the **orientation** of the principal meridians changes *from one point to another across the pupil*, or when the **amount** of astigmatism changes from one point to another;
- The further distinction of irregular astigmatism includes regularly or irregularly irregular astigmatism and relates to the presence of **pattern** recognition on computerized topography. Irregularly irregular astigmatism is rough or uneven, and shows no recognizable pattern on topography.

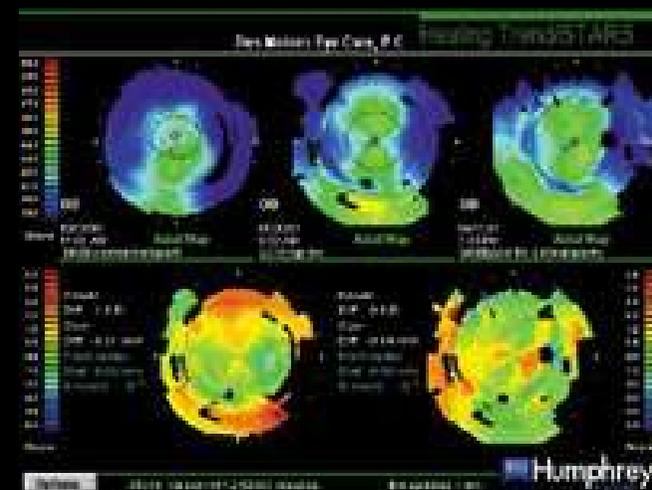
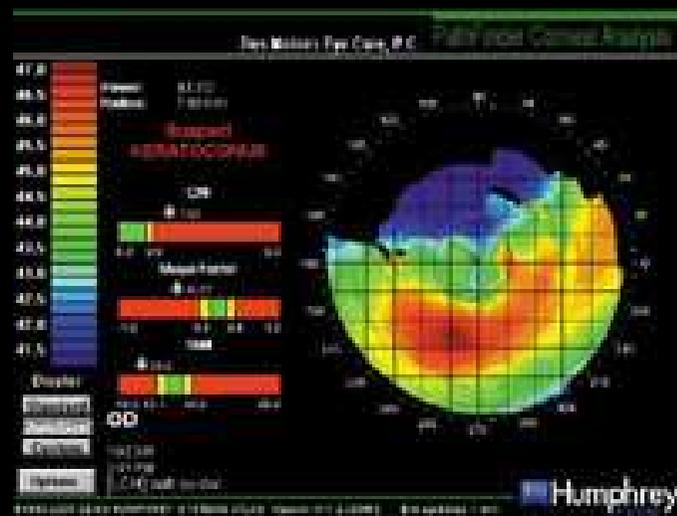
Classification

- Irregular astigmatism with defined pattern (**Macroirregular**, or **regularly irregular astigmatism**): There is a steep or flat area of at least 2 mm of diameter, which is the primary cause of the astigmatism.
- Irregular astigmatism with undefined **pattern** (**Microirregular**, or **irregularly irregular astigmatism**): Multiple irregularities; big and small, steep and flat, and profile maps are almost impossible to calculate.

Regular astigmatism



Irregular astigmatism: Astigmatism in which different parts of the same meridian have different degrees of curvature



Irregular astigmatism

- Definition and classification;
- **Statistical indices and KC risk indices;**
- Clinical causes;
- Other visually significant corneal changes;
- Topo-WF correlates of irregular astigmatism;
- Treatment.

Statistical indices and KC risk indices

- SimK, SAI, SRI;
- SF, CIM, MTK,
- KC risk index panel.

Sim K, SAI, SRI.

- **Simulated keratometry (SimK)** provides the power and axis of the steepest and flattest meridian similar to values provided by the keratometer. They are calculated from rings 7 to 9 corresponding to the position on the cornea at which keratometry measurements are obtained.
- **The surface asymmetry index (SAI)** is a centrally weighted summation of differences in corneal power between corresponding points 180° apart on 128 equally spaced meridians. The SAI approaches zero for a perfectly radially symmetrical surface and increases as the corneal shape becomes more asymmetrical.
- **The surface regularity index (SRI)** is calculated from a summation of local power fluctuations along 256 equally spaced meridians. The SRI rises with increasing irregular astigmatism and approaches zero for a smooth corneal surface.
- Numerous other indices have been developed such as potential visual acuity, average corneal power, coefficient of variation of corneal power, and algorithms for the detection of keratoconus.

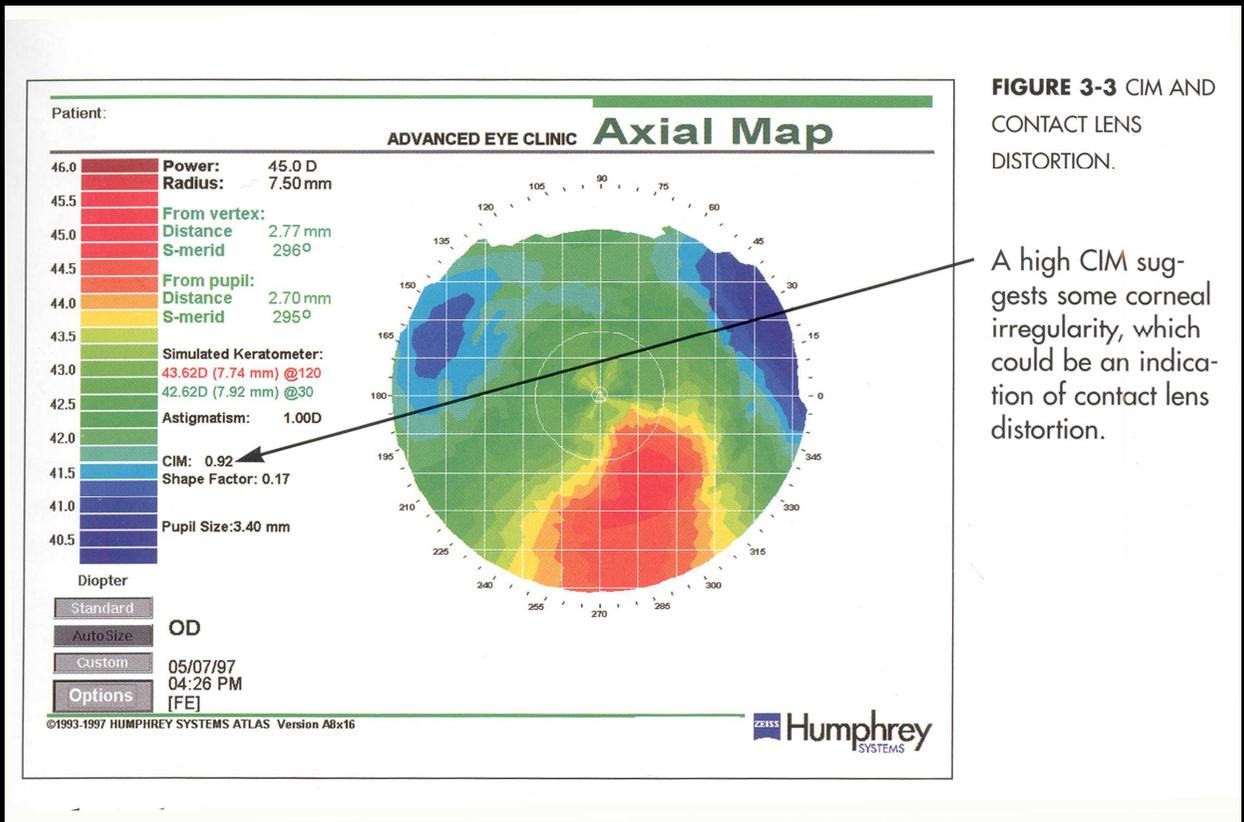
SF

- *Shape Factor (SF)* is the measurement of corneal **asphericity**. A negative SF usually indicates a post-refractive surgery eye with the center flatter than the periphery (oblate).
- Normal 0.13 to 0.35
- Borderline 0.02 to 0.12
- Abnormal -1.0 to 0.01 .

CIM

- *Corneal Irregularity Measurement (CIM)* is an index which represents the **irregularity** of the corneal surface. Higher the value of CIM predicts more irregularity
- Normal 0.03 μ m to 0.68 μ m
- Borderline 0.69 μ m to 1.0 μ m
- Abnormal 1.1 μ m to 5.0 μ m

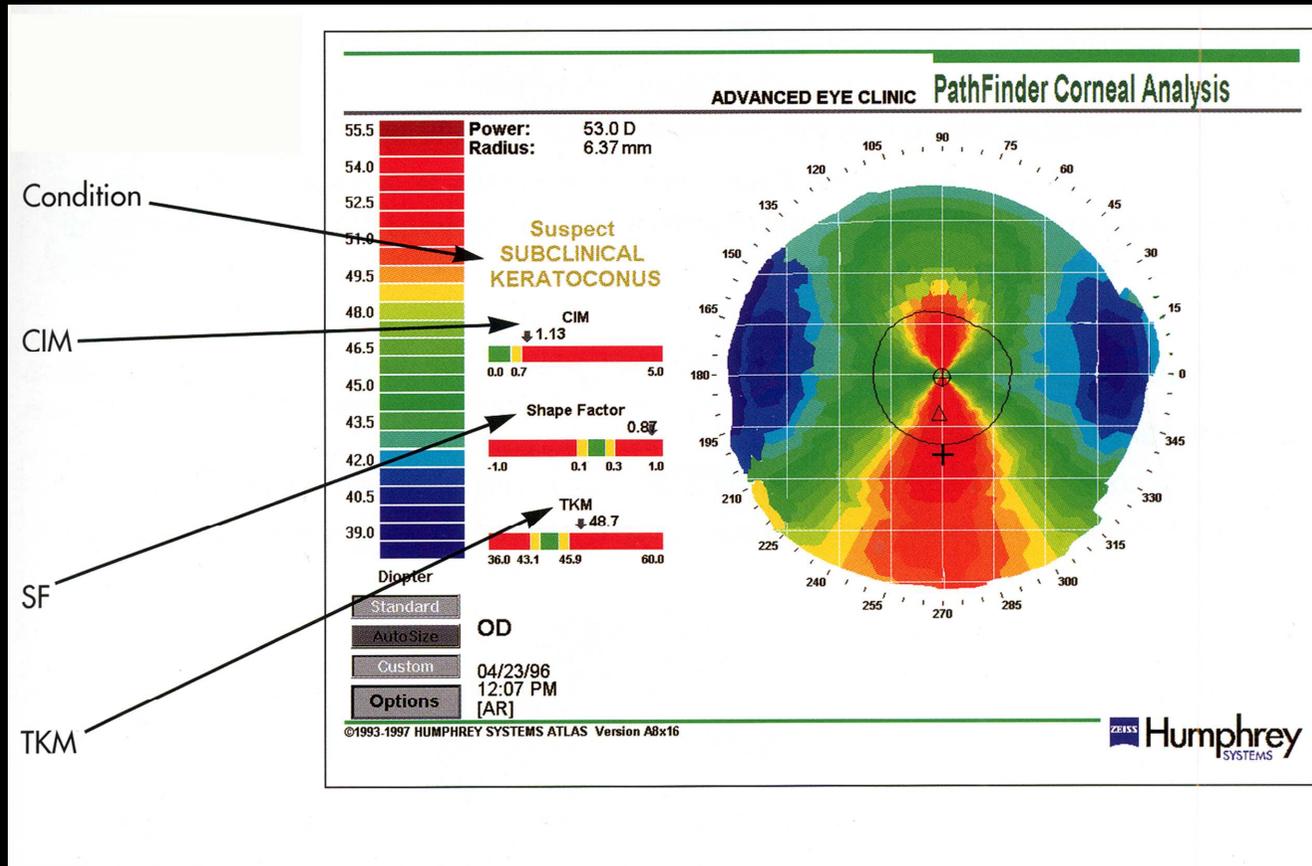
CIM



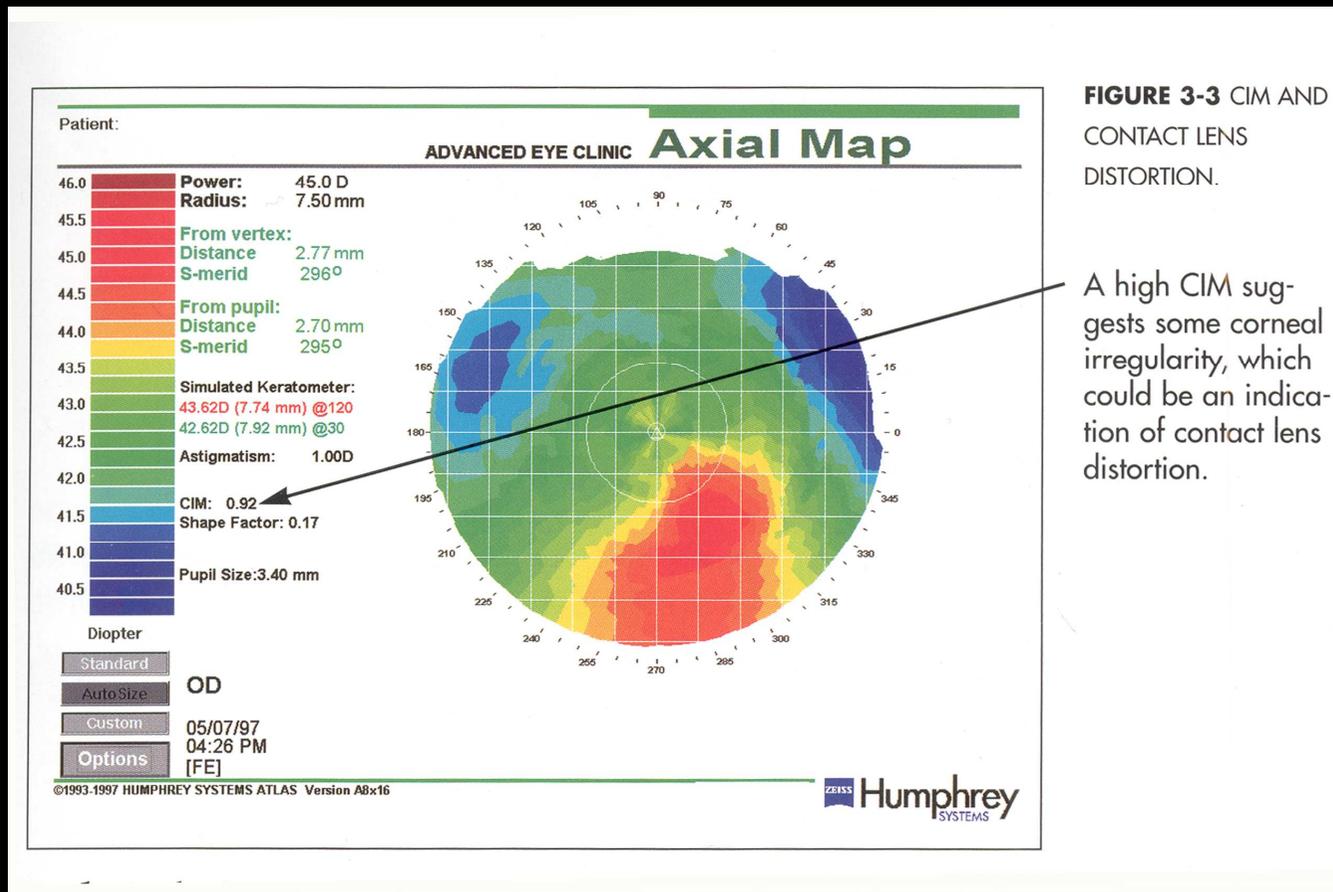
MTK

- *Mean Toric Keratometry (MTK)* indices use elevation data to compare the toric reference to the actual cornea. The mean apical curvature value helps select the **best toric fit** using a spherocylinder design. This provides the most accurate toric representation of a patient's cornea.
- Normal 43.10 diopters to 45.90 diopters
- Borderline 41.80 diopters to 43.00 diopters and 46.00 diopters to 47.20 diopters
- Abnormal 36.00 diopters to 41.70 diopters and 47.3 diopters to 60.0 diopters

Combining CIM, SF and MTK, to determine KC risk



CL Distortion



Subclinical keratoconus

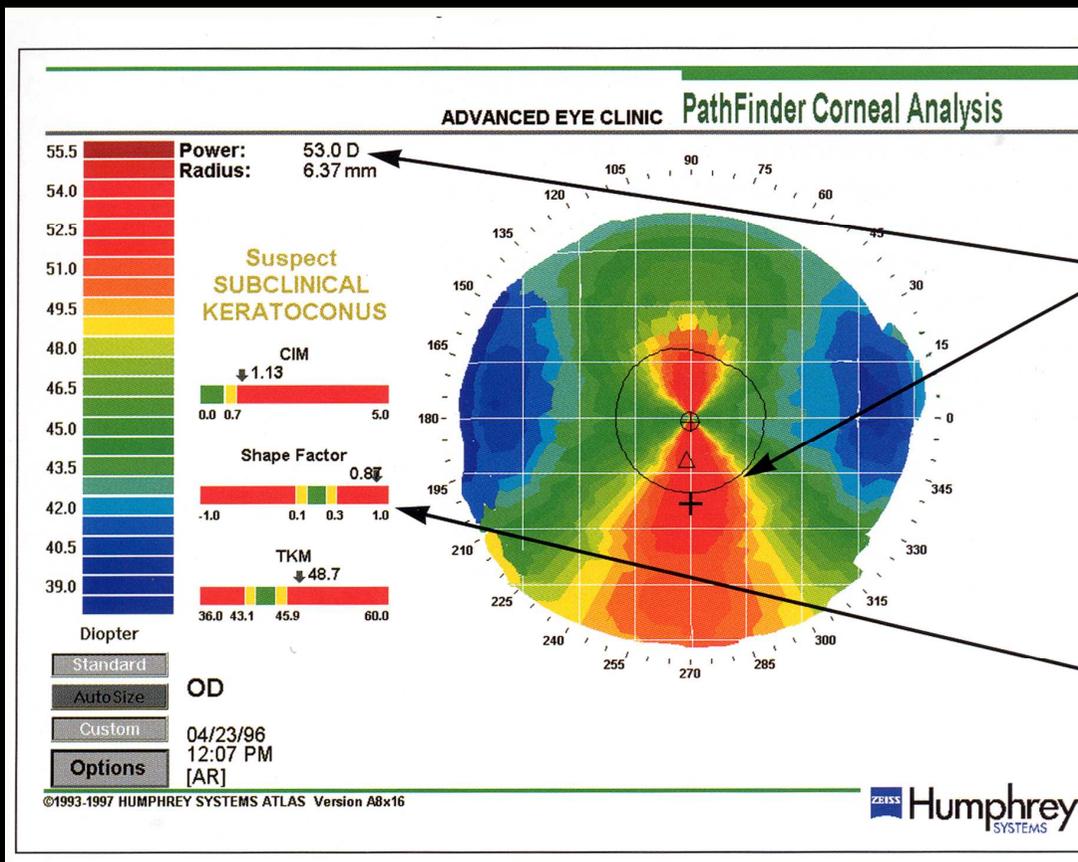


FIGURE 3-6 CASE 2.
PATHFINDER CORNEAL
ANALYSIS: SUBCLINICAL
KERATOCONUS

Corneal curvature at the steepest point is upwards of 53 diopters despite the normal "bow-tie" type pattern.

All statistical indices are in the "red" and are abnormal.

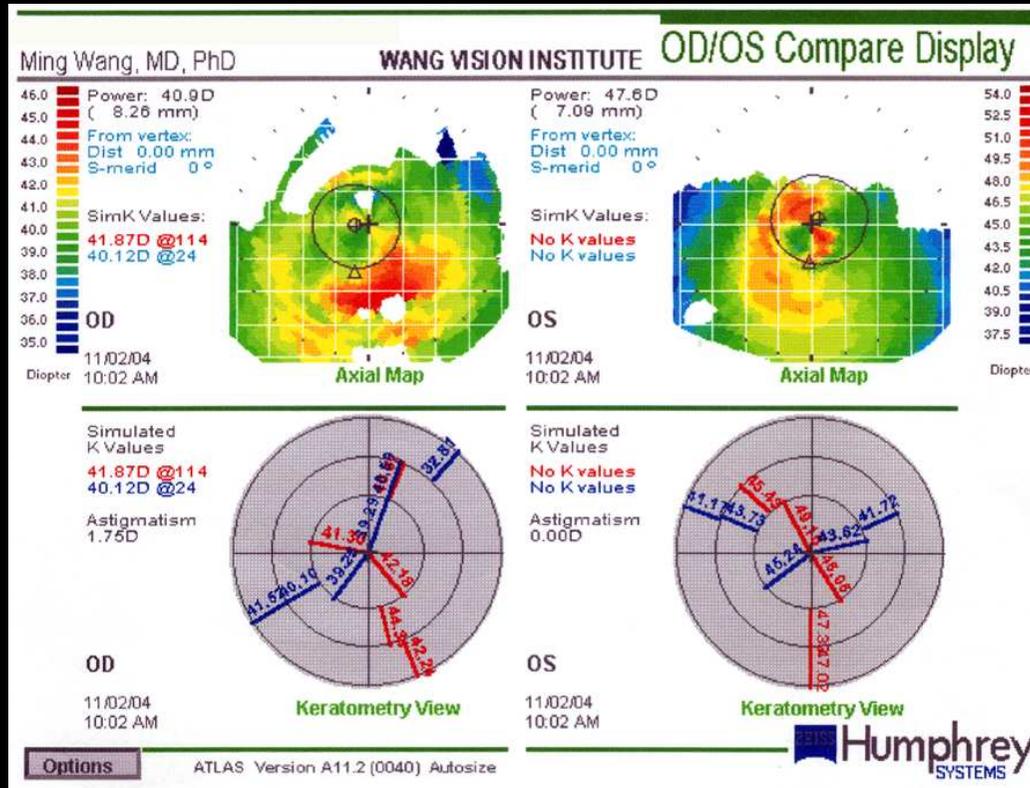
Irregular astigmatism

- Definition and classification;
- Statistical indices and KC risk indices;
- **Clinical causes;**
- Other corneal visually significant changes;
- Topo-WF of irregular astigmatism;
- Treatment.

Clinical causes of irregular astigmatism

- Irregular but **stable** cornea (e.g., irregular scar surface): cornea is irregular because of **LOCAL** geography;
- Irregular but **unstable** cornea (biomechanical decompensation): cornea is irregular because of **GLOBAL** corneal weakness;
- **Clinical causes:**
 - CL warpage/overwear
 - FFKC/KC/Pellucid
 - Chalazion
 - Pterygium
 - Trauma
 - Limbal/corneal dystrophies
 - Keratorefractive surgery (LASIK, PRK, CK, ectasia)
 - Others

CL warpage

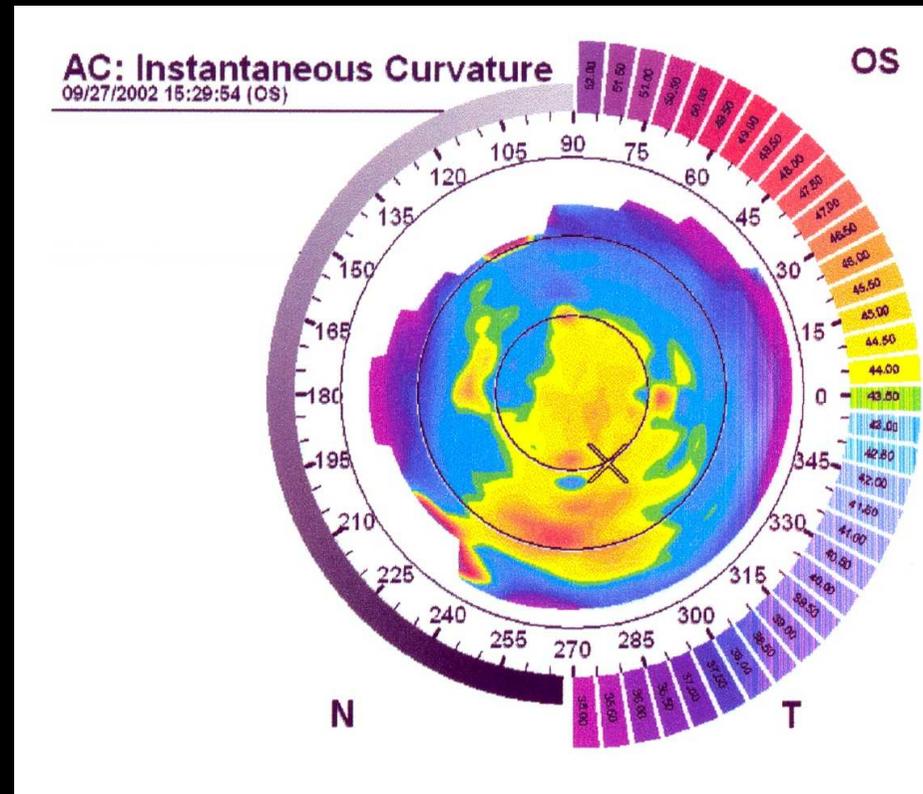


Irregular astigmatism (dry eyes)

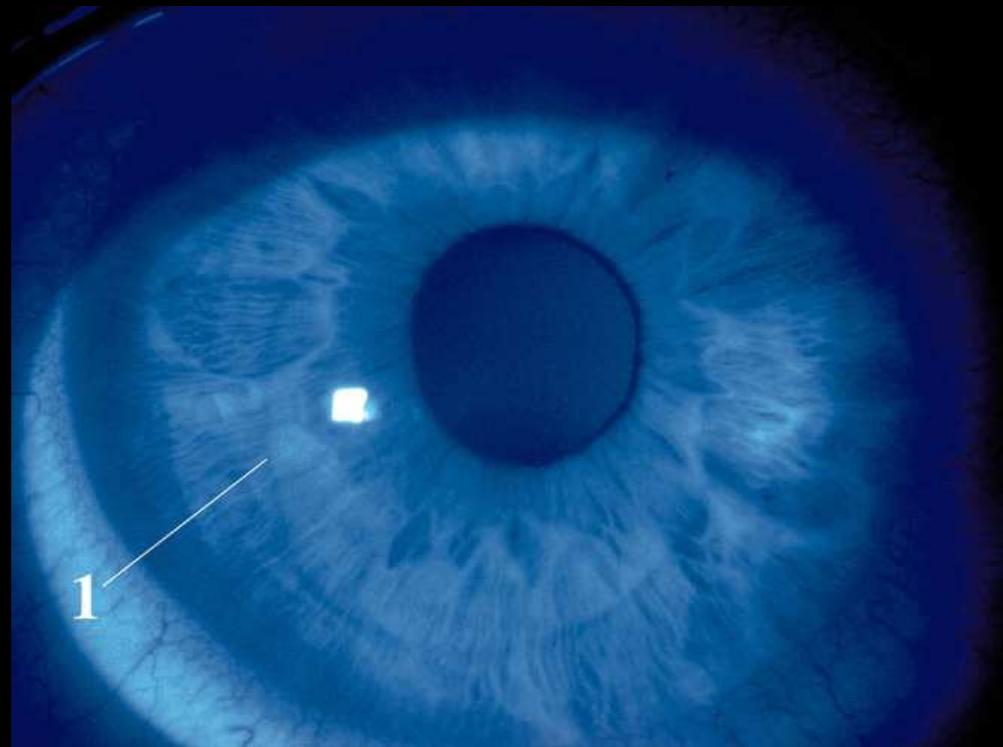
Our most
common
irregularity
without defined
pattern post
LASIK is *dry eye*
(*47% of HOA in
on study*)



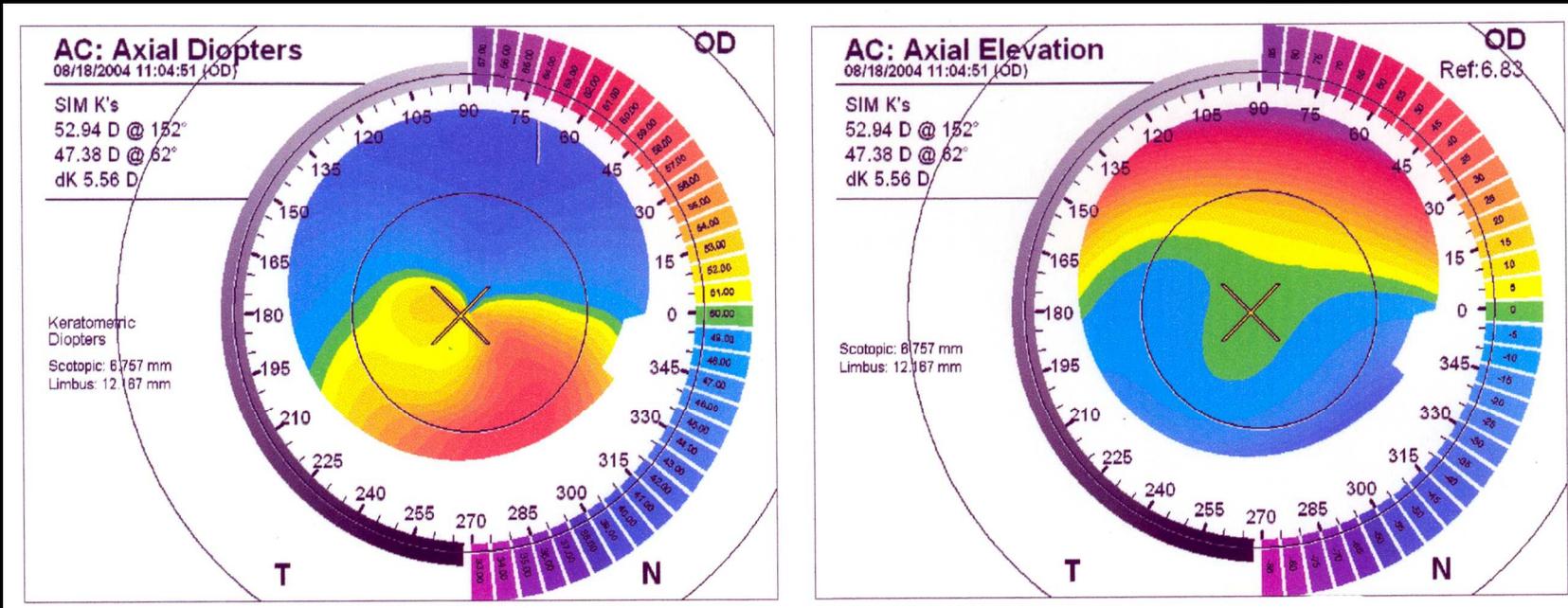
Irregular astigmatism (dry eyes con't)



KC



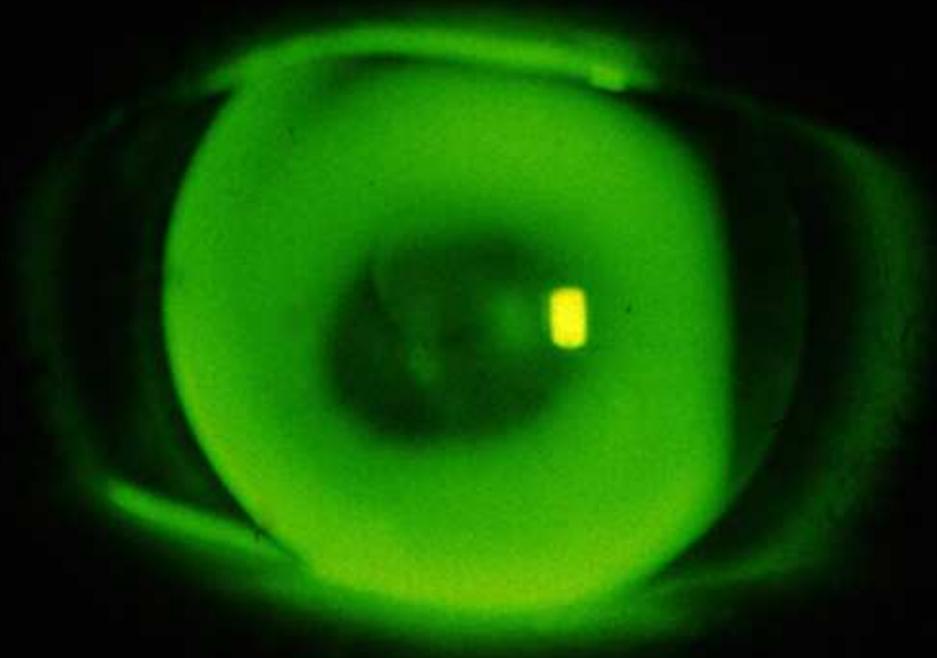
Elevation and curvature flipped with KC



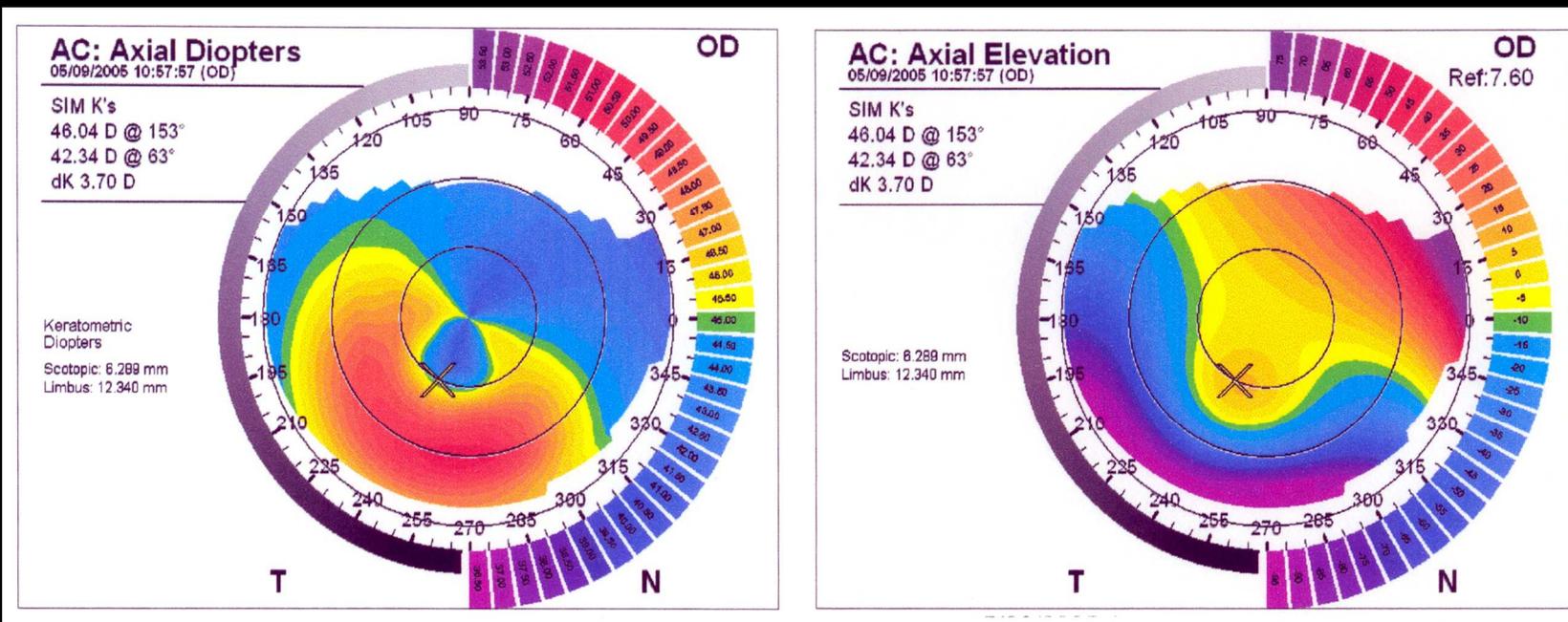
KC



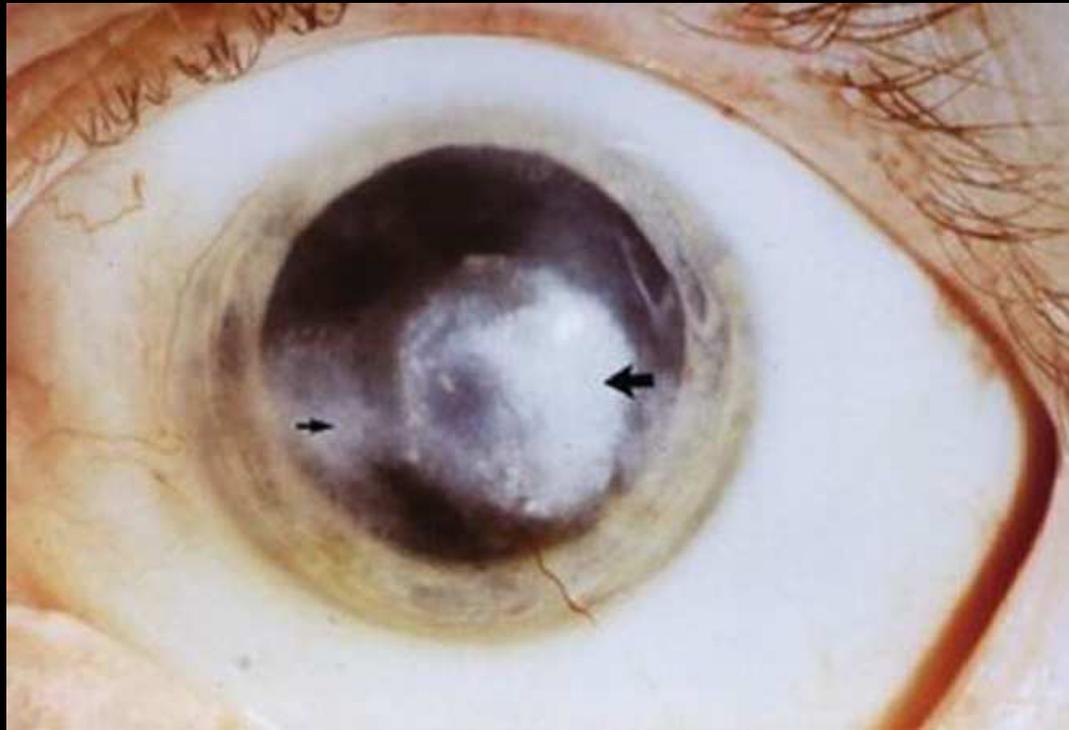
KC



Pellucid curvature and elevation maps



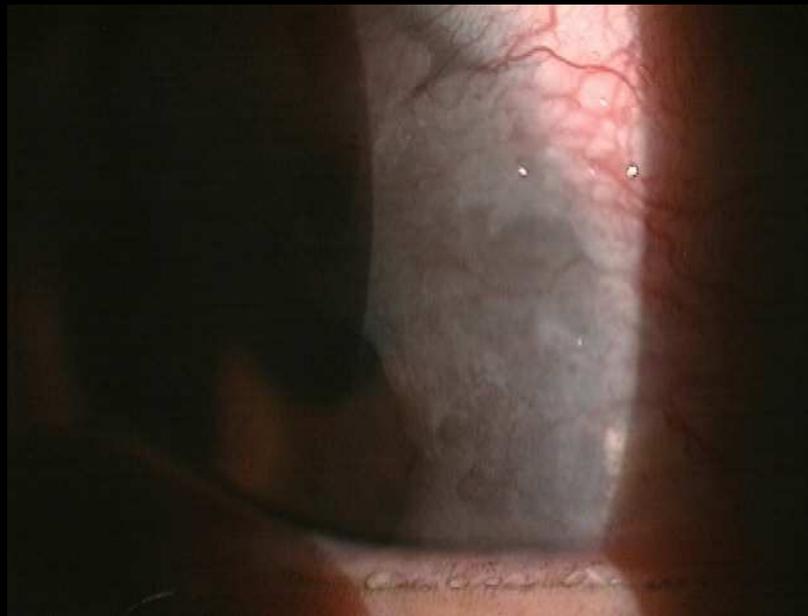
Corneal scarring



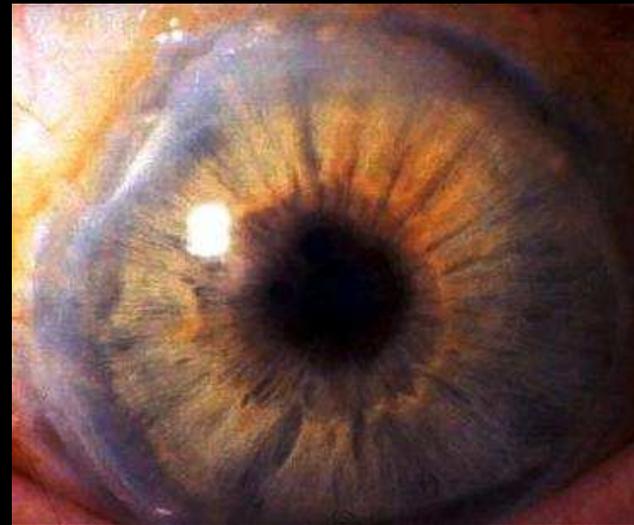
Extreme GPC or other lid disorders
may affect corneal shape



HPV CIN causing changes



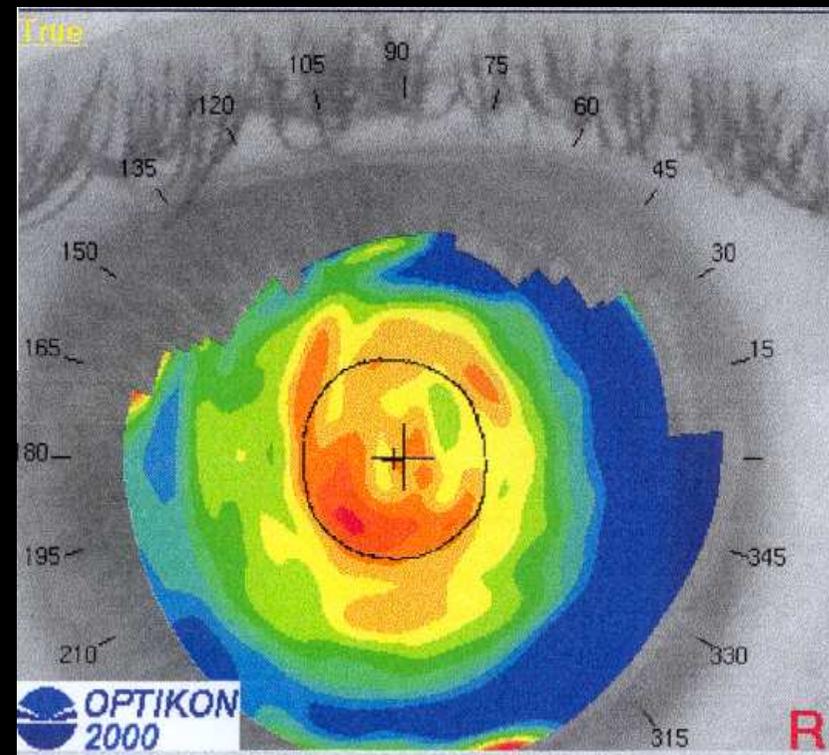
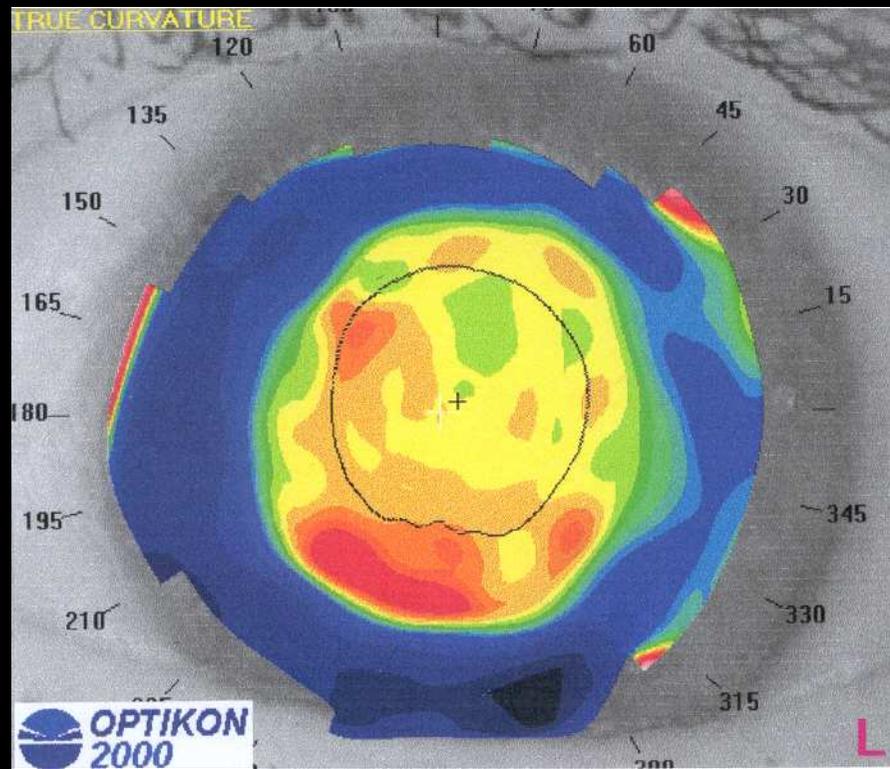
Peripheral melt/Mooren's



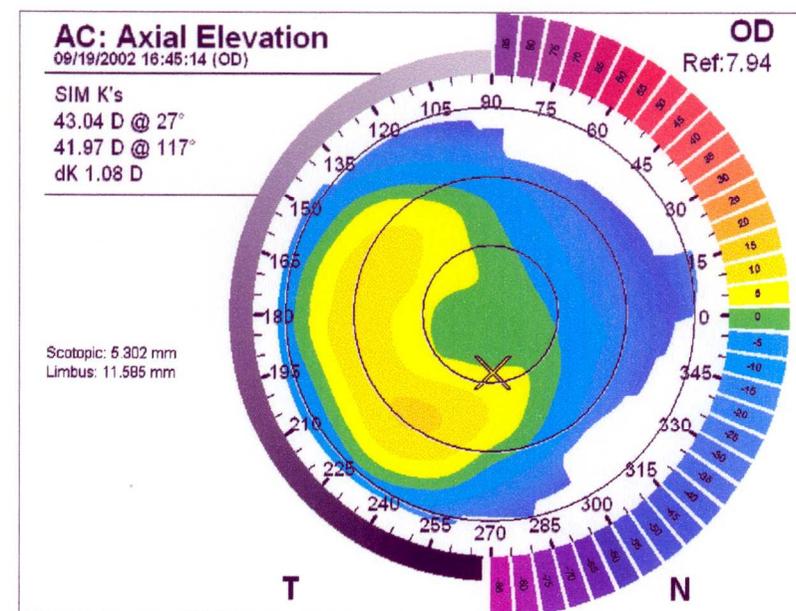
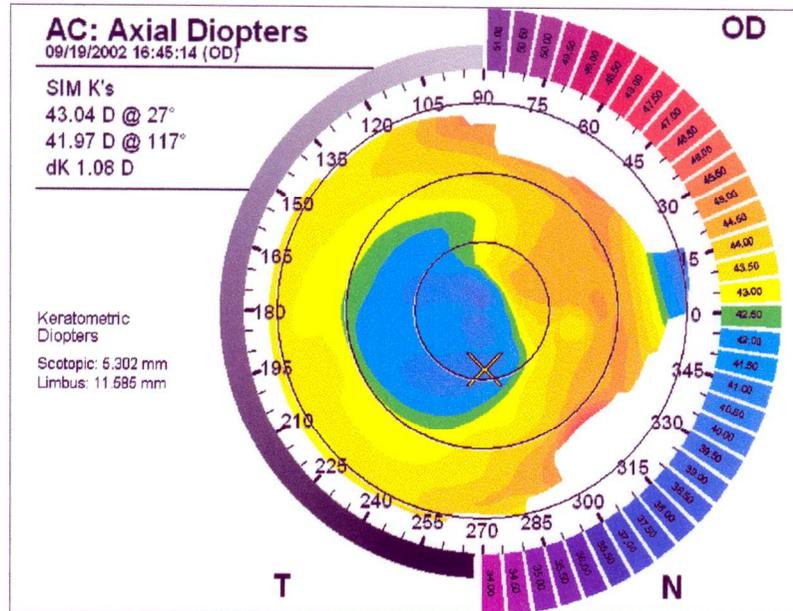
Pterygium



CK (left) vs. LASIK (right) for presbyopia (optical zone issues)



Decentered treatment

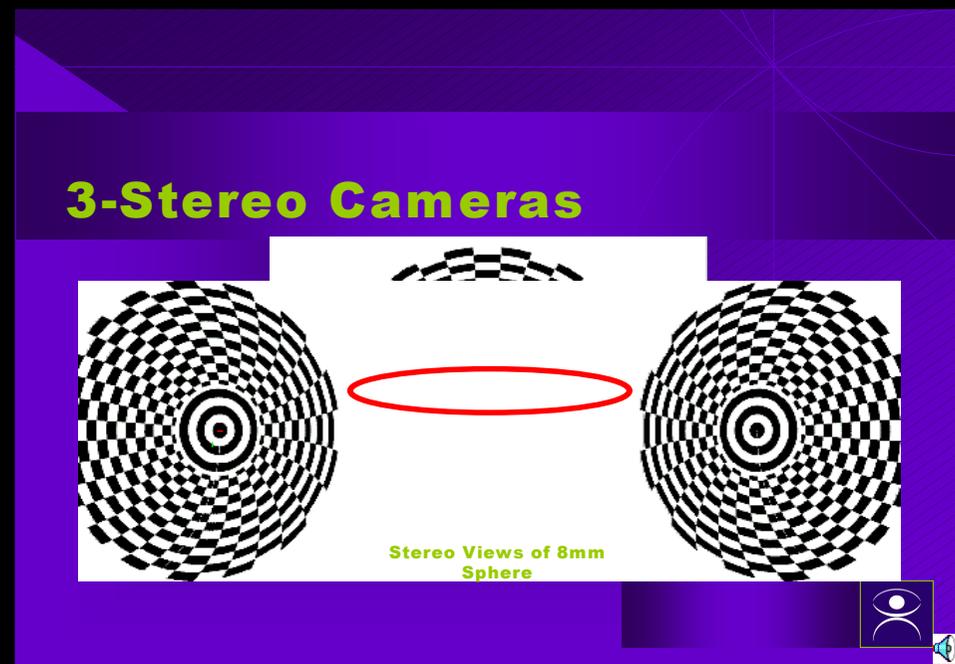


The power of 3 – 3-D stereo corneal topographer



astramax™
3 - D S T E R E O T O P O G R A P H E R

3-D stereo corneal topography:



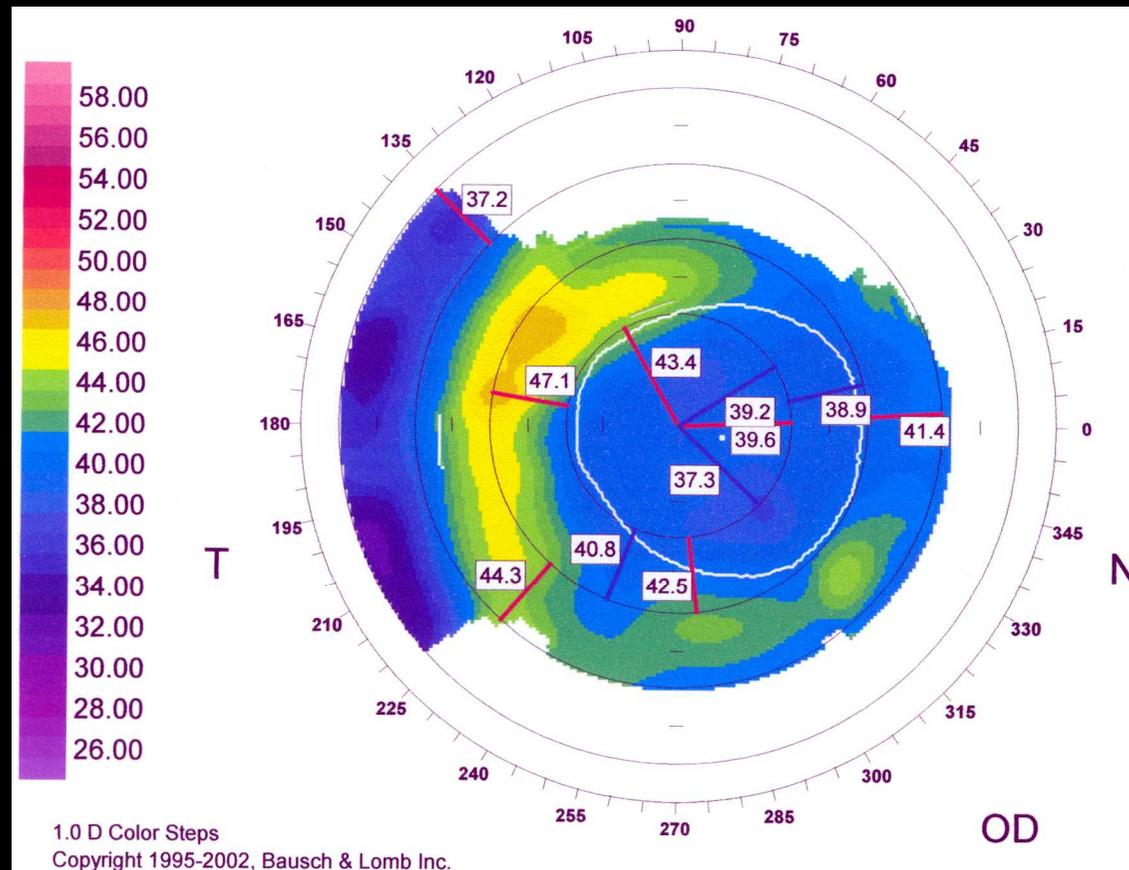
Initial Images (3-camera, checker board)

The screenshot displays a medical software interface for eye imaging. The main window is titled "Raw Eye Images" and shows a 3x3 grid of images for the right eye (OD) on 08/28/2002 at 11:05. The images are categorized as follows:

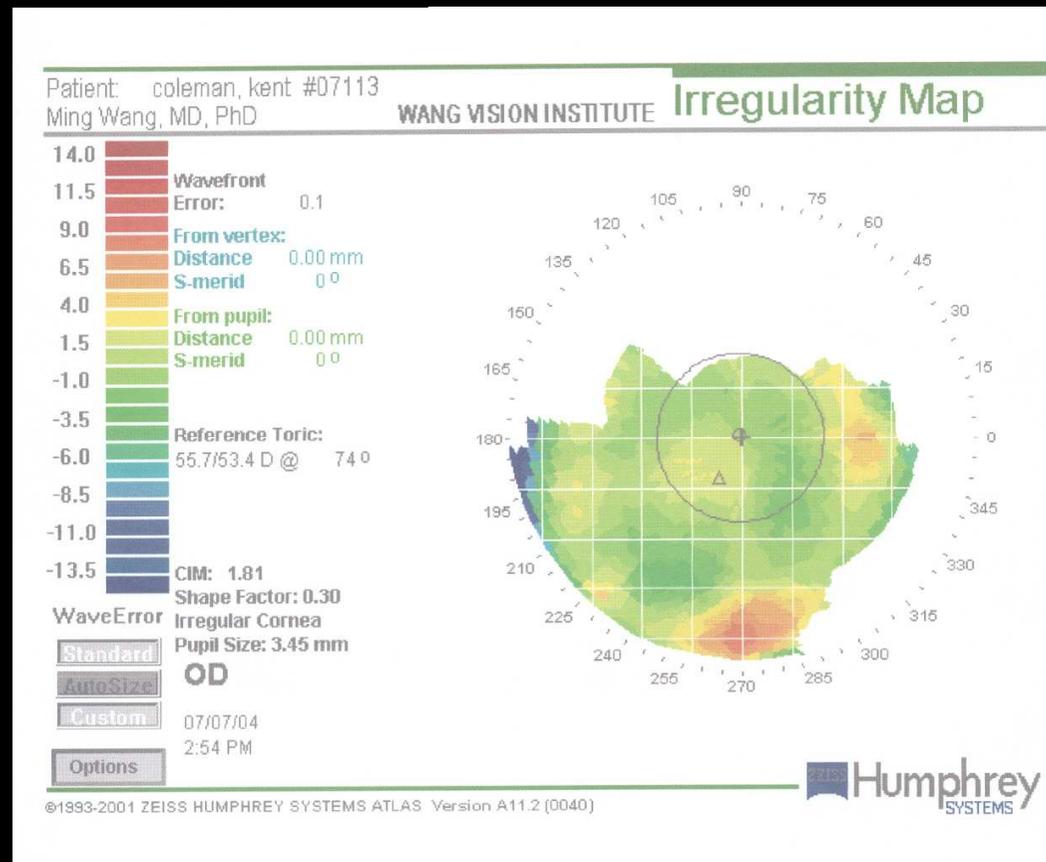
- Placido Images:** Three images showing the cornea with a Placido ring.
- Scotopic Pupil Images, Size: 5.454 mm:** Three images showing the pupil in a dark environment.
- Photopic Pupil Images, Size: 3.968 mm:** Three images showing the pupil in a bright environment.
- Cross/Pachymetry Images:** Three images showing the cornea with a crosshair pattern.

The left sidebar contains patient information for **LECROY, DOROTHY**, including birth date (08/17/1947), sex (Female), and physician (Ming Wang). The bottom of the interface features a "LASERSIGHT" logo, a copyright notice "Copyright © 2002 LaserSight Technologies, Inc.", and a toolbar with icons for Save, Process, Print, and Help.

S/P myopic LASIK with ridge



S/p LASIK (irregularity map)



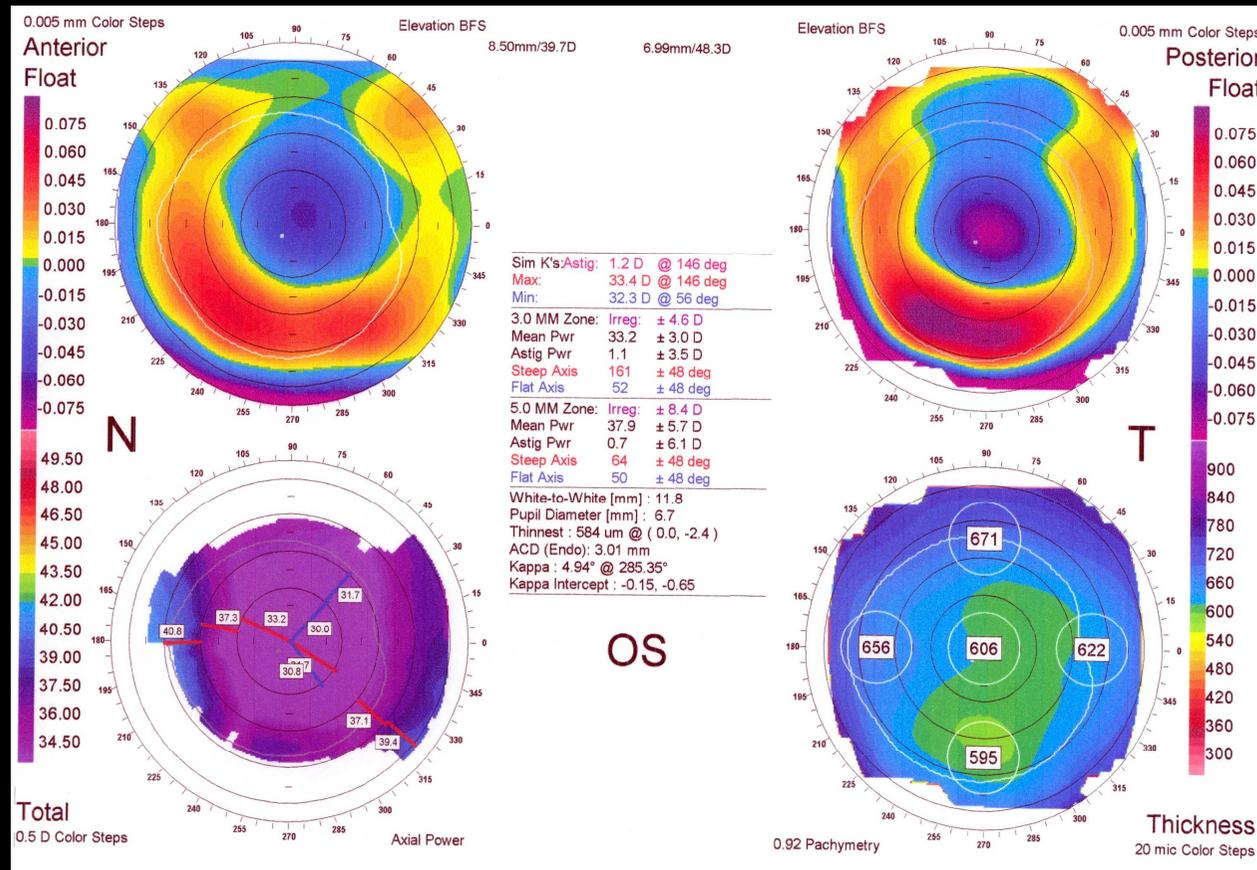
Irregular astigmatism

- Definition and classification;
- Statistical indices and KC risk indices;
- Clinical causes;
- **Other visually significant corneal changes;**
- Topo-WF correlates of irregular astigmatism;
- Treatment.

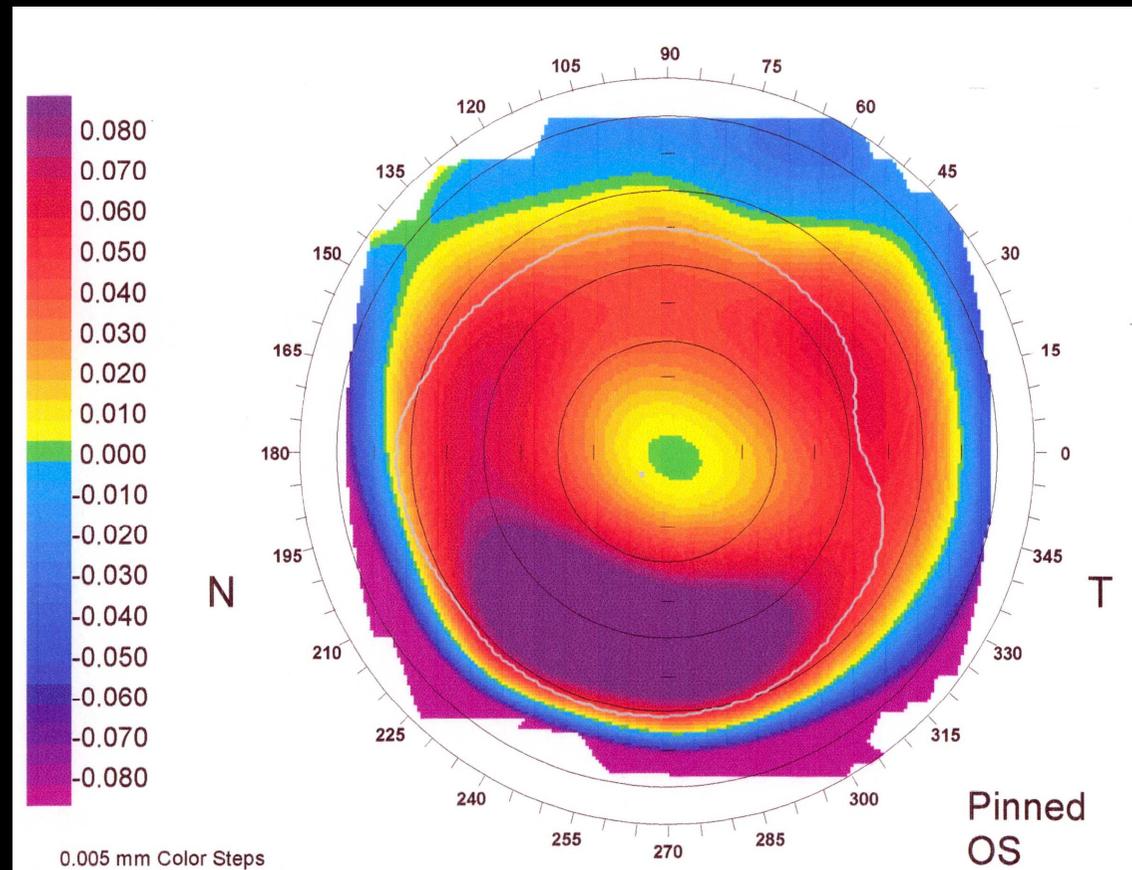
Other visual significantly corneal changes

- Extremely flat (or steep) corneas;
- Small optical zones;
- Posterior corneal changes (anterior and posterior corneal surface become *decoupled after anterior ablative procedure*).

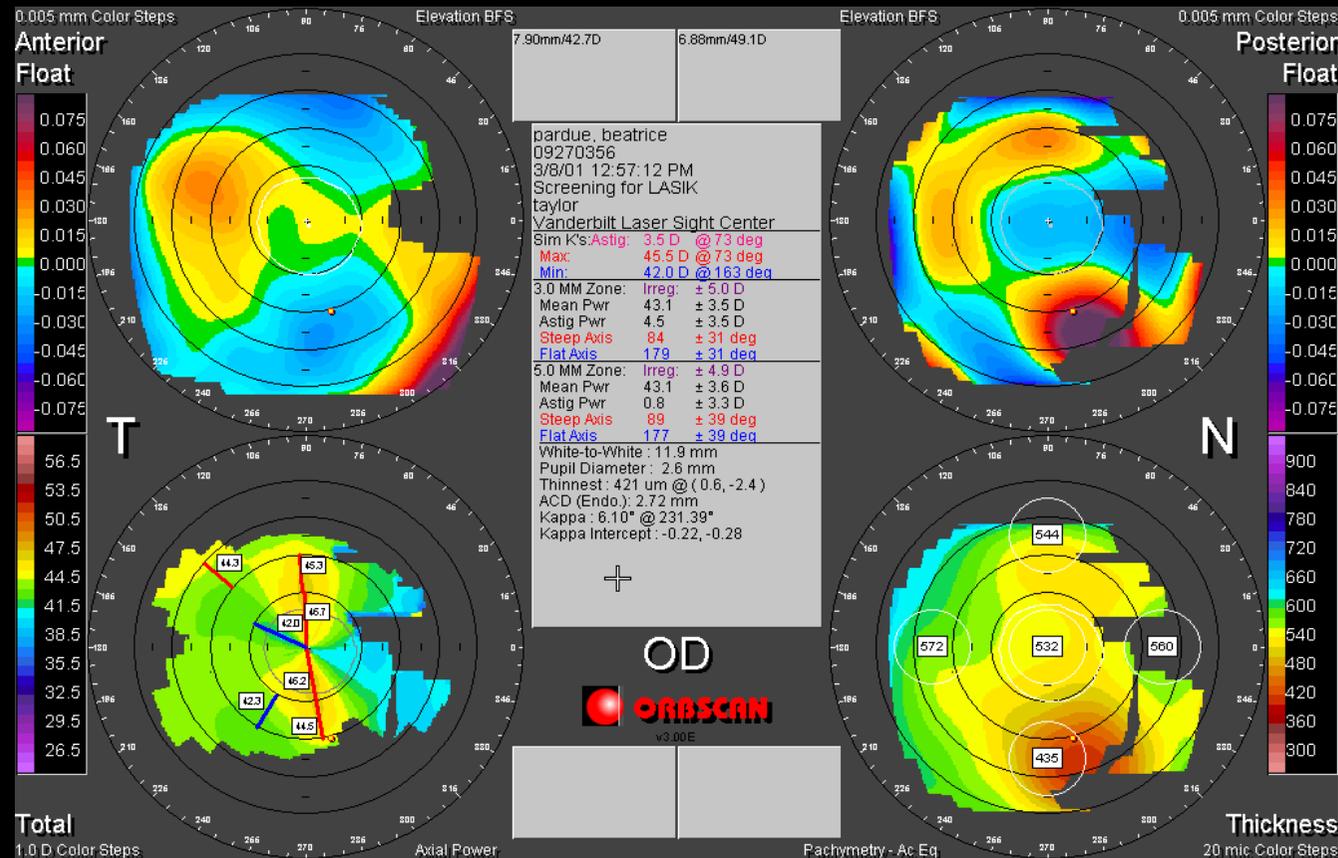
Flat cornea s/p LASIK (visual quality issues)



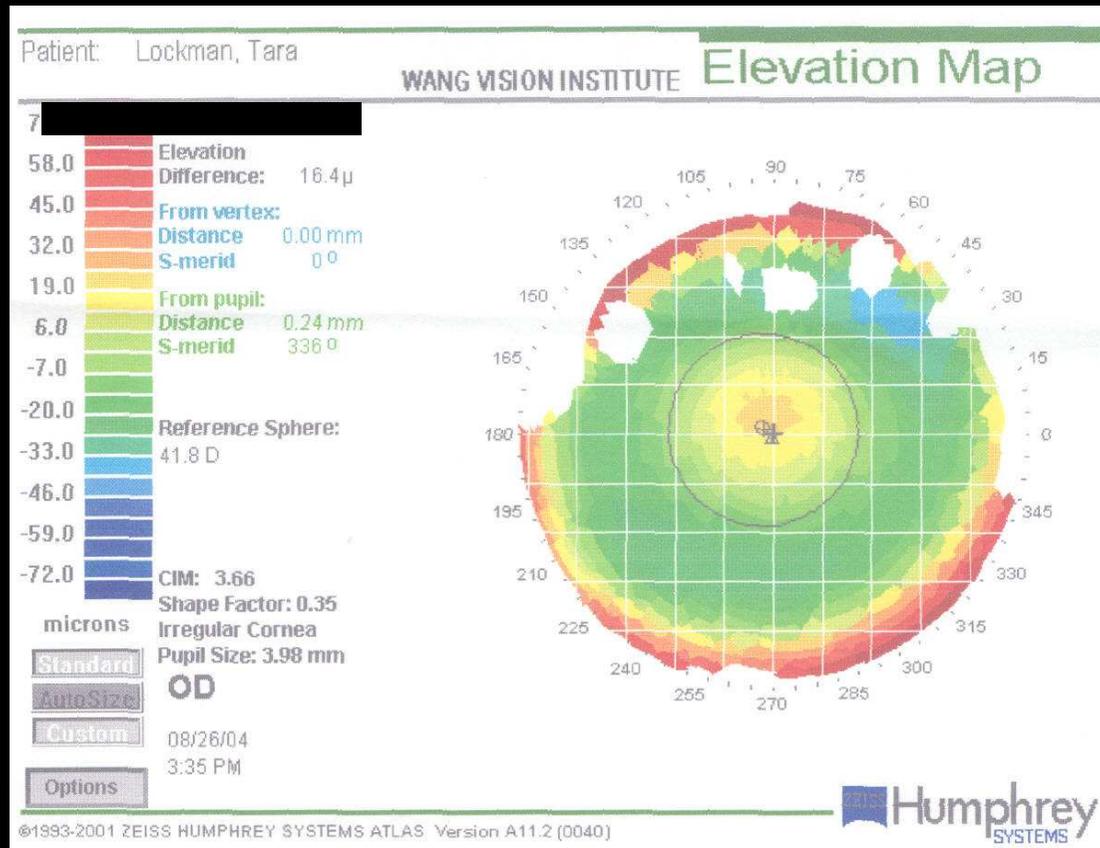
Posterior Surface changes after LASIK



Posterior changes with normal anterior corneal surface (visual quality issue)



S/P H-LASIK, small optical zone (night vision problems)



Irregular astigmatism

- Definition and classification;
- Statistical indices and KC risk indices;
- Clinical causes;
- Other corneal visually significant changes;
- **Topo-WF correlates of irregular astigmatism;**
- Treatment.

Corneal topographers

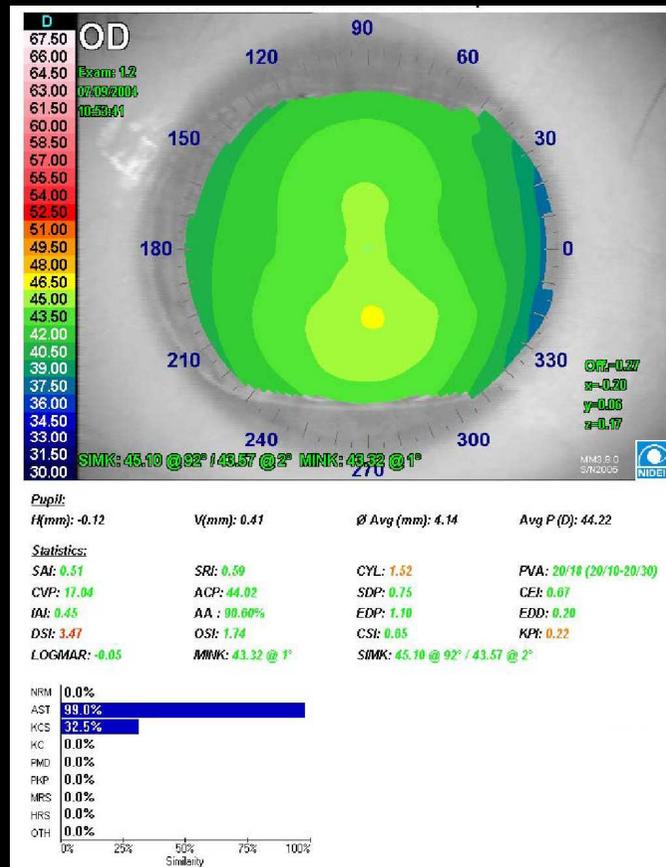
- Placido disc: Humphrey, EyeSys, Tomey Optikon, Topcon, Magellan, Orbscan, AstraMax 3-D;
- Scanning/projecting slit: Orbscan, AstraMax 3-D;
- 3-D stereo: AstraMax 3-D;
- Schimpflug rotating camera: Pentacam; Precisio;
- Ultrasound: Artemis.

3-D stereo checkboard AstraMax



A screenshot of the AstraMax software interface. The window title is "Raw Eye Images" and the patient name is "LECROY, DOROTHY". The interface shows a grid of eye images categorized into "Placido Images", "Scotopic Pupil Images, Size: 5.454 mm", "Photopic Pupil Images, Size: 3.968 mm", and "Cross/Pachymetry Images". The patient information section includes: Last (*): LECROY, First (*): DOROTHY, Middle: , Acct (*): 01371, Birth (*): 05/11/1947, Sex (*): Female, Phys: Ming Wang, Ref Phys: , Ref Group: , Diagnosis: , and Notes: . The bottom of the interface shows the LASERSIGHT logo, a copyright notice "Copyright © 2002 LaserSight Technologies, Inc.", and icons for Save, Process, Print, and Help.

Magellan

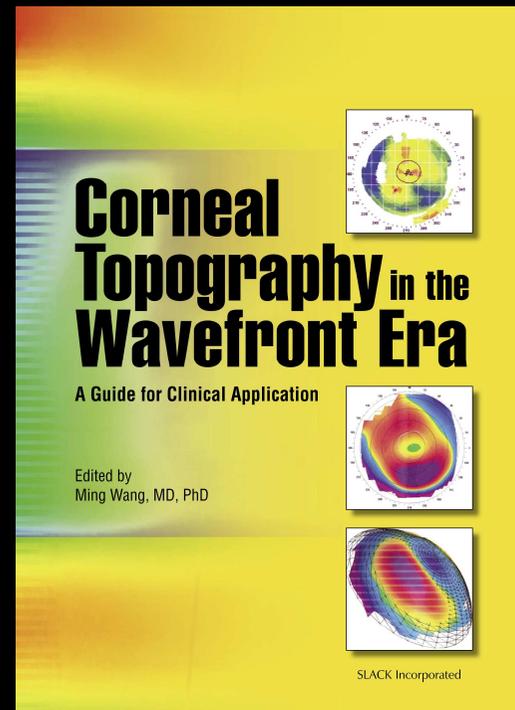


Corneal topo and combined systems

- Placido disc: Humphrey, EyeSys, Tomey Optikon, Topcon, Magellan, Orbscan, AstraMax 3-D;
- Scanning/projecting slit: Orbscan, AstraMax 3-D;
- 3-D stereo: AstraMax 3-D;
- Schimpflug rotating camera: Pentacam;
- Ultrasound: Artemis;
- Topo-WF combined systems.

New Book: "Irregular Astigmatism"
(SLACK)

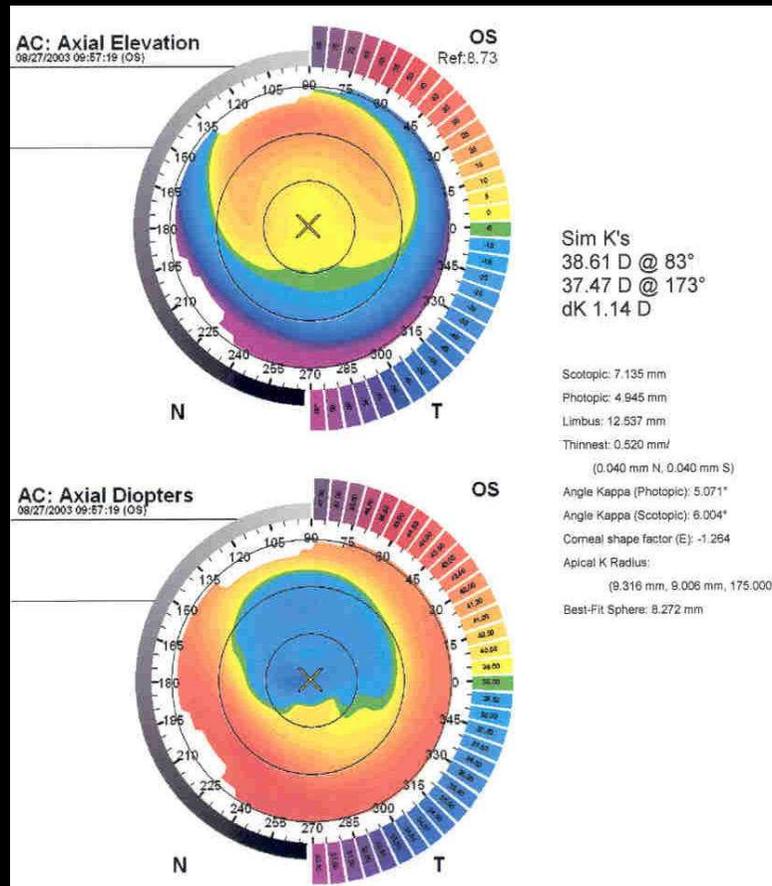
New comprehensive textbook



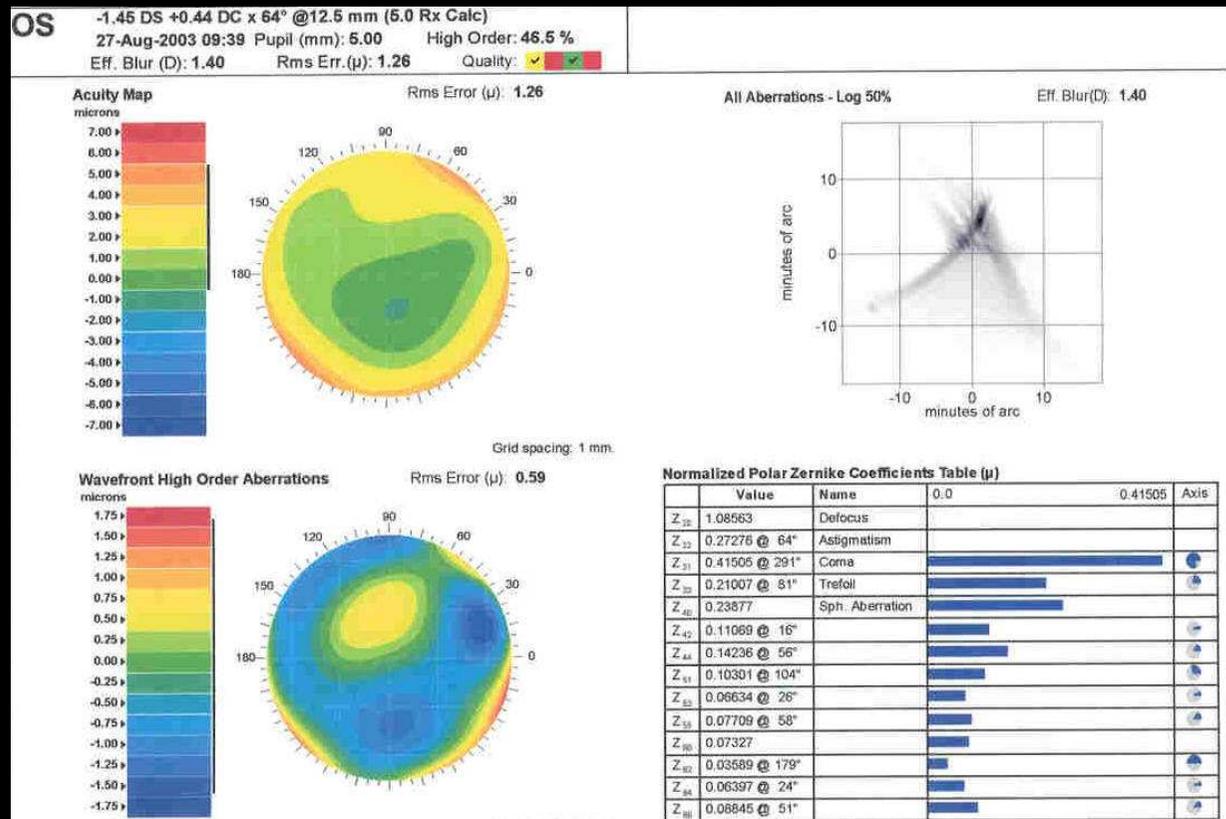
Topo-WF correlates of irregular astigmatism

TOPOGRAPHY	WAVEFRONT ABERROMETRY
Loss of prolate cornea, small optical zone	Increase in spherical aberration
Irregular astigmatism	Increase in coma and trefoil
Decentered ablations	Coma

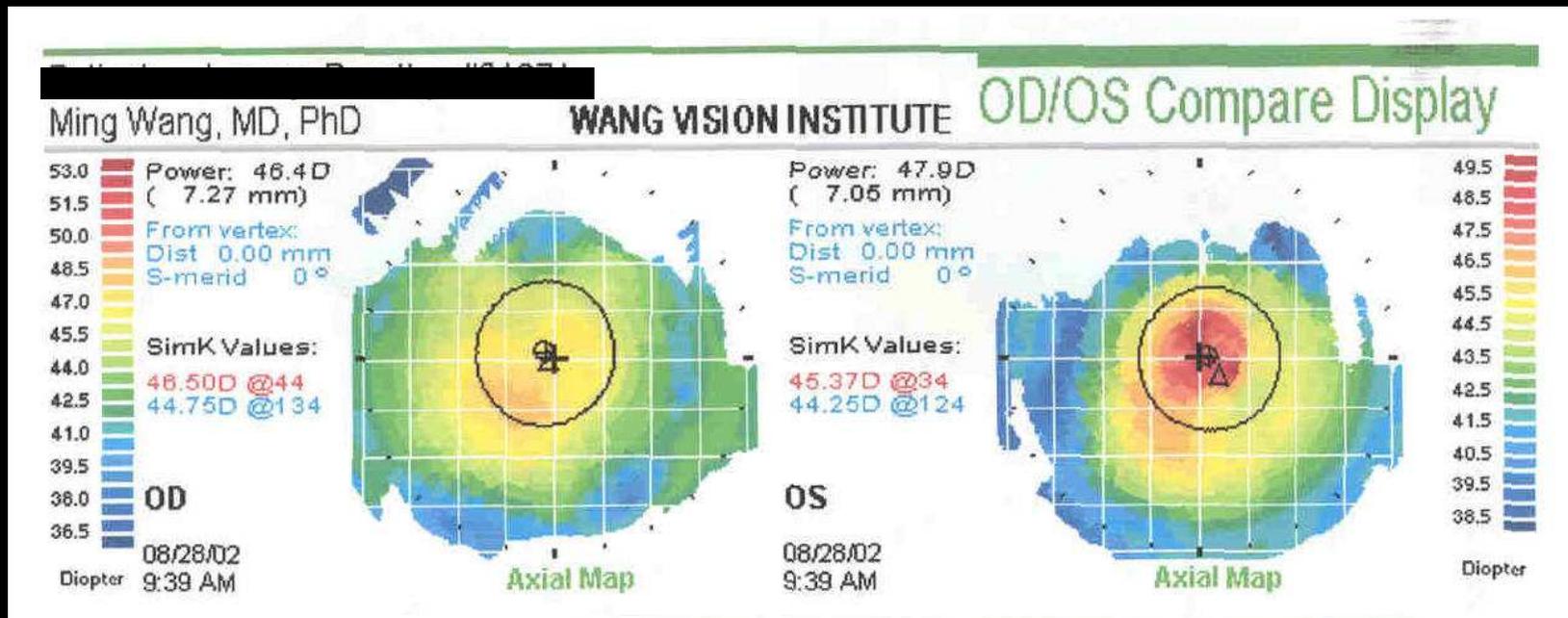
Decentered ablation (topo)



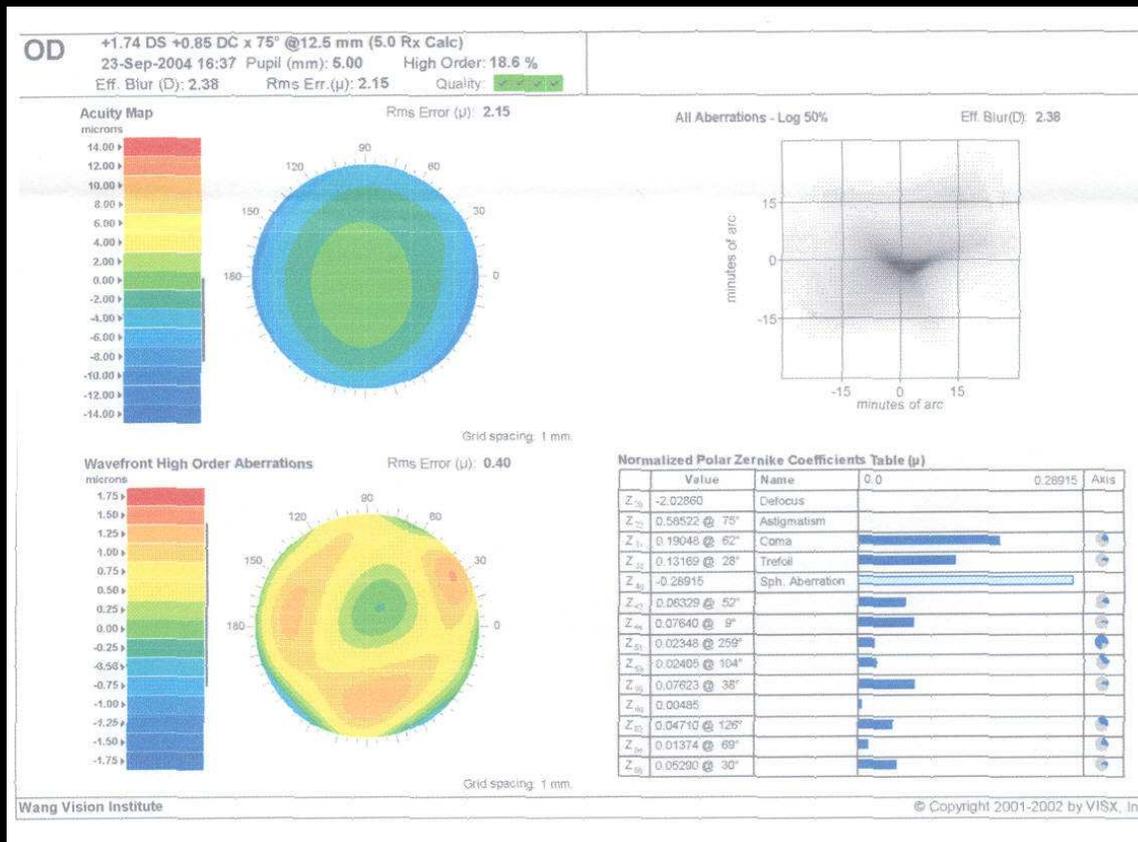
Decentered ablation (WF: coma)



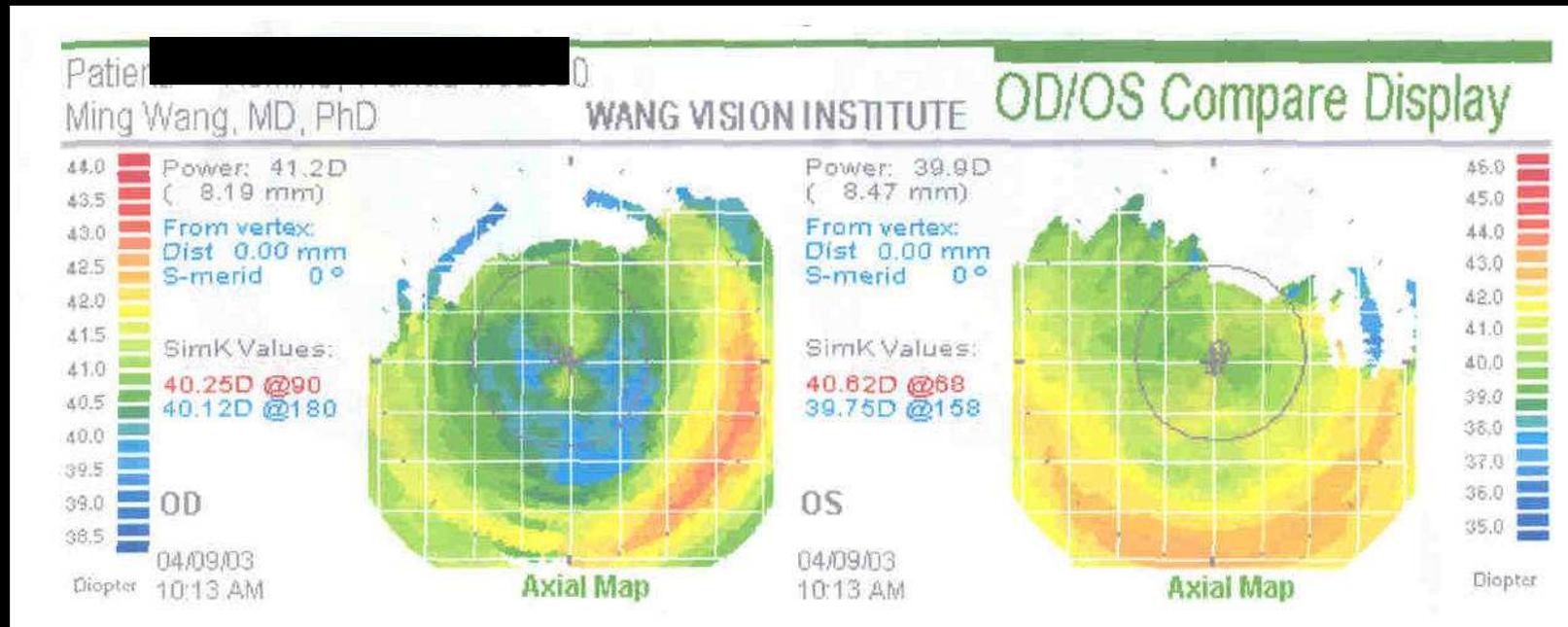
Small optic zone s/p H-L (topo)



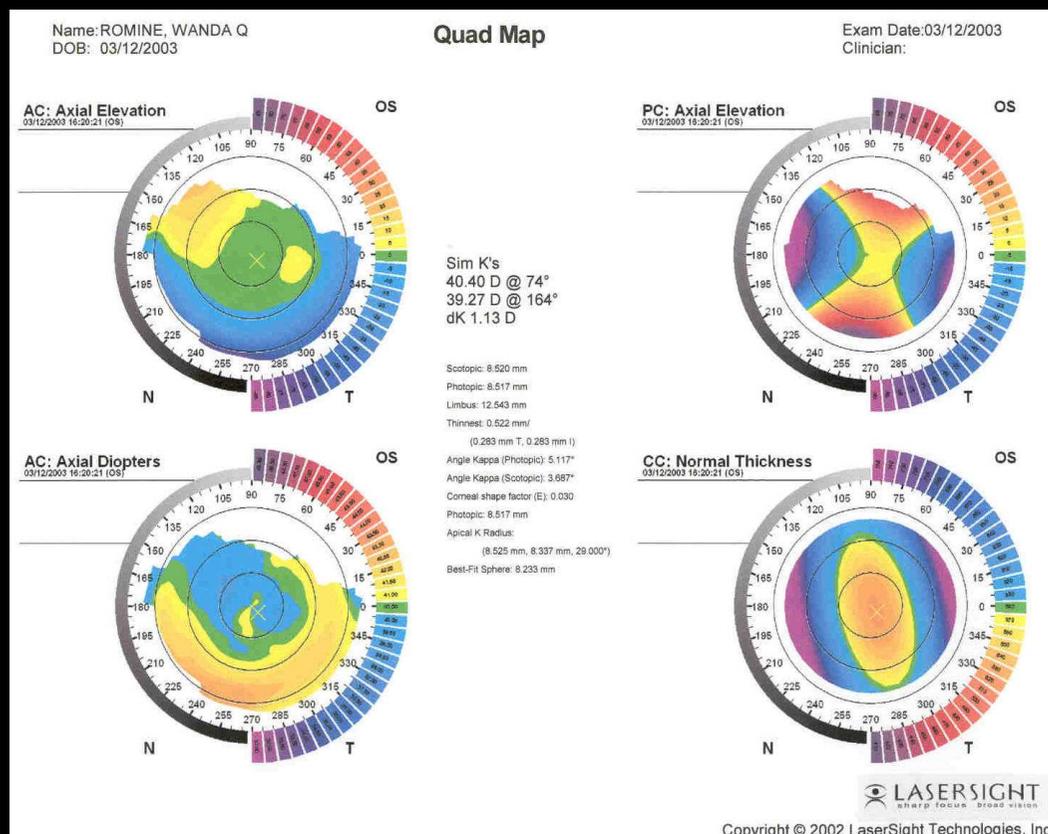
Small optical zone s/p H-L (WF: spherical aberration)



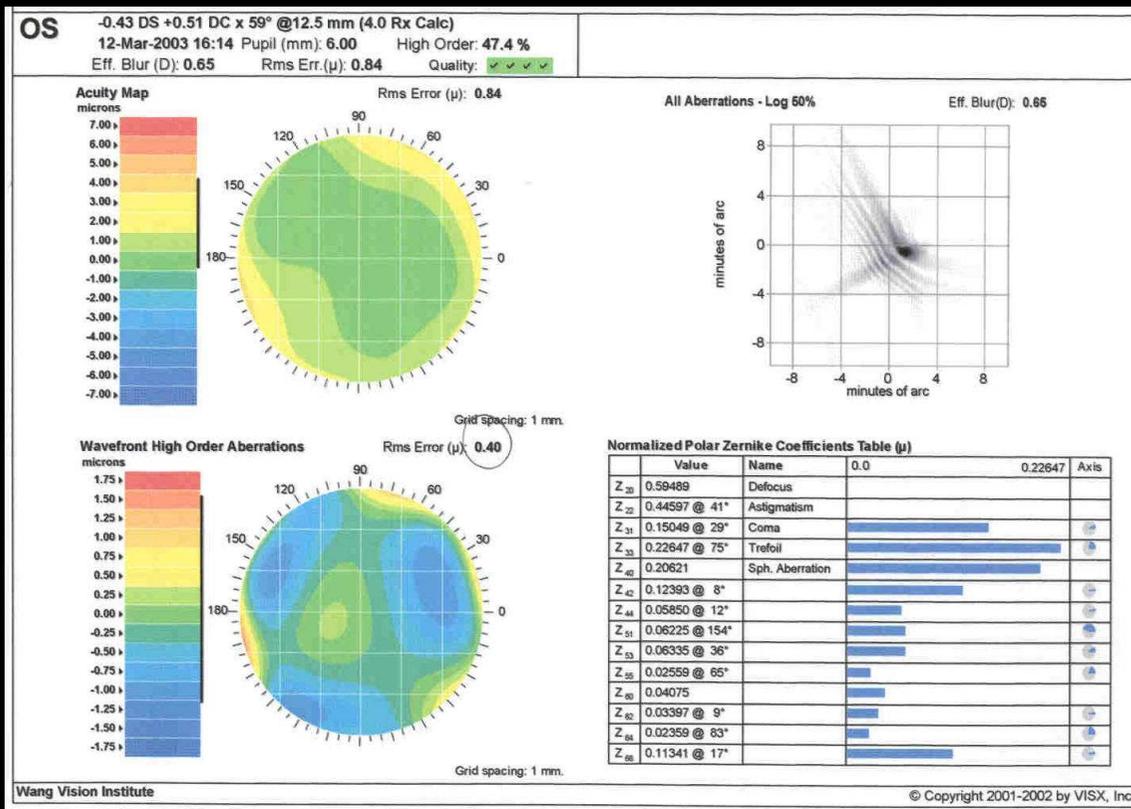
Irregular astigmatism (topo): night glare and decreased BSCVA



Irregular astigmatism (topo, 3-D)



Irregular astigmatism (WF: trefoil, SA, coma)



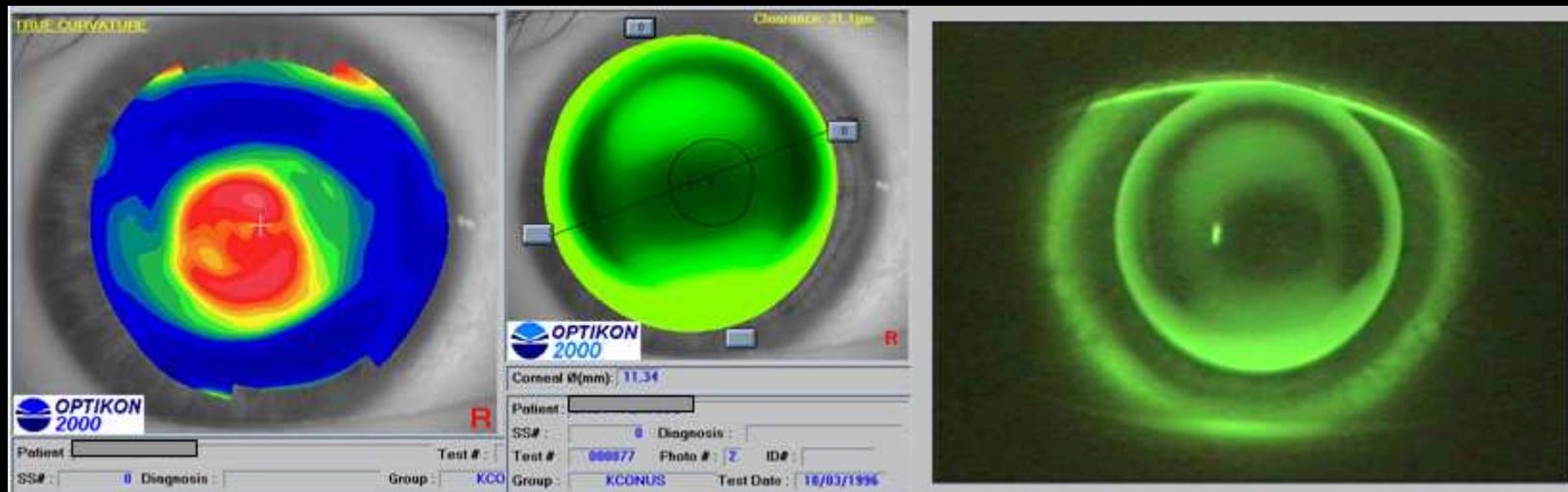
Irregular astigmatism

- Definition and classification;
- Statistical indices and KC risk indices;
- Clinical causes;
- Other visually significant corneal changes;
- Topo-WF correlates of irregular astigmatism;
- **Treatment.**

Treatment options for irregular astigmatism

- RGP;
- C-CAP for decentered treatment;
- Wavefront-driven custom;
- Topo-driven custom;
- Intacs for KC;
- Topo-wavefront combined approach (ACAP);
- Others.

RGP



C-CAP for decentered treatment

Ming Wang, MD, PhD
WANG VISION INSTITUTE

Vision Pro VISX Star S3 Ablation Planner
Ablated Map

Elev. Diff.: -2.3 μ

From Vertex
X Offset: 0.0 mm
Y Offset: 0.0 mm

From Pupil
X Offset: 0.2 mm
Y Offset: -0.1 mm

Ref. Sph.: 43.33 D
Pupil Size: 3.02 mm

Standard
AutoSize
Custom

OD 09/19/2002
3:38:47 PM

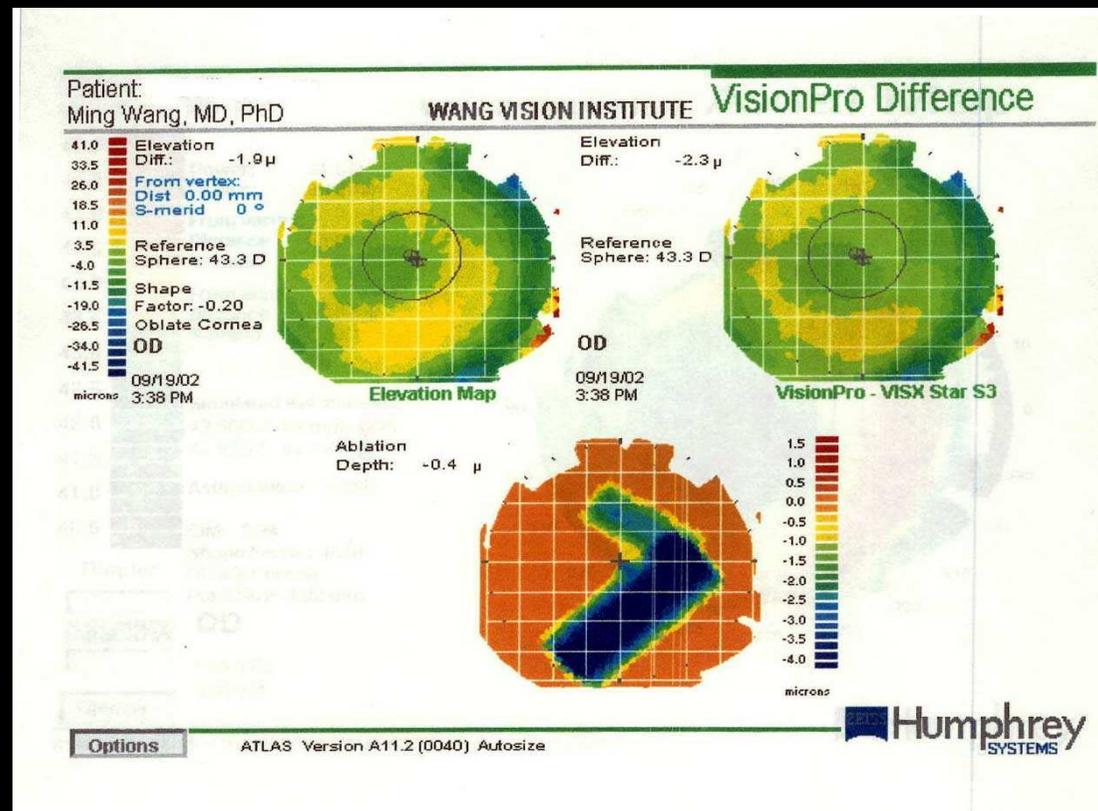
VTX: 13.1 mm K1: 43.50 D. K2: 42.62 D. K2 Axis: 116 Deg.

#	Sph	Cyl	Axis	Dim.1	Dim.2	Trans	XOff	YOff	Depth	Surf.
1		-2.50	147	4.0	1.8	0.5	0.9	1.0	3	M Cylinder
2		-2.00	43	6.0	2.7	0.4	0.6	-1.8	5	M Cylinder

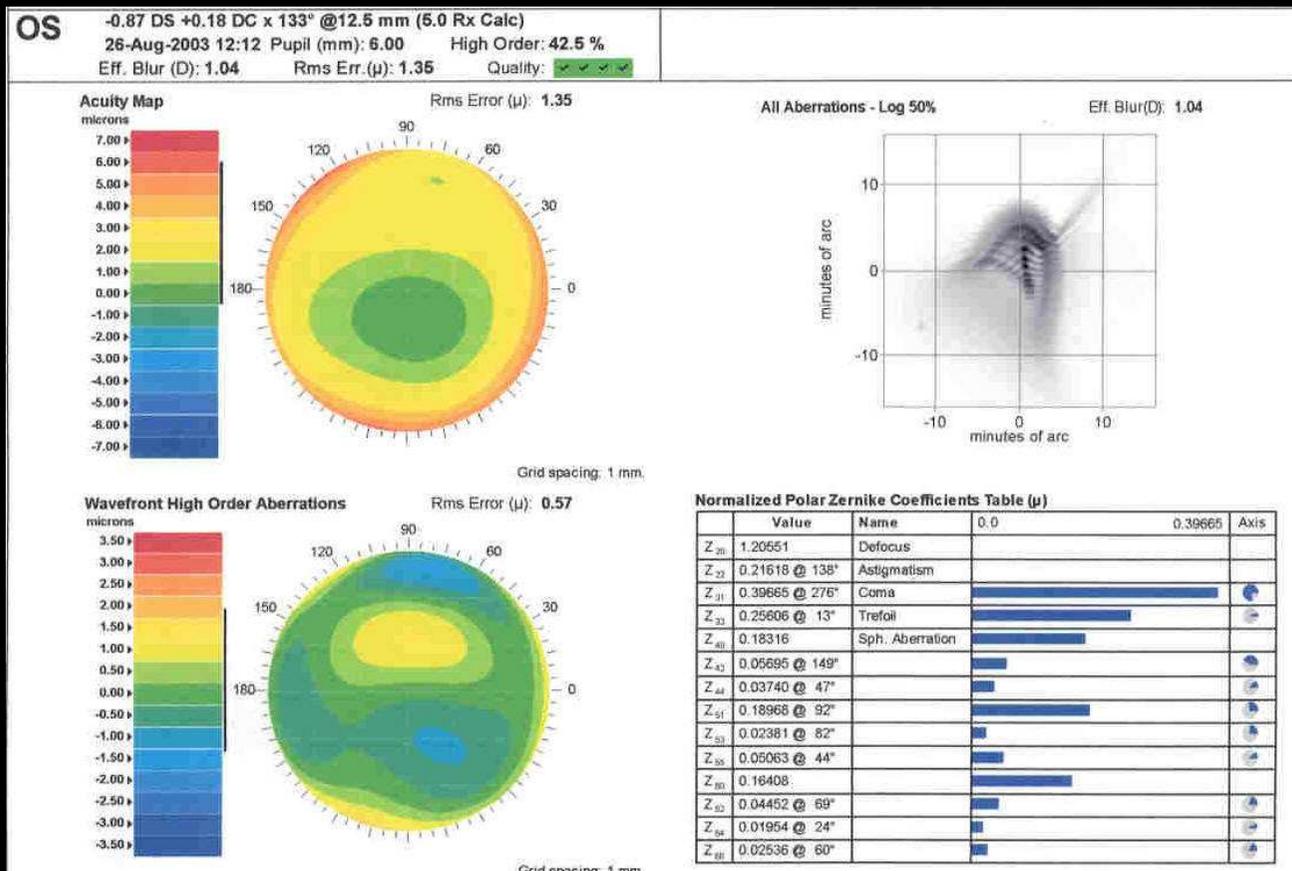
Treatment: CAP Method Ablate Reset Print Save & Exit Cancel Help

©1993-2002 Carl Zeiss Ophthalmic Systems Atlas Ver. A11.2 (0040) - VisionPro Ver. Humphrey SYSTEMS

C-CAP: pre and post and difference (volume of corneal tissue removed) map



Wavefront-driven custom: Irregular astigmatism (coma, trefoil)



Wavefront-driven custom Rx for irregular astigmatism (coma and trefoil, volume of corneal tissue removed Rx plan)

OS	-0.84 DS +0.23 DC x 170° @12.5 mm (4.0 Rx Calc)
	26-Aug-2003 12:13 Pupil (mm): 6.00 High Order: 46.2 %
	Eff. Blur (D): 1.02 Rms Err.(μ): 1.33 Quality: ✓✓✓✓

Manifest: -1.75 DS +0.00 DC @ 12.50 mm
Cycloplegic:
Auto:
Auto+Cyclo:
K1 (D): 43.50 K2 (D): 43.50 K2 axis(°):
Corneal Thickness (μ): 444
Scotopic Pupil Size (mm): 6.00
Treatment Type: LASIK Correction Type: Wavefront

Physician Adjustments - SPH (D): -0.50 CYL (D): +0.00 Axis(°):	VTX(mm): 0.00
Total Correction - SPH (D): -1.33 CYL (D): +0.23 Axis(°): 170	VTX(mm): 0.00

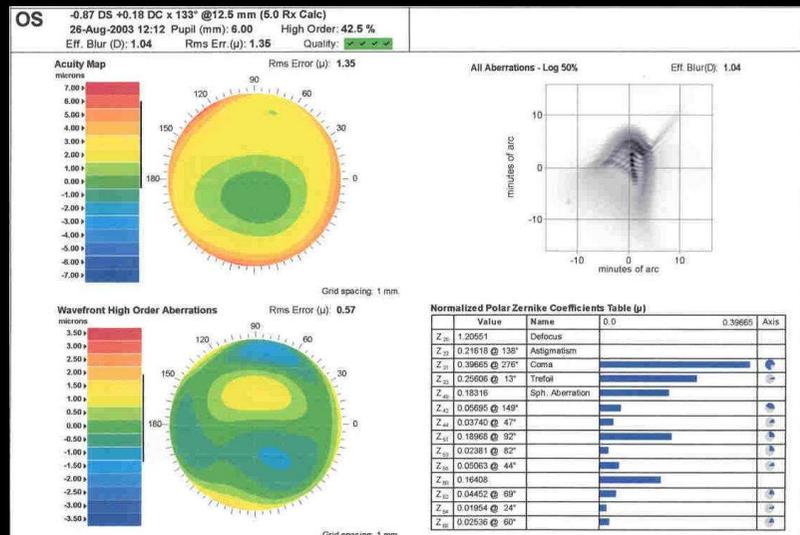
Treatment Parameters	
Optical Zone (mm): 6.00 x 6.53	
Ablation Zone (mm): 8.00	
Max. Ablation Depth (μ): 27.3	
No. of Tissue Pulses: 146	
Treatment Time (sec): 15	
Surgical Parameters	
Flap Diameter (mm): 9.00	
Flap Thickness (μ): 130	
Residual Bed (μ): 287	
Additional Information	
The Manifest and WaveScan refractions do not match	

Distribution of VSS Pulse Diameters

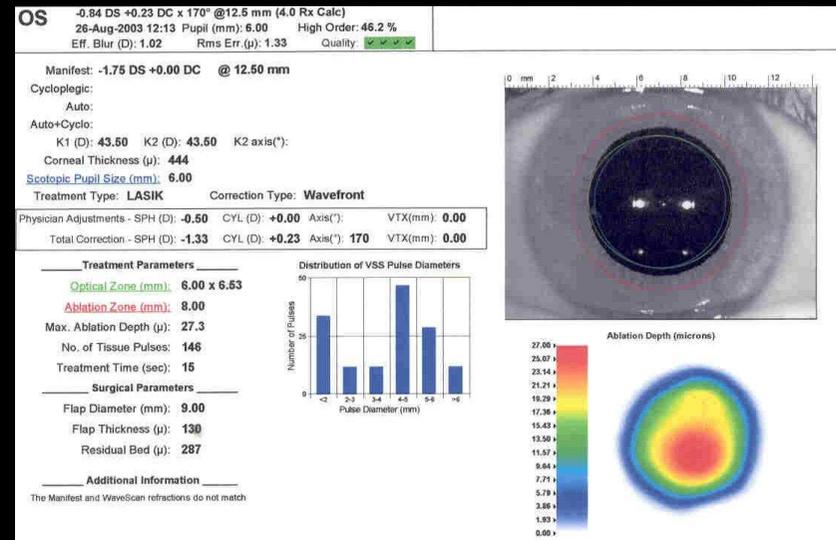
Pulse Diameter (mm)	Number of Pulses
<2	38
2-3	18
3-4	18
4-5	48
5-6	32
>6	18

Ablation Depth (microns)

Wavefront-driven custom for irregular astigmatism: preop WF and corneal removal volume Rx plan

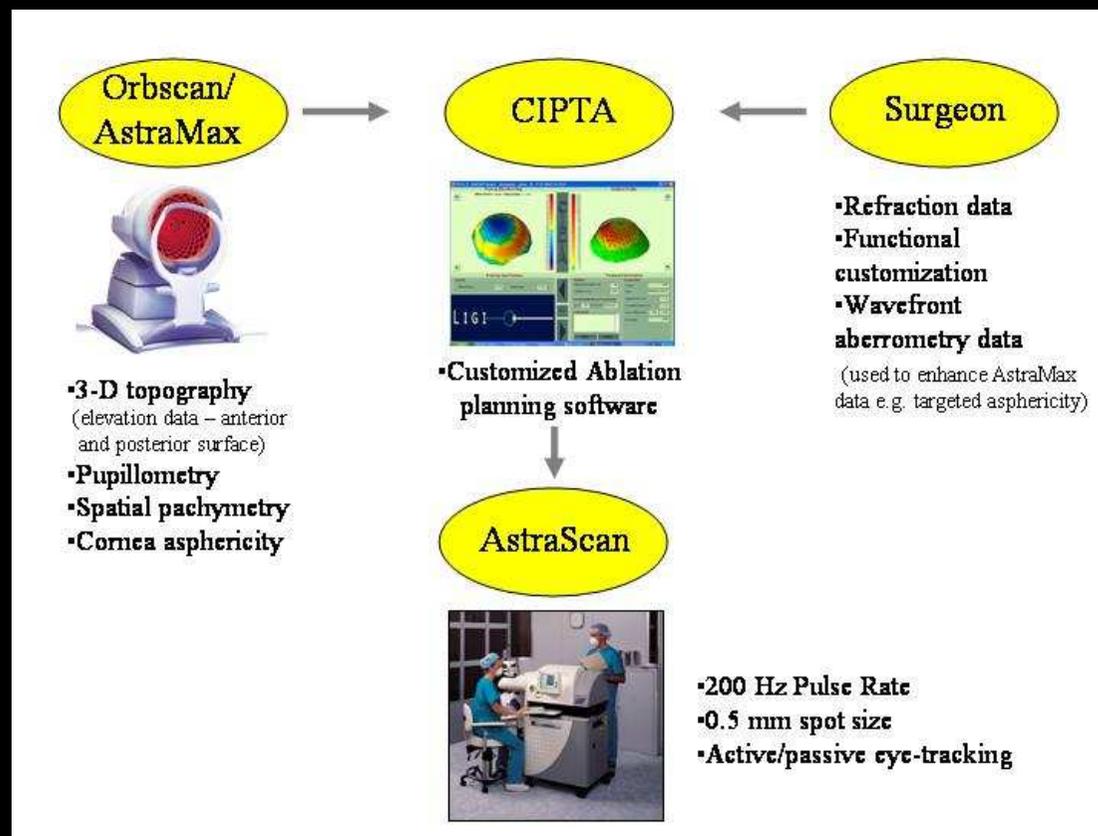


Preop WF



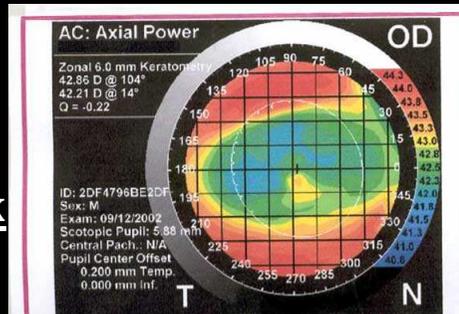
Rx plan (corneal tissue to be removed)

Topography-guided custom LASIK



Topo-driven custom: preop topo (central island) and postop topo, comparing custom (OD) with non-custom (OS) (Stojanovic)

Pre-therapeutic Rx



O.d. 12.09.2002

preop



O.s. 12.09.2002

preop

Pre-therapeutic Rx

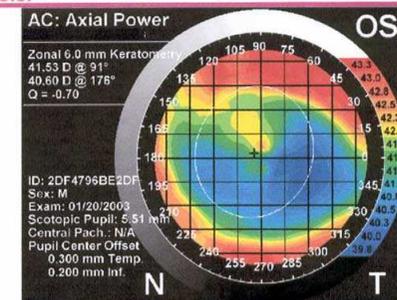
Post (custom)

Central island corrected



O.d. 20.01.2003

RL



O.s. 20.01.2003

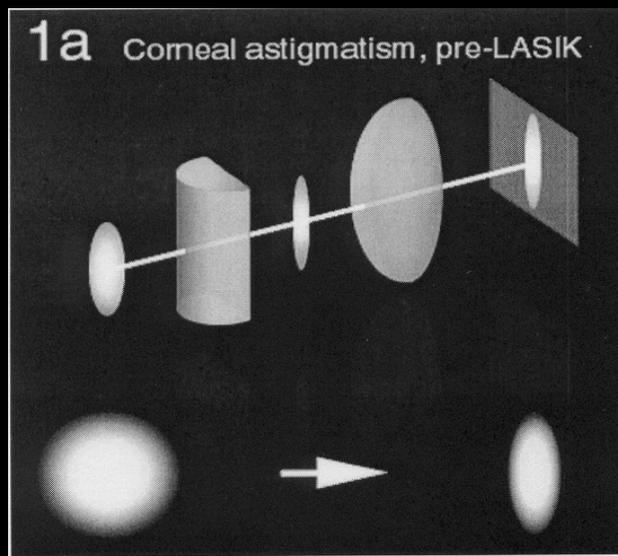
Post (conventional)

Central island remains

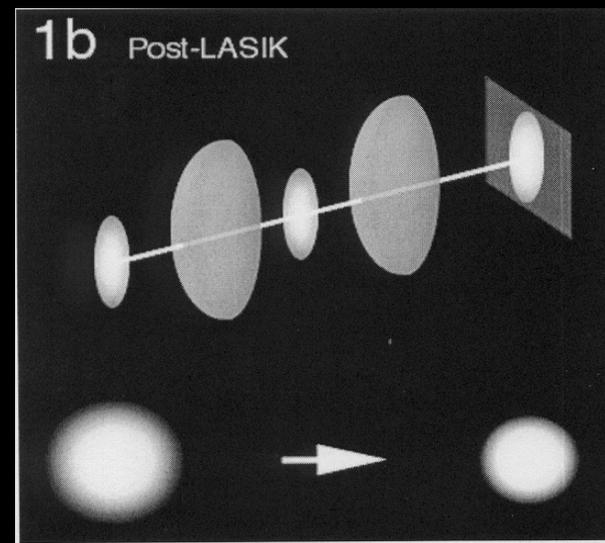
What to base to treat, topo or WF?

- Topo-driven: correct **where** the problem is (s/p keratorefractive surgery). Can create ideal cornea, but can have non-ideal overall WF, and hence may not have as good vision as WF-driven; **Let the cornea bear what is rightfully its burden**;
- WF-driven: Can create ideal overall WF, but can have irregular cornea. Vision can be good (but can be temporally, since cornea is corrected to compensate HOA of lens, and lens HOA changes more sensitively over time). **Let the poor cornea bear the ENTIRE visual axis WF error correction burden (i.e., assuming location of aberration, i.e., lens vs cornea, does not matter)**.
- Topo-WF weighted approach: Alpin's. But, how about the issue of non-simultaneity of optimization of lens and cornea?

Location of aberration along visual axis DOES make a difference: Treating **anterior corneal astigmatism **on cornea** gives good result (lesser untreated cylinder)**

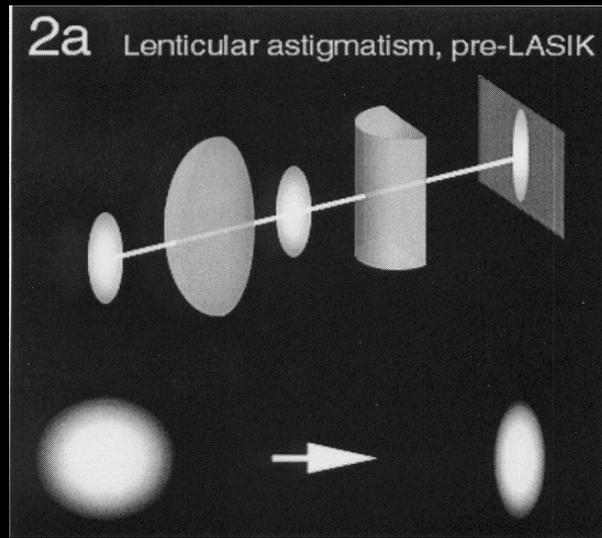


Circular incoming light.

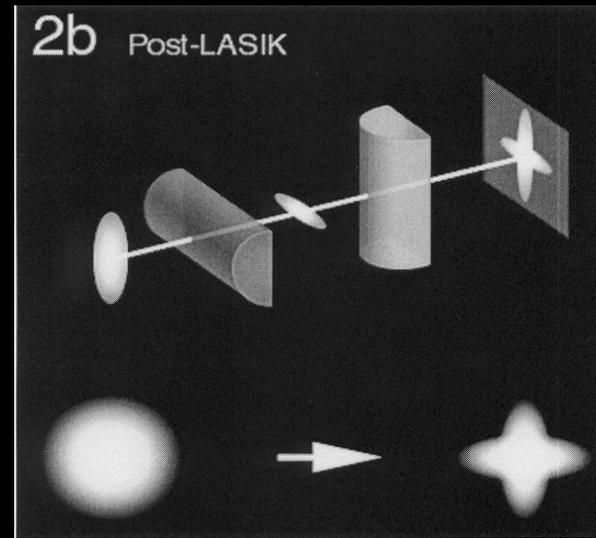


End result: a nice circular image on retina, minimal residual uncorrected cylinder.

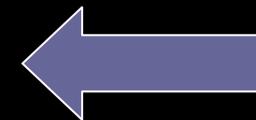
Location of aberration along visual axis DOES make a difference: treating *non-anterior* corneal cyl on cornea gives unsatisfactory result (more cyl left untreated)



Circular incoming light.

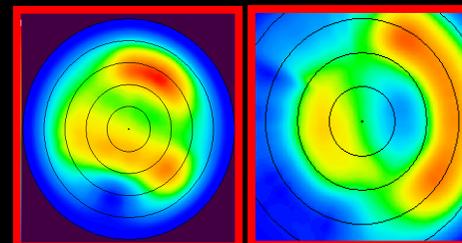
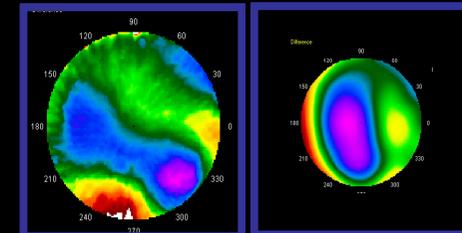
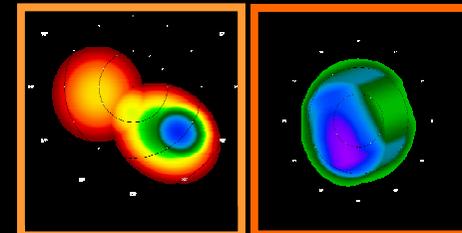
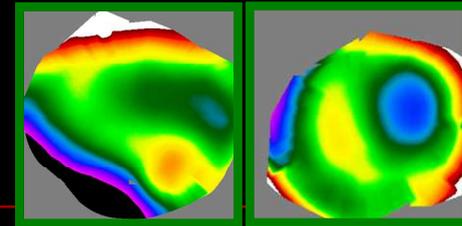


End result: a bizarre imperfect image on retina, due to more residual *uncorrected* cylinder.



Combined topo- WF approach

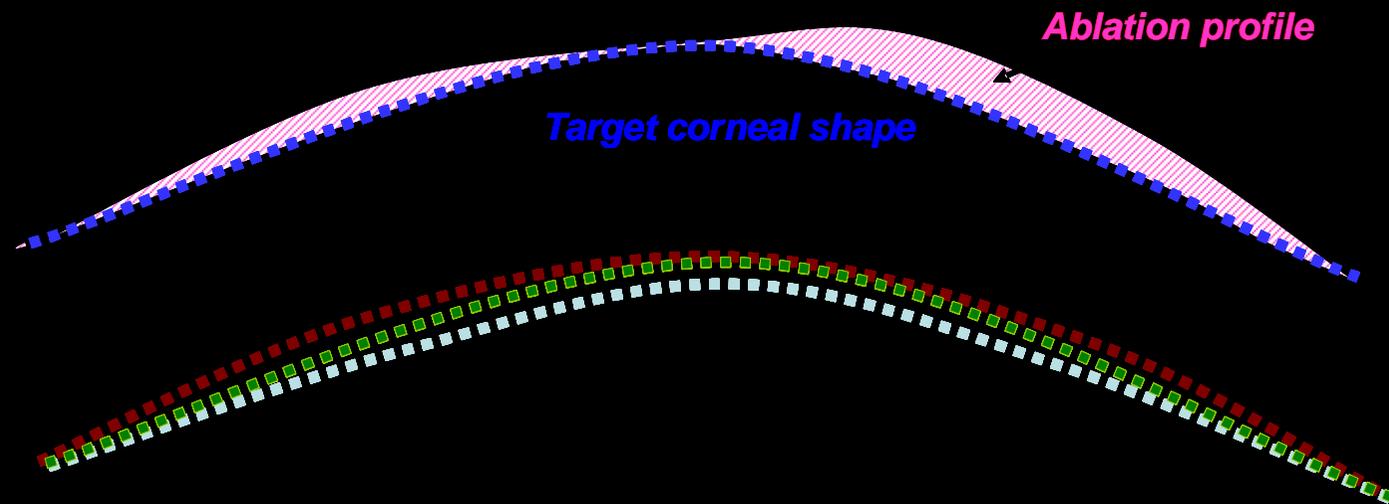
VISX model:
the Advanced
Corneal Ablation
planner (ACAP)



ACAP-topo-WF combined approach

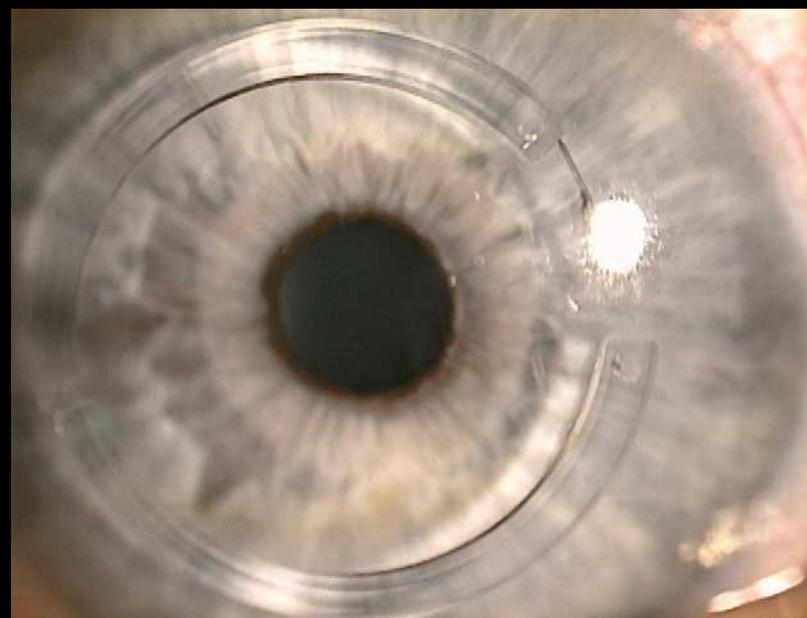
- Integration of wavefront, topography, and VISX laser using WaveStar software;
- Software allows surgeons to build various models representing the “optical target”, defining the desired optical properties of the cornea after surgery based on combinations of wavefront and topographic information.

ACAP-topo-WF combined approach

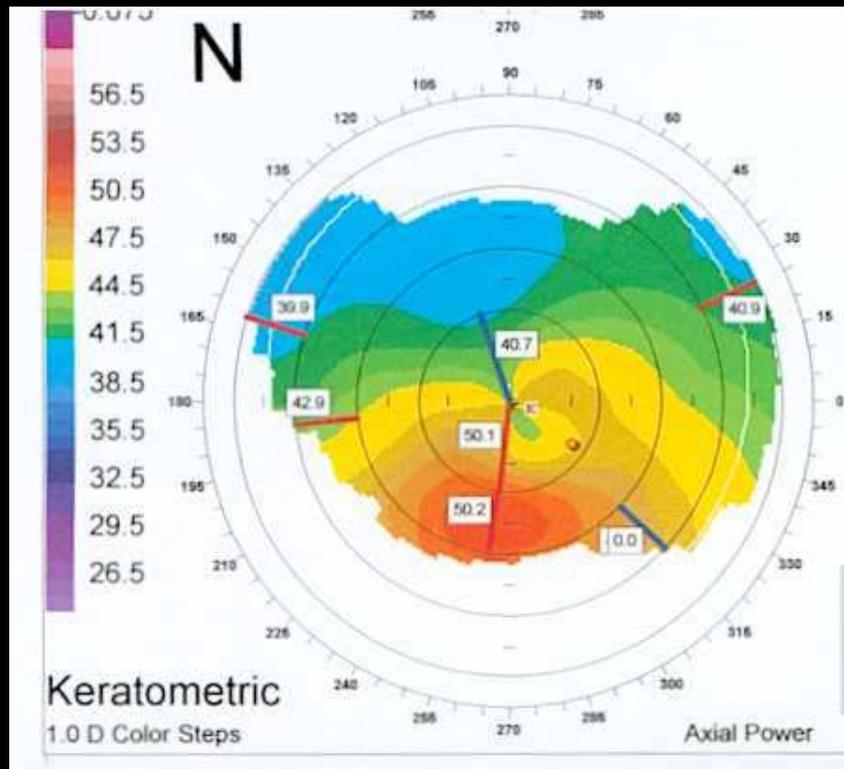


Various models for treatment (corneal tissue removal volume) based on various weighted combinations of wavefront and topography data.

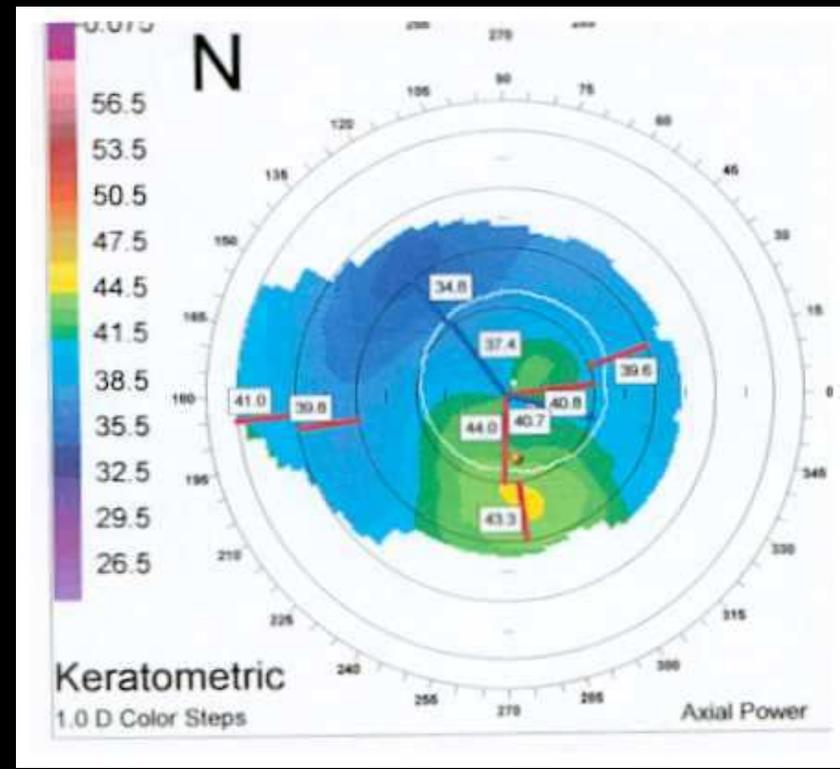
Intacs for KC



Intacs for KC



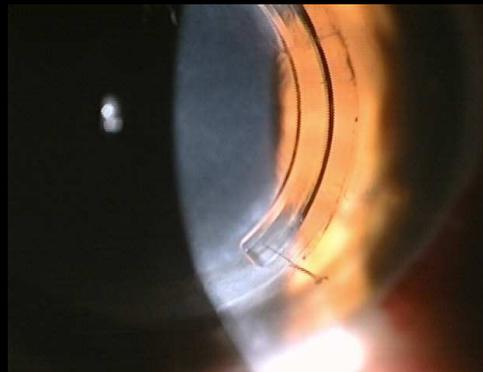
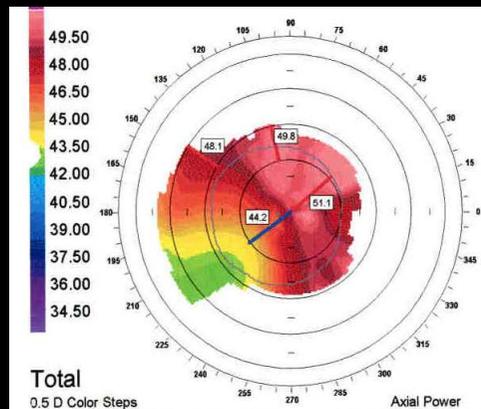
PRE-OP



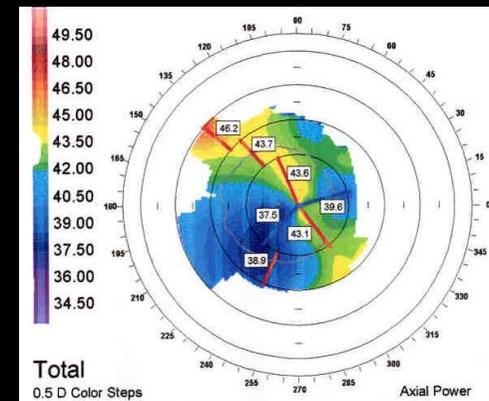
POST-OP

The first case of femtosecond laser- Intacs for recurrent KC on graft

BSCVA=20/200
Diplopia
RGP intolerant
Needs repeat graft



BSCVA=20/20
Happily wearing
SPECTACLES
No diplopia



Irregular astigmatism

- Definition and classification;
- Statistical indices and KC risk indices;
- Clinical causes;
- Other visually significant corneal changes;
- Topo-WF correlates of irregular astigmatism;
- Treatment.

