Understanding Topography and Corneal Aberrations

How to use this technology to its fullest

American Society of Cataract and Refractive Surgery

IC-218

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Disclosure statement

Warren E. Hill, MD

Alcon Laboratories

Consultant, Speaker

Haag-Streit, Switzerland

Consultant, Speaker, Research, Licensing

Omega Ophthalmics

Consultant, Stockholder

Optos

Consultant, Speaker

Carl Zeiss Digital Innovations

Consultant

LensAR

Consultant, Research, Speaker

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Subject line: ASCRS Topography course handout

Placido topography can be used for…

	True	False
Surface elevation, irregularity and curvature.	☑	☐
Refractive data (sphere, cylinder & axis).	☐	☑
Regional pachymetry.	☐	☑
Anterior corneal aberration profile.	☑	☐
Identifying the location of the corneal apex.	☑	☐
Posterior corneal power mapping.	☐	☑
~~Keratoconus screening…~~ Accurate diagnosis.	☑	☑
Multifocal IOL screening.	☑	☐
Sophisticated image simulation.	☑	☐

Many Placido topography devices available

Handheld Placido disk

Zeiss Atlas 9000

Nidek OPD Scan III

ReSeevit-Modi

Oculus Keratograph 5M

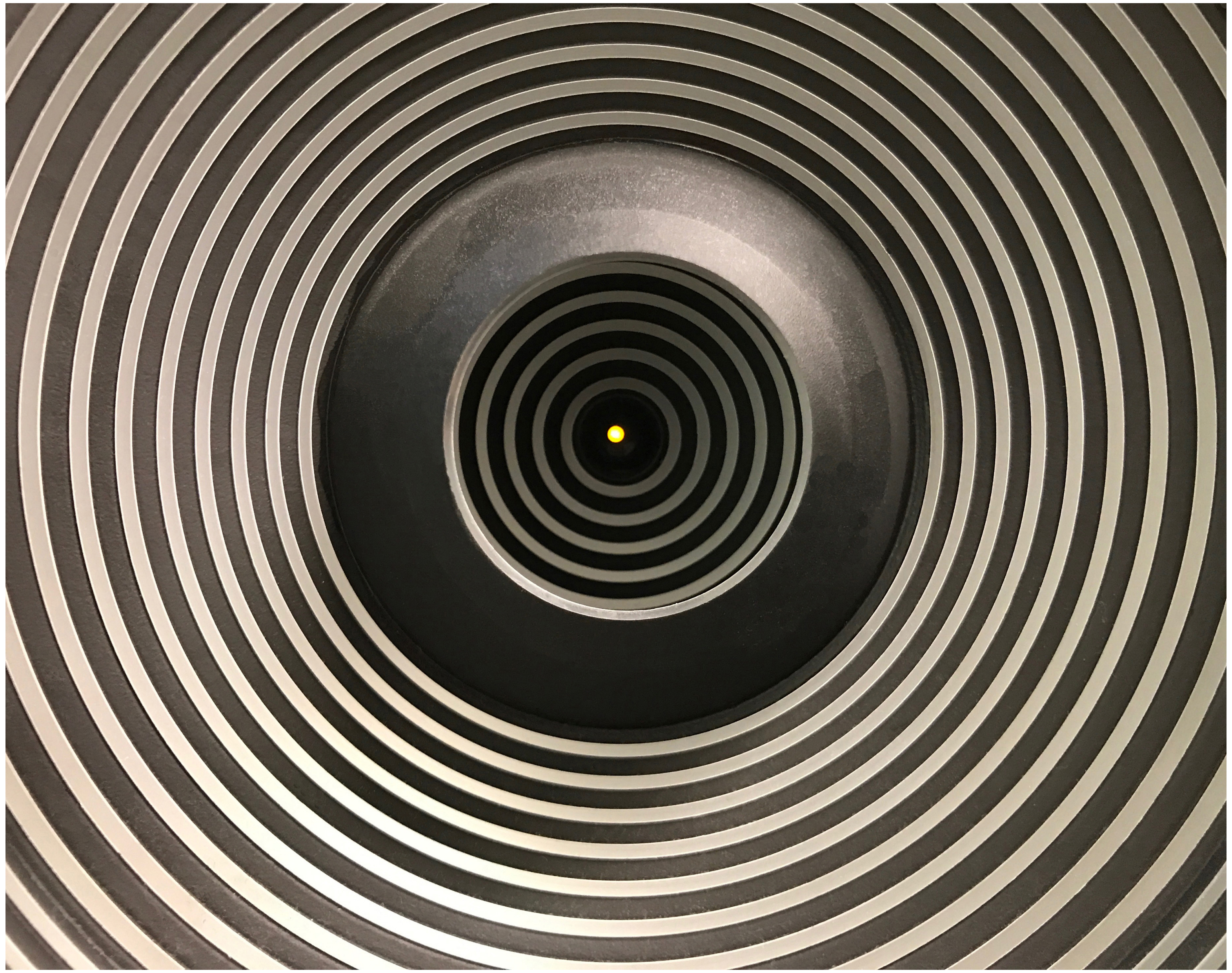
EyeSys Vision

Magellan Mapper

MedMont E300

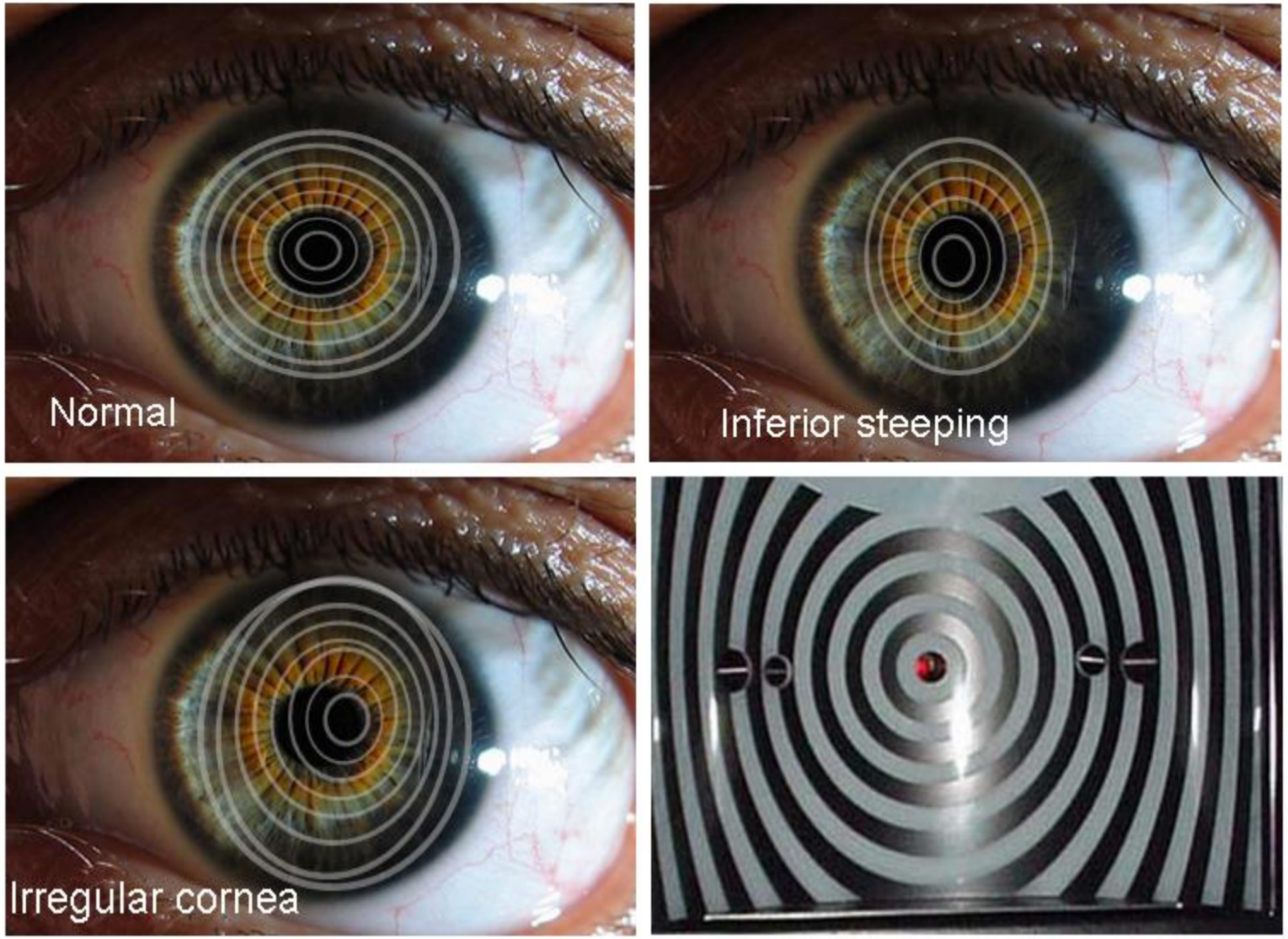
Technology Base - The Placido Disk

- 1880: The Portuguese ophthalmologist Antonio Placido painted alternating black and white rings on a flat disk.
- 1950s: Wesley-Jensen used a curved bowl to improve measurement accuracy in the periphery.
- 1990s: Gersten / NYE&E Infirmary → Automation.
- The image reflected by the tear film describes anterior corneal contour lines.
- These contour lines can be converted into corneal curvature using a mathematical model.
- The result is a 3-dimensional map of the corneal surface.
- Modern topographers use VKG & fast computers to capture and rapidly process corneal images.



Placido topographer

Axial curvature map



What other popular ophthalmic instruments use technology dating back to the 19th century?

Most optical biometers.

Michelson - 1881.

Reflective keratometry.

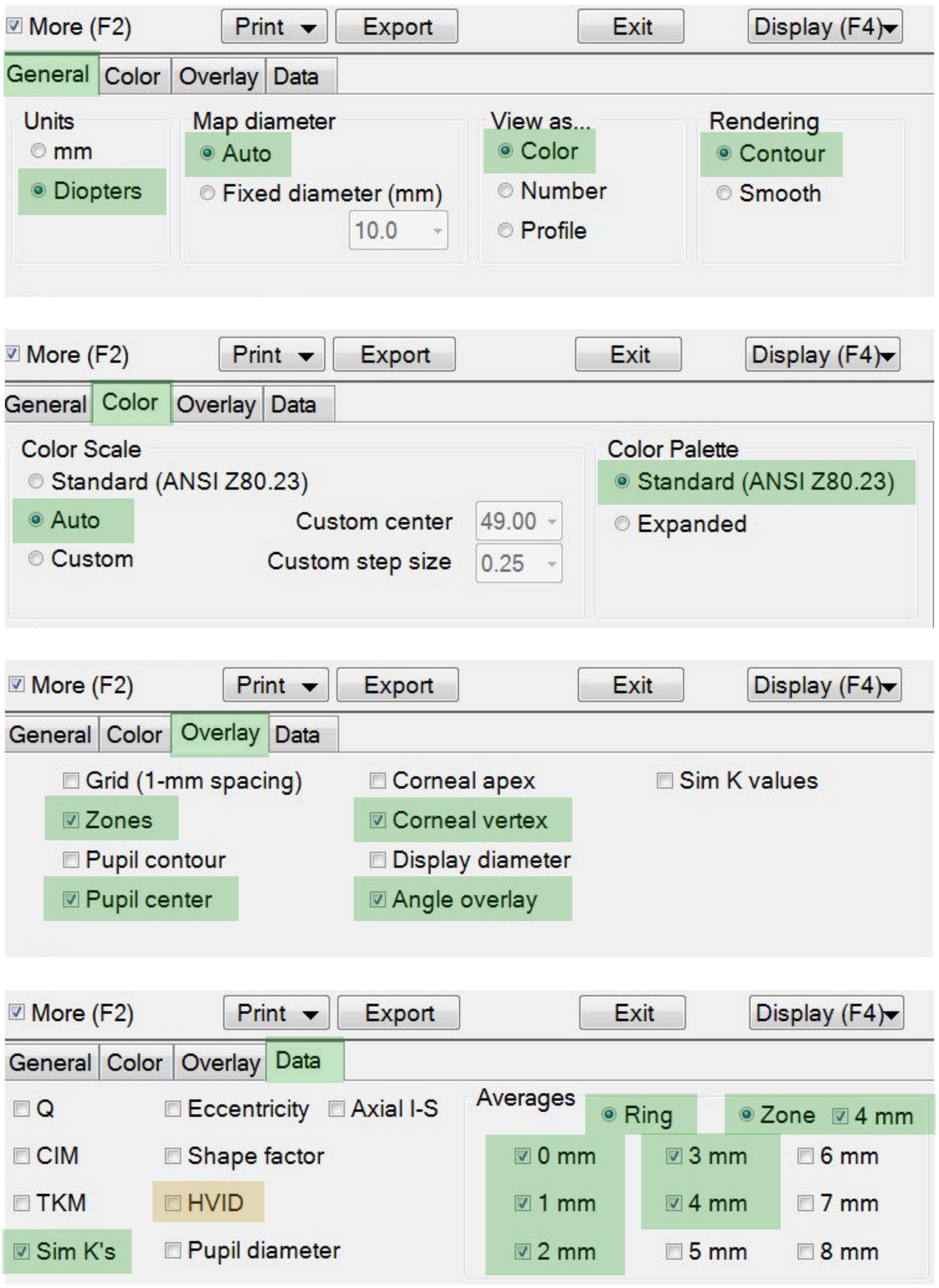
Helmholtz - 1851.

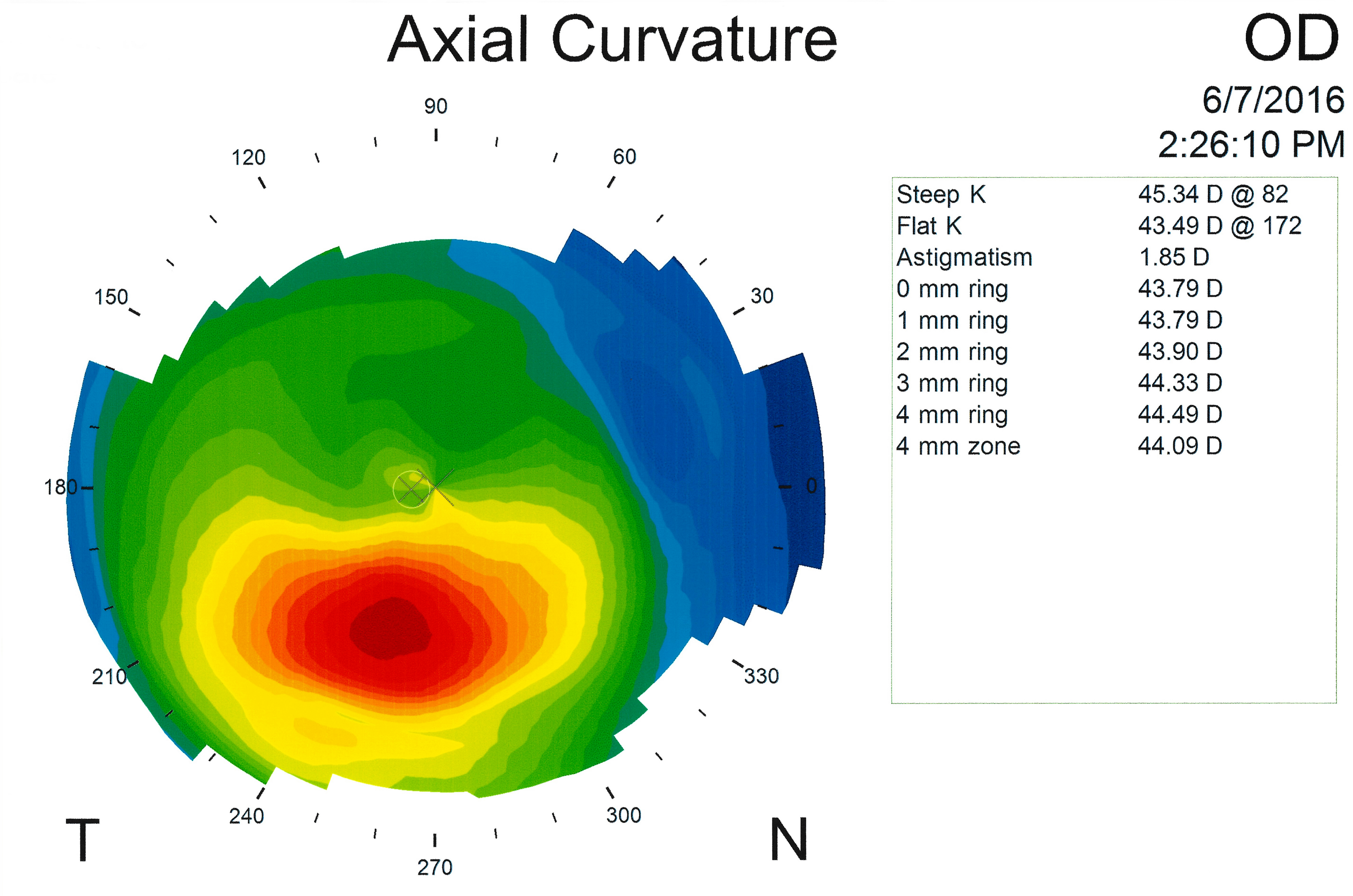
An instrument is only as good as the person using it.

The meaningful use of any ophthalmic instrument involves careful thought rather than “button pushing.”

Getting Started

Initial Instrument Setup for an Ophthalmology Clinic





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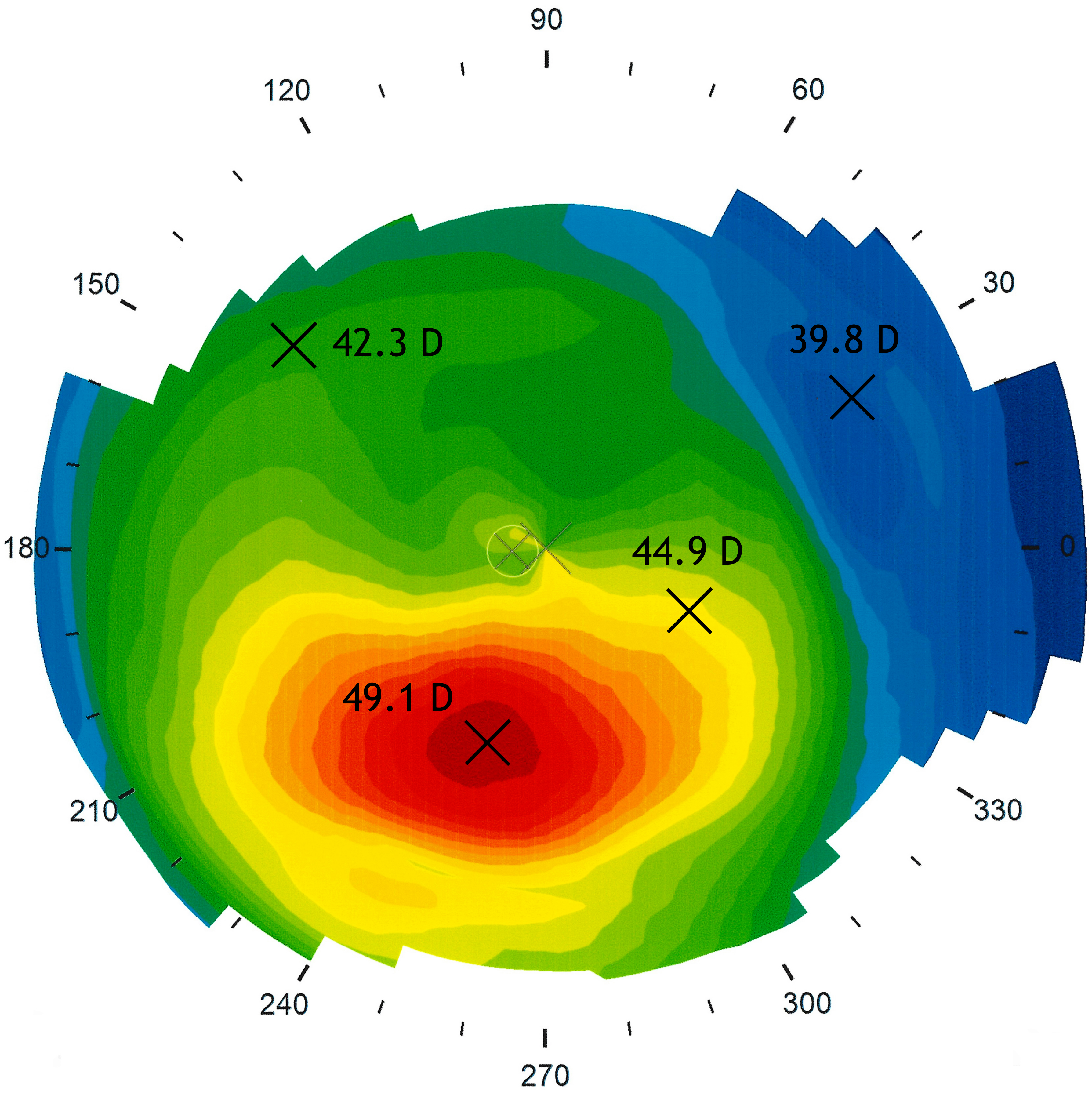
Each topographic map is simply a different representation of the same corneal shape.

All of the examples that follow will be of the same eye of the same patient.

Axial Curvature Map

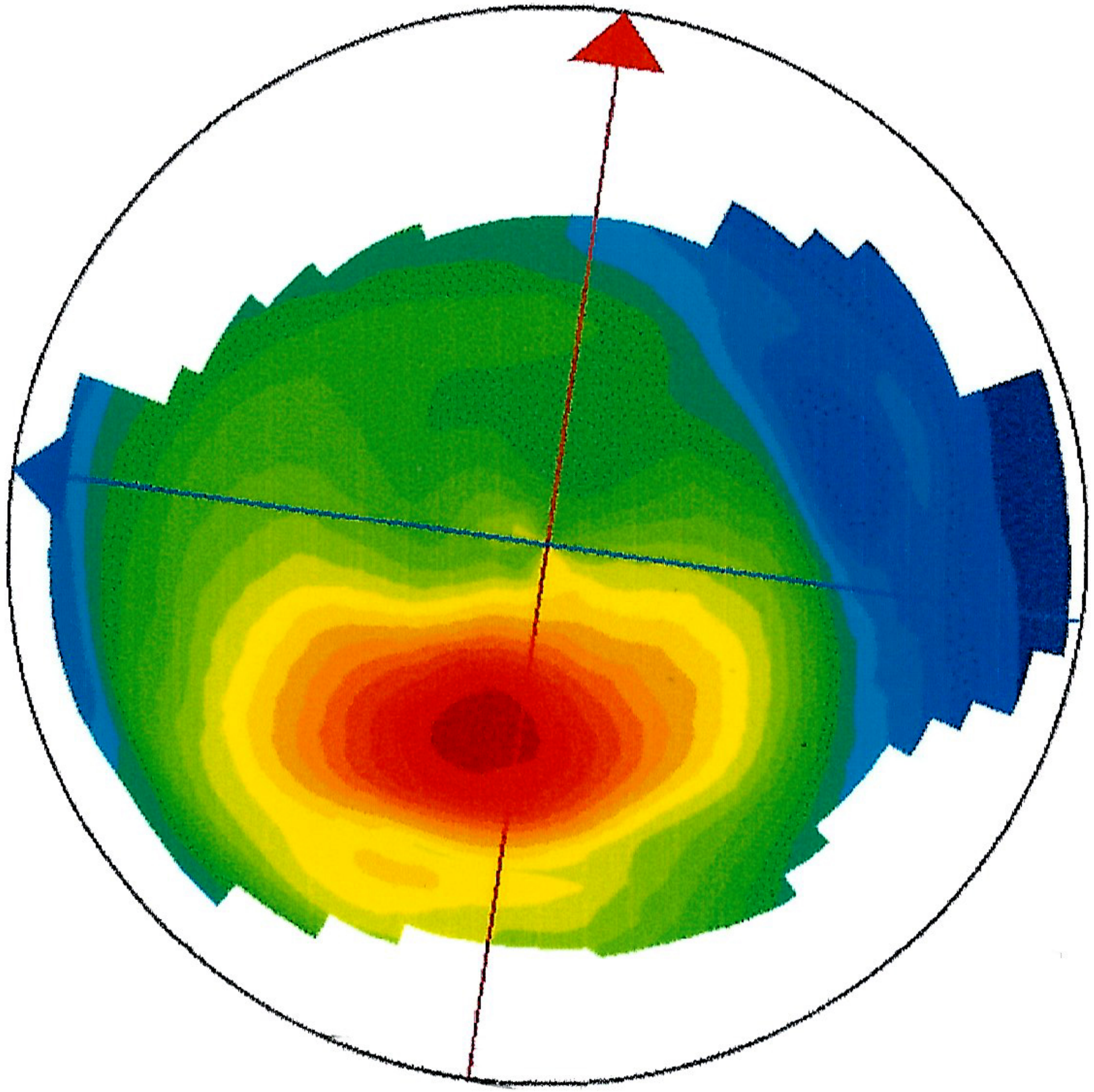
Axial Curvature Map

- Most commonly used topographic map feature… aka: power, or sagittal map.
- Limitation: Assumes that all refracted light rays pass though a central optical axis and typically excludes extreme values.
- Displays an average of scaled values with smoothing. Some detail may be lost.
- Preferred clinically because it relates corneal shape to corneal power.
- Often used to characterize the astigmatism type (irregular), alignment (asymmetric) and location (WTR vs. ATR vs. oblique).
- Greatest accuracy is near the region of the central cornea.



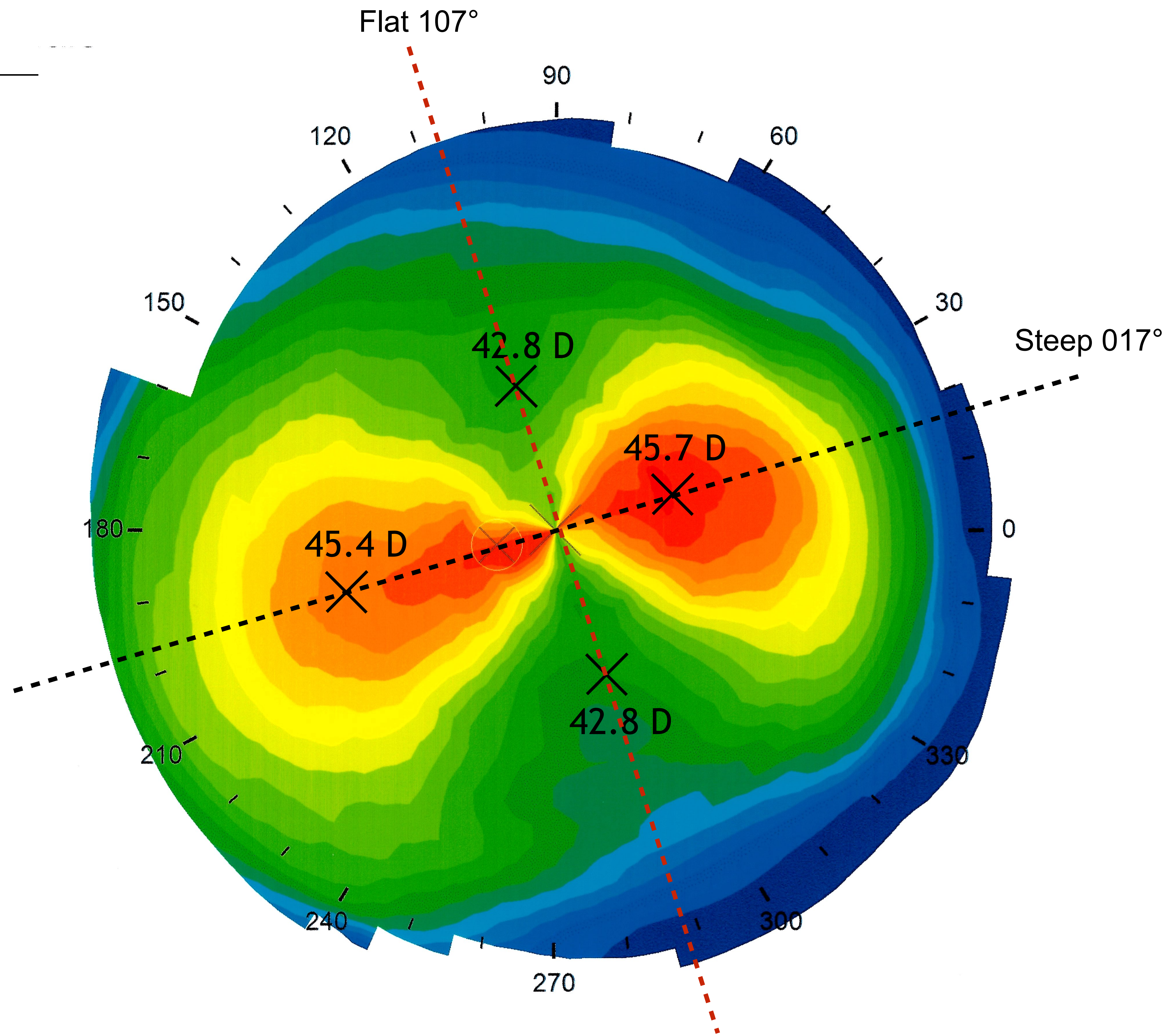
Axial Curvature Map

- Useful for the characterization of the astigmatism type (irregular), alignment (asymmetric) and location (WTR).



Corneal aberrations

Axial curvature map

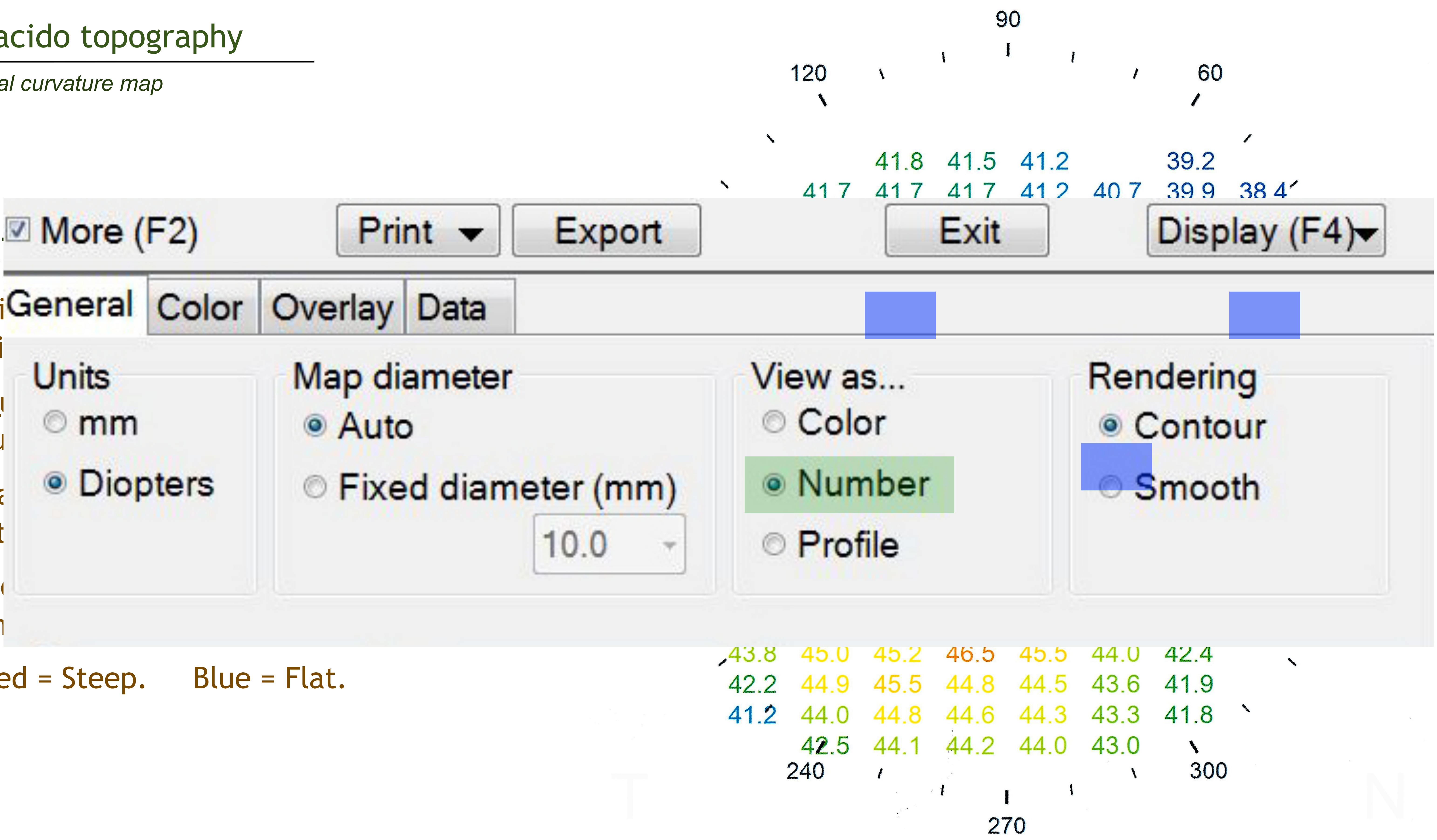


Placido topography

Axial curvature map

Ax

- Di di
- Qu ju
- Ca ot
- Mo th



- Red = Steep. Blue = Flat.

Placido topography

Numerical view - Keratoconus evaluation

Superior Nasal		Central		Superior Temporal
2nd Left 2nd Above	1st Left 2nd Above	2nd Above	1st Right 2nd Above	2nd Right 2nd Above
42.00	43.90	48.40	50.50	**46.10**
2nd Left 1st Above	1st Left 1st Above	1st Above	1st Right 1st Above	2nd Right 1st Above
42.30	**44.30**	47.40	**48.60**	46.50
2nd Left of Pupil	1st Left of Pupil	Pupil Center	1st Right of Pupil	2nd Right of Pupil
42.80	45.10	**48.90**	48.10	47.50
2nd Left 1st Below	1st Left 1st Below	1st Below	1st Right 1st Below	2nd Right 1st Below
43.40	**46.20**	52.00	**52.00**	49.00
2nd Left 2nd Below	1st Left 2nd Below	2nd Below	1st Right 2nd Below	2nd Right 2nd Below
43.90	47.00	53.00	54.70	**50.40**
Inferior Nasal		Central		Inferior Temporal

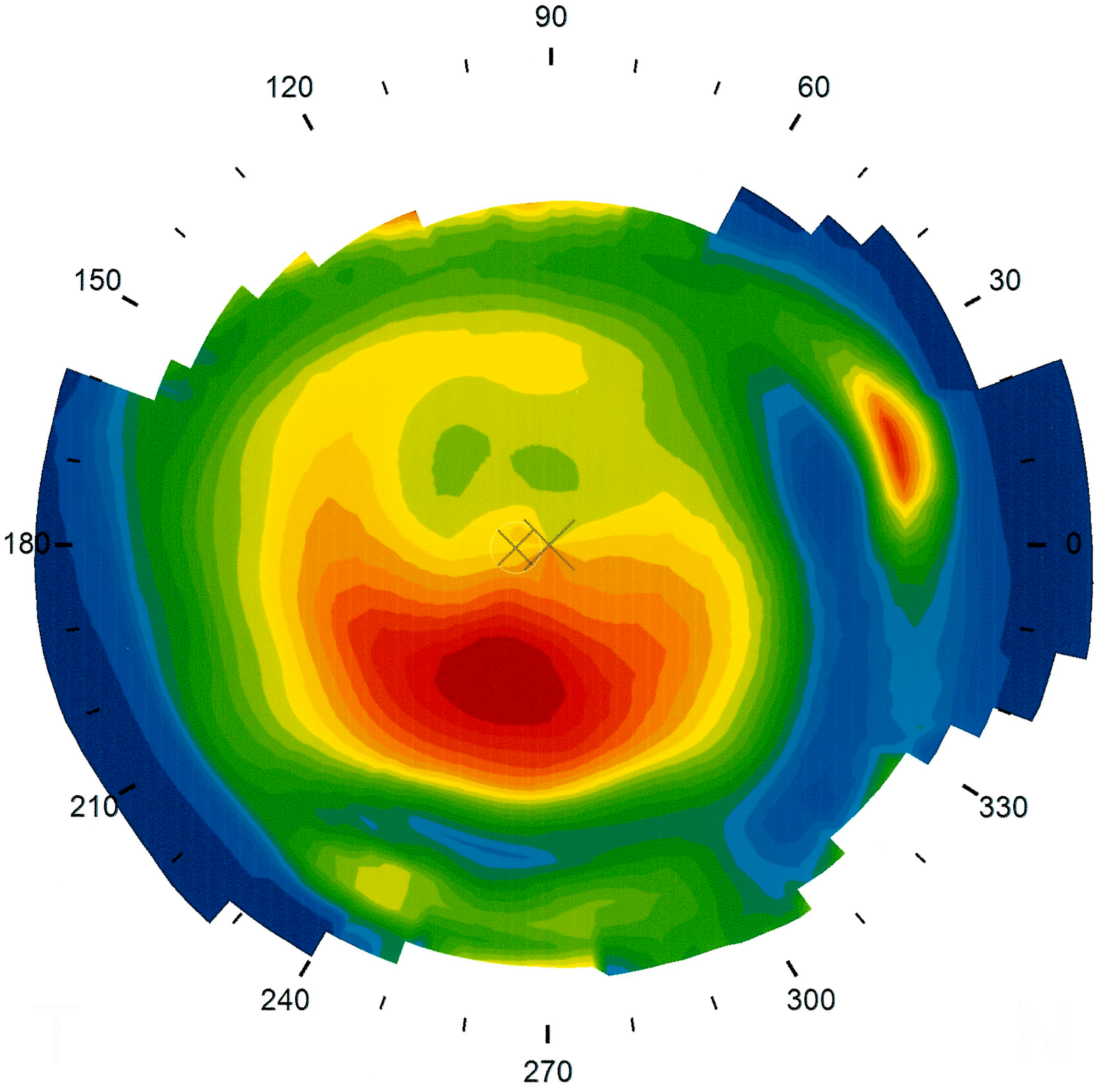
Placido topography

View options

Tangential Curvature

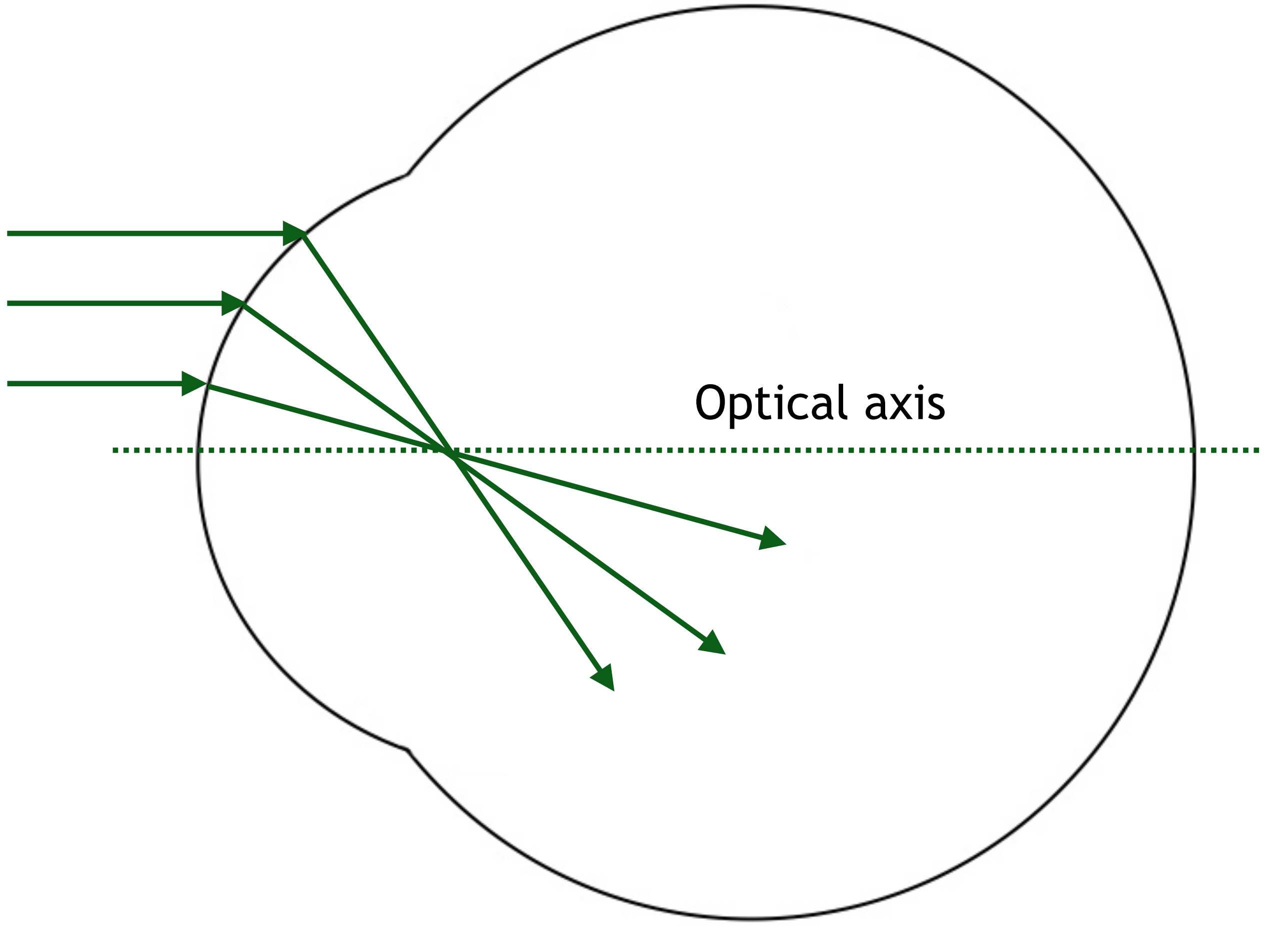
Tangential Curvature Map

- Calculates measured data points at a 90° tangent to the corneal surface.
- Correctly assumes that all refracted light does not fall on a central reference axis.
- A detailed representation of the corneal surface. Smaller patterns. Useful for understanding the size and the shape of unusual areas (e.g.: Cone in keratoconus).
- Sensitive to local irregularities of the corneal surface and generally better for showing transitions in curvature than an axial curvature map. Typically has less data smoothing.
- Used frequently to determine an ideal contact lens design and optic zone size.

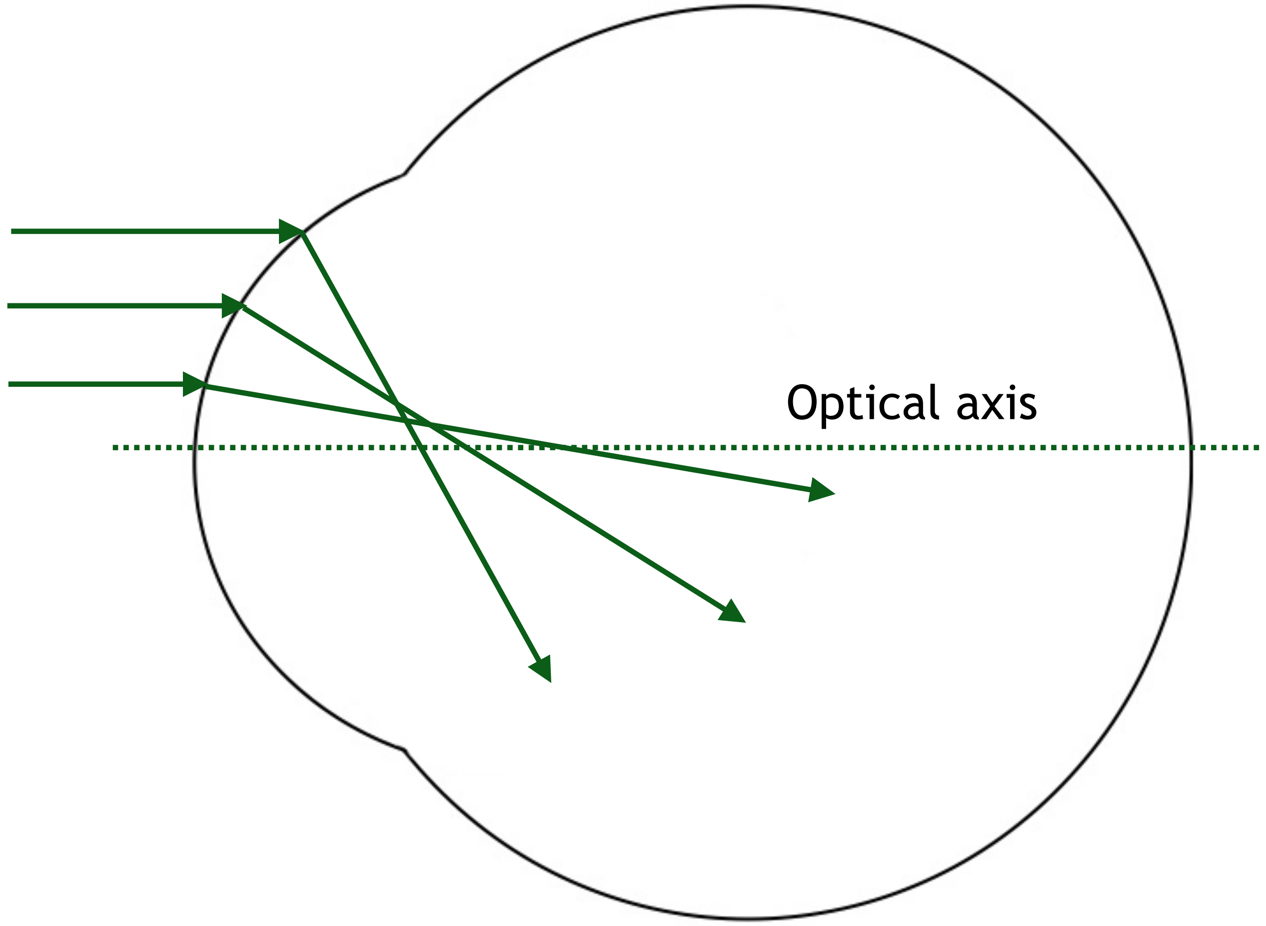


Placido topography

Instrument setup



An **axial assumption** forces the focus along the optical axis.

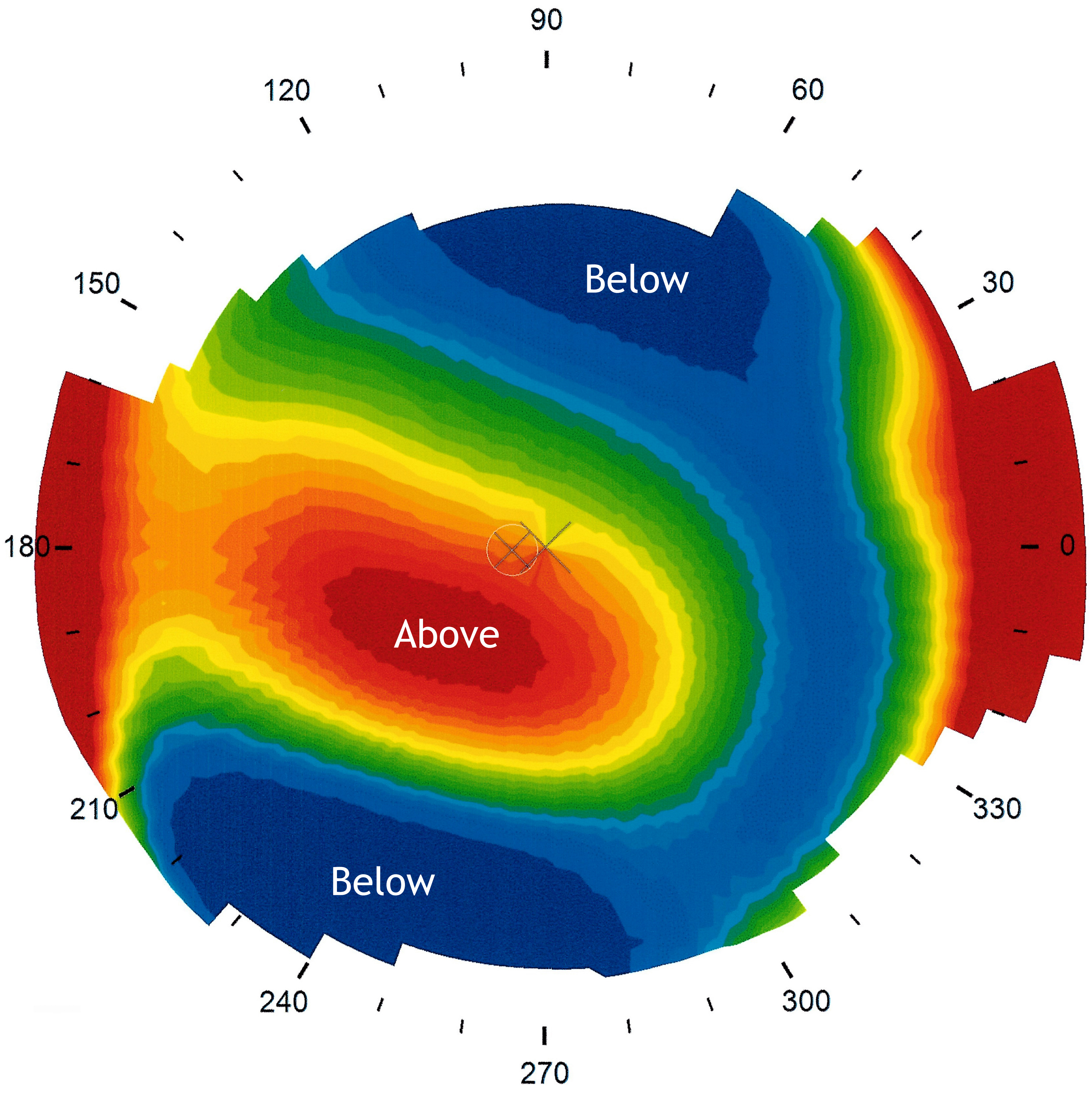


A **tangential assumption** allows for off-axis focal lengths.

Elevation Map

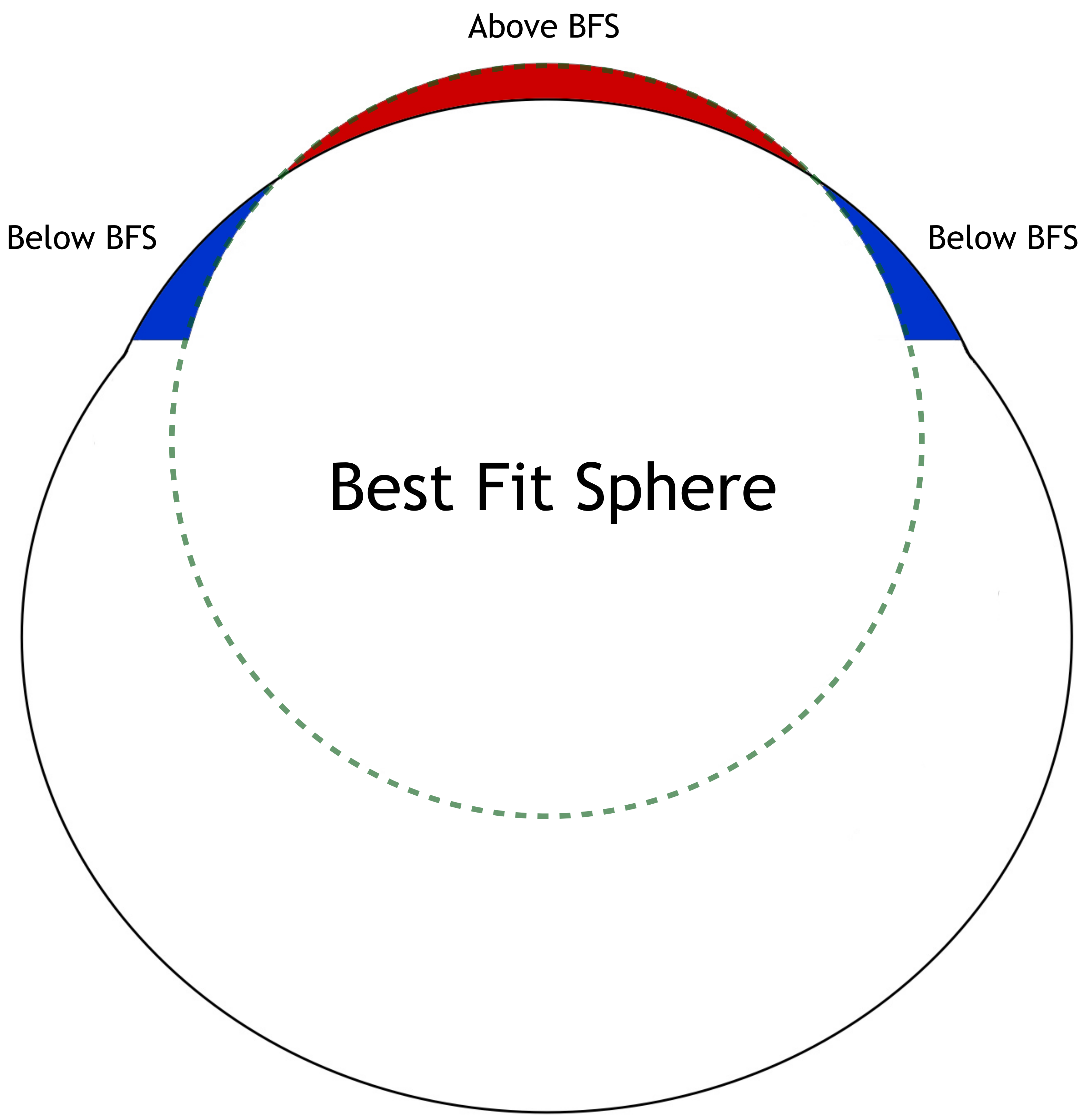
Elevation Map

- Displays corneal height and is often used for CL fitting.
- Referenced against theoretical **best fit sphere** placed on the corneal surface.
- Elevation data is derived from corneal curvature data using an algorithm.
- Shows areas corresponding to depressions & elevations that are above/below the best fit sphere.
- Red = Above BFS. Blue = Below BFS.



Placido topography

Elevation map



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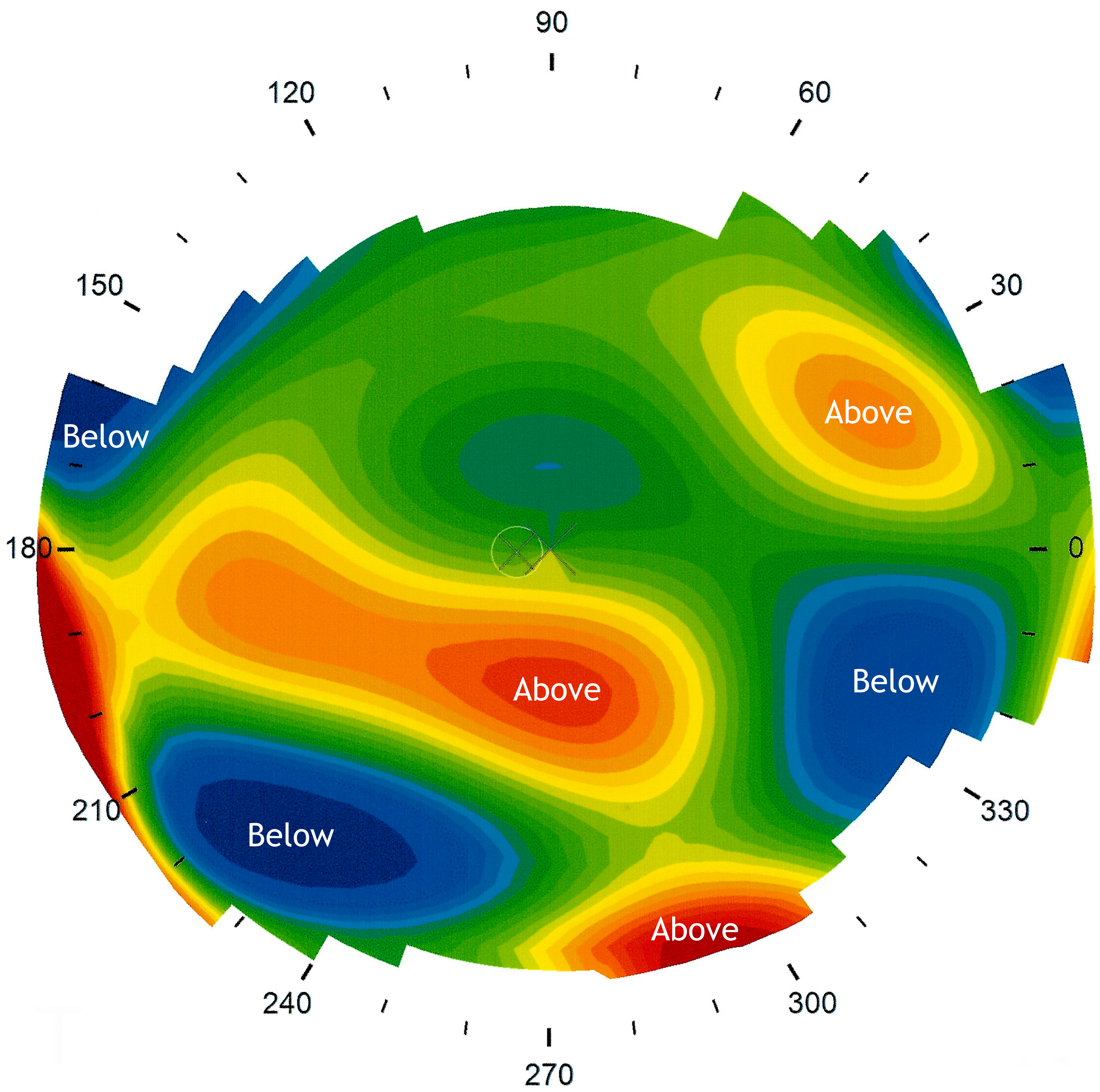
Irregularity Map

Placido topography

Irregularity map

Irregularity Map

- Displays areas of anterior corneal surface irregularity.
- Uses a **best fit toric surface** as the reference in an attempt to eliminate toricity from the map display.
- Displays elevation differences that cannot be accounted for with a best fit toric reference.
- Similar to an elevation map, except the reference is a best fit toric surface rather than a best fit sphere surface.
- Red = Above BFTS.   Blue = Below BFTS.



View options

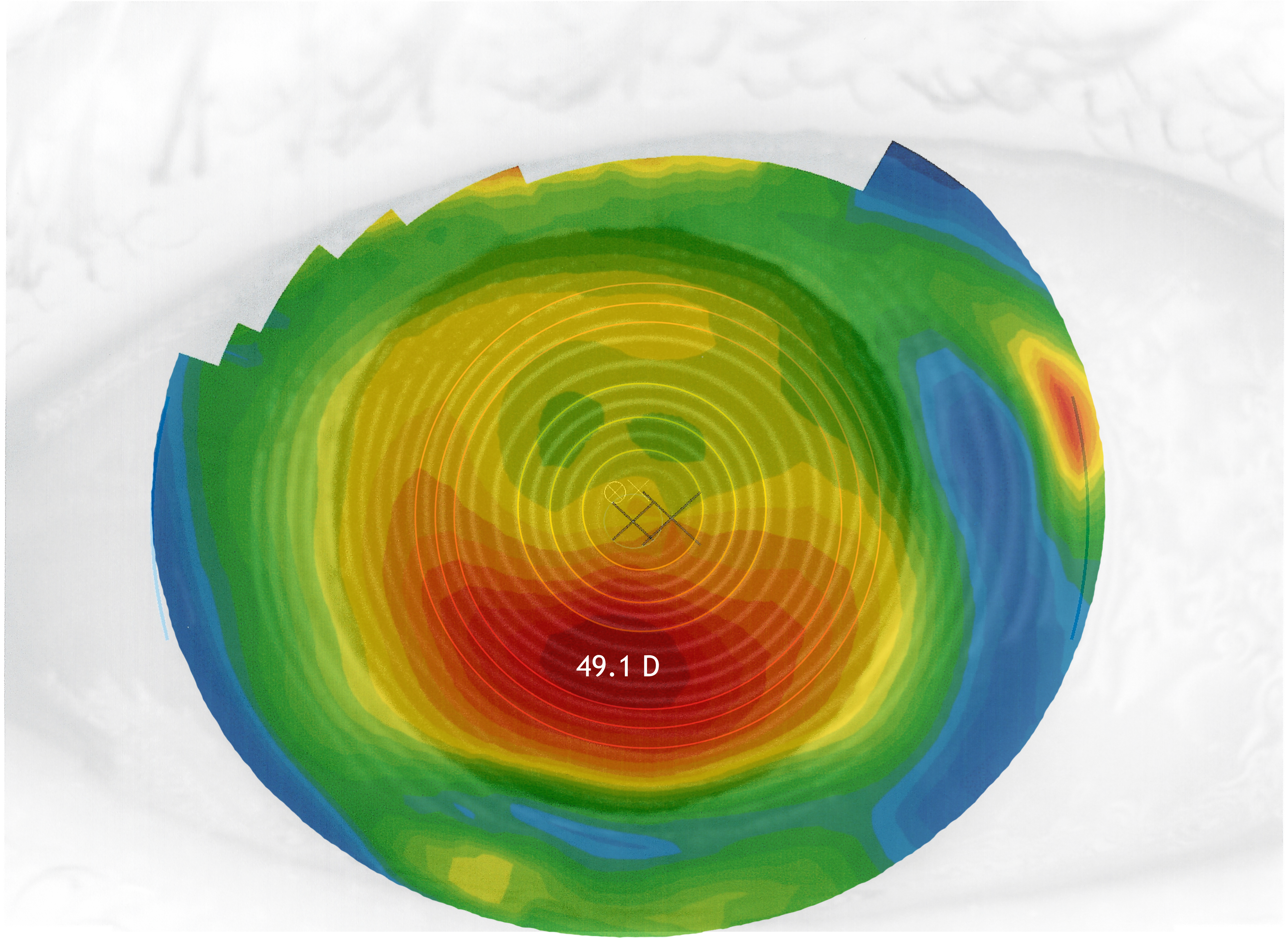
Rings Image

Placido topography

Rings image

Rings Image

- A reflected contour map of the corneal surface.
- Contour lines demonstrate areas of steepening and flattening.
- A broad overview of the anterior corneal surface.
- Useful for keratoconus, corneal scarring & prior refractive surgery.
- Based on sophisticated videokeratographic imaging.



Superimposed tangential curvature map

View options

Simulated keratometry

Simulated Keratometry

- A topographer simulating a standard keratometer.
- May not completely correlate with the outcomes of common autokeratometry, especially for the low astigmat.
- A useful screen for the identification of irregular and/or asymmetric astigmatism.
- Helpful for contact lens fitting showing the intermediate and marginal curvatures.

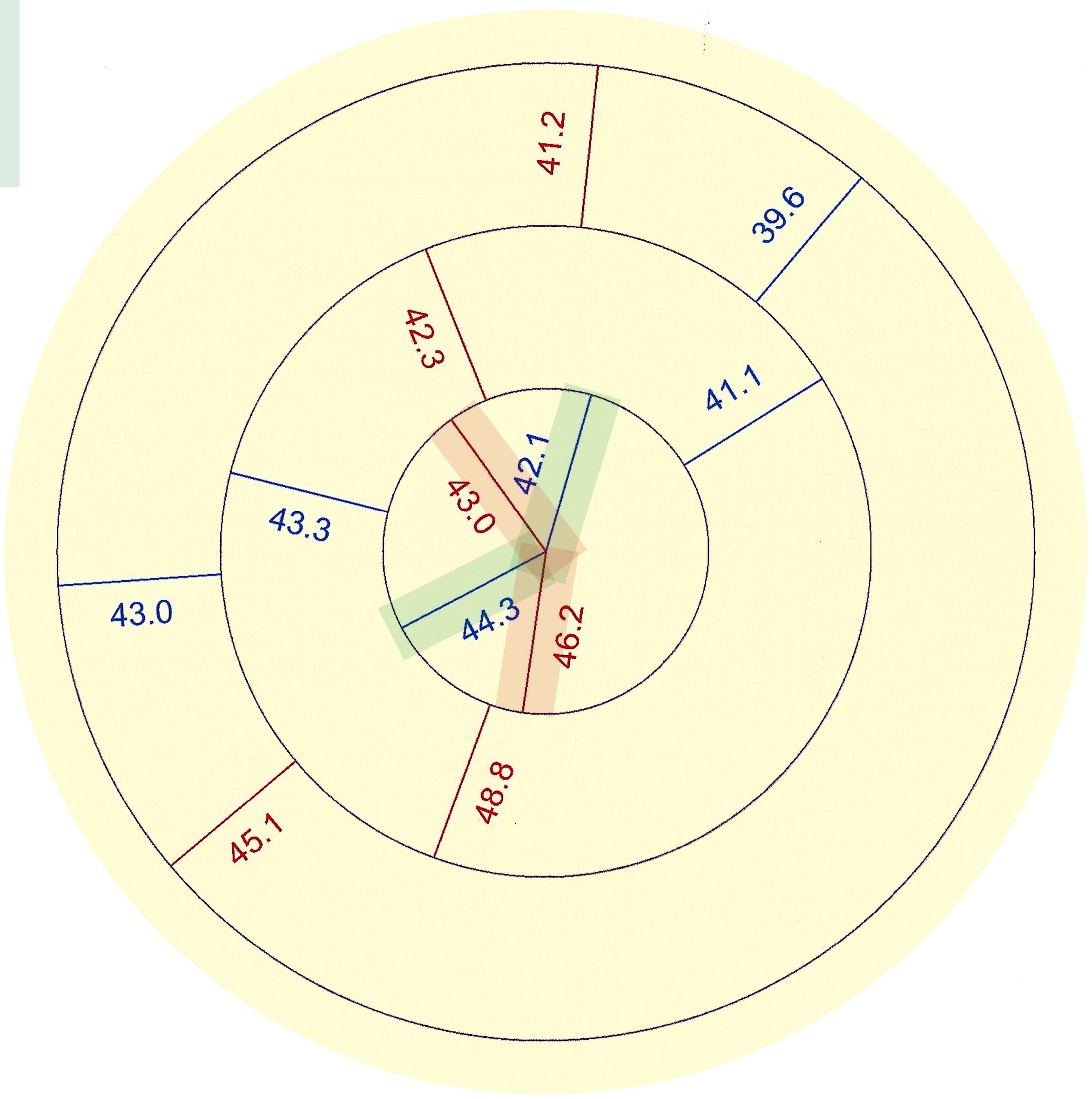
Sim Ks (3 mm)
45.34 D (7.44 mm) @ 82
43.49 D (7.76 mm) @ 172

Total astigmatism 1.85 D

Central (0-3 mm)
46.19 D (7.31 mm) @ 262
43.01 D (7.85 mm) @ 126
42.10 D (8.02 mm) @ 74
44.31 D (7.62 mm) @ 208

Midperiphery (3-6 mm)
48.82 D (6.91 mm) @ 250
42.33 D (7.97 mm) @ 112
41.06 D (8.22 mm) @ 32
43.30 D (7.79 mm) @ 166

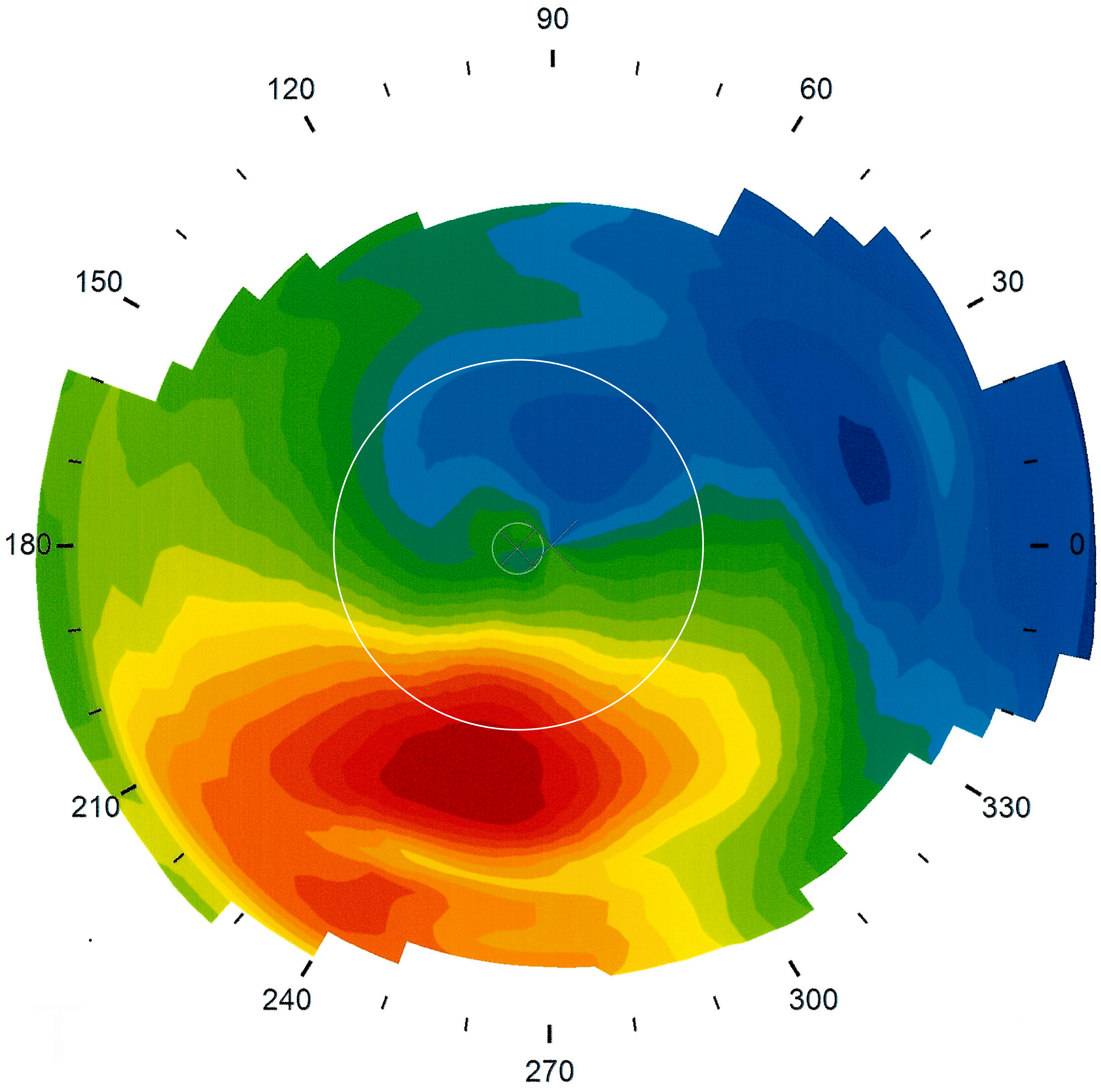
Periphery (6-9 mm)
45.14 D (7.48 mm) @ 220
41.21 D (8.19 mm) @ 84
39.62 D (8.52 mm) @ 50
42.99 D (7.85 mm) @ 184



Refractive Power Map

Refractive Power Map

- Displays the refractive power of the cornea based on Snell's law.
- Useful for documenting pre & post refractive surgery corneal shaping.
- Often used to demonstrate uniformity within the pupil zone.
- Takes into account spherical aberration.
- May directly correlate with overall visual quality.



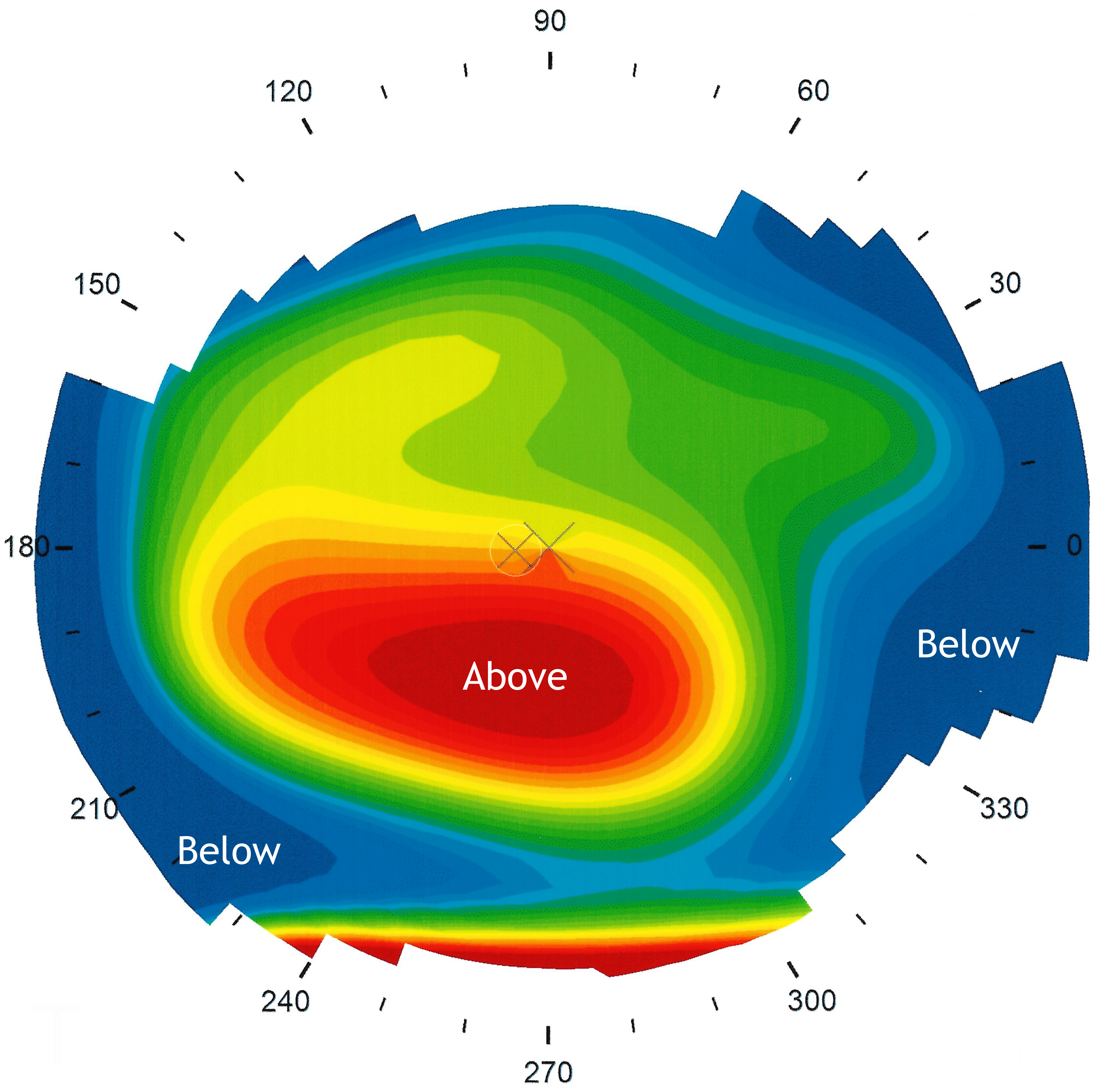
Placido topography

View options

Mean Curvature Map

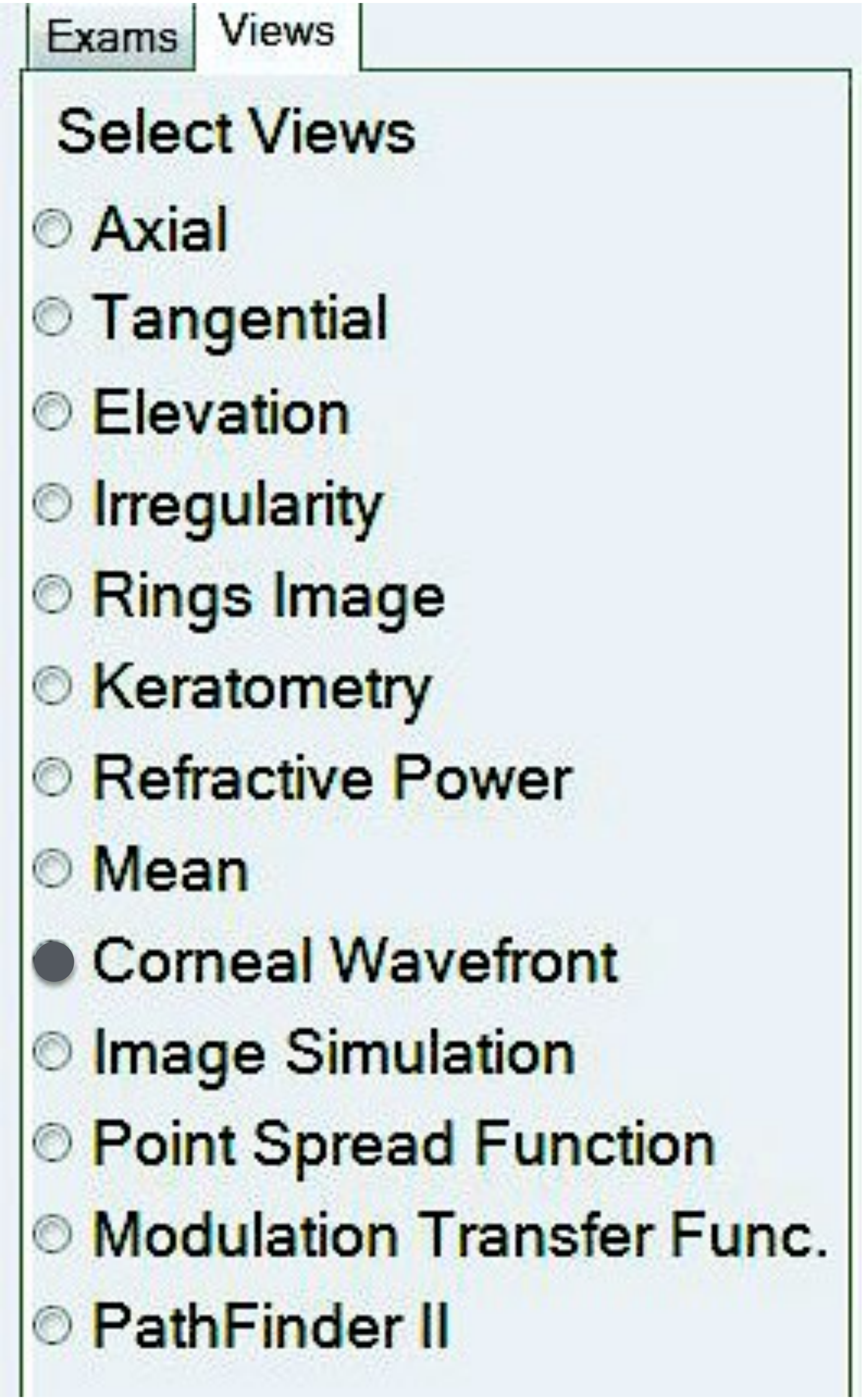
Mean Curvature Map

- Uses an infinite number of spheres to fit the corneal curvature at a given point.
- An algorithm determines the minimum and maximum **best fit sphere** for the corneal curvature.
- Calculates the average BFS for single points on the anterior cornea.
- More sensitive to power changes in the peripheral cornea.
- Not commonly used in clinical practice by ophthalmologists.



View options

Corneal Wavefront



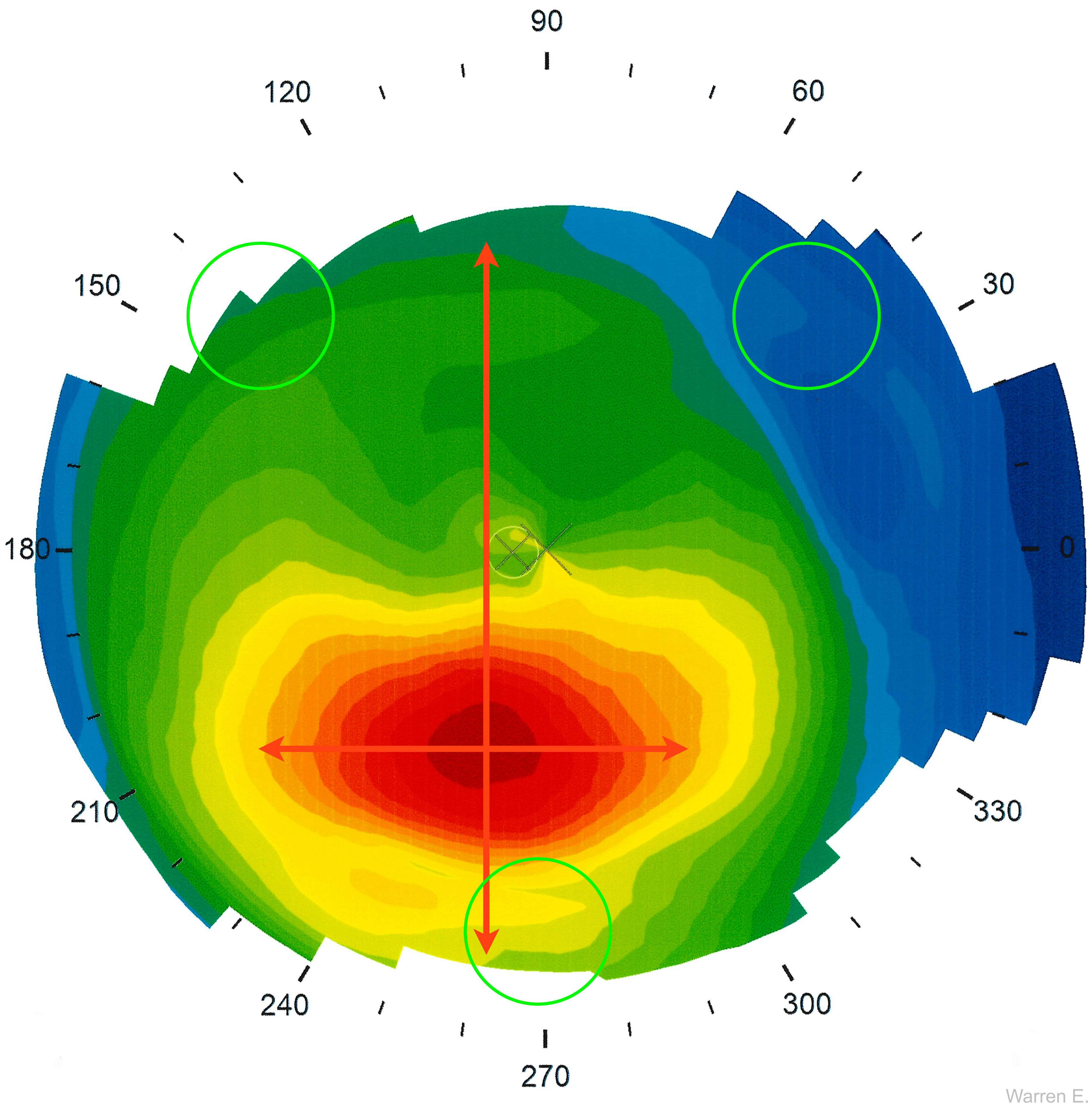
Aberrations

Corneal wavefront

Keratoconus.

Apex displacement.

Dissimilar power distribution at intermediate & marginal areas.



Aberration Profile

- Quantitative representation of corneal aberrations (Zernike pyramid).
- Extremely useful for understanding the reason for a reduction in visual quality.
- 2nd order aberrations correspond to a patient's spectacle correction.
- 3rd and 4th order aberrations elevated with KCN & following refractive surgery.
- **Mandatory pre-operative screen for premium IOL candidates.**
- **An important part of evaluating all patients with prior refractive surgery.**

Zernike common name		µm
Z(2,-2)	Oblique Astigmatism	0.342
Z(2, 0)	Defocus	0.000
Z(2, 2)	WTR/ATR Astig.	-1.664
Z(3,-3)	Oblique Trefoil	0.003
Z(3,-1)	Vertical Coma	-1.815
Z(3, 1)	Horizontal Coma	-0.542
Z(3, 3)	Horizontal Trefoil	0.687
Z(4,-4)	Oblique Quatrefoil	-0.419
Z(4,-2)	Oblique 2nd Astig.	0.159
Z(4, 0)	Spherical Aberration	0.365
Z(4, 2)	WTR/ATR 2nd Astig.	-0.240
Z(4, 4)	Horizontal Quatrefoil	0.081

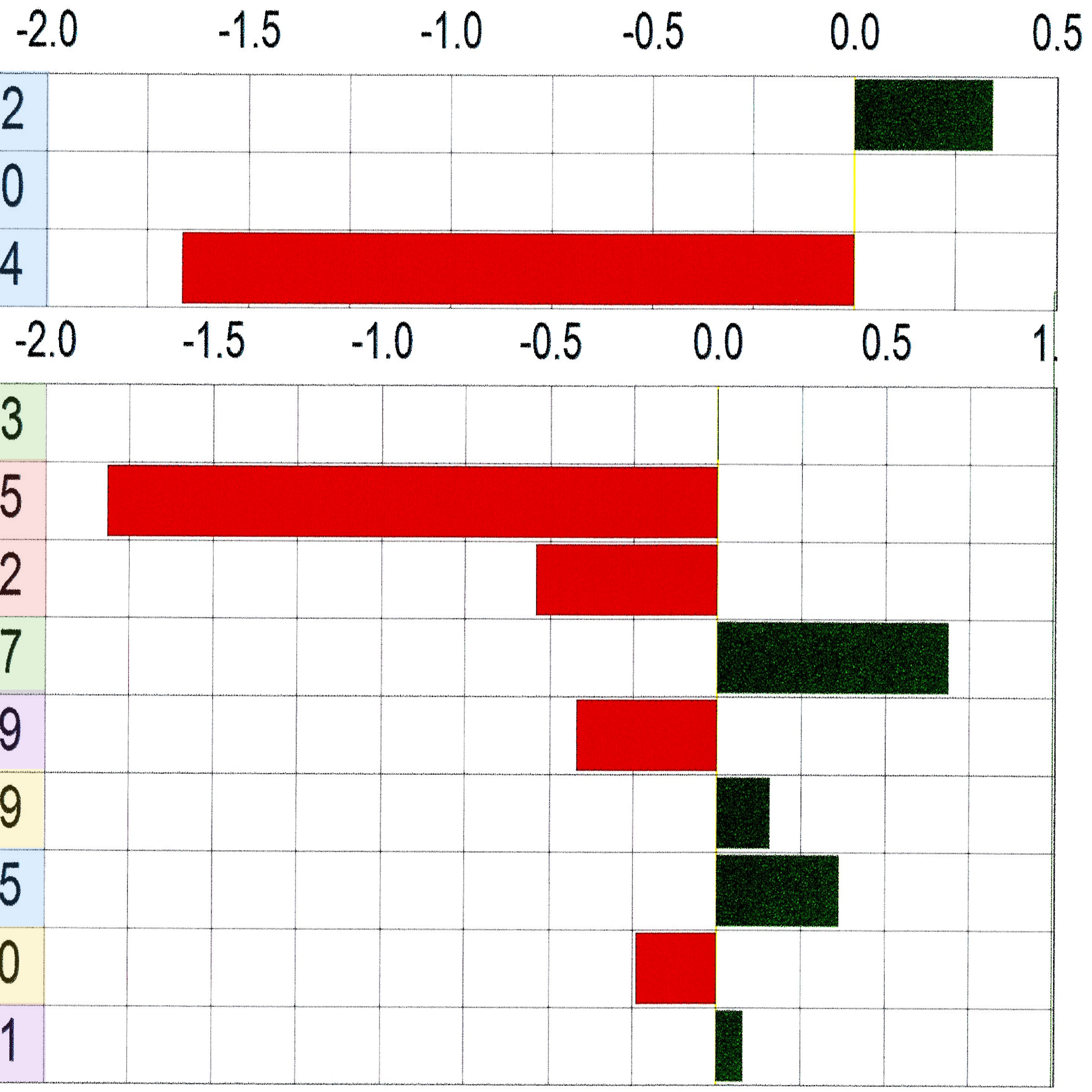


Image Simulation

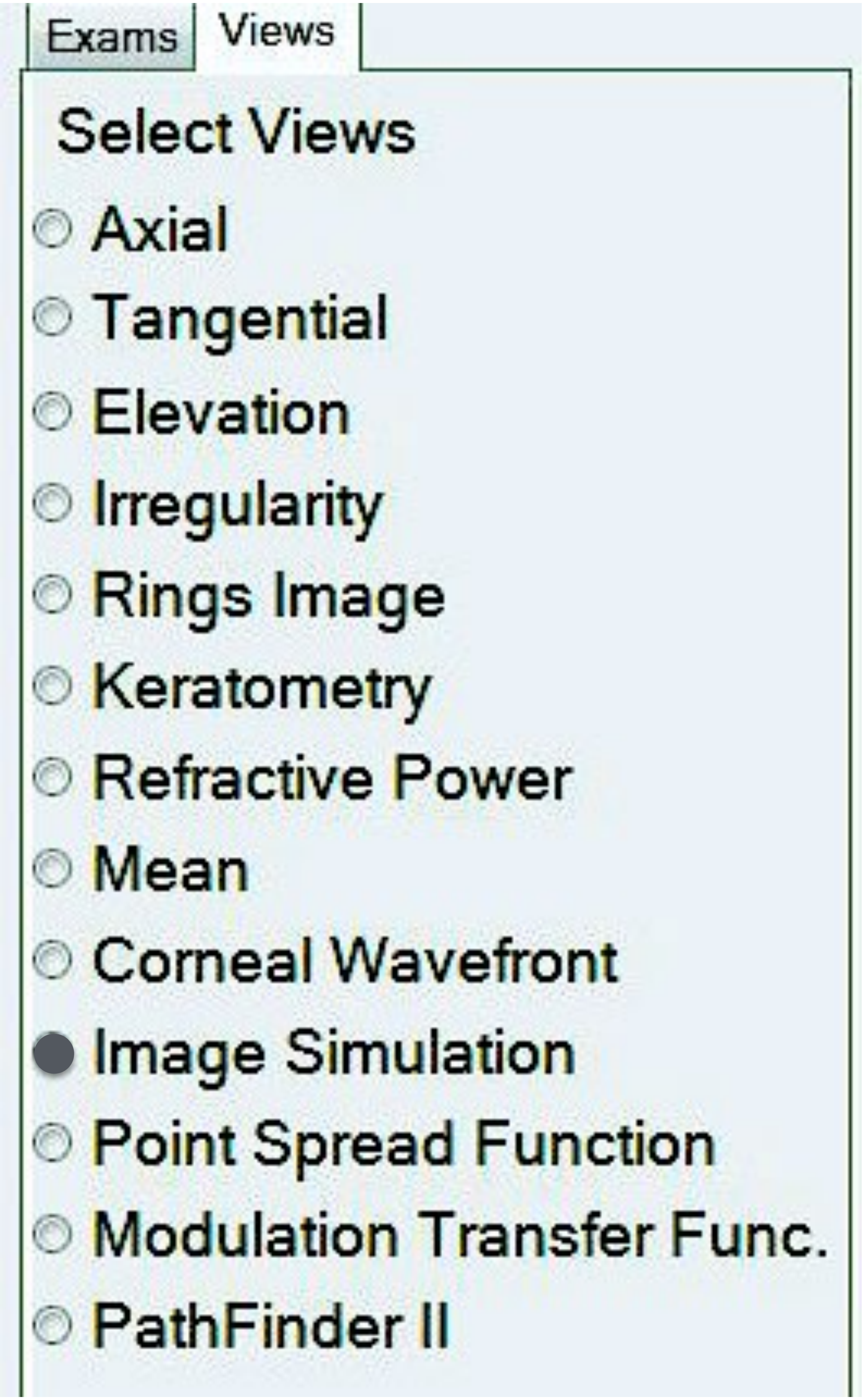
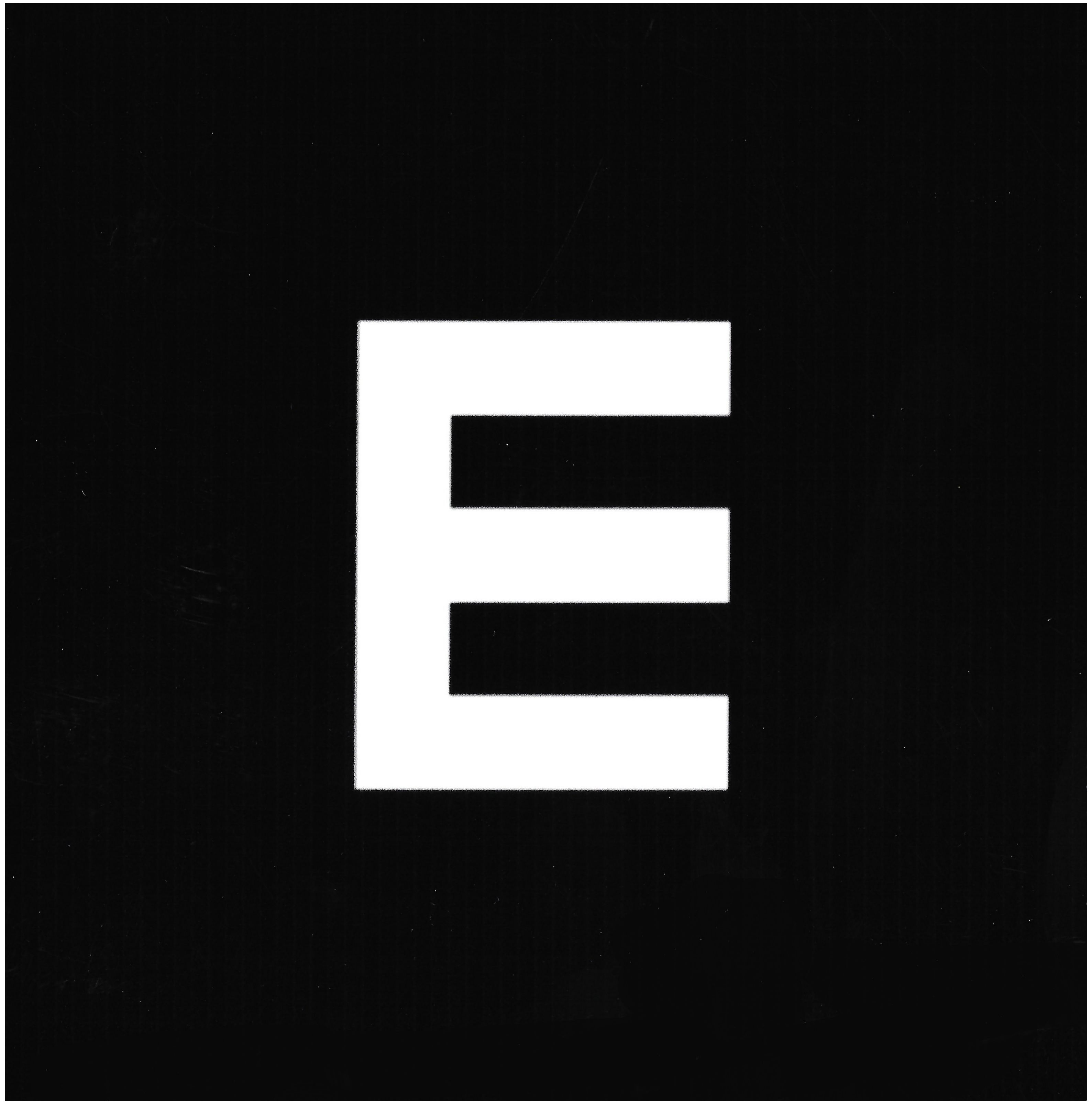


Image Simulation

- Ideal tool for showing patients the impact of elevated higher order aberrations.
- By removing 2nd order aberrations, the spectacle prescription is simulated.
- Reducing the pupil size simulates photopic, daytime vision; lessens aberrations.
- Removing 2nd, 3rd & 4th order aberrations, simulates a RGP contact lens.
- An opportunity for the user to demonstrate an understanding of what the patient sees.

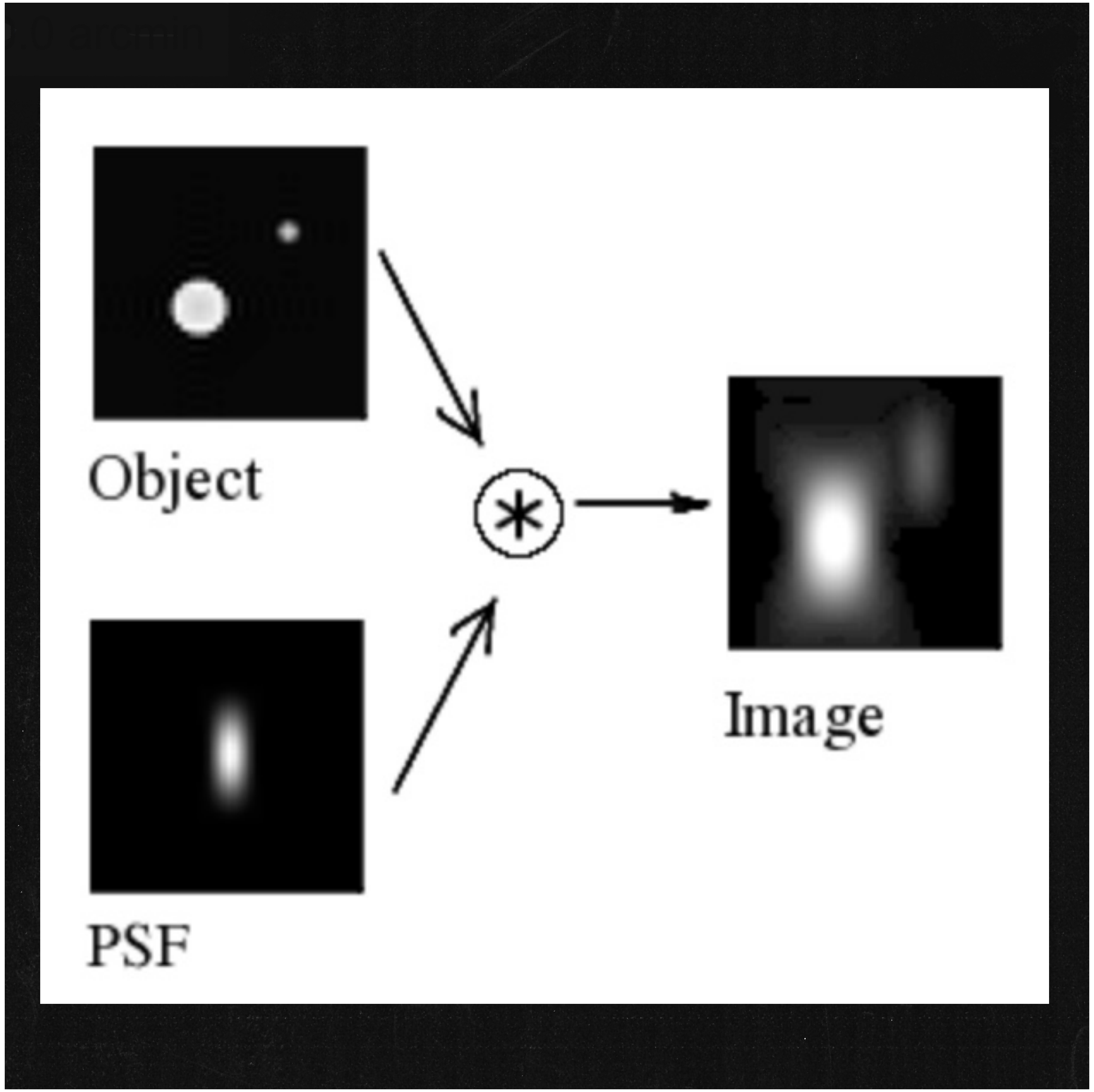


Keratoconus 6mm pupil
Keratoconus 3mm pupil
Keratoconus with glasses
Keratoconus with RGP lens

Point Spread Function

Point Spread Function

- Graphically illustrates the response of an optical system to a point source of light.
- Represents of the degradation (spreading) of an image when passing through the optics of the ant. cornea.
- The degree of spreading of a point object is a measure of the quality of an imaging system.
- Thought of as the extended “blob” of an image that represents an unresolved object.
- Rarely used in clinical practice. An advanced tool used by optical engineers.



Explaining a concept is good,
but showing it is better.

Modulation Transfer Function Plot

Placido topography

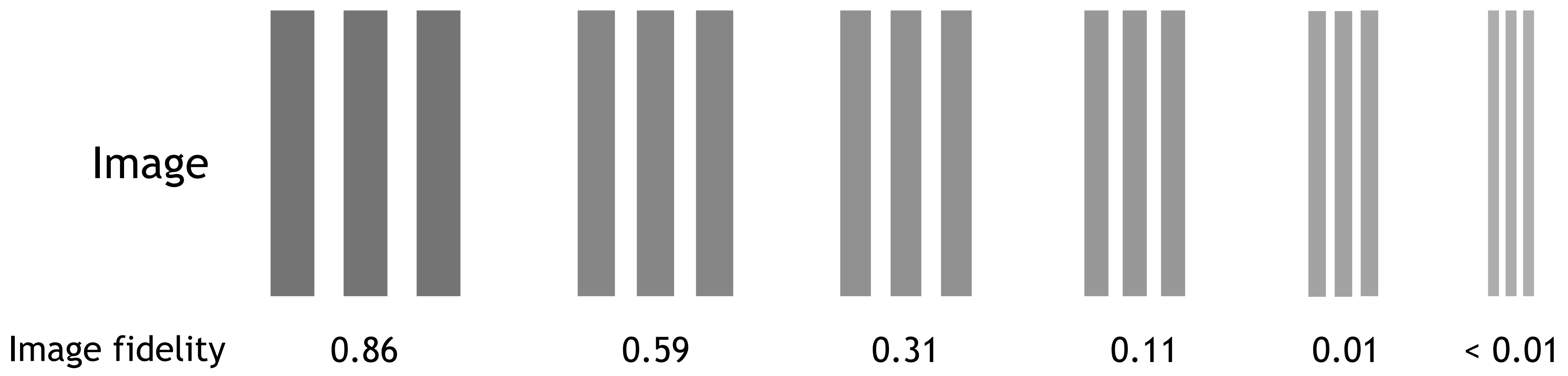
Modulation transfer function plot

$200

$3,360

F P	2	20/100
T O Z	3	20/70
L P E D	4	20/50
P E C F D	5	20/40
E D F C Z P	6	20/30

An increase in spatial frequency results in a decrease in image contrast.

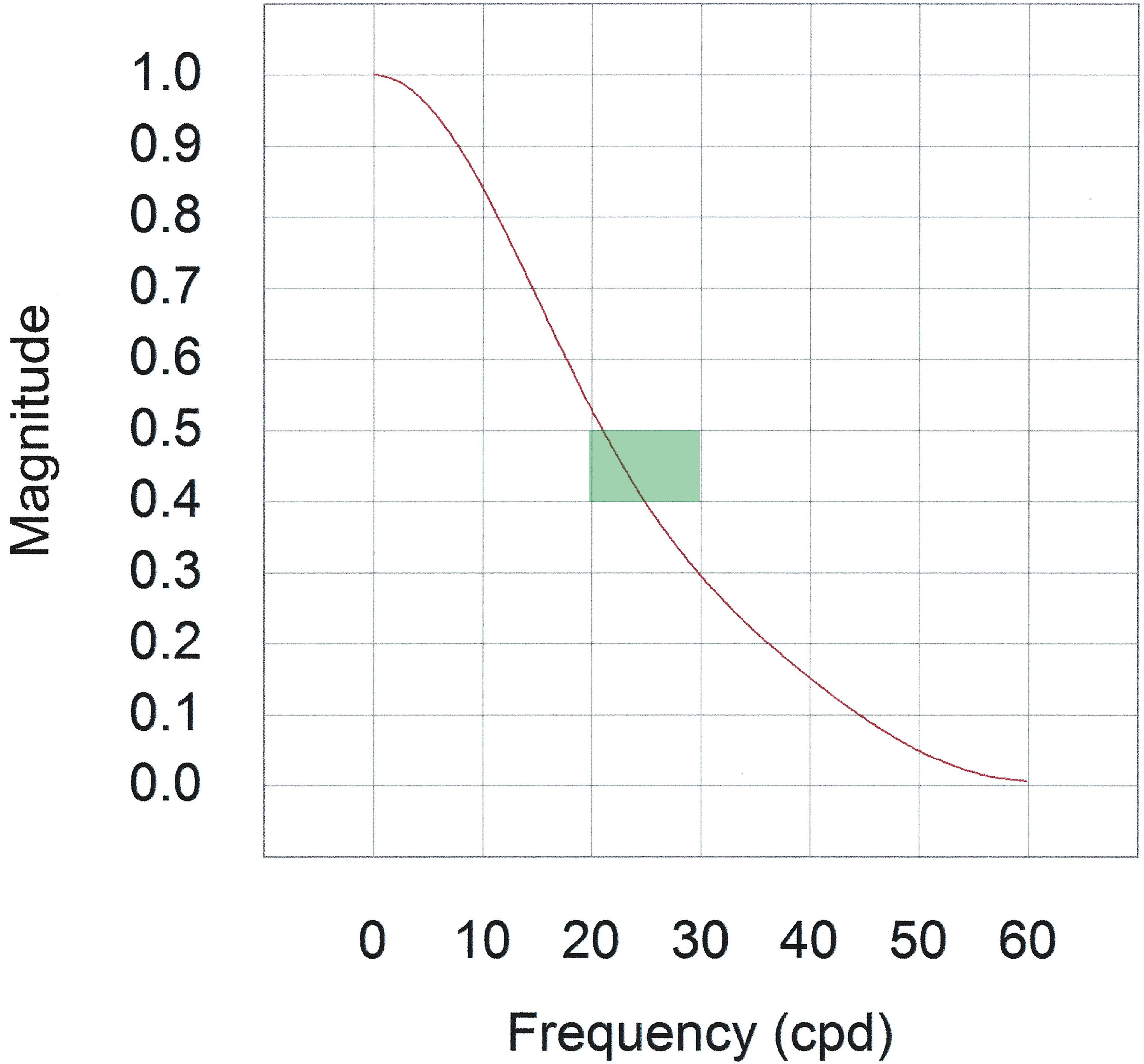


A decrease in image contrast results in a decrease in image quality (fidelity).

MTF Plot

- Graphic representation of the ability of an optical system to transfer contrast from the object viewed to the image formed.
- Magnitude. 1.0 = Black image / white background

  0.0 = White image / white background
- (Spatial) Frequency. 0 = Black line (Snellen chart)
- Visual performance = Image quality/fidelity.
- Normal visual function. ≥ 45% contrast, 20-30 cpd.
- The MTF plot is a graphic representation of the performance of any optical system.
- Example of a normal eye MTF plot.



Zeiss Atlas 9000 topographer

View options

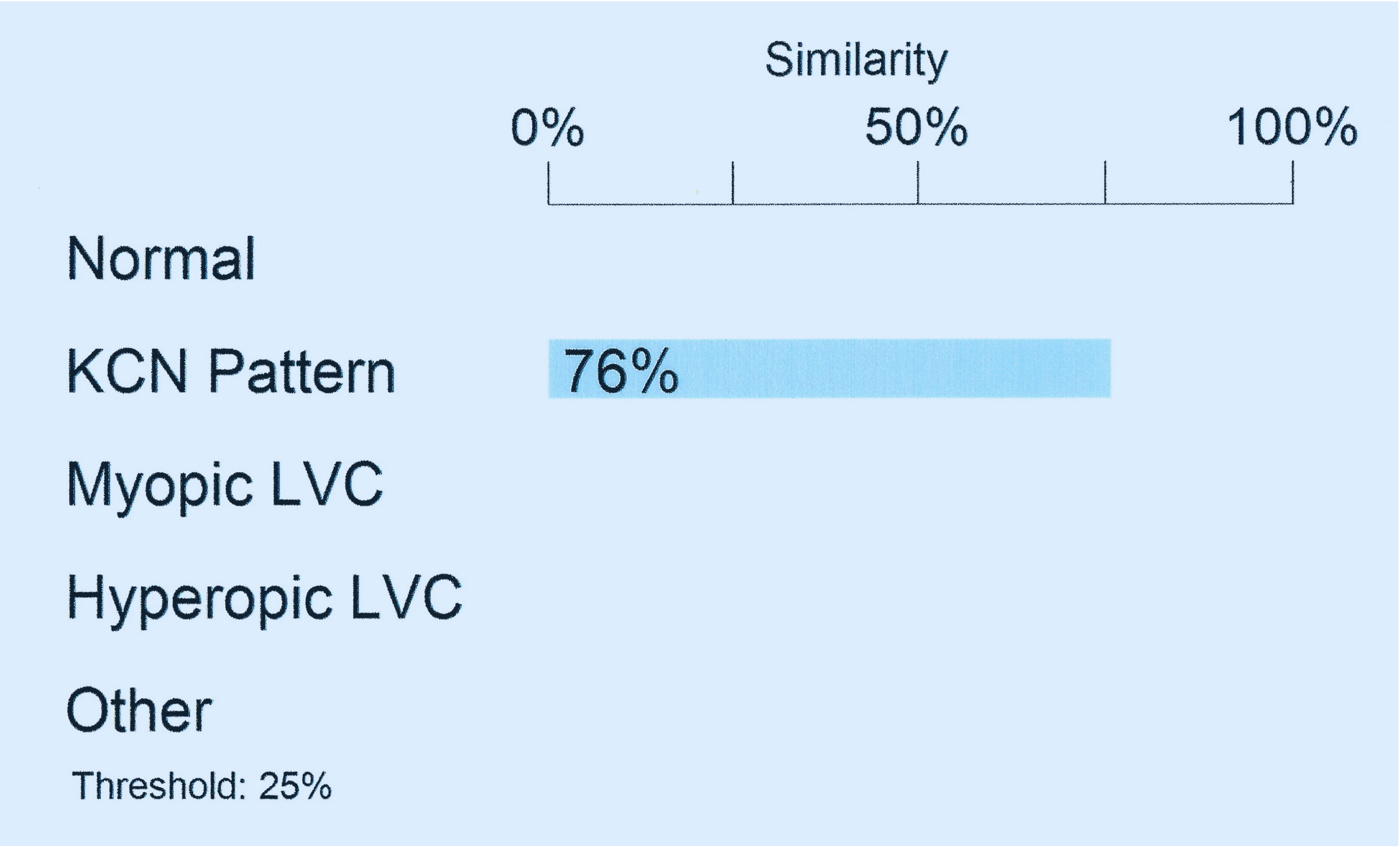
Pathfinder II

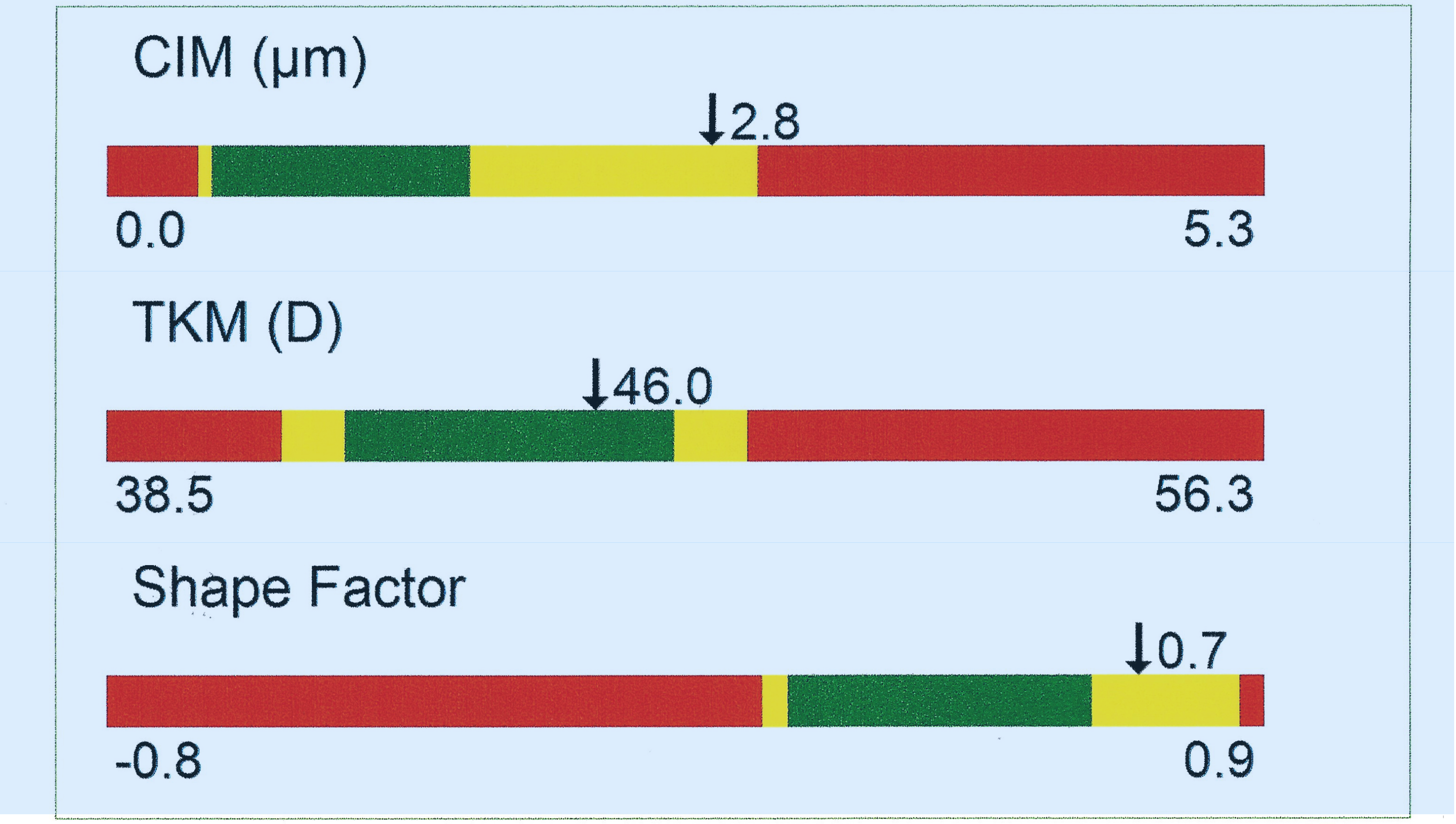
Zeiss Atlas 9000 topographer

Pathfinder II

Pathfinder II (contact lens evaluation)

- **Power distribution pattern.**
  Uses the CIM, TKM and SF to aid in identifying known patterns of corneal power distribution.
- **Corneal irregularity measurement** (CIM).
  Measurement of irregularity of the corneal surface. The higher the value, the more difficult the CL fit.
- **Mean toric corneal measurement** (TKM).
  The mean of the two flattest meridian apex values. Generated using the elevation map.
- **Shape factor** (SF).
  Indirect measurement of corneal asphericity. Generated by the axial curvature map. Negative SF = Oblate. Positive SF = Prolate





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Other uses.

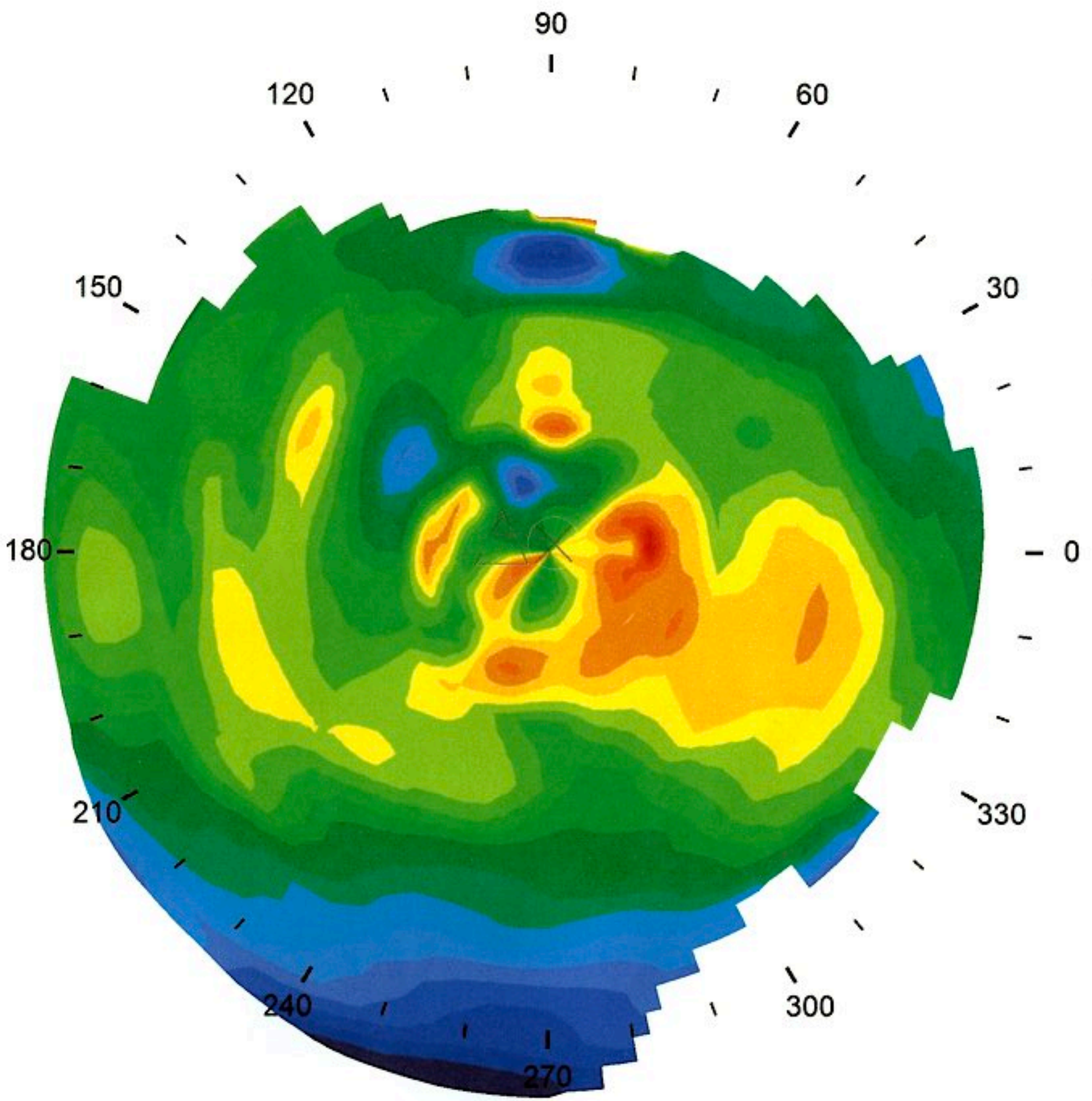
Evaluating the ocular surface.

Placido topography

Axial curvature map

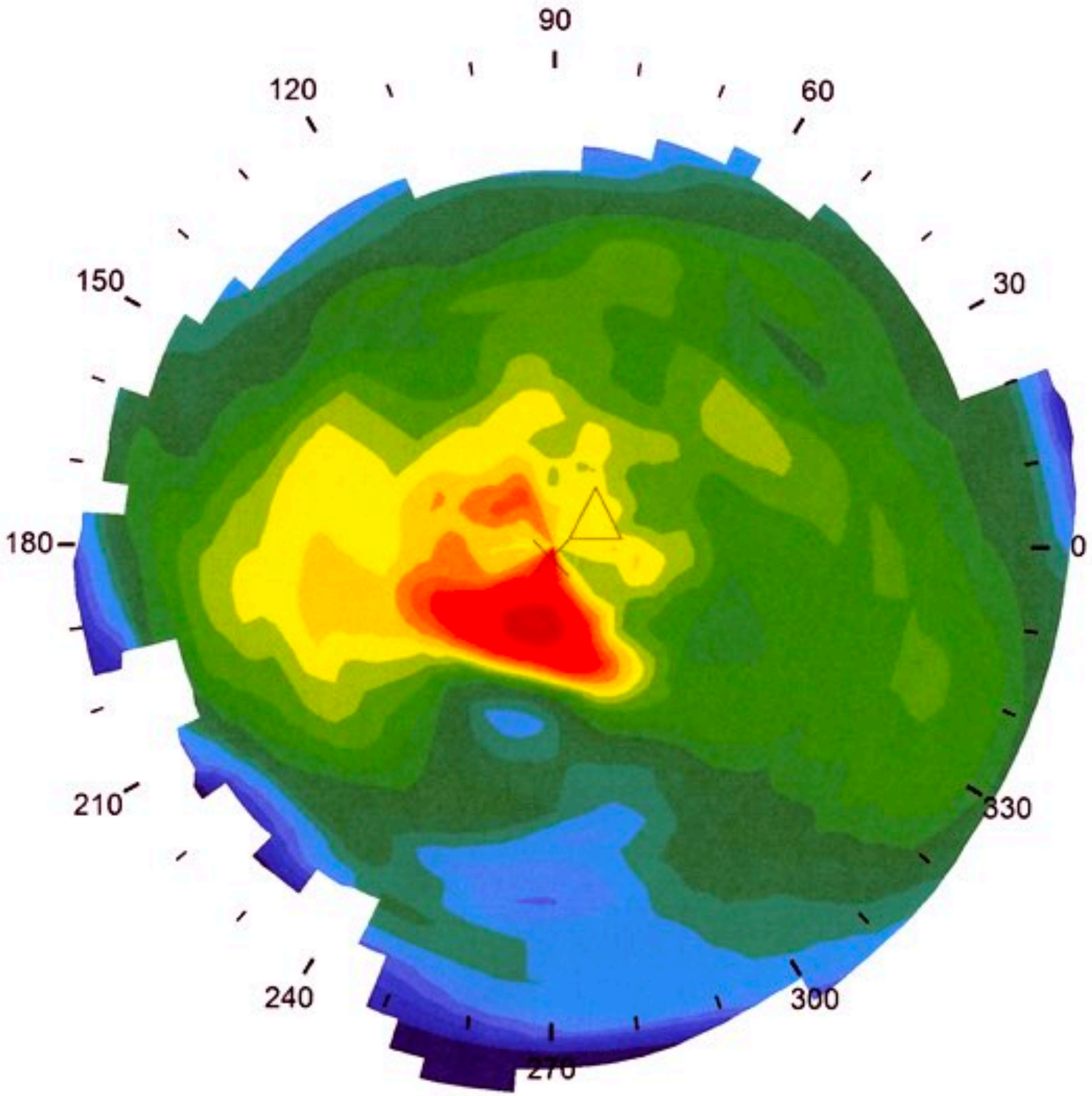
The Dry Eye / Unstable Ocular Surface

- Multiple small steep and flat islands across the anterior corneal surface.
- May show dramatic variability between blinks and individual measuremens.
- Widely variable Ks on biometer-based autokeratometry.
- Poor rings image that will also change between blinks.
- A 1.00 D error at the corneal plane is a 1.00 D post-operative refractive error.

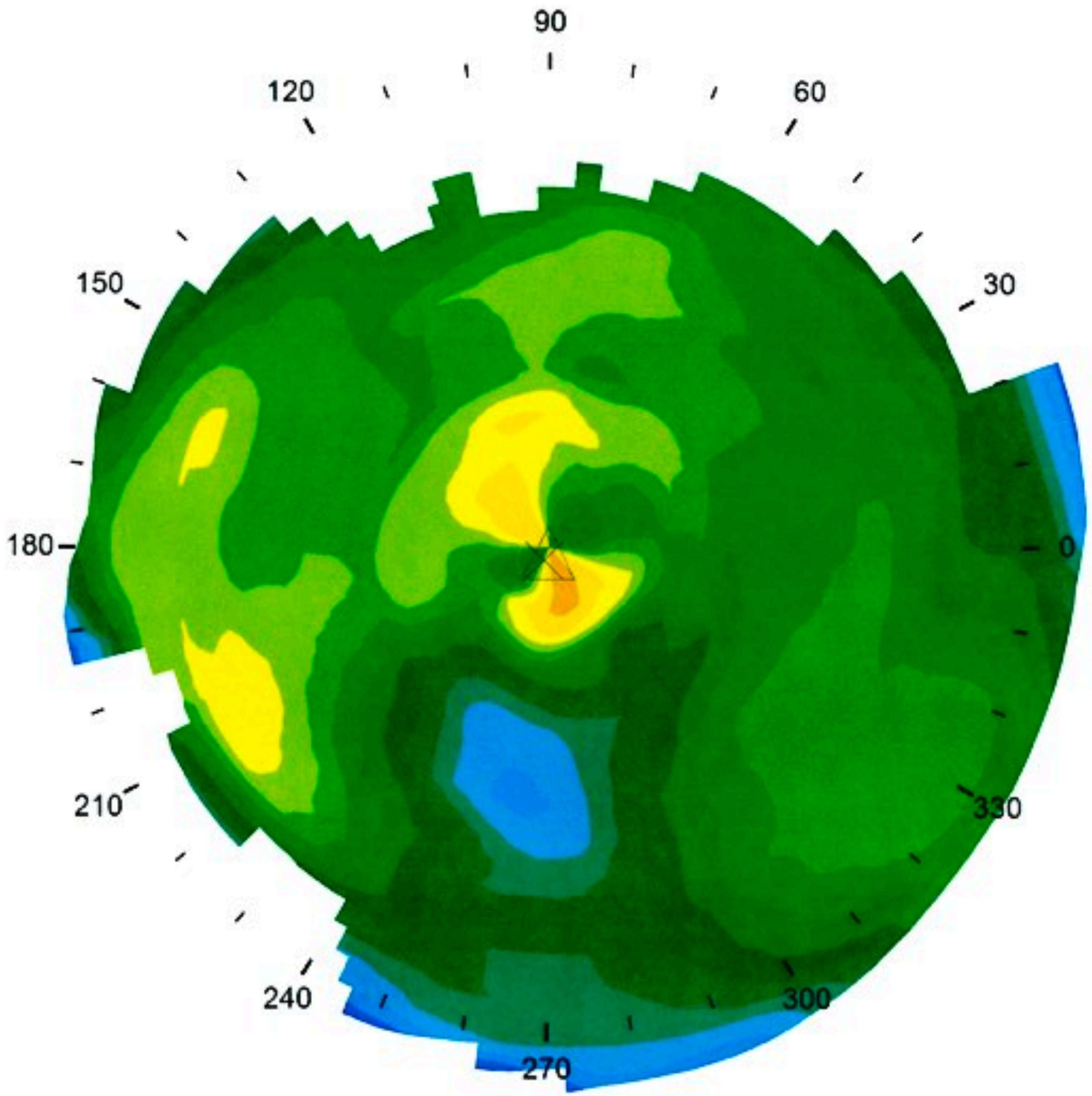


Placido topography

+1.50 D refractive surprise



Initial Topography - Central area of corneal steepening.



Same Patent 30 Minutes Later - Normalization of corneal power distribution.

T0741
6/9/1952

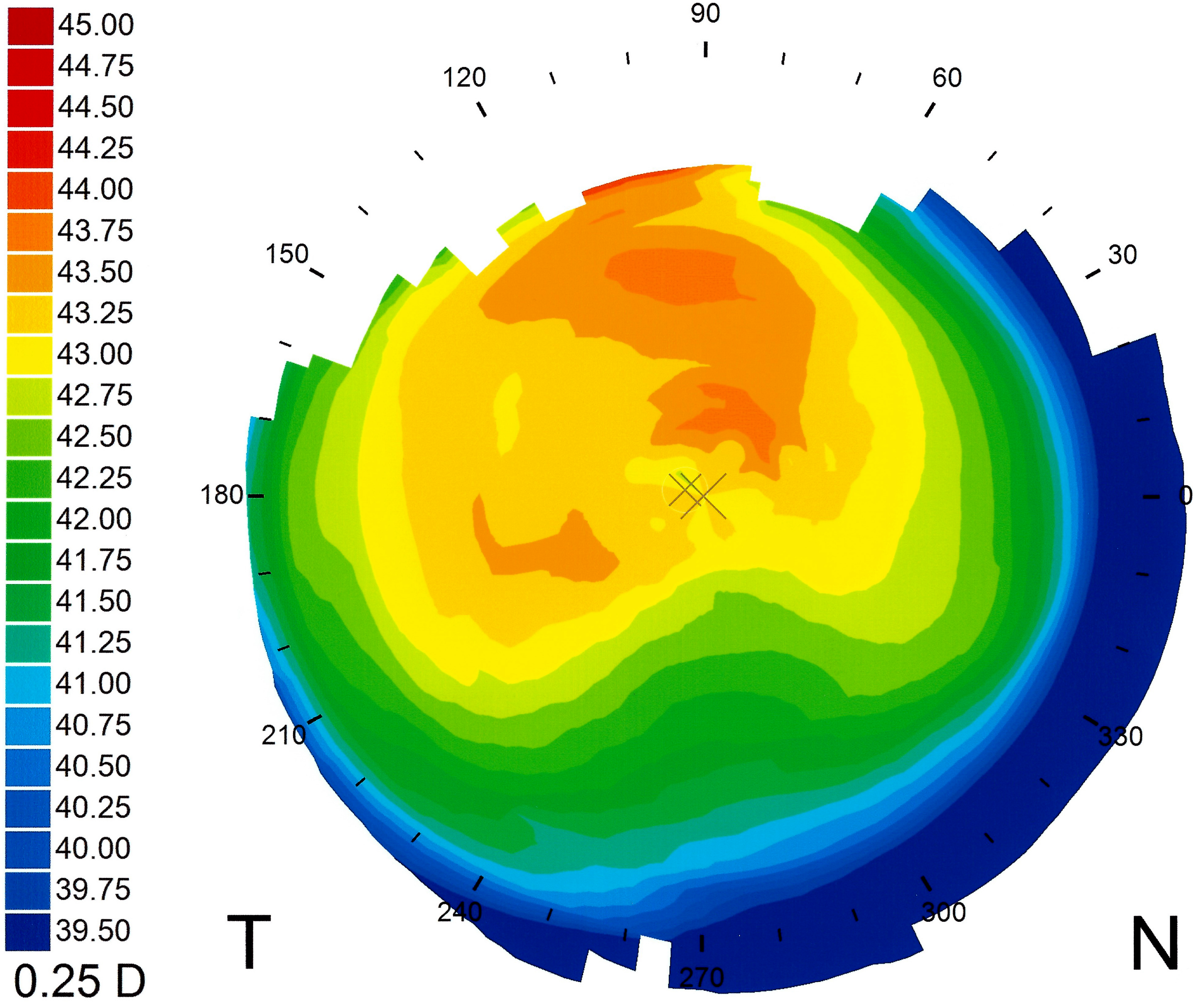
Dr Warren Hill **Single View**

Standard palette
Auto scale

Axial Curvature

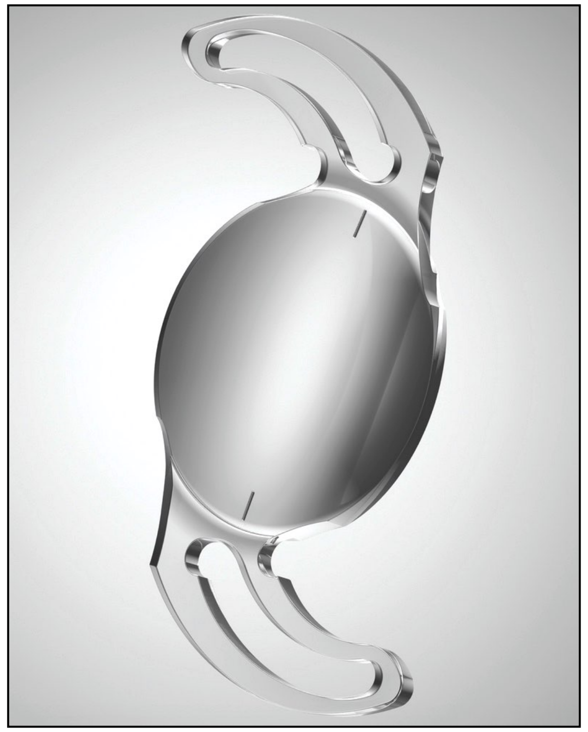
OD

5/24/2016
9:59:35 AM



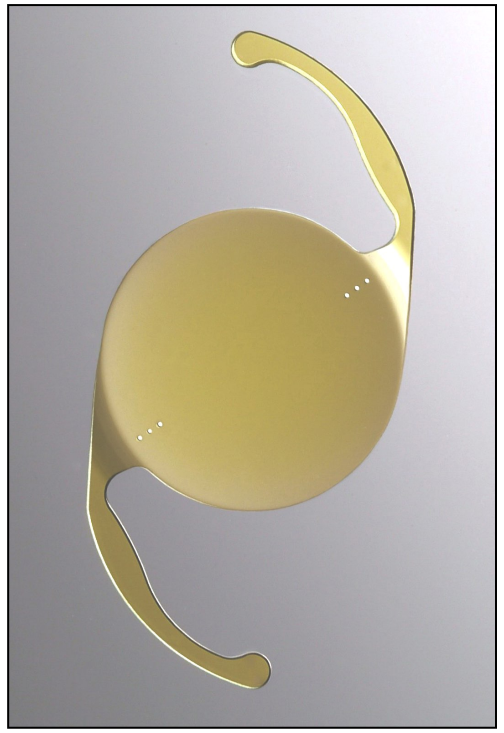
Steep K	43.21 D @ 21
Flat K	42.88 D @ 111
Astigmatism	0.33 D
0 mm ring	43.13 D
1 mm ring	43.20 D
2 mm ring	43.23 D
3 mm ring	43.14 D
4 mm ring	43.04 D
4 mm zone	43.17 D

The toric IOL.

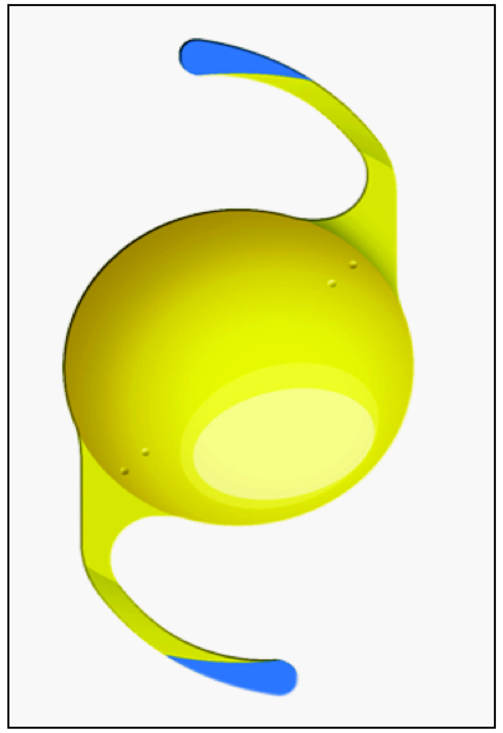


Medicountur Bi-Flex T

J & J Tecnis / Symfony



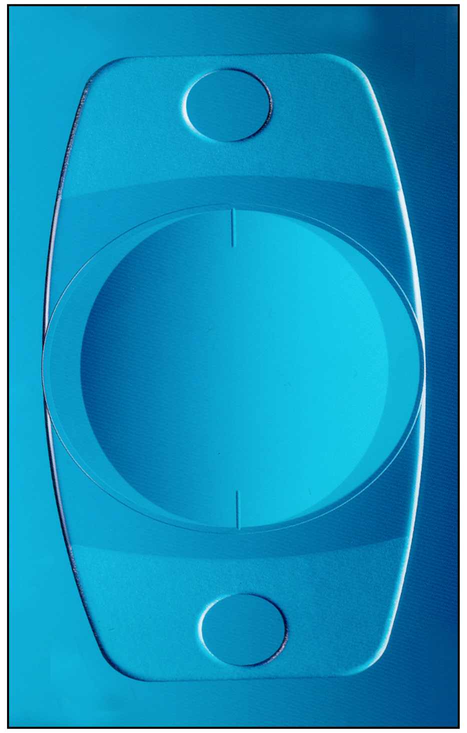
Alcon IQ / ReSTOR



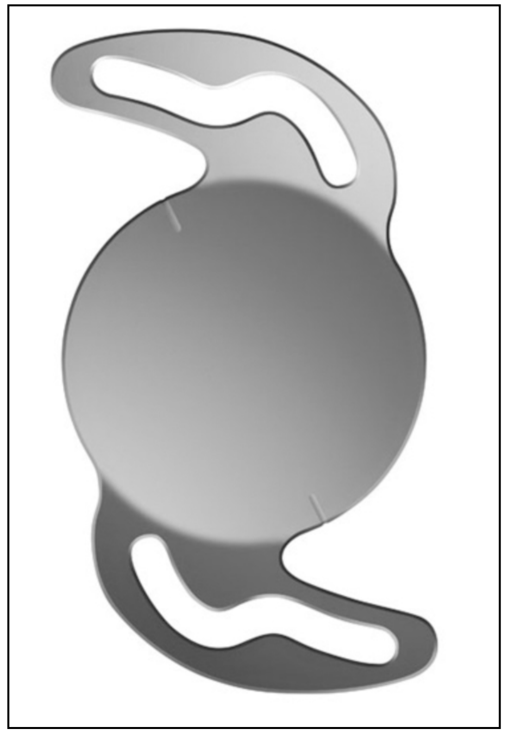
Hoya iSert

Zeiss AT TORBI

FineVision



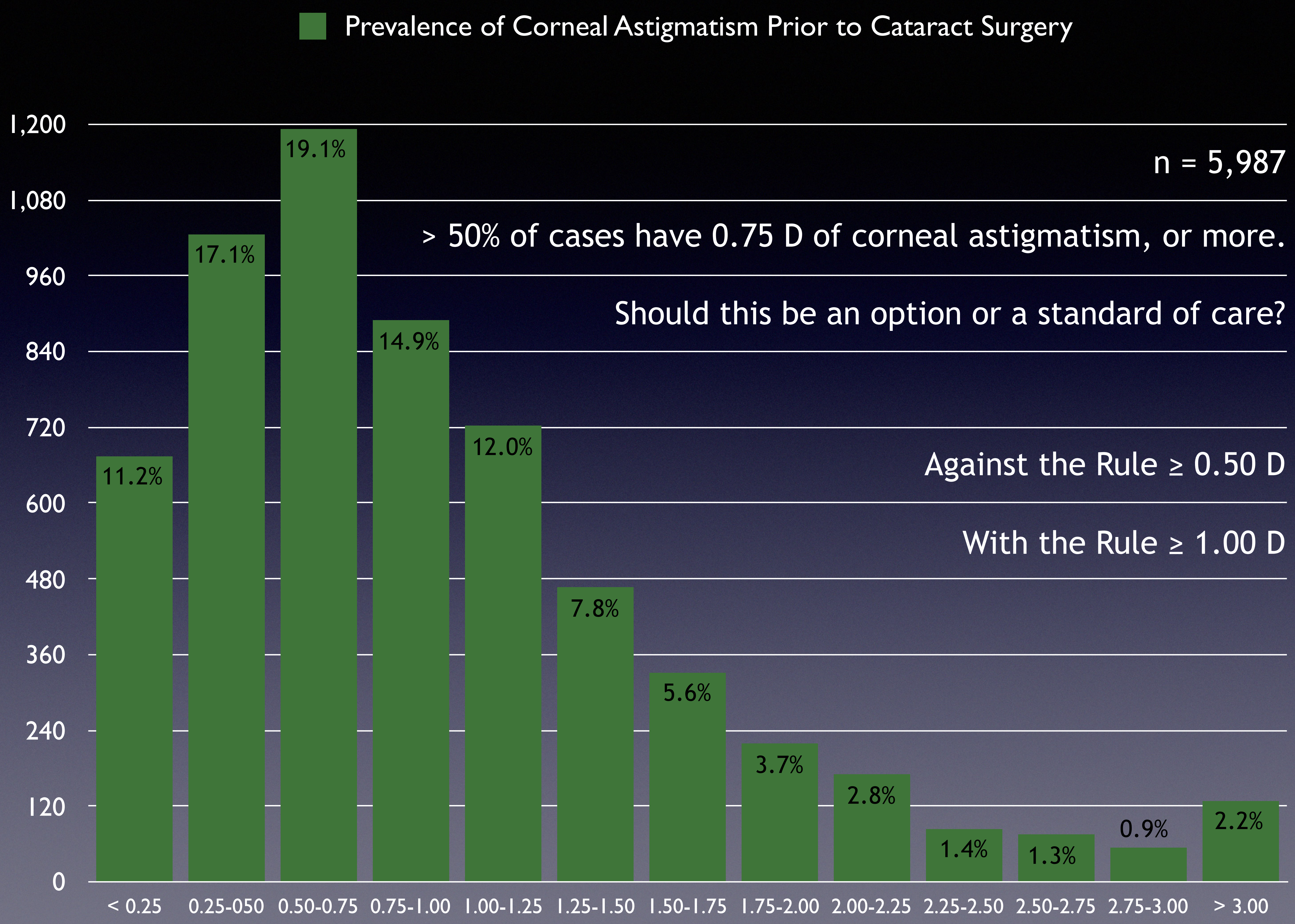
Staar



Rayner T-flex

Lentis M Plus

B&L enVista



Typical toric candidates.

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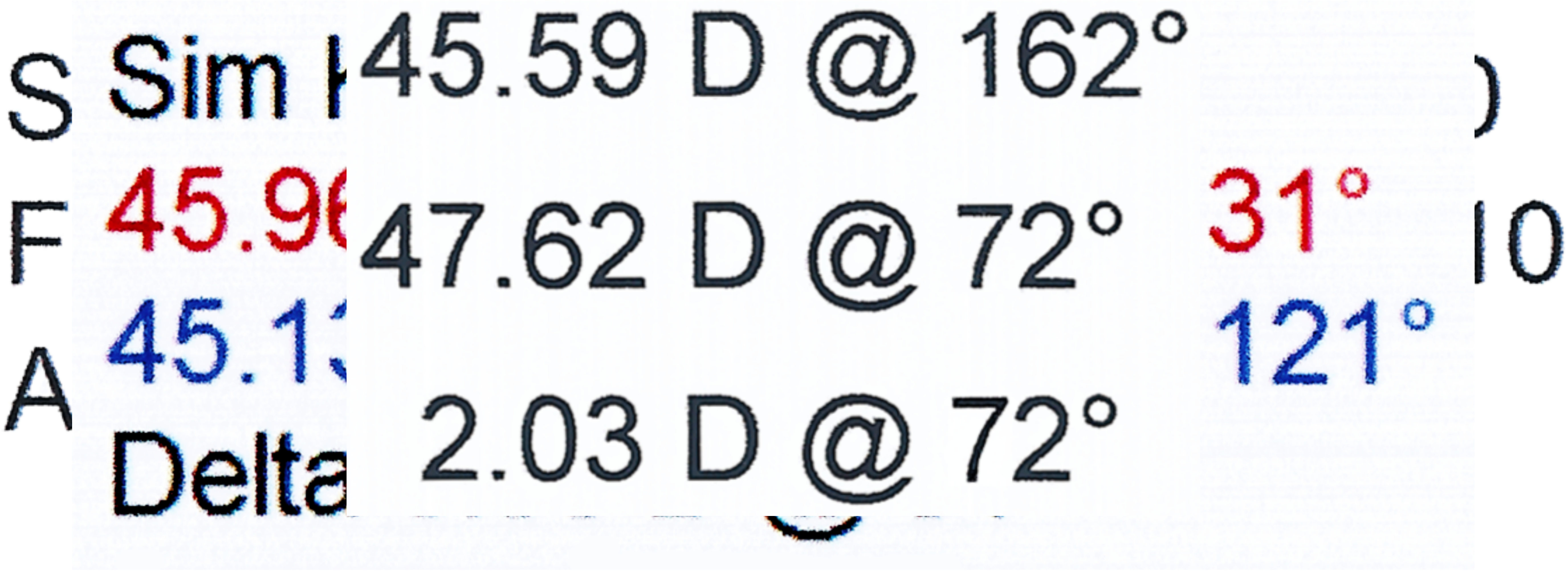
Instrument-to-instrument variability

Why am I getting such different information?



Would it be surprising to learn that all of these measurements were taken from the same eye of the same patient?

What’s your plan?

Instrument-to-instrument variability

Why am I getting such different information?

Six blind men were asked by the King to determine what an elephant looked like by touching different parts of the elephant's body.

Each man asserted that the elephant is something different: like a pillar (leg), a rope (tail), a tree branch (trunk), a hand fan (ear), a wall (belly) and a solid pipe (tusk).

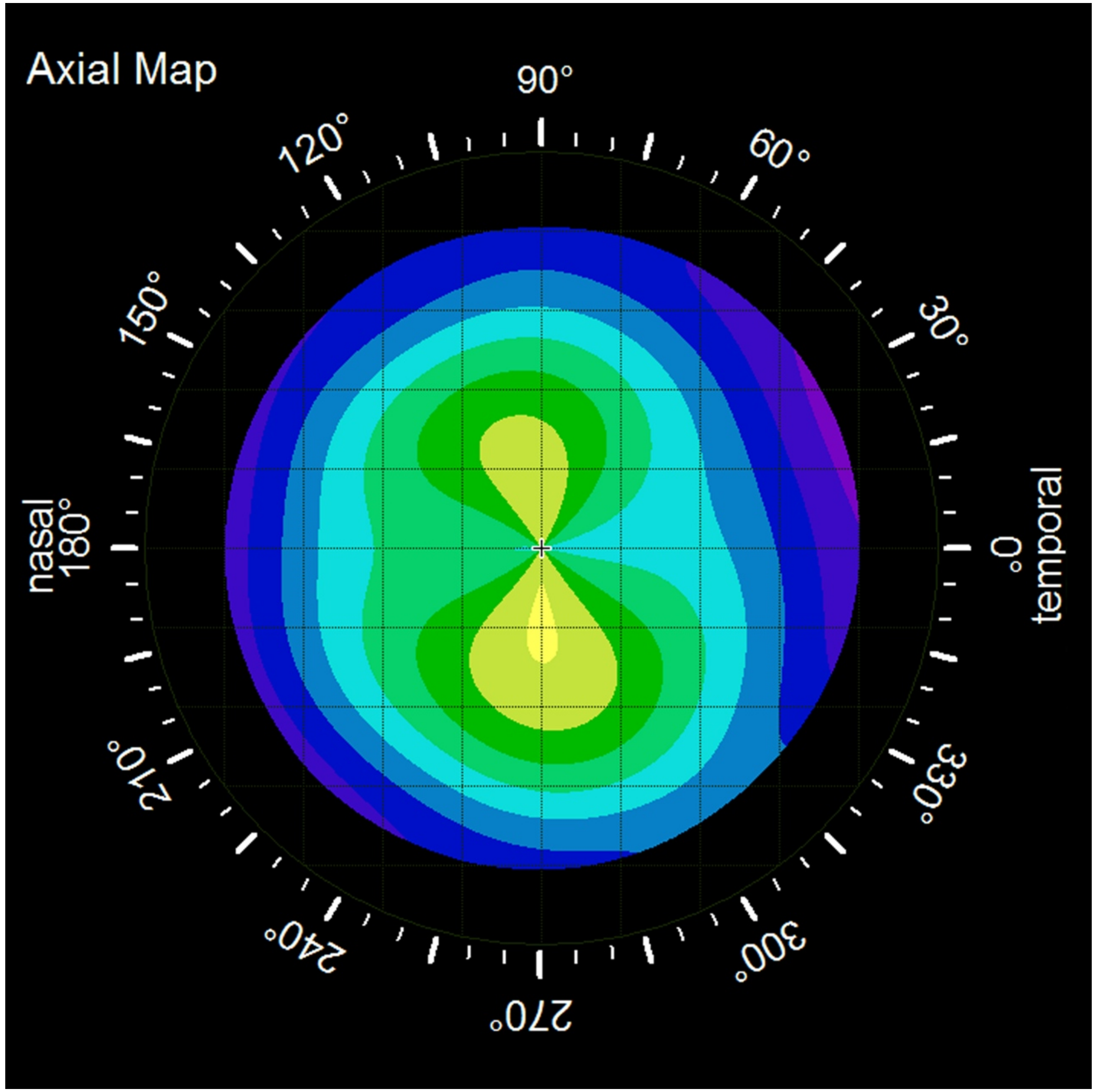
The King explained to them:
“All of you are correct…

Every one of you is telling it differently is because each one of you touched a different part of the elephant…

The elephant has all the features you mentioned.”

Instrument-to-instrument variability

Why am I getting such different information?



Six new cornea fellows were asked by the department chairman to calculate the power and orientation of a toric IOL. Each asserted that the cornea is something different using:

Simulated-Ks

Auto Ks

Scheimpflug Ks

Slit scanning Ks

Manual Ks

Ray-tracing Ks

The department chairman explained to them: "Every one of you is correct. The cornea has all the features that you describe. But not all of these instruments are equally useful for the toric IOL."

How do we know which method of many is most likely to be correct?

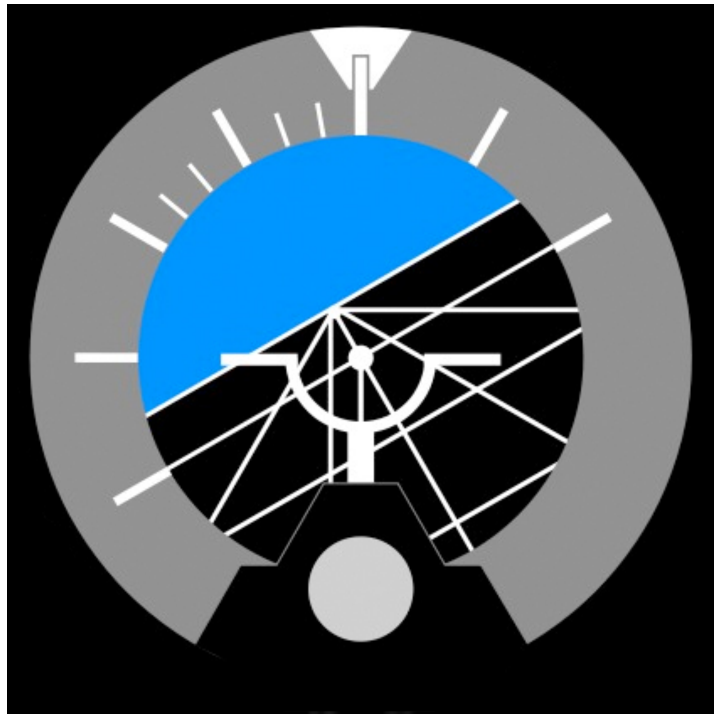

swiss
HB-IOK

Aviation triangle of agreement

Straight ahead flight

Primary Instrument
HEADING INDICATOR - No Turn

Supporting Instrument
ATTITUDE - Descending Right Turn
ATTITUDE - No Turn



Supporting Instrument
TURN & BANK - No Turn

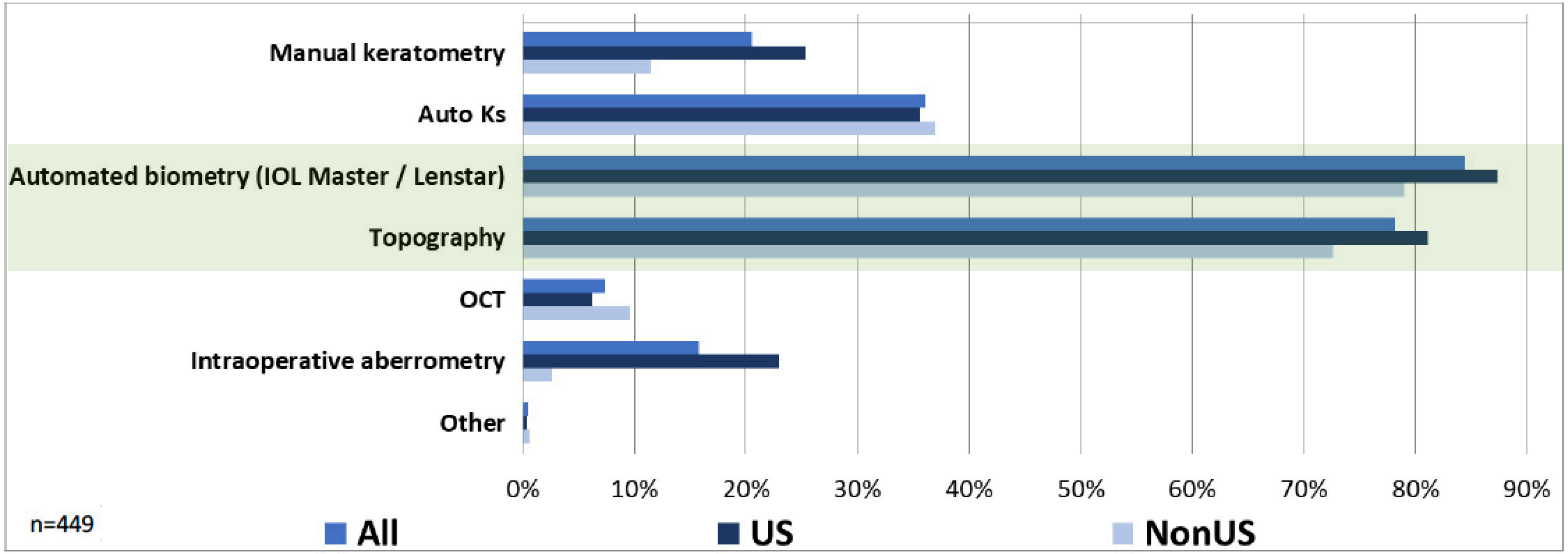
The instrument in disagreement with what we know to be correct is the one most likely to be in error.

Astigmatism Management

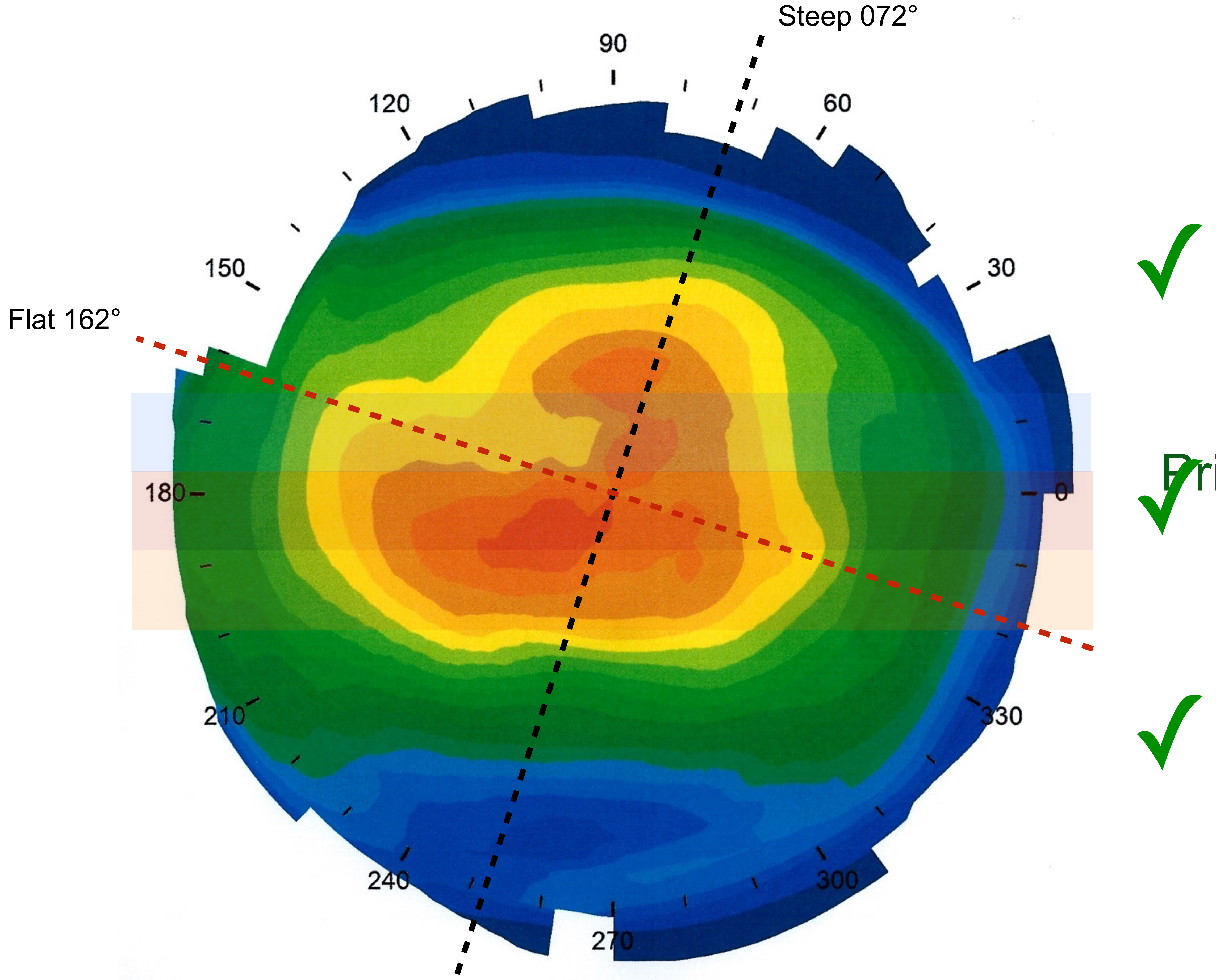
ASCRS Clinical Survey 2018

What are the primary preoperative measurements that influence your astigmatism power and axis decisions when implanting a toric IOL? (Select all that apply)

- Automated biometry (IOL Master / Lenstar): 84%
- Topography: 78%
- On average US respondents selected slight more than 2.5 measurements, 2.6 to 2.1 for Non US



How can we use topography and autokeratometry to arrive at the correct answer?



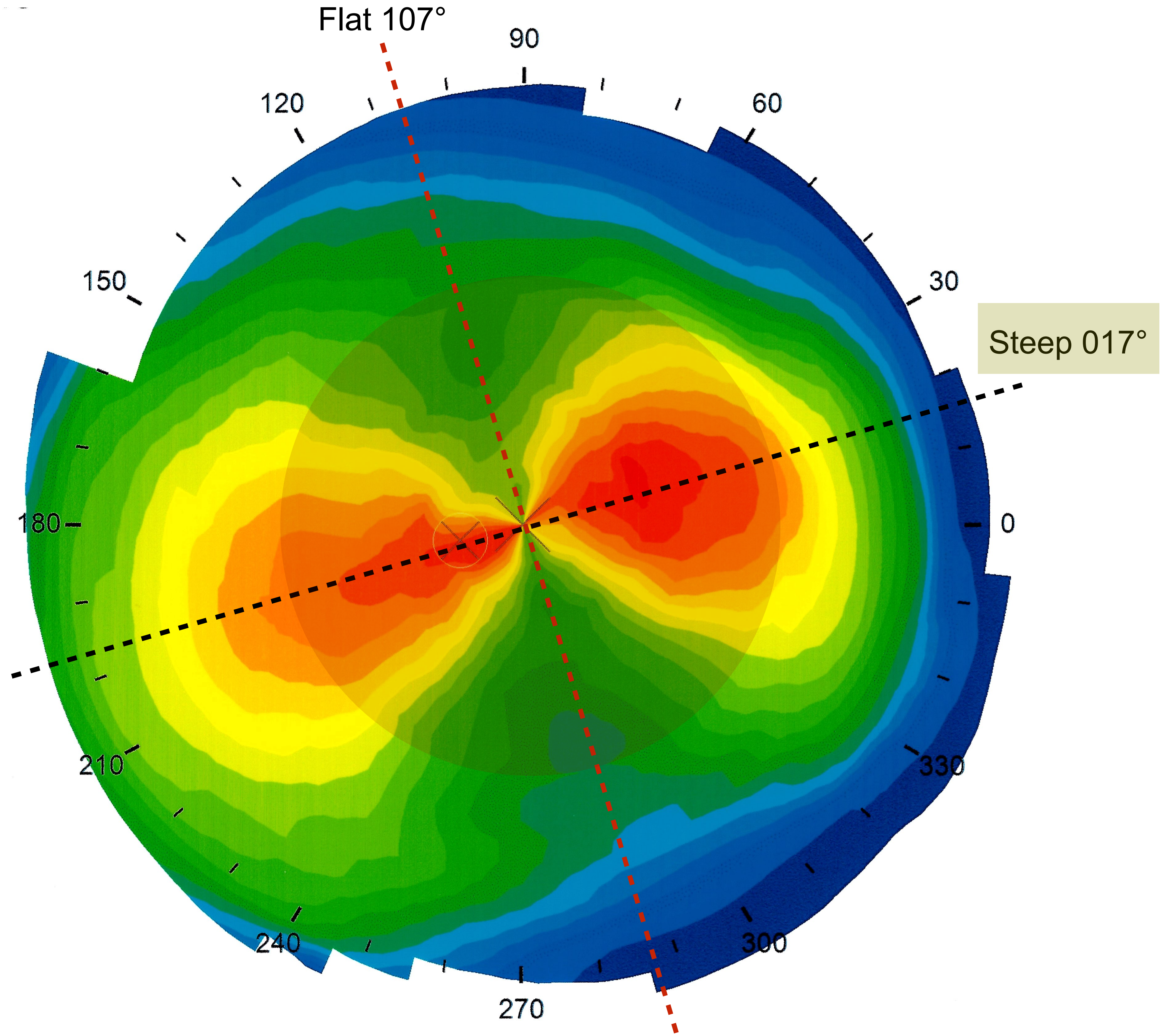
Prior hyperopic LASIK

What are the basic requirements of a toric calculator?

Step 1 - Determine the orientation of the steep and the flat meridians.

Step 2 - Measure the power difference between these two meridians.

Option - Directly measure the posterior cornea. (Not quite ready for prime time)



Topographic axial curvature map

Primary instrument for the steep meridian.

Supporting instrument for the power difference.

Confirms regular, symmetrical astigmatism.

46.16 D @ 107°	±0.074 D
48.19 D @ 17°	±0.055 D
2.03 D @ 17°	±1.5° ✓

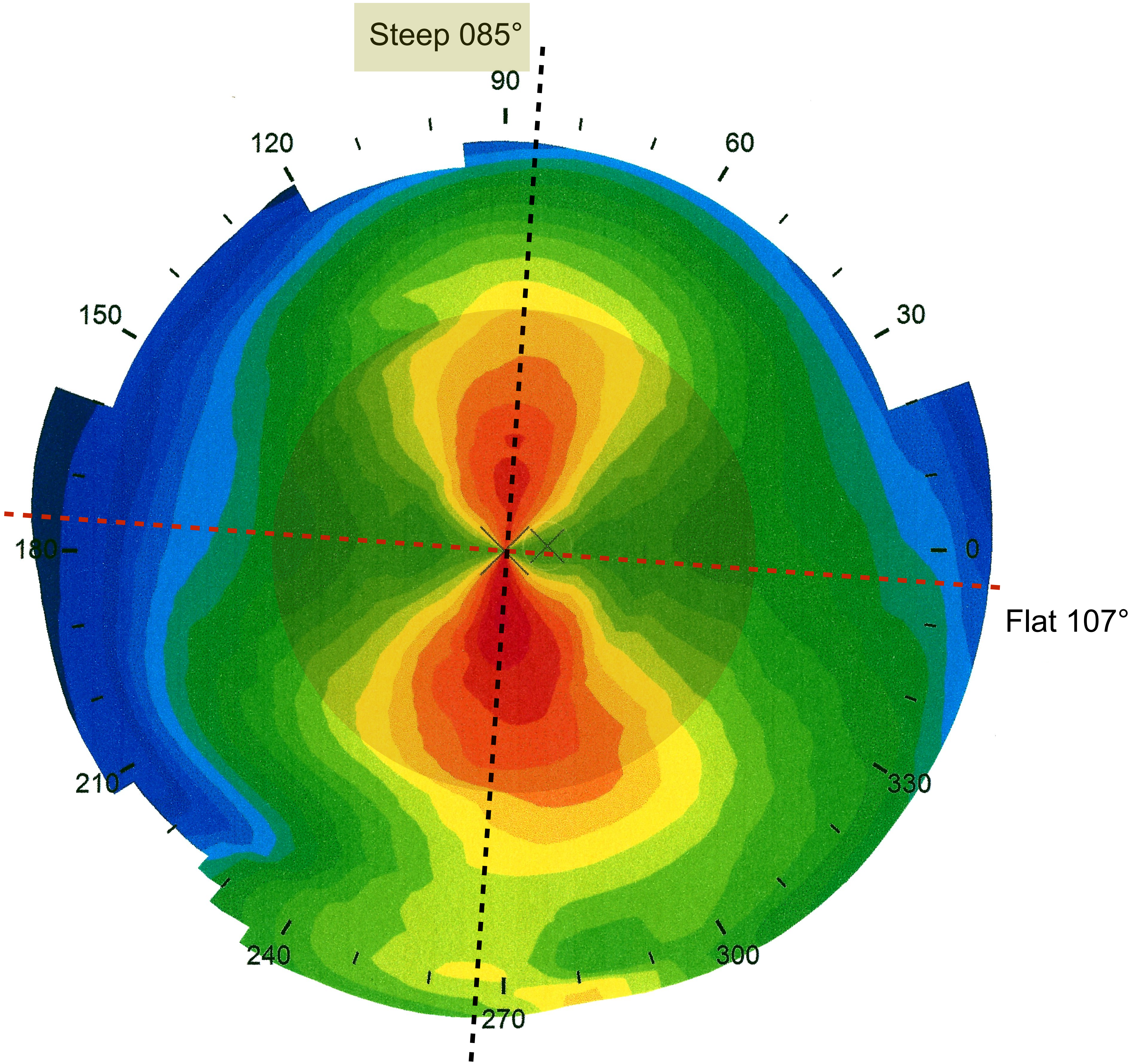
Autokeratometry (not simulated Ks)

Primary instrument for the power difference.

Supporting instrument for the steep meridian.

Multiple devices with Barrett integrated Ks.

Asymmetric and / or irregular astigmatism is a different discussion.

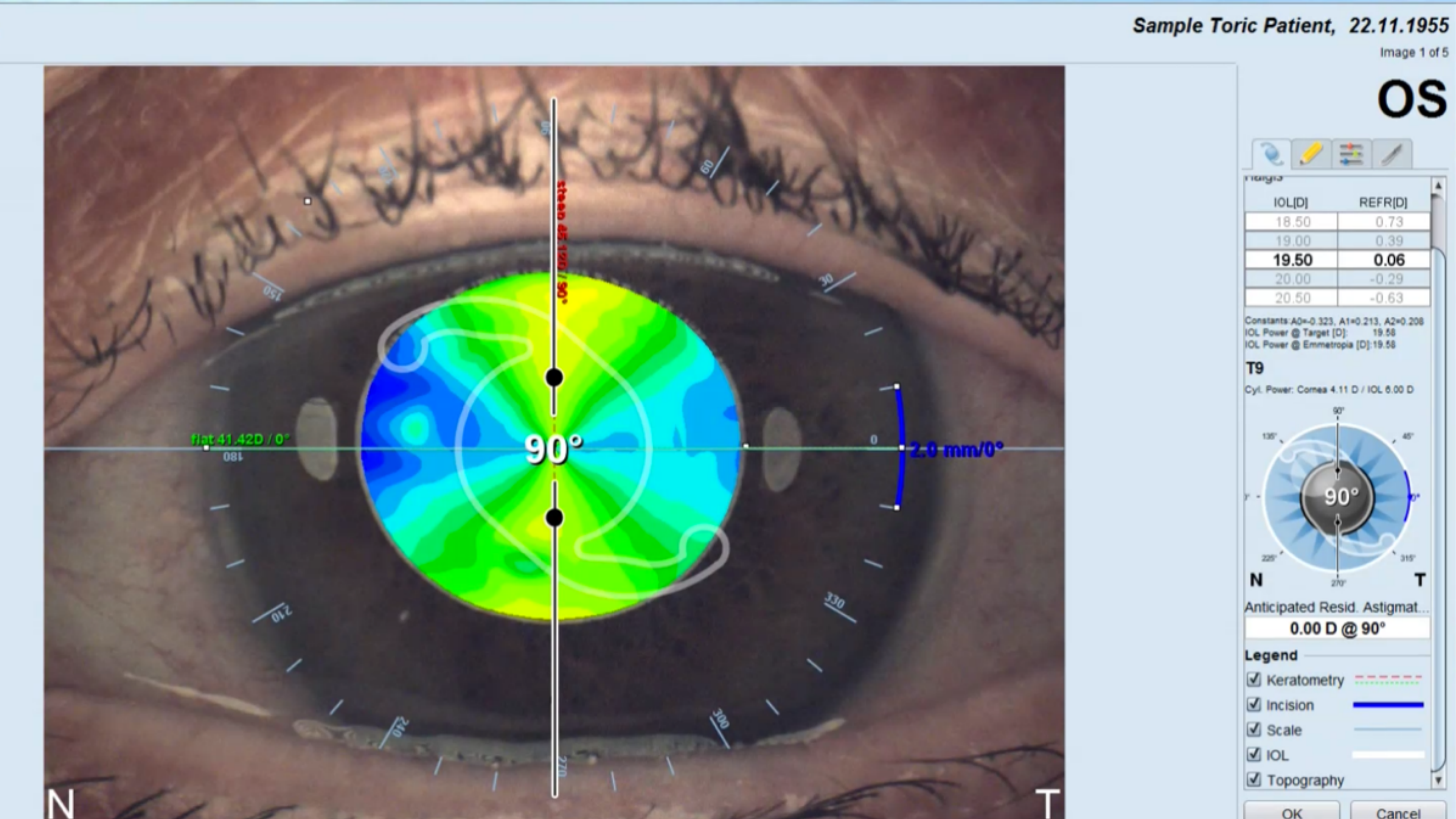


42.68 D @ 175°	±0.061 D	
44.47 D @ 85°	±0.082 D	
1.79 D @ 85°	±0.8°	✓

Do not use simulated keratometry.

Axial Curvature Map

Warren E. Hill, MD

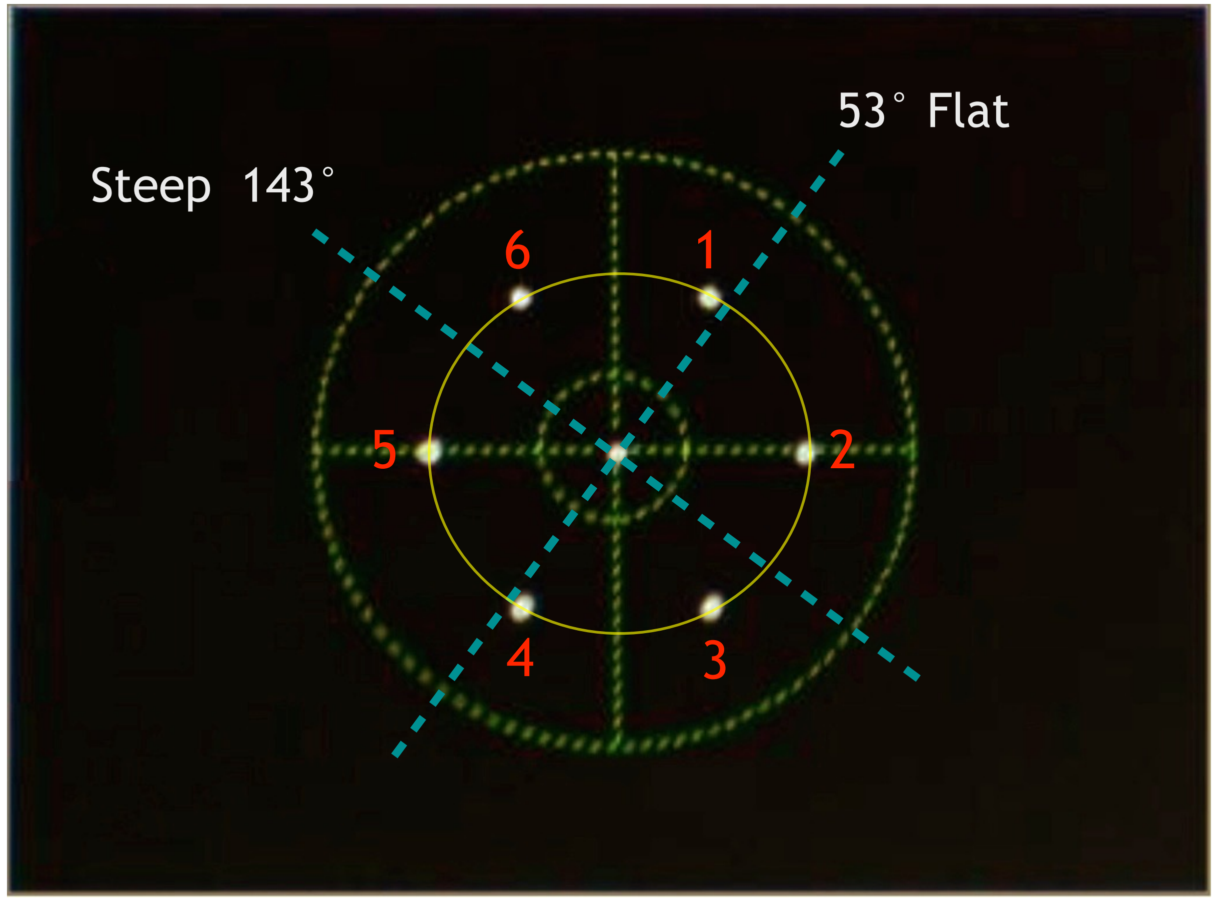

Sample Toric Patient, 22.11.1955
Image 1 of 5
OS
steep 45.12D / 90°
flat 41.42D / 0°
90°
2.0 mm/0°
N
T
IOL[D]
REFR[D]
18.50
0.73
19.00
0.39
19.50
0.06
20.00
-0.29
20.50
-0.63
Constants:A0=-0.323, A1=0.213, A2=0.208
IOL Power @ Target [D]: 19.58
IOL Power @ Emmetropia [D]:19.58
T9
Cyl. Power: Cornea 4.11 D / IOL 6.00 D
Anticipated Resid. Astigmat...
0.00 D @ 90°
Legend
Keratometry
Incision
Scale
IOL
Topography
OK
Cancel

Measuring preoperative corneal astigmatism

Low measurement density keratometer - Original IOLMaster strategy

OD (right)	
K1: 46.42 D @ 57°	7.27 mm
K2: 47.14 D @ 147°	7.16 mm
ΔD: +0.72 D @ 147°	
K1: 46.42 D @ 53°	7.27 mm
K2: 47.14 D @ 143°	7.16 mm
ΔD: +0.72 D @ 143°	
K1: 46.42 D @ 42°	7.27 mm
K2: 47.14 D @ 132°	7.16 mm
ΔD: +0.72 D @ 132°	
n: 1.3375	

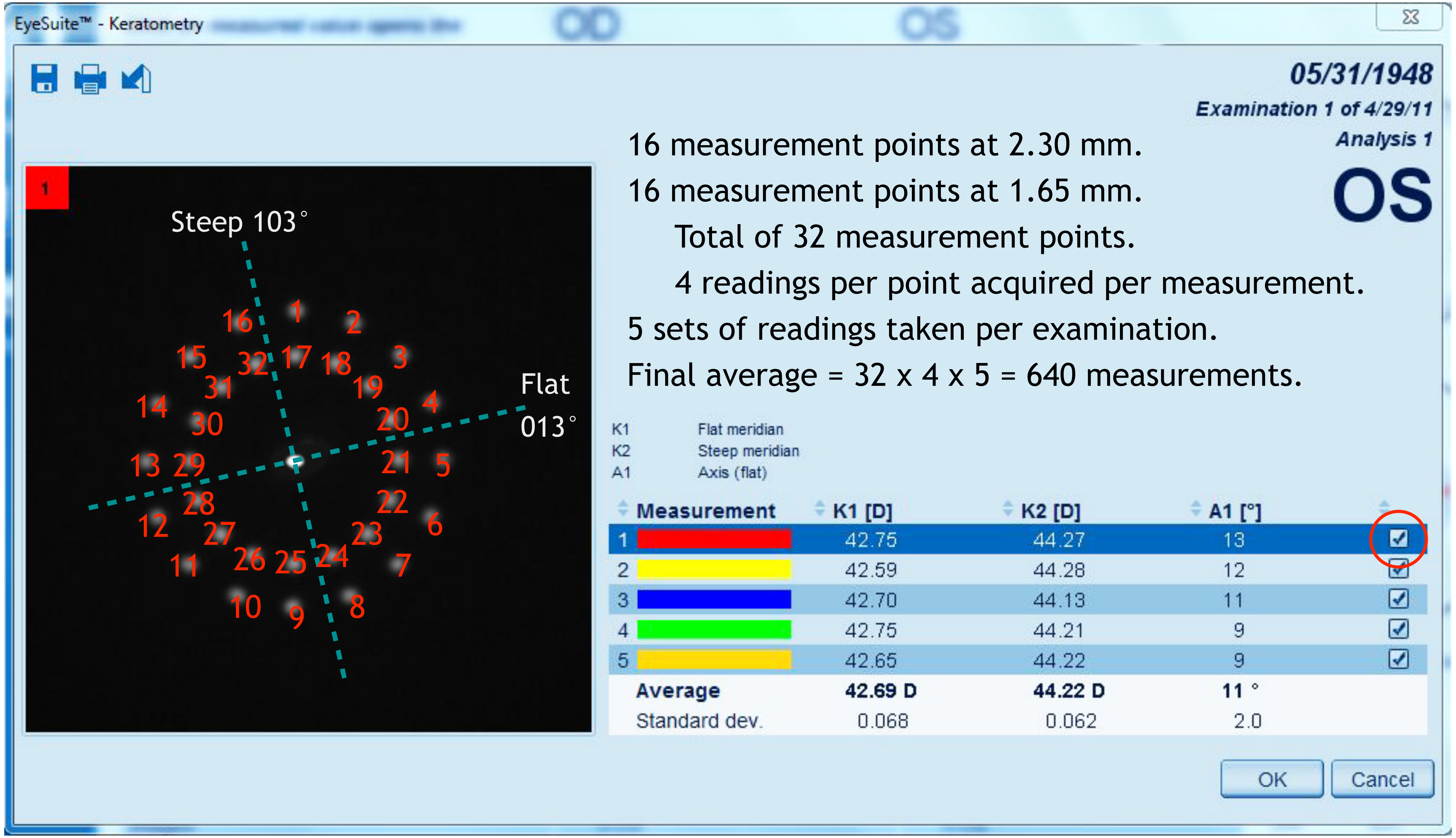
Without validation of the steep meridian,
may not be reliable as a primary instrument.



6 locations sampled over 360 degrees.
Measurement points separated by 60 degrees.
Widest spacing at 30°, 90° and 150°.
Originally intended to calculate the spherical power.

Measuring preoperative corneal astigmatism

High measurement density keratometer - Lenstar



Measurement	K1 [D]	K2 [D]	A1 [°]
1	42.75	44.27	13
2	42.59	44.28	12
3	42.70	44.13	11
4	42.75	44.21	9
5	42.65	44.22	9
Average	**42.69 D**	**44.22 D**	**11 °**
Standard dev.	0.068	0.062	2.0

Two keratometry readings

What are the consequences of an angular error?

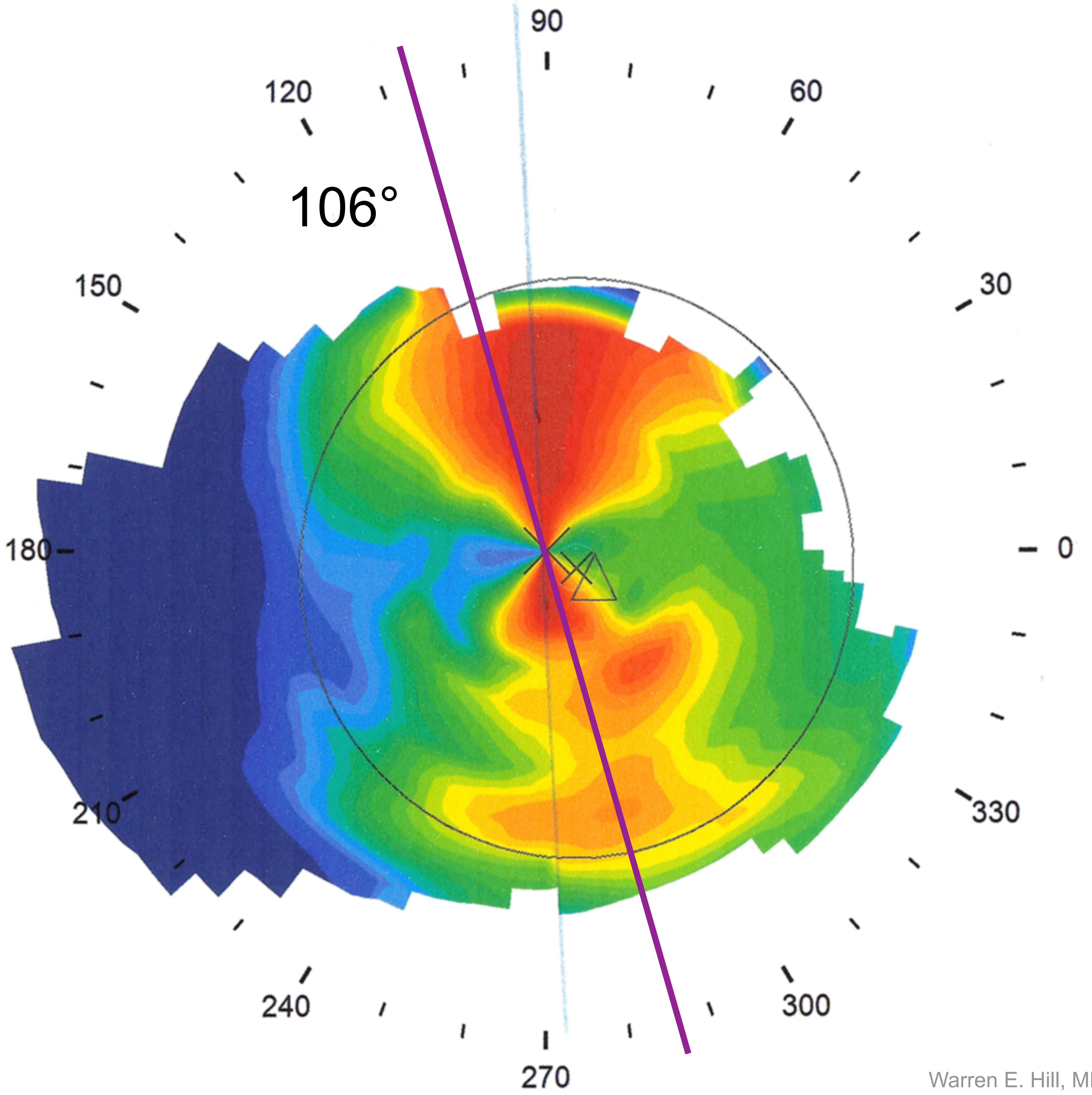
K1:	40.81	D	@	15°
K2:	43.89	D	@	105°
ΔD:	+3.08	D	@	105°
K1:	40.81	D	@	18°
K2:	44.18	D	@	108°
ΔD:	+3.37	D	@	108°
K1:	40.91	D	@	16°
K2:	44.18	D	@	106°
ΔD:	+3.27	D	@	106°

40.92	D	@	3°	±0.123 D
44.46	D	@	93°	±0.128 D
3.54	D	@	93°	±1.9°

Two keratometry readings

What are the consequences of an angular error?

K1:	40.81	D	@	15°
K2:	43.89	D	@	105°
ΔD:	+3.08	D	@	105°
K1:	40.81	D	@	18°
K2:	44.18	D	@	108°
ΔD:	+3.37	D	@	108°
K1:	40.91	D	@	16°
K2:	44.18	D	@	106°
ΔD:	+3.27	D	@	106°



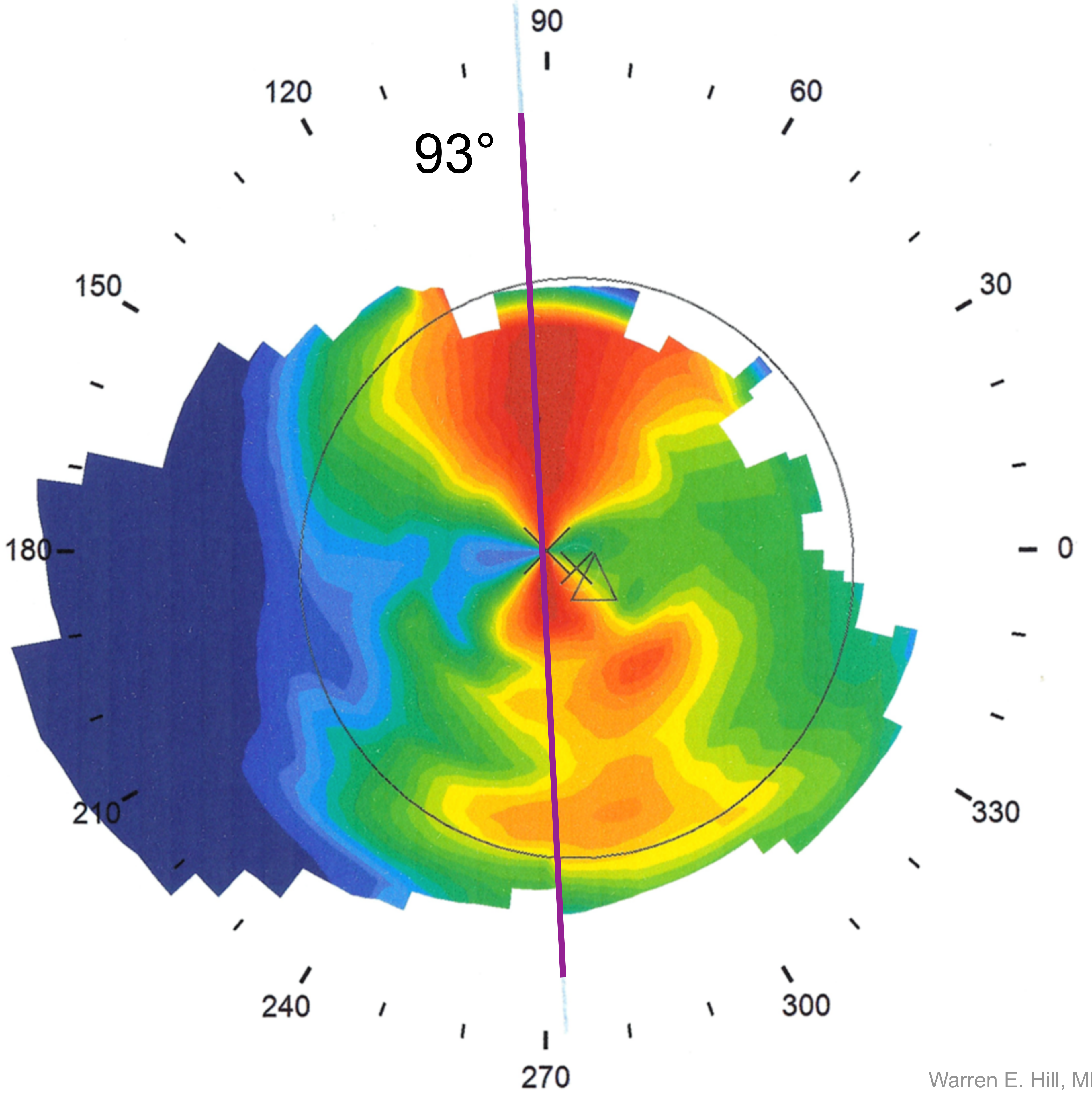
Warren E. Hill, MD

Two keratometry readings

What are the consequences of an angular error?

40.92 D @ 3°		±0.123 D
44.46 D @ 93°		±0.128 D
3.54 D @ 93°		±1.9°

✓



Warren E. Hill, MD

Доверяй но проверяй.

Trust but verify.

Understanding alterations.

Keys to the kingdom.

Warren E. Hill, MD, FACS

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East Valley Ophthalmology

Telephone: (480) 981-6111

Name: John J. Smithfield

Date: 05/5/2019

Address: 1234 Baseline Drive, Mesa, AZ

Age: 59

		Defocus Z(2,0)	1st Order Astig. Z(2,2)	Vertical Coma Z(3,-1)	Horiz. Coma Z(3,1)	Vert. Trefoil Z(3,-3)	Obliq. Trefol. Z(3,3)	Sph. Aberration Z(4,0)
Distance	OD	-1.25	+1.25 x 123	0.25 x 045	0.01 x 180	0.23 x 030	0.23 x 022	0.17
	OS	-1.25	+2.25 x 180	0.02 x 045	0.09 x 180	0.29 x 030	0.27 x 022	0.31
Reading	OD	+2.25						
	OS	+2.25						

Optician Please Note: higher order aberration values are in microns.

☑ Adaptive Progressive

☐ Bifocal ☐ Trifocal

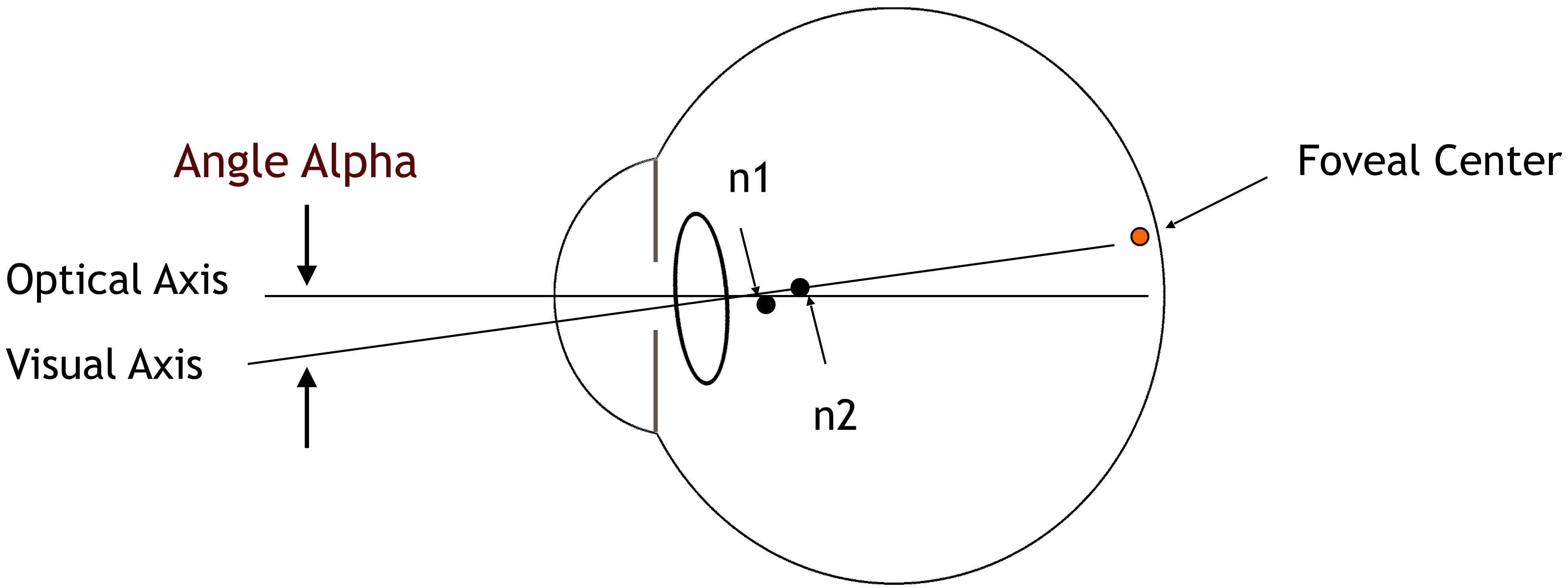
_______________ MD

Aberrations & The Human Eye

"Now, it is not too much to say that if an optician wanted to sell me an instrument [the eye] which had all these defects, I should think myself quite justified in blaming his carelessness in the strongest terms and giving him back his instrument."

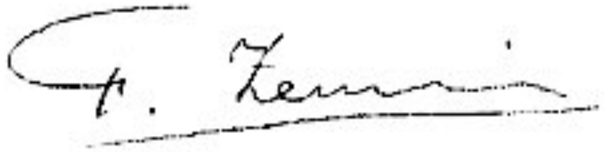
- 1875, Hermann von Helmholtz
  University of Berlin

Question: Why can't everyone be corrected to 20/12.5?



The eye is an axially asymmetric, aspheric biologic system, with its principle elements (cornea, pupil and lens) decentered, and tilted, with respect to other components.

This frequently renders the eye an optical system dominated by spherical aberration and smaller amounts of coma at the foveal center.



Optical Aberrations & The Human Eye

- 1953 - Nobel Prize in physics.
- Originator of the modern system of mathematics for describing optical aberrations - Zernike polynomials.
- Professor of Physics at the University of Groningen, The Netherlands.
- Dr. Zernike's work impacts a wide range of ophthalmology applications on a daily basis.

Zernike

What are my qualifications?

For many years have worked with industry in this area of optics.

On a daily basis, see patients with multiple aberration-related problems.

Have a dog named Zernike.

What are the Zernike coefficients (aberration profile)?

How do aberrations influence image contrast?

In 2019, what should we be looking for?

How to read a modern aberration profile.

Can a modulation transfer plot be helpful in daily practice?

How can we effectively explain all of this to patients?

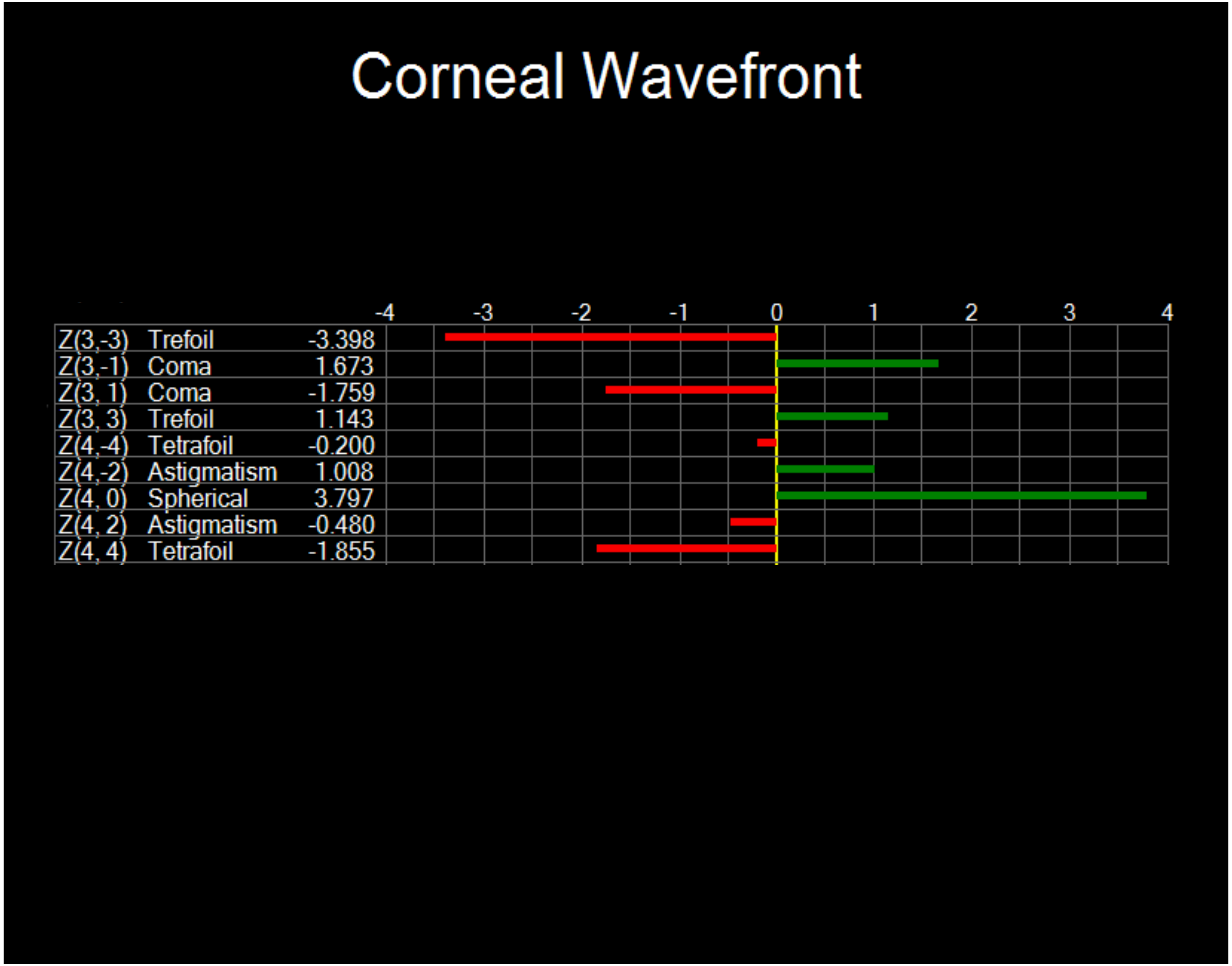
Aberrations

What the hell is this?

Presentation of a typical aberration profile.

What does all of this mean?

Is this relevant to daily practice?



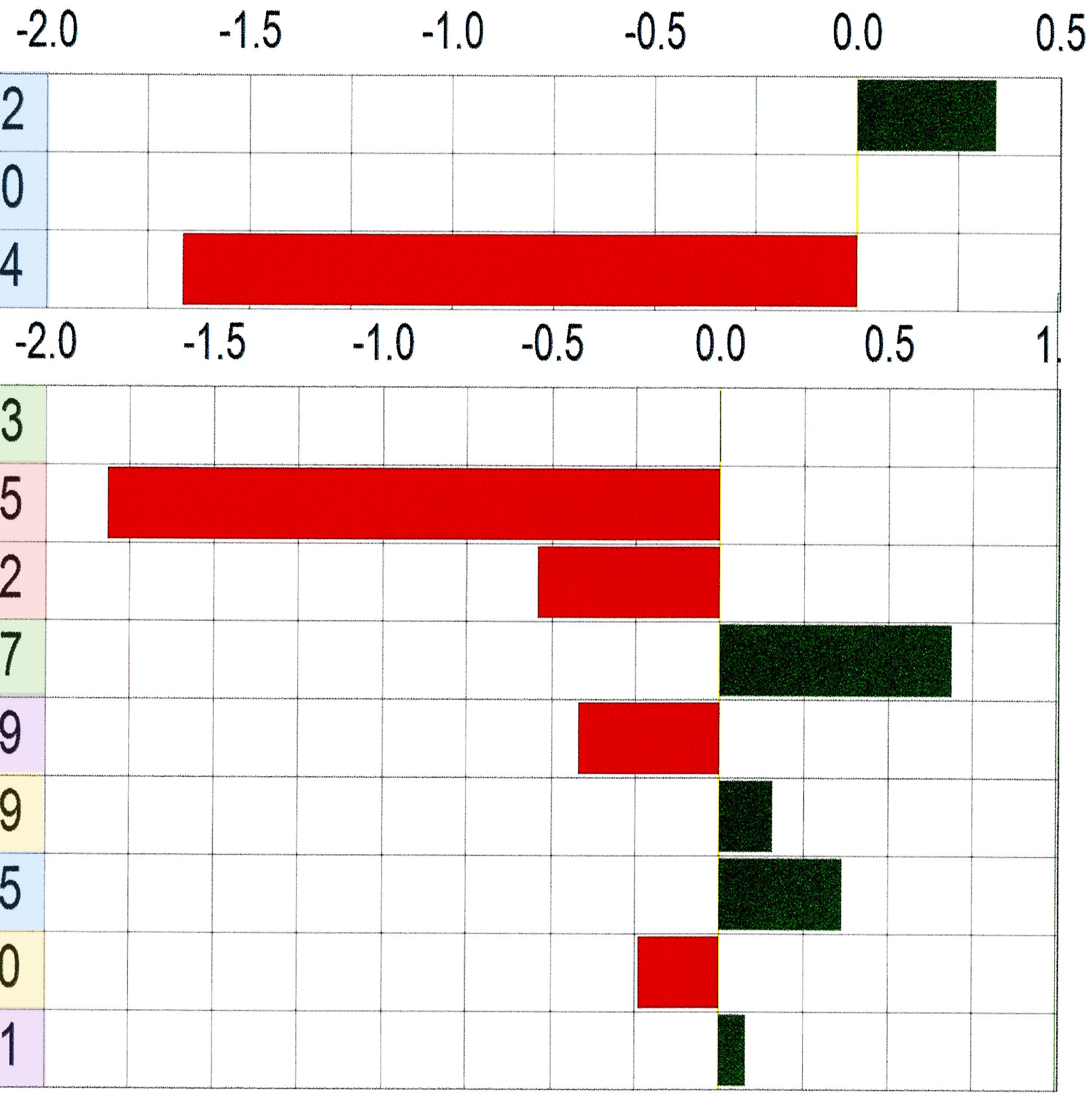
Placido topography

Zernike table

Aberration Profile

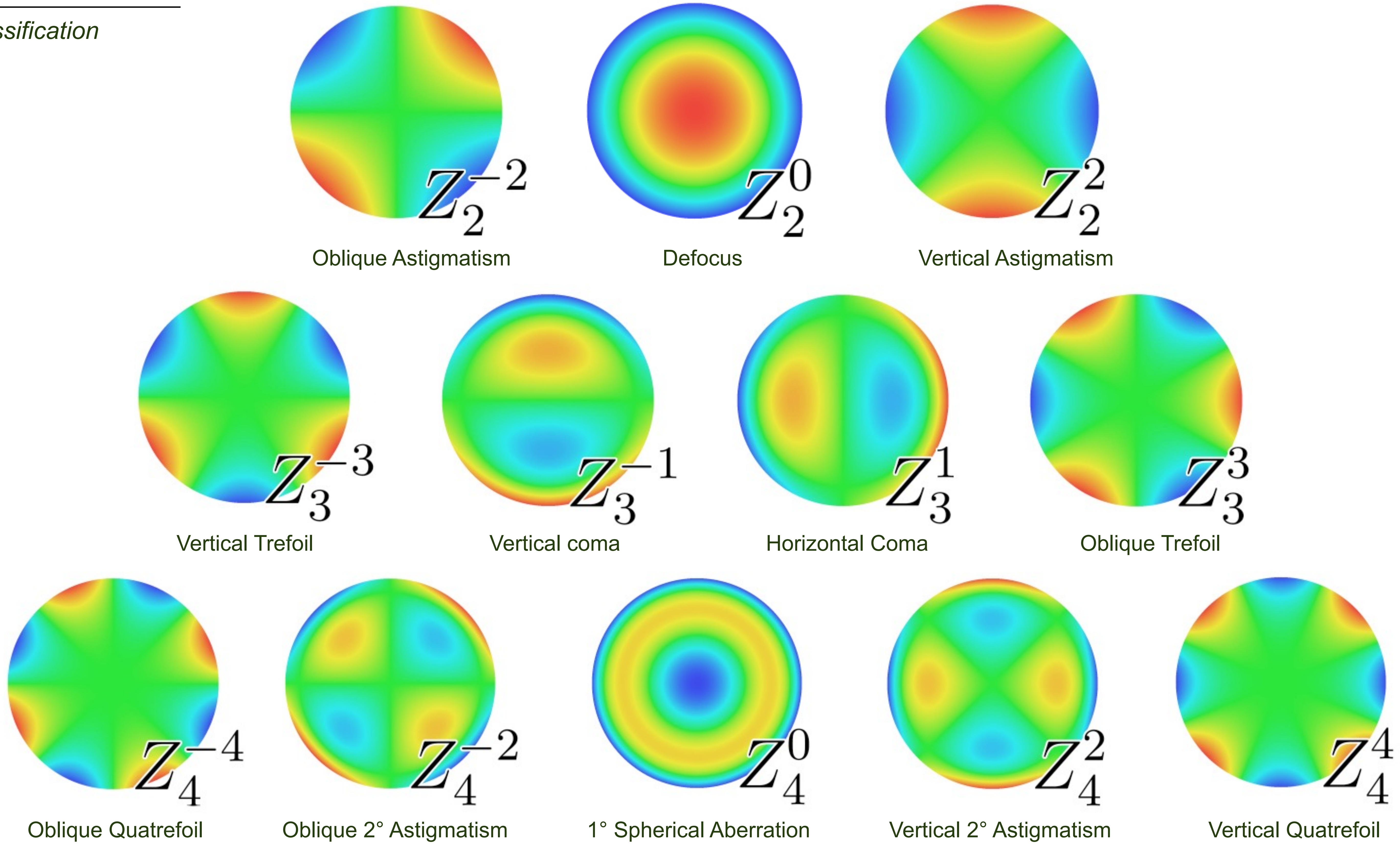
- Quantitative representation of corneal aberrations (Zernike pyramid).
- Extremely useful for understanding the reason for a reduction in visual quality.
- 2nd order aberrations correspond to a patient's spectacle correction.
- 3rd and 4th order aberrations elevated with KCN & following refractive surgery.
- **Mandatory pre-operative screen for premium IOL candidates.**
- **An important part of evaluating all patients with prior refractive surgery.**

Zernike common name		µm
Z(2,-2)	Oblique Astigmatism	0.342
Z(2, 0)	Defocus	0.000
Z(2, 2)	WTR/ATR Astig.	-1.664
Z(3,-3)	Oblique Trefoil	0.003
Z(3,-1)	Vertical Coma	-1.815
Z(3, 1)	Horizontal Coma	-0.542
Z(3, 3)	Horizontal Trefoil	0.687
Z(4,-4)	Oblique Quatrefoil	-0.419
Z(4,-2)	Oblique 2nd Astig.	0.159
Z(4, 0)	Spherical Aberration	0.365
Z(4, 2)	WTR/ATR 2nd Astig.	-0.240
Z(4, 4)	Horizontal Quatrefoil	0.081



Aberrations

Zernike image classification

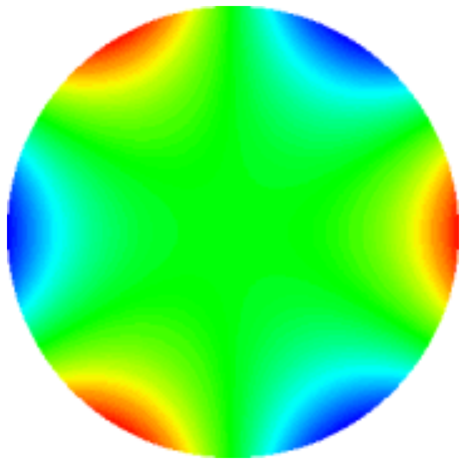


Aberrations

The human visual system

Z(3,3)

Oblique Trefoil

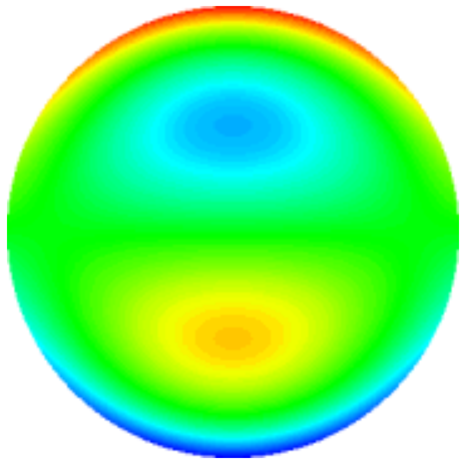


$$(3r^3 - 2r)\sin\theta$$

n = 3
m = 3

Z(3,-1)

Vertical Coma

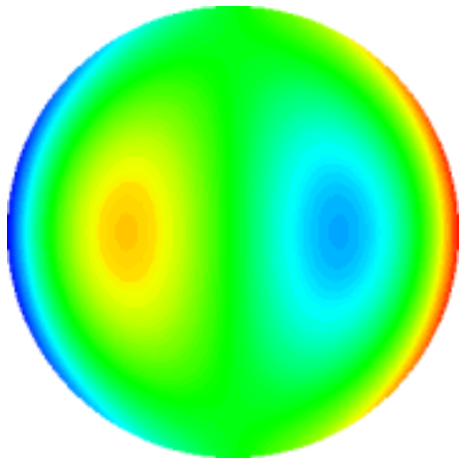


$$r^3 \sin 3\theta$$

n = 3
m = -1

Z(3,1)

Horizontal Coma

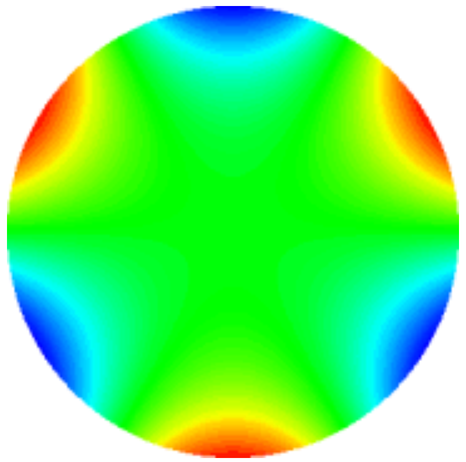


$$(3r^3 - 2r)\cos\theta$$

n = 3
m = 1

Z(3,-3)

Vertical Trefoil



$$r^3 \cos 3\theta$$

n = 3
m = -3

The human visual system is mostly a contrast sensitivity detection system.

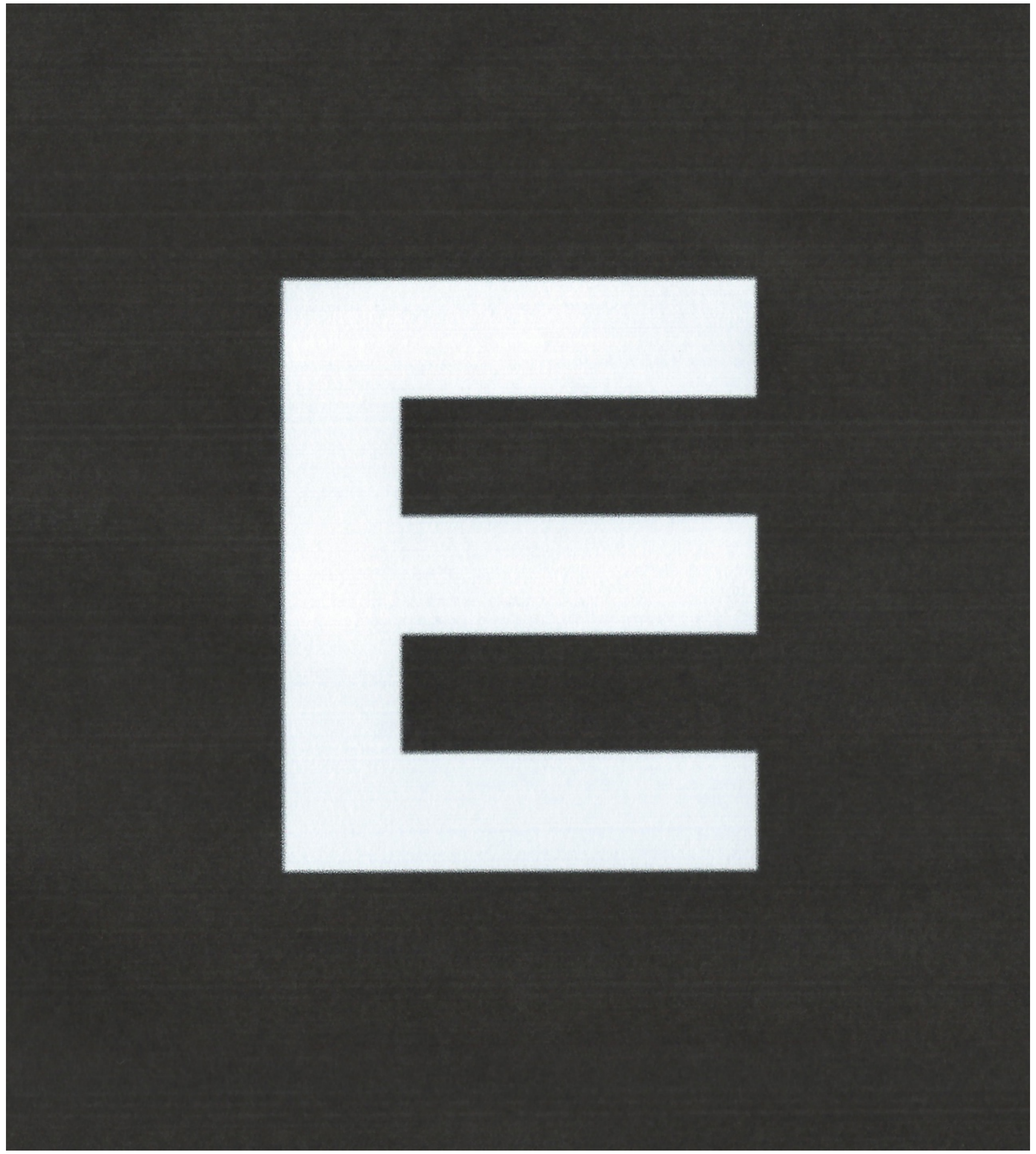
The quality of any optical system is measured by its ability to transfer contrast from the object viewed to the image formed.

An increase in a specific aberration reduces image contrast in a specific way.

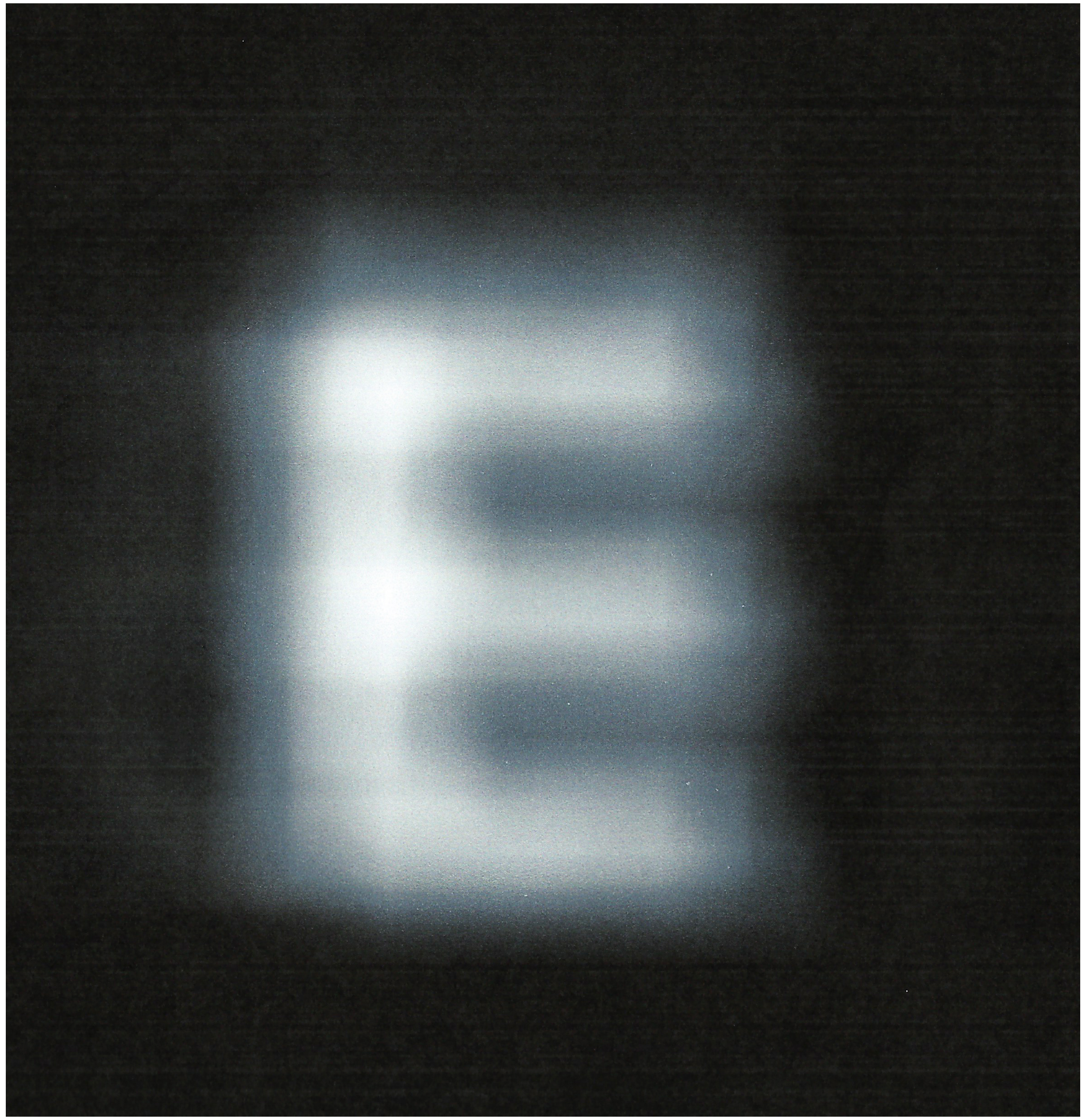
The reduction in contrast by individual aberrations is additive. Aberrations on the same surface do no cancel each other.

Aberrations

The human visual system



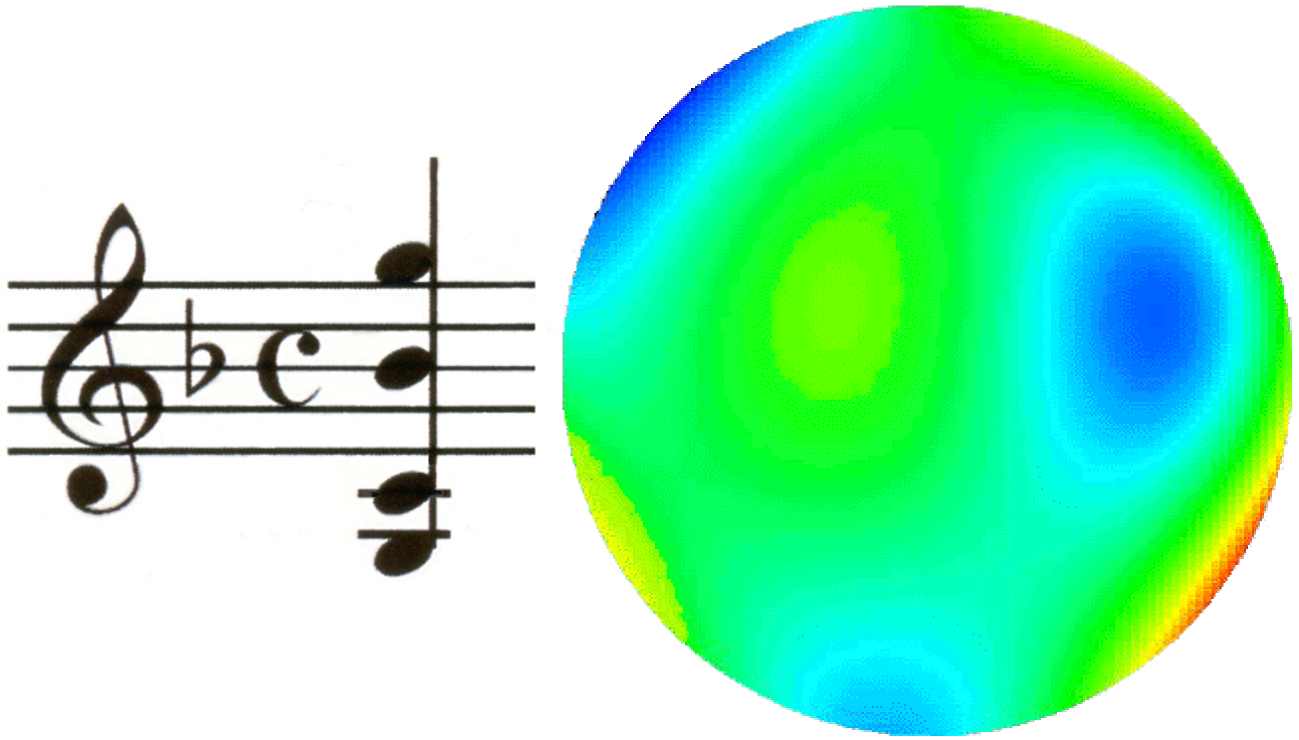
Normal contrast



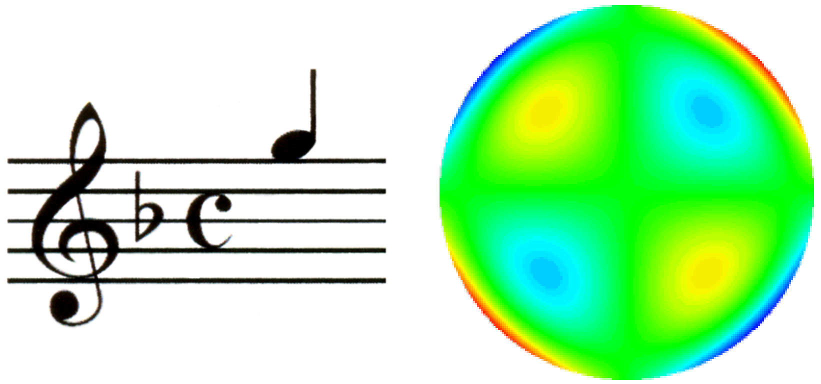
Reduced contrast from elevated corneal aberrations.

Aberrations

Rarely exist in individual forms

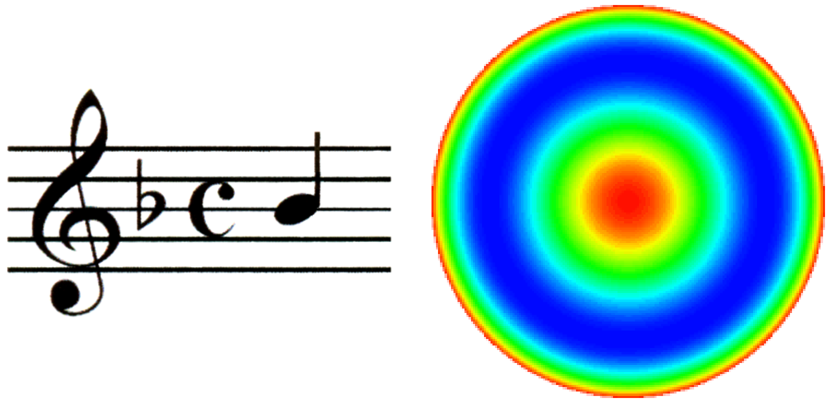


An aberration profile
is a composite, consisting
of multiple aberrations.



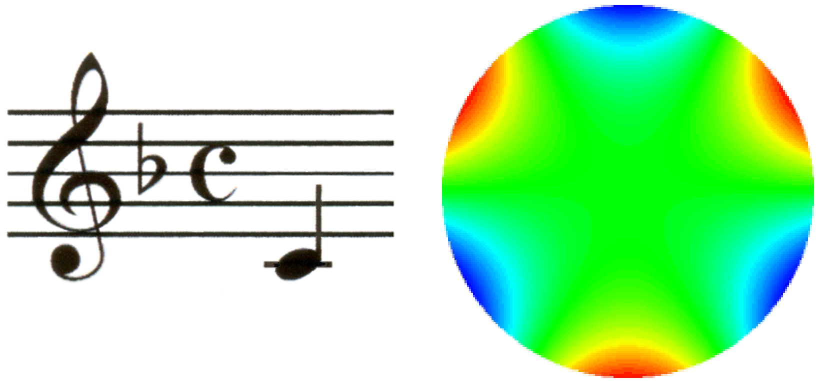
Z(4,-2)

Oblique 2°
Astigmatism



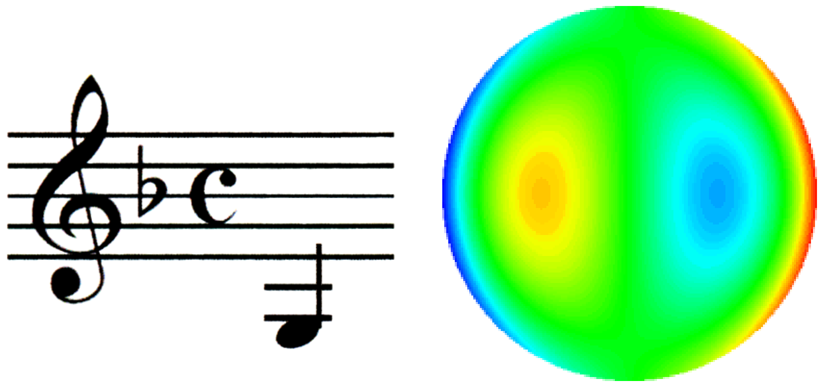
Z(4,0)

Spherical
Aberration



Z(3,3)

Oblique
Trefoil

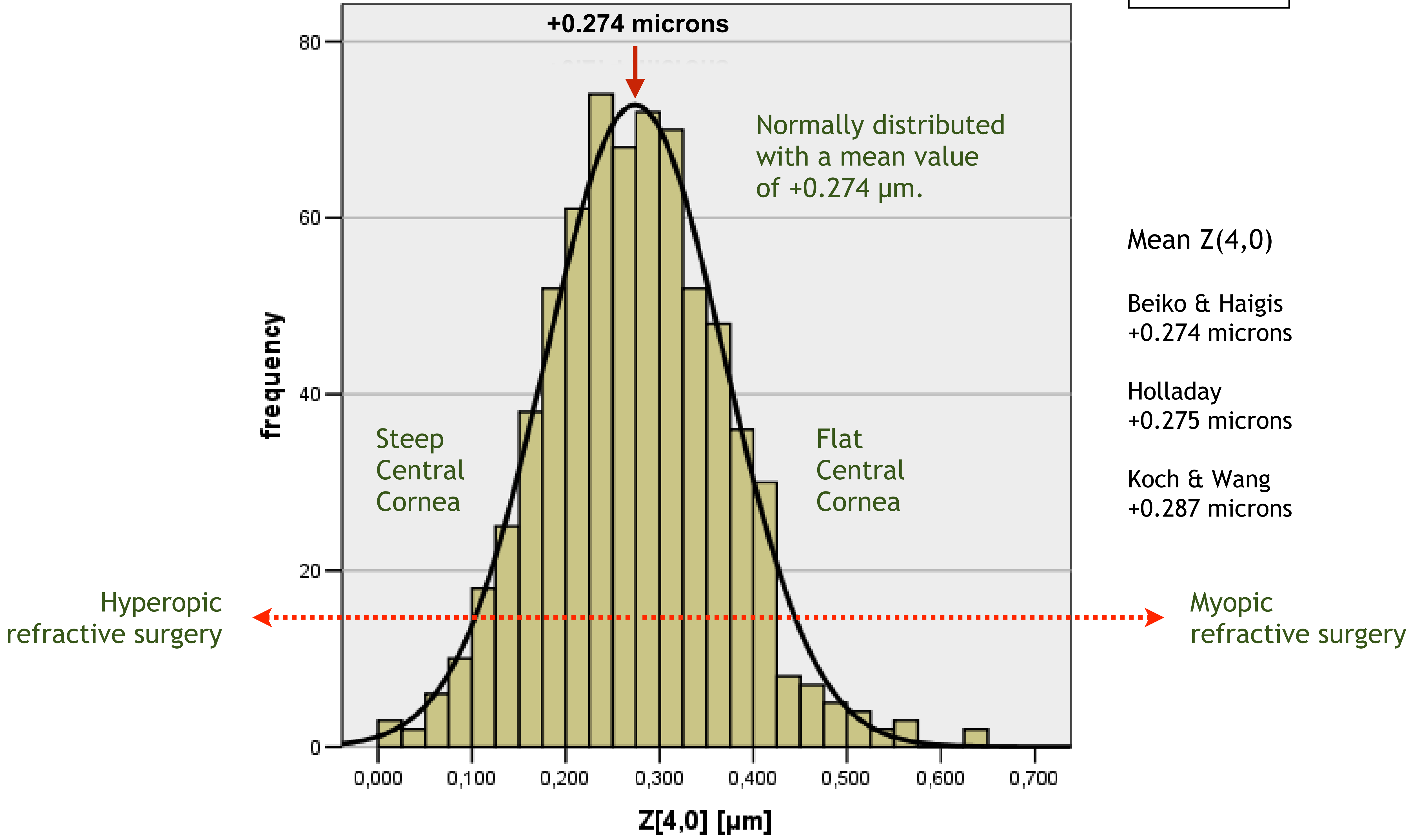


Z(3,1)

Horizontal
Coma

Spherical aberration Z(4,0)

Anterior Corneal Spherical Aberration Z(4,0)



Mean Z(4,0)

Beiko & Haigis
+0.274 microns

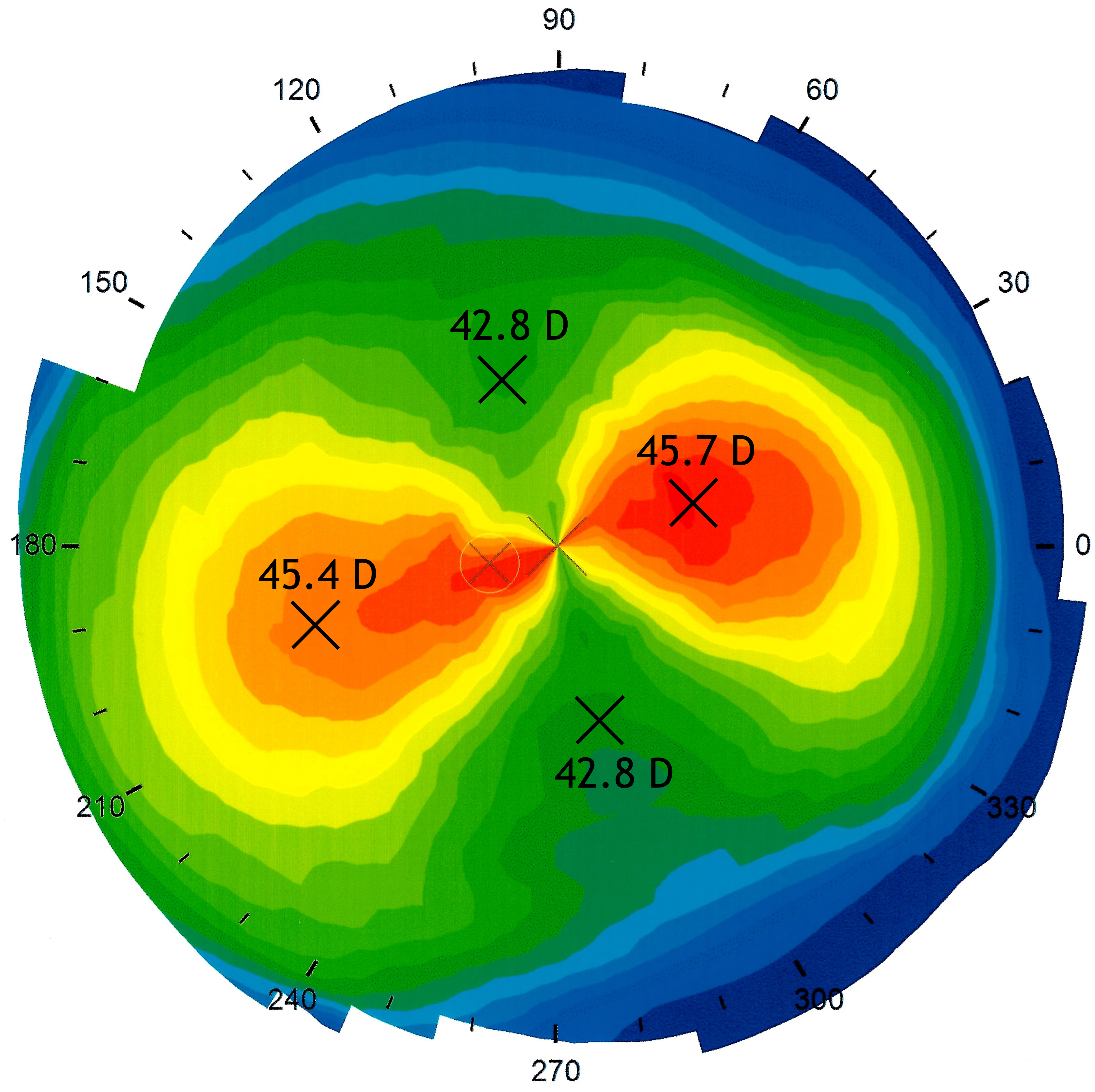
Holladay
+0.275 microns

Koch & Wang
+0.287 microns

Beiko G, Haigis W. Presented at AAO 2005.

Axial Curvature Map

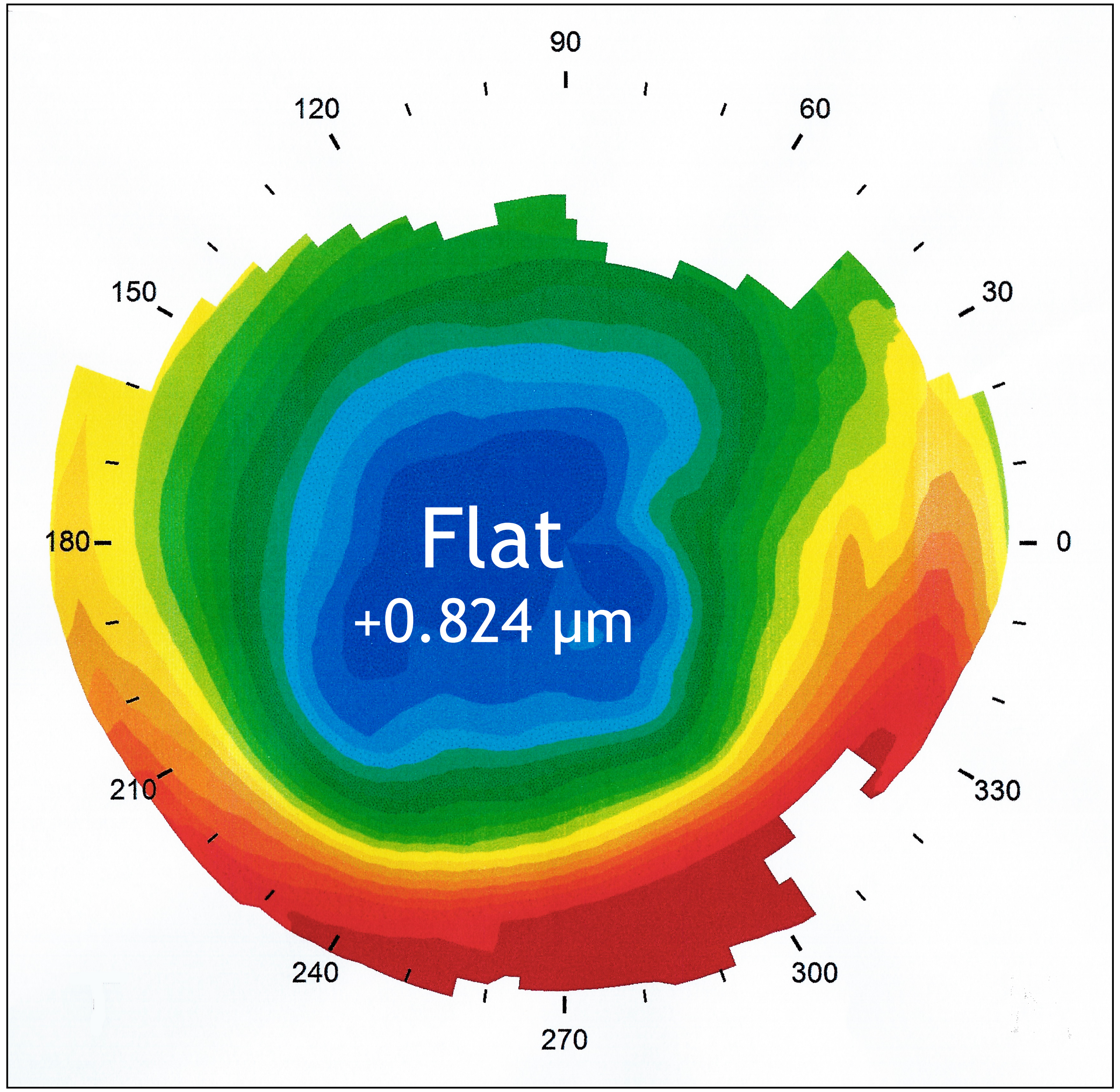
- Most commonly used topographic map feature… aka: power, or sagittal map.
- Limitation: Assumes that all refracted light rays pass though a central optical axis and typically excludes extreme values.
- Displays an average of scaled values with smoothing. Some detail may be lost.
- Preferred clinically because it relates corneal shape to corneal power.
- Often used for the characterization of the astigmatism type (irregular), alignment (asymmetric) and location (WTW).
- Greatest accuracy is near the region of the central cornea.



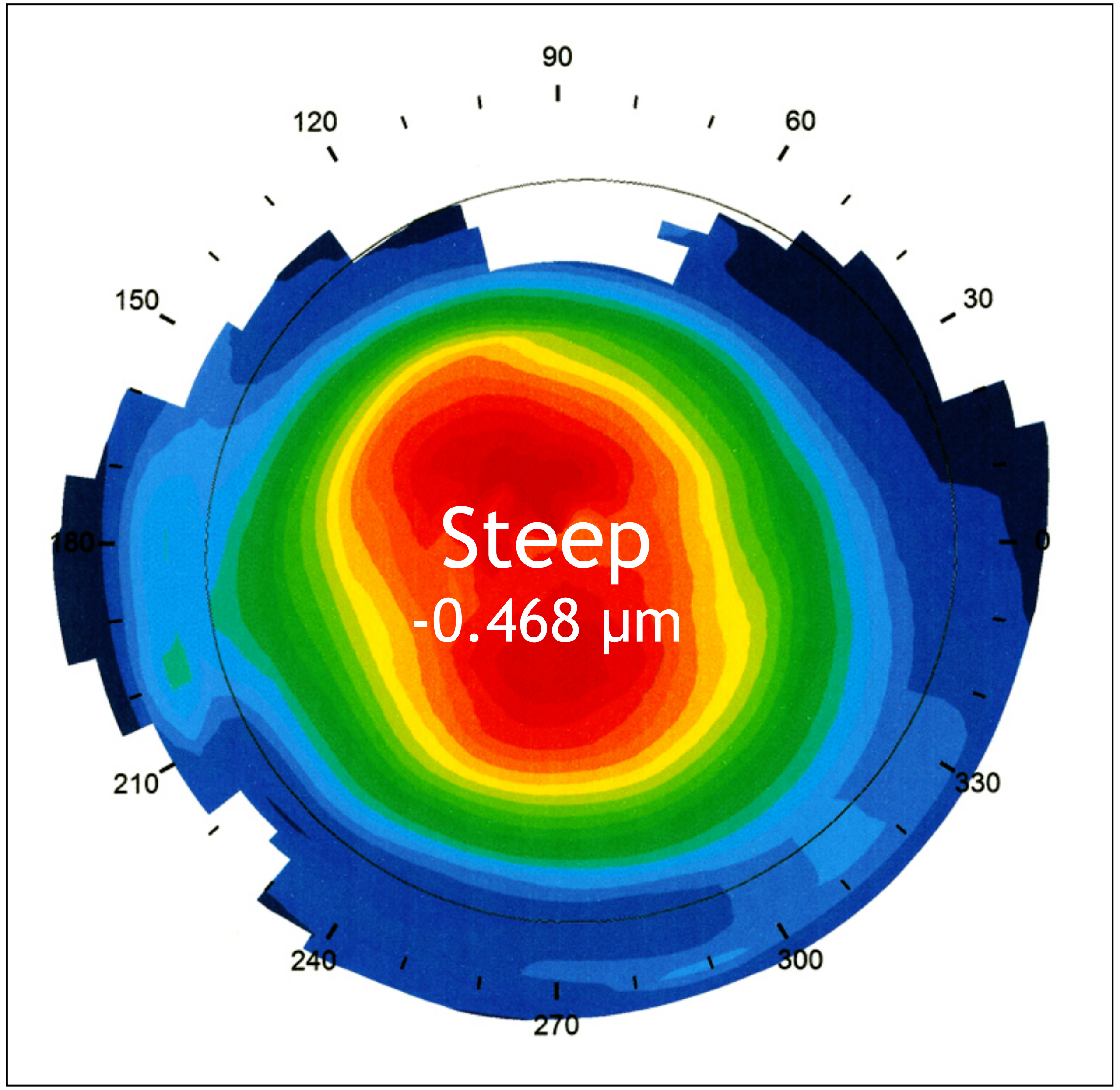
Aberrations

Spherical aberration Z(4,0)

Anterior Corneal Spherical Aberration



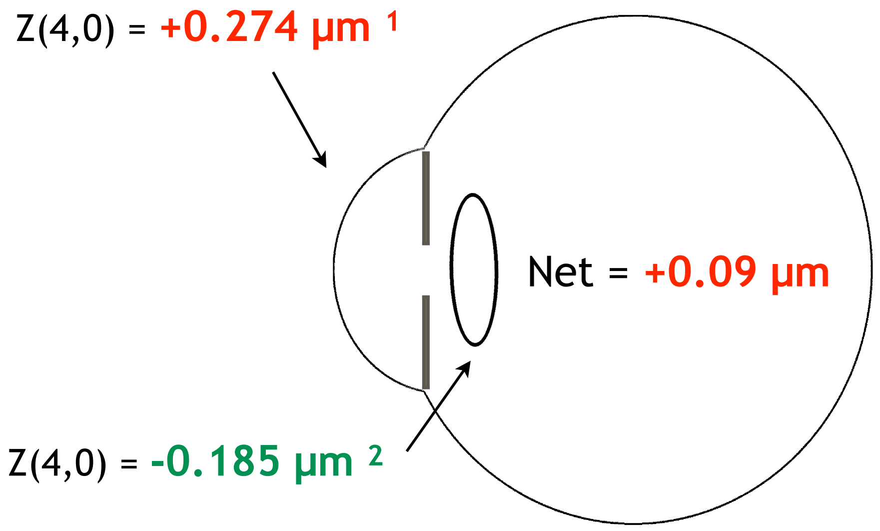
Myopic LASIK - Increased Spherical Aberration



Hyperopic LASIK - Reduced Spherical Aberration

Aberrations

Spherical aberration Z(4,0)



"Average" Youthful Eye

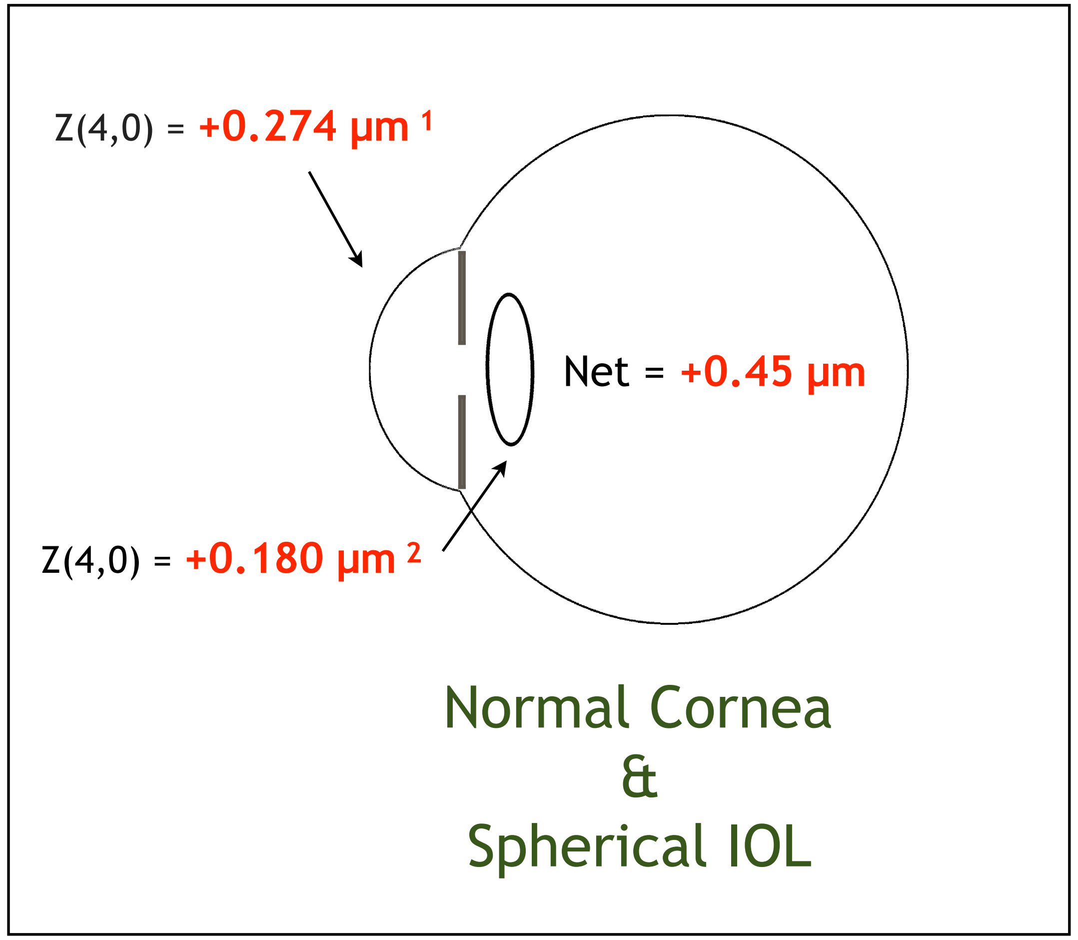
Simulated retinal image: Z(4,0) = +0.09 µm [3]

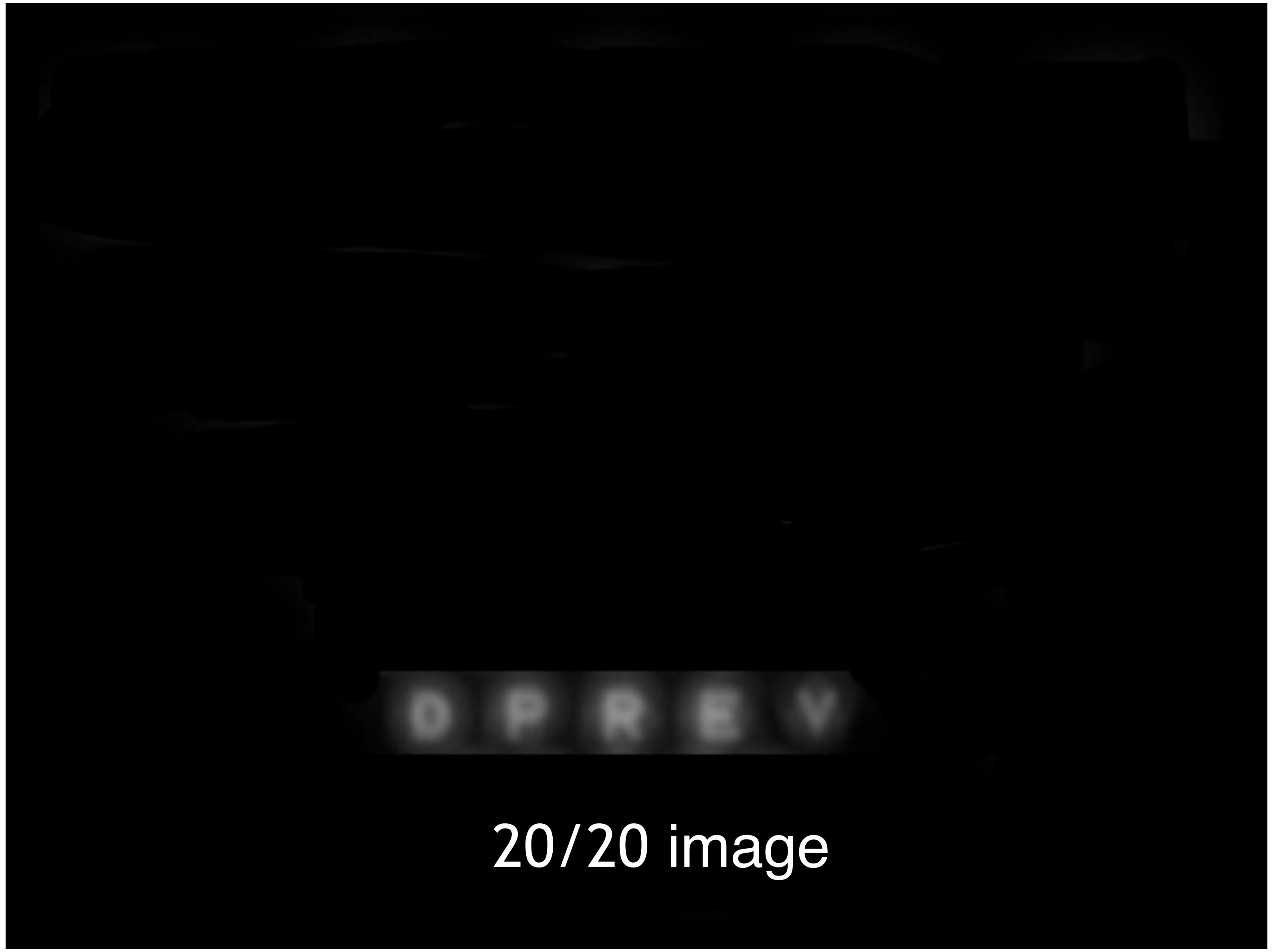
6.0 mm pupil size

1. Beiko and Haigis, AAO, 2005.
2. Wang, *et al*. *JCRS* 2005.
3. Optical engineers, Carl Zeiss Meditec, Dublin, California.

Aberrations

Spherical aberration Z(4,0)





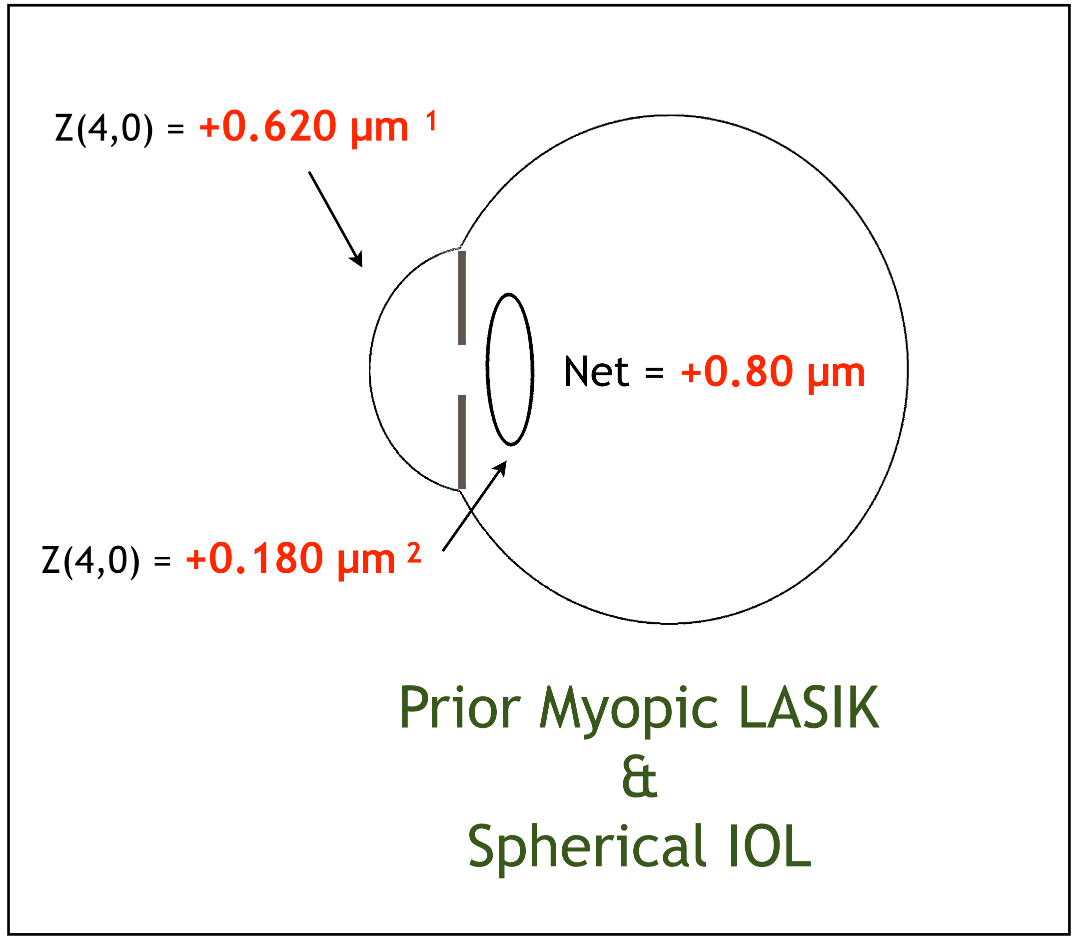
Simulated retinal image: Z(4,0) = +0.45 µm [3]

6.0 mm pupil size

1. Beiko and Haigis, AAO, 2005.
2. Terwee, *et al*, ESCRS, 2002.
3. Optical engineers, Carl Zeiss Meditec, Dublin, California.

Aberrations

Spherical aberration Z(4,0)



Simulated retinal image: Z(4,0) = +0.80 µm[3]

6.0 mm pupil size

1. Hill, ASCRS, 2005.
2. Terwee, *et al*, ESCRS, 2002.
3. Optical engineers, Carl Zeiss Meditec, Dublin, California.

While modern LASIK is now much letter, the majority if patients that we are seeing for cataract surgery had older forms of LASIK.

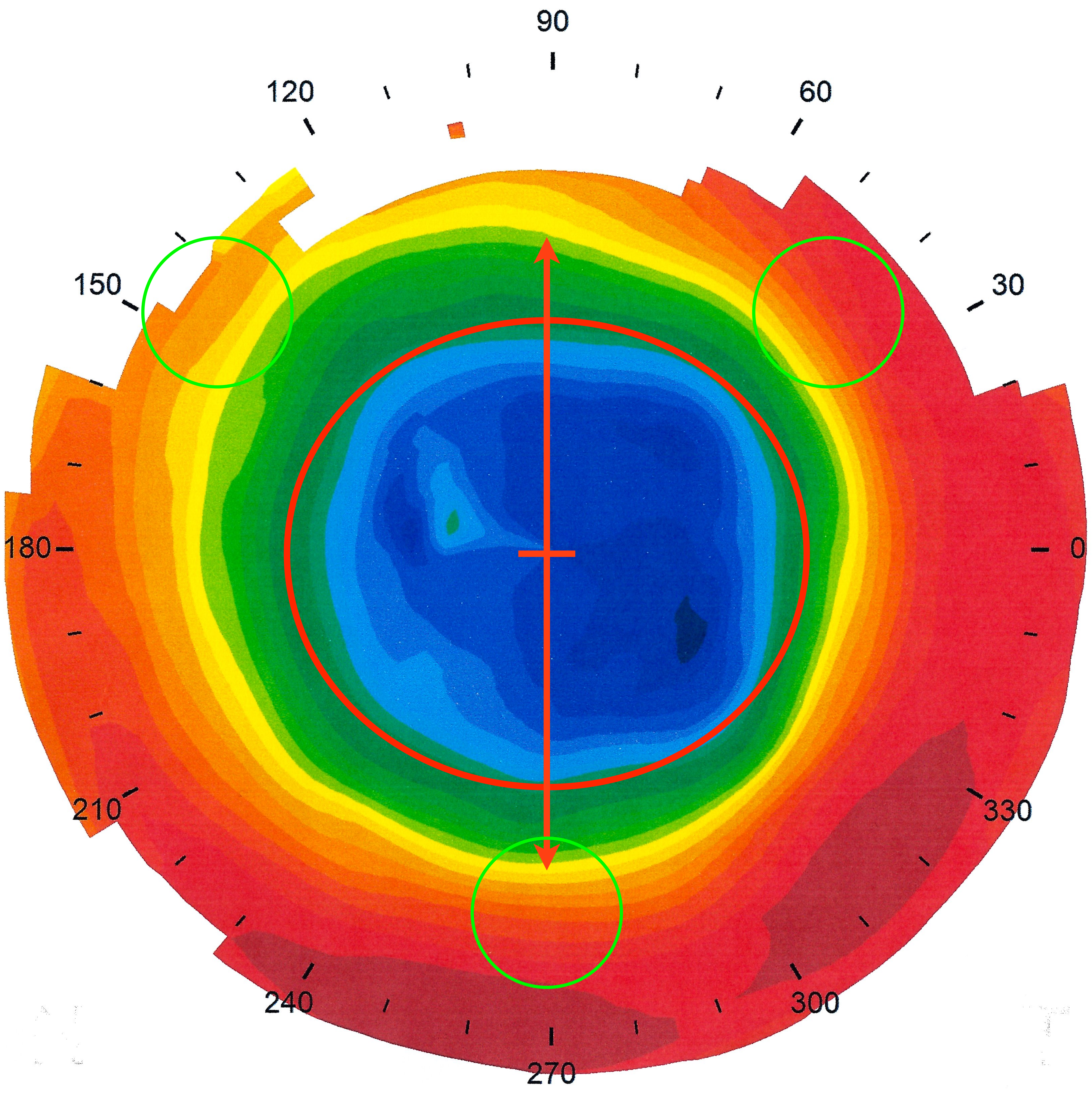
Aberrations

Why am I not seeing better after refractive surgery?

-9.00 D myopic ablation.

Ablation mostly centered.

Similar power distribution at intermediate & marginal areas.



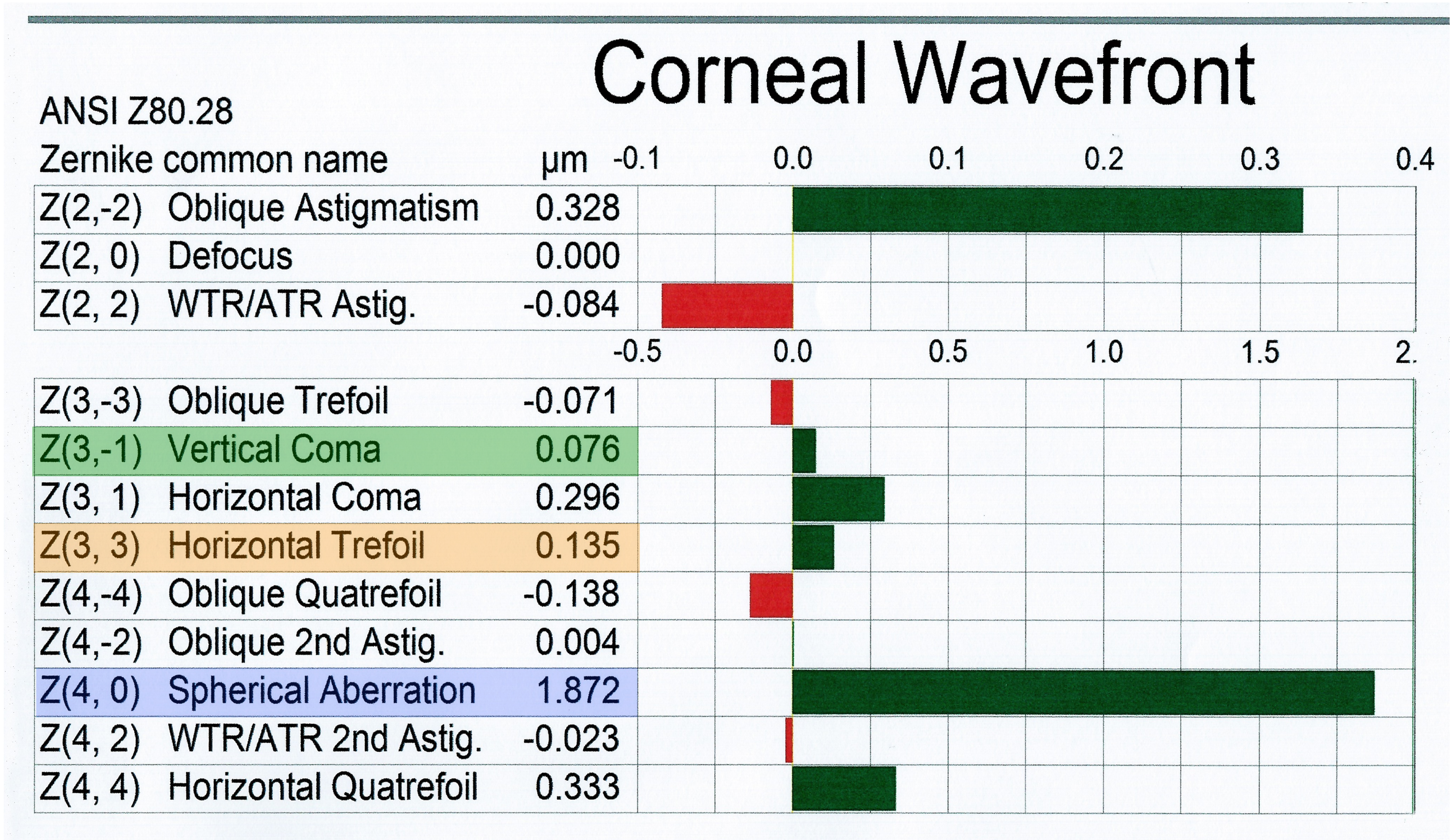
Refractive surprise

Why am I not seeing any better after cataract surgery?

Mostly centered ablation.

Regular intermediate zone.

-9.00 D myopic ablation.



Corneal Wavefront

ANSI Z80.28

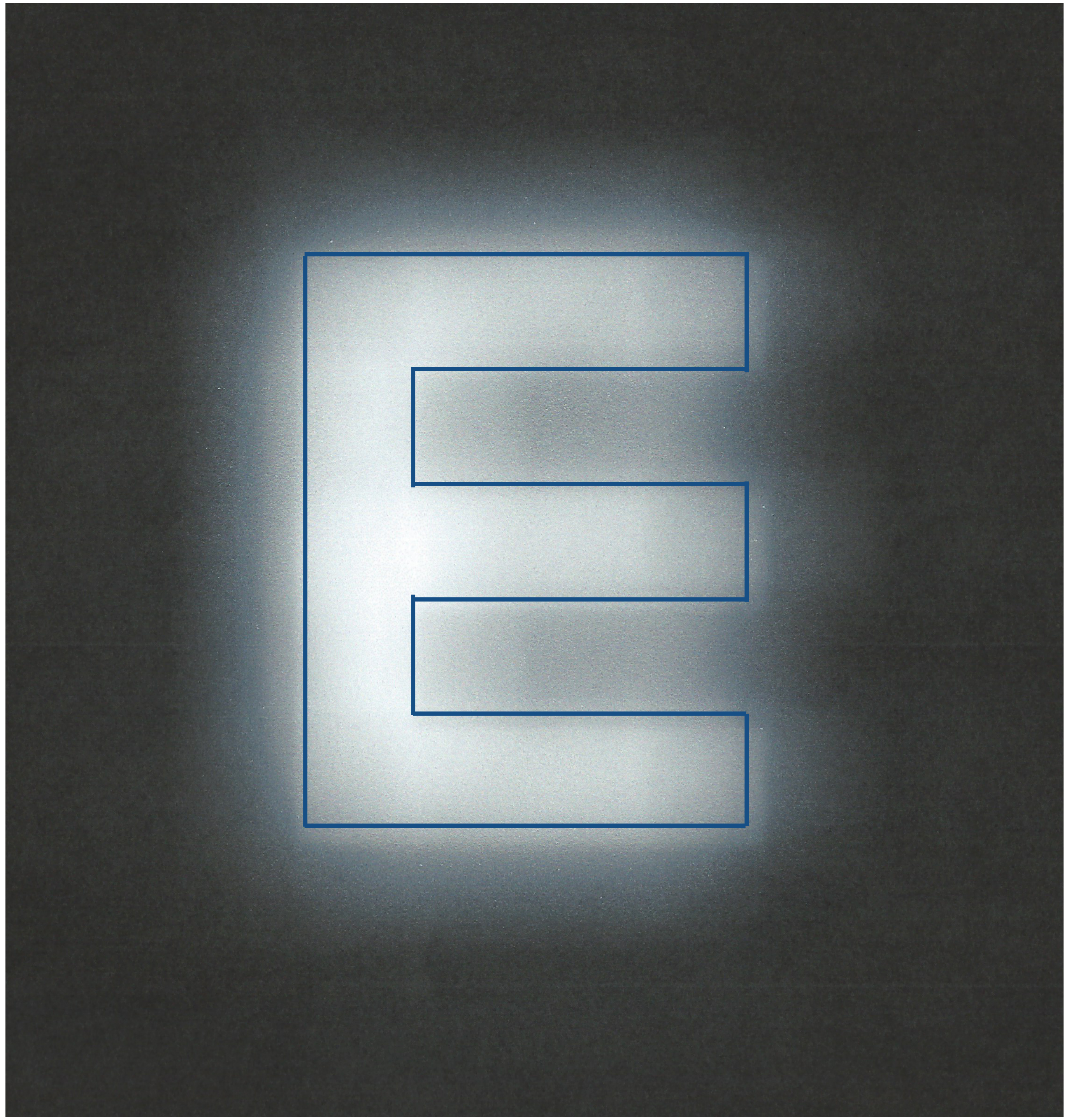
Zernike common name		µm
Z(2,-2)	Oblique Astigmatism	0.328
Z(2, 0)	Defocus	0.000
Z(2, 2)	WTR/ATR Astig.	-0.084
Z(3,-3)	Oblique Trefoil	-0.071
Z(3,-1)	Vertical Coma	0.076
Z(3, 1)	Horizontal Coma	0.296
Z(3, 3)	Horizontal Trefoil	0.135
Z(4,-4)	Oblique Quatrefoil	-0.138
Z(4,-2)	Oblique 2nd Astig.	0.004
Z(4, 0)	Spherical Aberration	1.872
Z(4, 2)	WTR/ATR 2nd Astig.	-0.023
Z(4, 4)	Horizontal Quatrefoil	0.333

Refractive surprise

Why am I not seeing any better after cataract surgery?

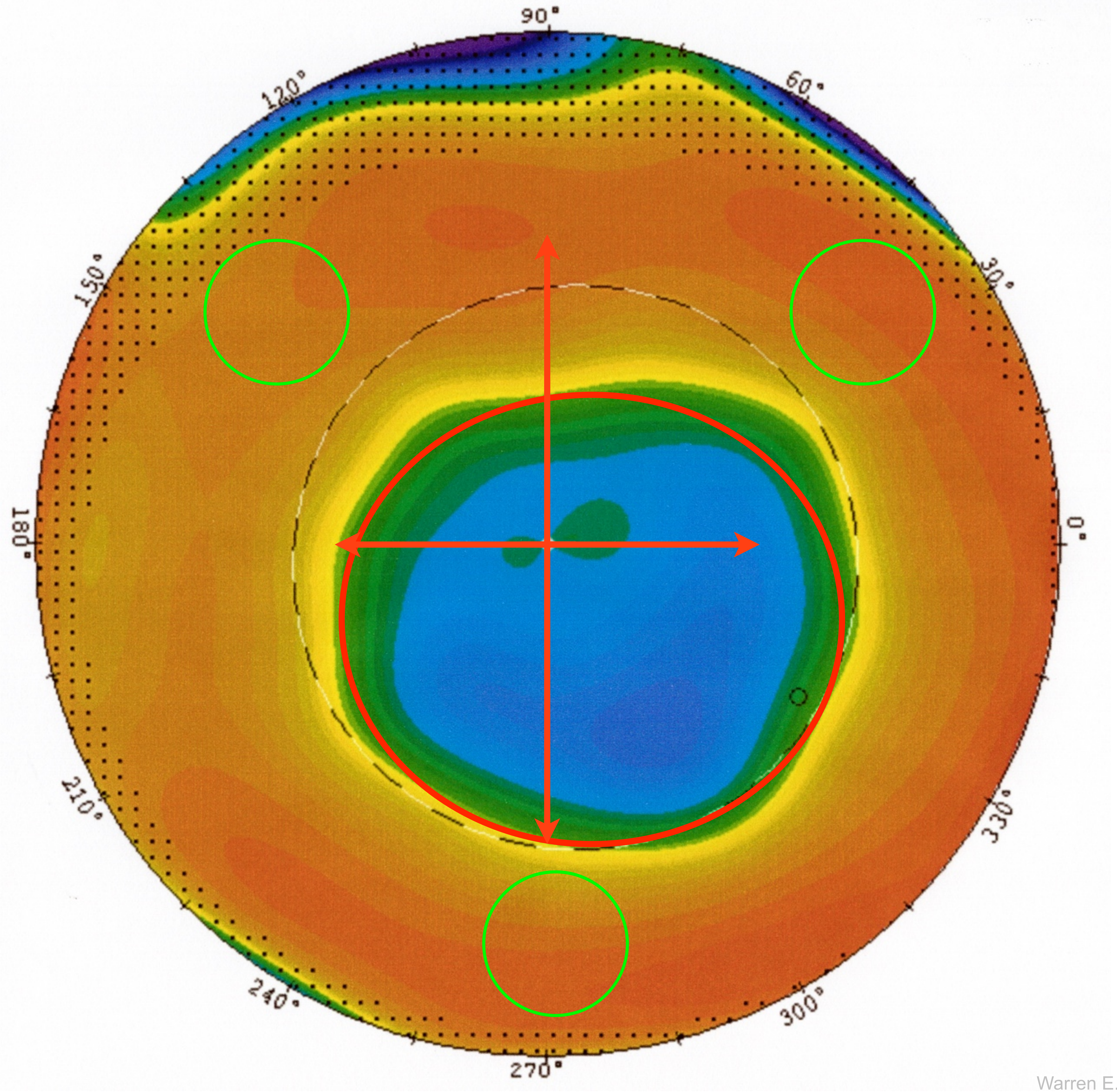
Elevated spherical aberration.

Characteristic image halo / glow.



Aberrations

Why am I not seeing better after refractive surgery?



-7.00 D myopic ablation.

Ablation decentered.

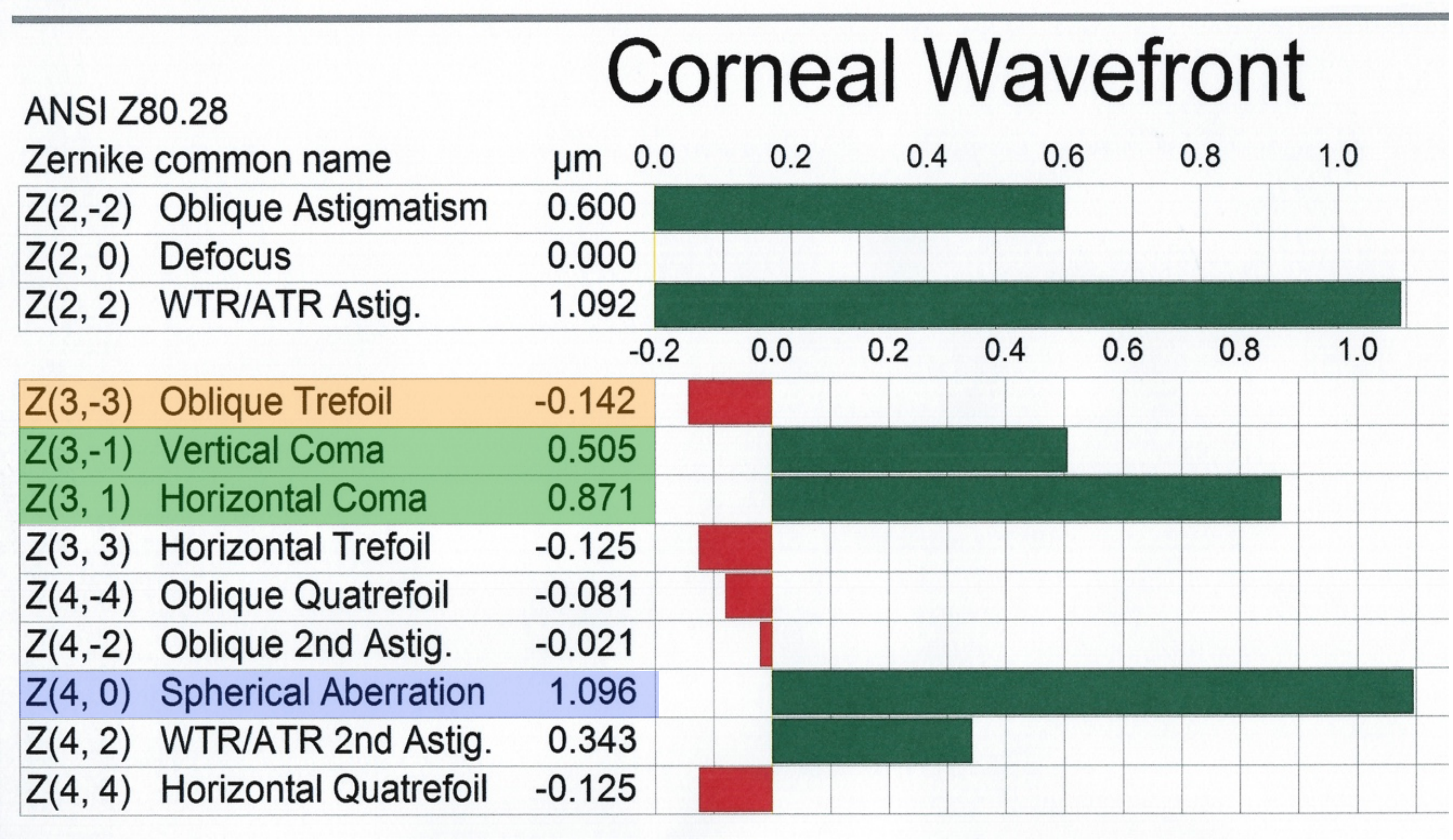
Similar power distribution at intermediate & marginal areas.

Refractive surprise

Why am I not seeing any better after cataract surgery?

Regular intermediate zone.
Ablation decentered.

-8.50 D myopic ablation.



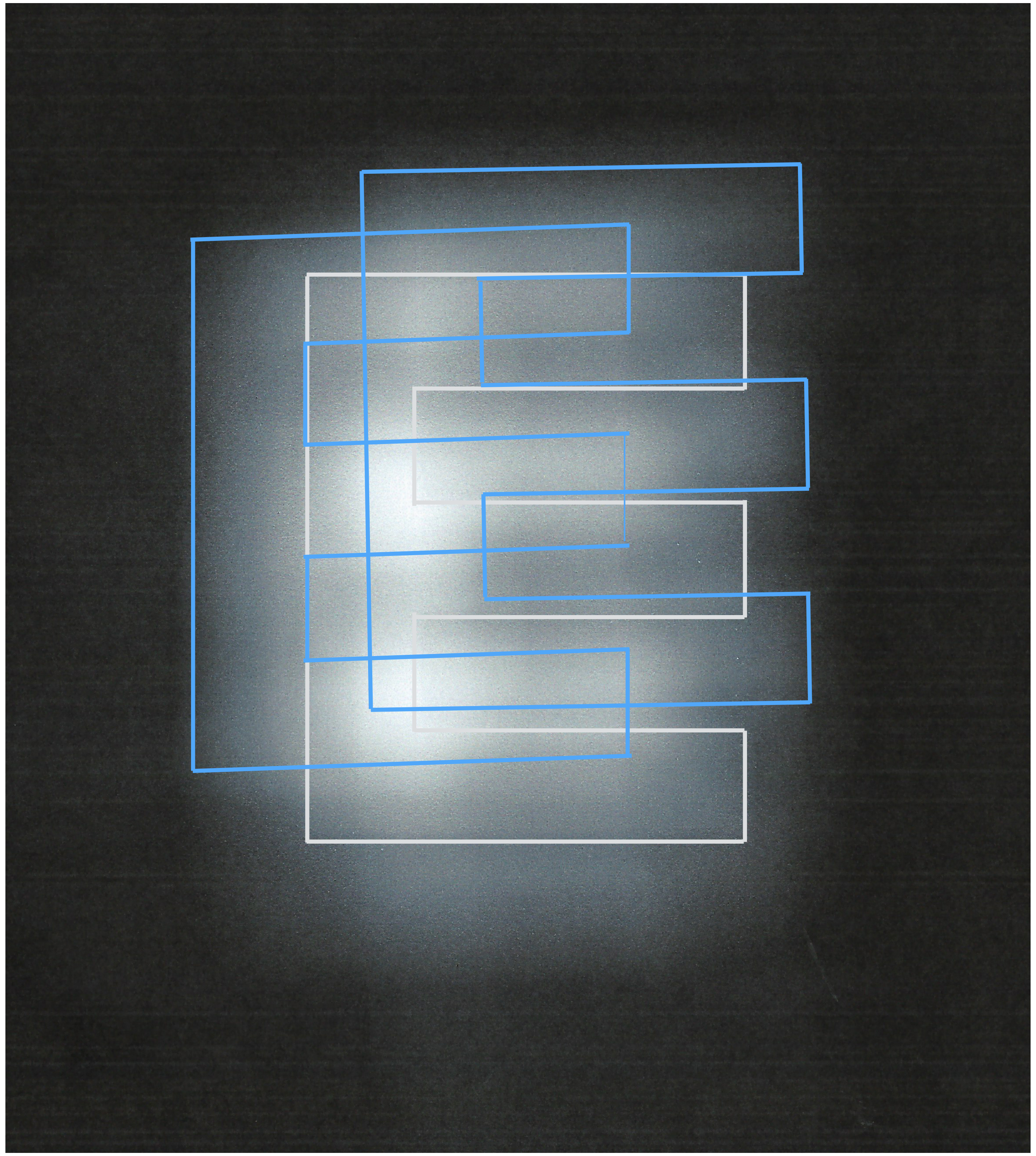
Corneal Wavefront

ANSI Z80.28

Zernike common name		µm
Z(2,-2)	Oblique Astigmatism	0.600
Z(2, 0)	Defocus	0.000
Z(2, 2)	WTR/ATR Astig.	1.092
Z(3,-3)	Oblique Trefoil	-0.142
Z(3,-1)	Vertical Coma	0.505
Z(3, 1)	Horizontal Coma	0.871
Z(3, 3)	Horizontal Trefoil	-0.125
Z(4,-4)	Oblique Quatrefoil	-0.081
Z(4,-2)	Oblique 2nd Astig.	-0.021
Z(4, 0)	Spherical Aberration	1.096
Z(4, 2)	WTR/ATR 2nd Astig.	0.343
Z(4, 4)	Horizontal Quatrefoil	-0.125

Refractive surprise

Why am I not seeing any better after cataract surgery?



Elevated spherical aberration.

Elevated horizontal coma.

Elevated vertical coma.

Why am I not seeing better after cataract surgery?

History: Radiologist. High axial myope. 2+ nuclear cataract.
Early generation (1998) myopic LASIK as monovision.
Treatment: OD: -5.75 D (near eye) OS: -8.50 D (distance eye)
+20.00 D ZMB00 diffractive multifocal IOL placed.

Surgery: Femtosecond laser with intraoperative aberrometry.
Flawless 5.5 mm capsulorrhexis; perfectly centered IOL.

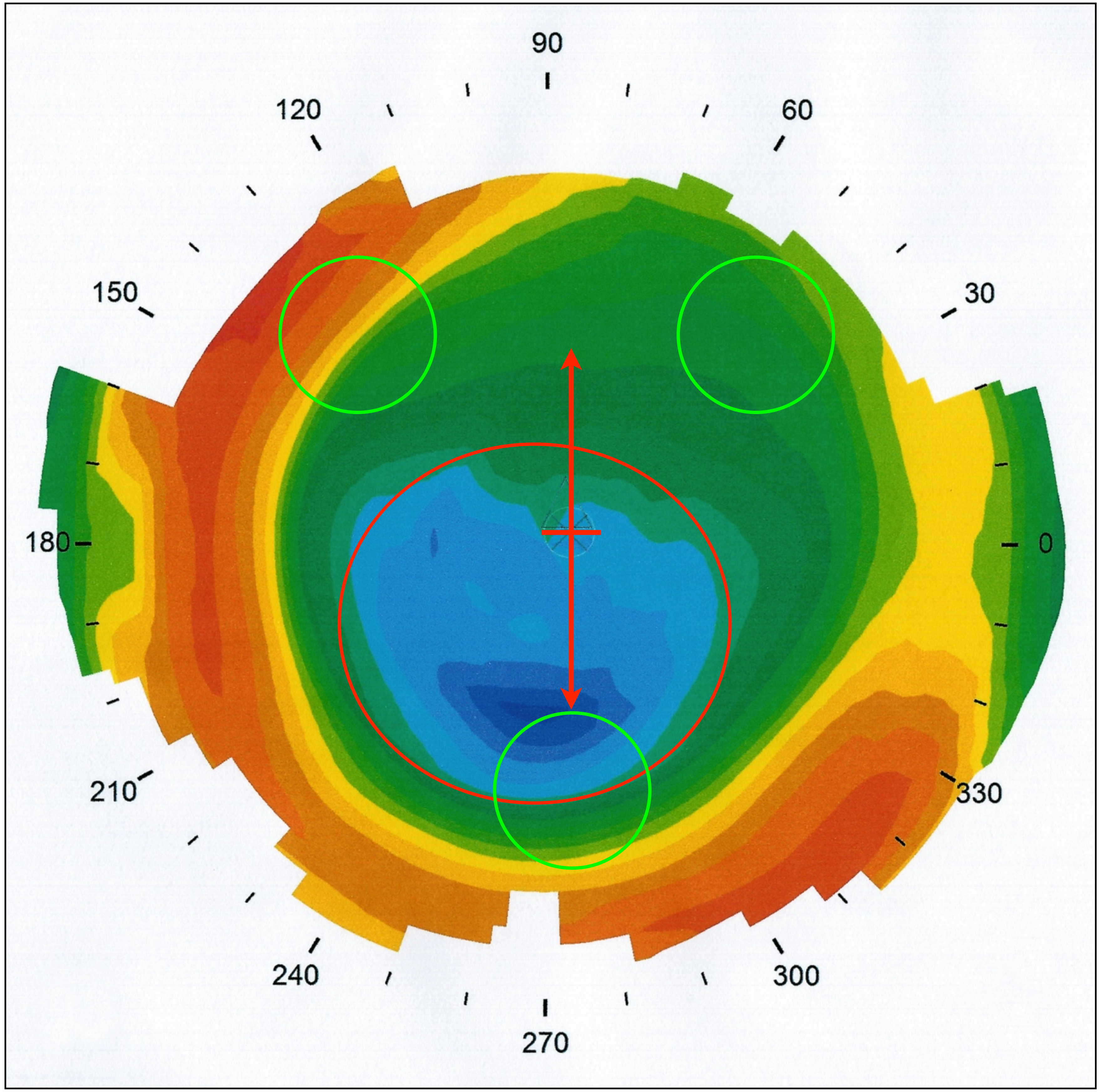
Outcome: +0.50 +0.50 x 180 = 20/30.
"Vision worse than before surgery." Unable to drive at night.
What happened?

Left eye

-8.50 D myopic ablation.

Ablation decentered.

Widely variable power at intermediate & marginal areas.

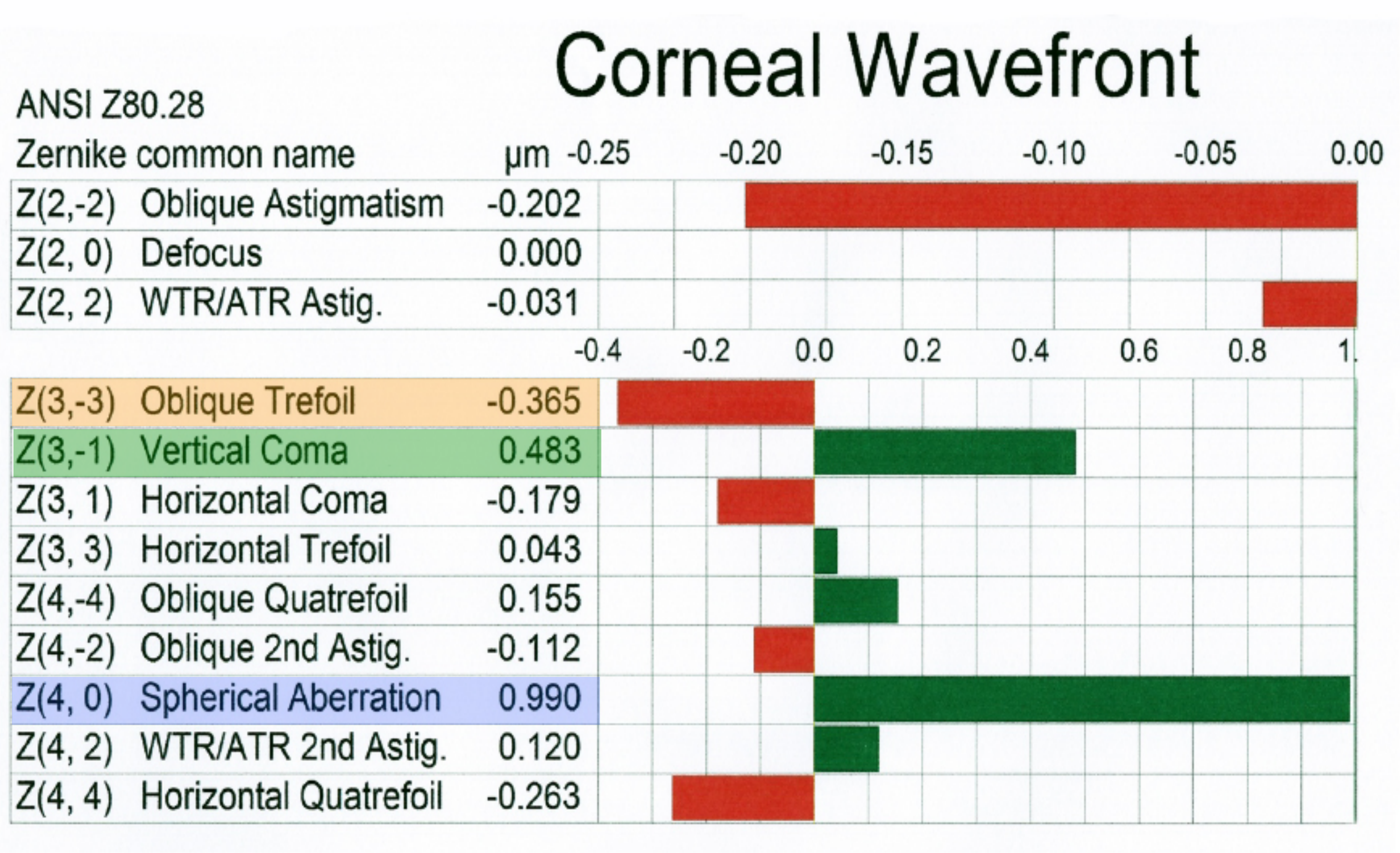


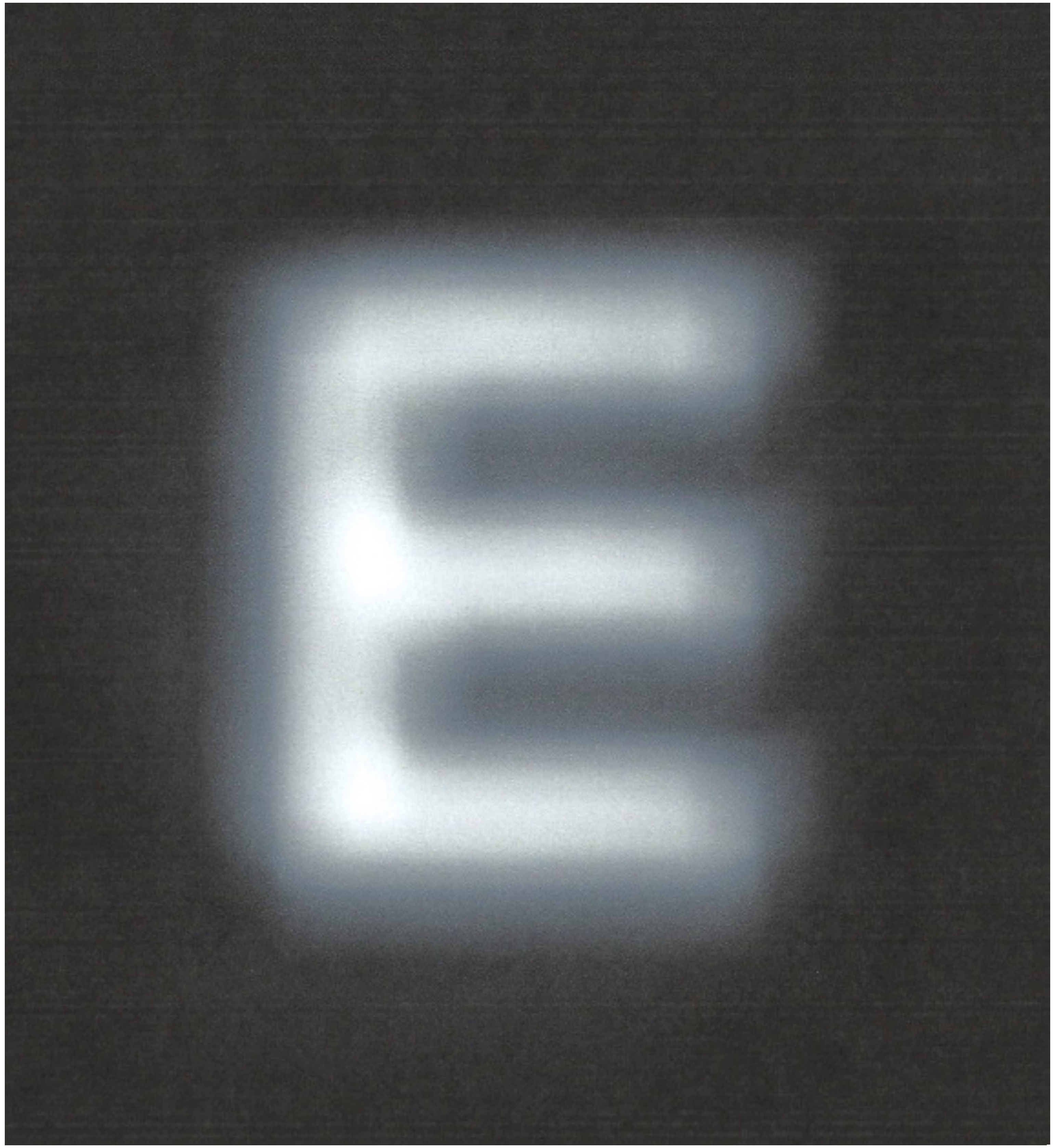
Aberrations

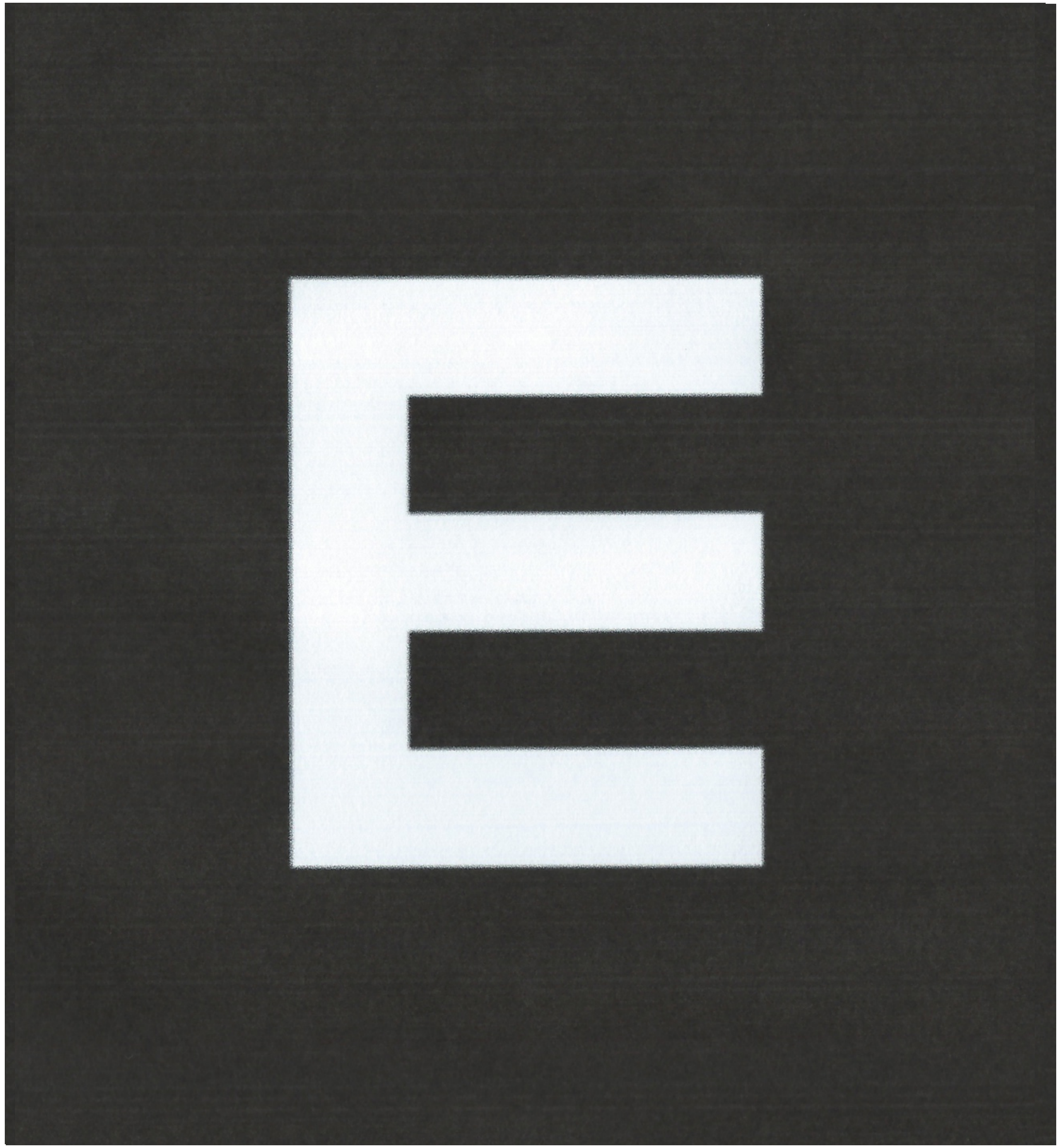
Why am I not seeing better after cataract surgery?

Intermediate zone variability.
Ablation decentered.

-8.50 D myopic ablation.







Warren E. Hill, MD

This patient underwent an IOL exchange in favor of a monofocal IOL with the addition of negative spherical aberration and was able to return to work and drive at night.

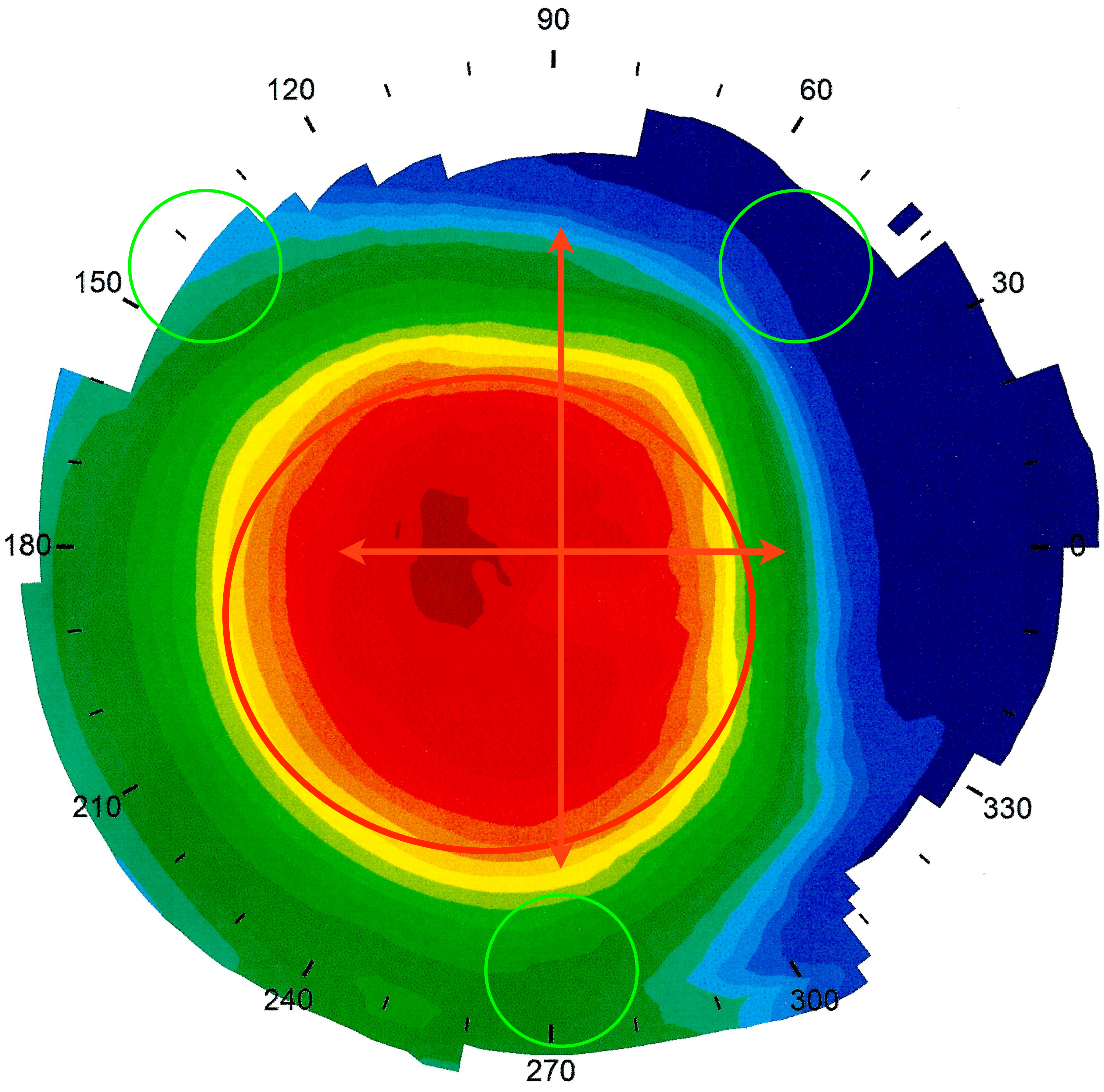
Aberrations

Why am I not seeing better after refractive surgery?

+3.50 D hyperopic treatment.

Decentered ablation.

Dissimilar power distribution at intermediate & marginal areas.



Refractive surprise

Why am I not seeing any better after cataract surgery?

Corneal Wavefront

ANSI Z80.28

Zernike common name		µm
Z(2,-2)	Oblique Astigmatism	-0.042
Z(2, 0)	Defocus	0.000
Z(2, 2)	WTR/ATR Astig.	-0.506
Z(3,-3)	Oblique Trefoil	0.348
Z(3,-1)	Vertical Coma	-1.072
Z(3, 1)	Horizontal Coma	-1.365
Z(3, 3)	Horizontal Trefoil	-0.536
Z(4,-4)	Oblique Quatrefoil	-0.093
Z(4,-2)	Oblique 2nd Astig.	-0.066
Z(4, 0)	Spherical Aberration	-0.833
Z(4, 2)	WTR/ATR 2nd Astig.	-0.203
Z(4, 4)	Horizontal Quatrefoil	-0.241

Irregular intermediate zone. (Z(3,-3) Oblique Trefoil)

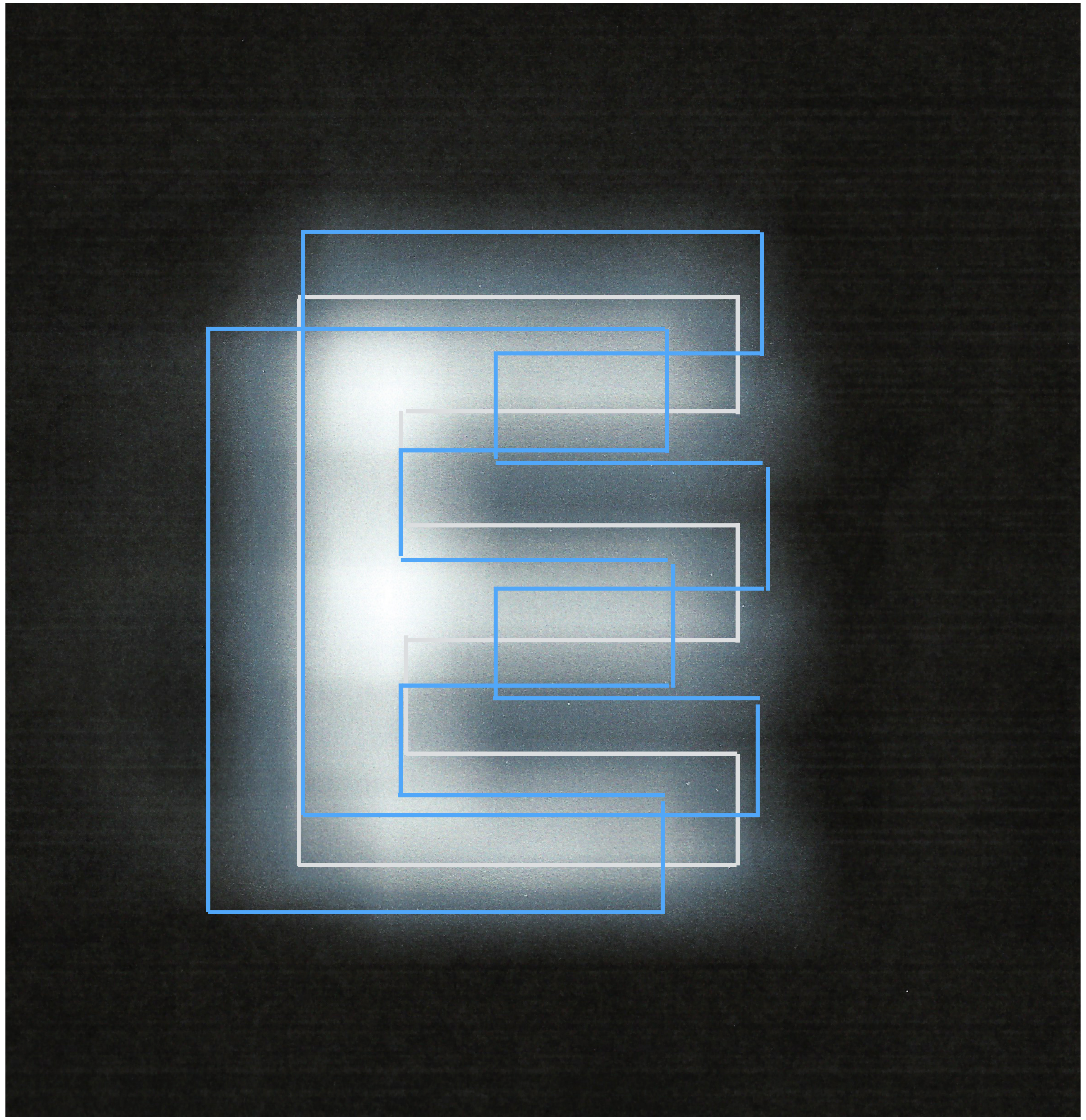
Decentered ablation. (Z(3,-1) Vertical Coma, Z(3, 1) Horizontal Coma)

Irregular intermediate zone. (Z(3, 3) Horizontal Trefoil)

+3.50 D hyperopic ablation. (Z(4, 0) Spherical Aberration)

Refractive surprise

Why am I not seeing any better after cataract surgery?



Elevated spherical aberration.

Elevated horiz. & vertical coma.

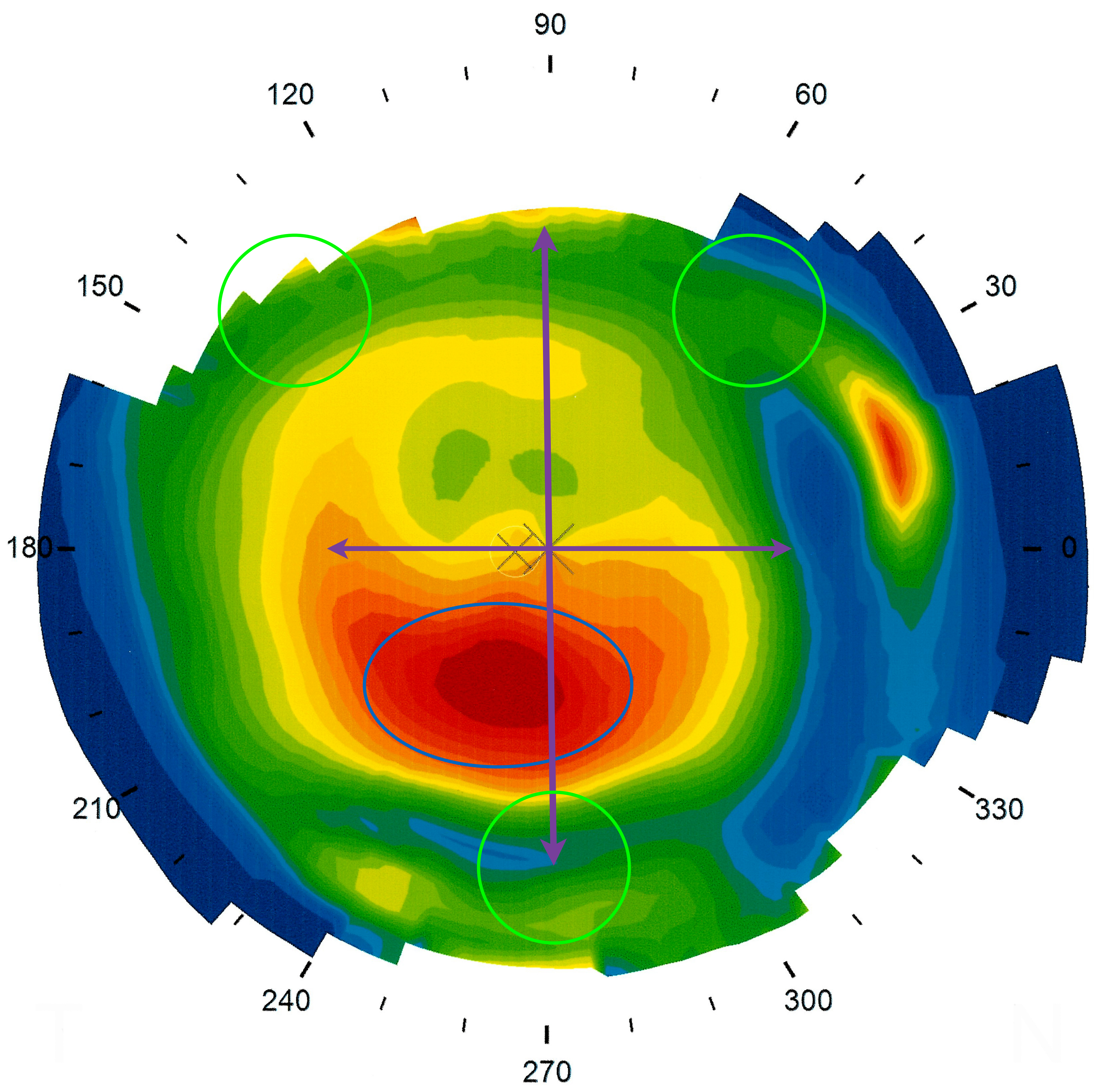
Aberrations

Why am I not seeing better after refractive surgery?

Keratoconus.

Inferior area of steepening.

Variable power distribution at intermediate & marginal areas.



Aberrations

Why am I not seeing any better after cataract surgery?

Corneal Wavefront

ANSI Z80.28

Zernike common name		µm
Z(2,-2)	Oblique Astigmatism	0.342
Z(2, 0)	Defocus	0.000
Z(2, 2)	WTR/ATR Astig.	-1.664
Z(3,-3)	Oblique Trefoil	0.003
Z(3,-1)	Vertical Coma	-1.815
Z(3, 1)	Horizontal Coma	-0.542
Z(3, 3)	Horizontal Trefoil	0.687
Z(4,-4)	Oblique Quatrefoil	-0.419
Z(4,-2)	Oblique 2nd Astig.	0.159
Z(4, 0)	Spherical Aberration	0.365
Z(4, 2)	WTR/ATR 2nd Astig.	-0.240
Z(4, 4)	Horizontal Quatrefoil	0.081

Inferior steepening.

Irregular intermediate zone.

Near normal corneal vertex.

Quatrefoil

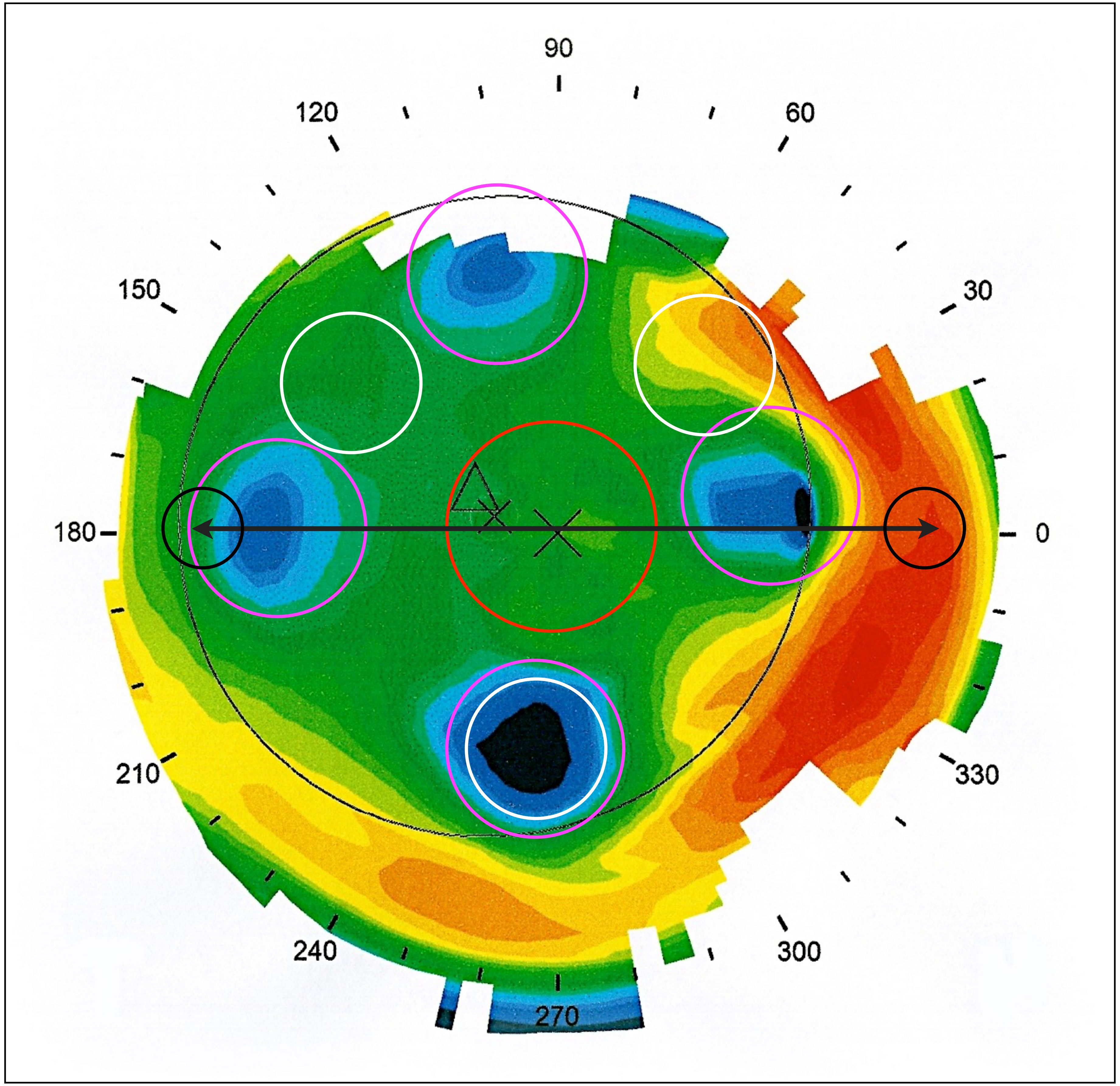
Why am I not seeing any better after cataract surgery?

4-incision radial keratotomy.

Normal central cornea.

Variable horizontal power.

Variable power at intermediate & marginal areas.



Quatrefoil

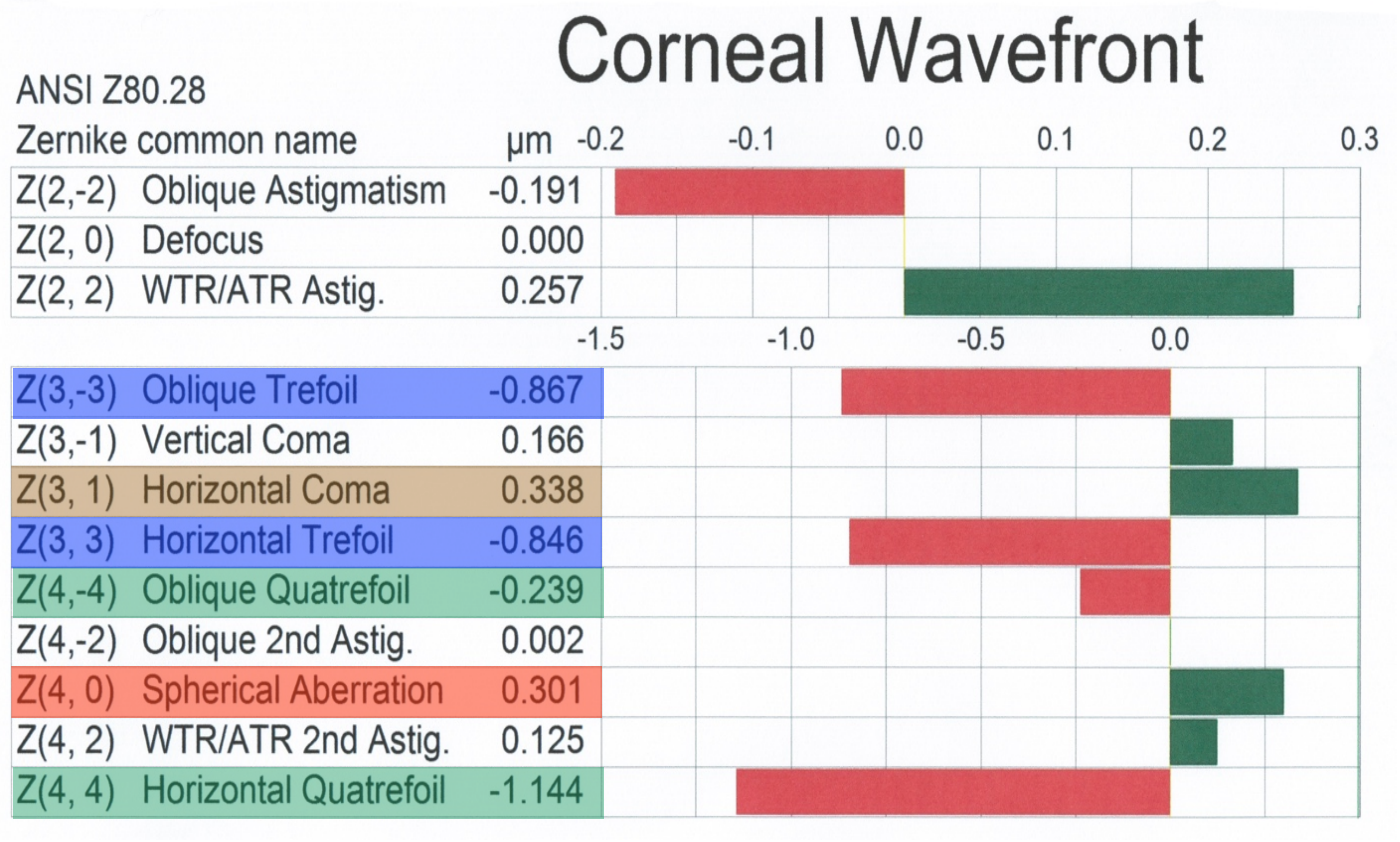
Why am I not seeing any better after cataract surgery?

Variable power intermediate & marginal areas.

Variable horizontal power.

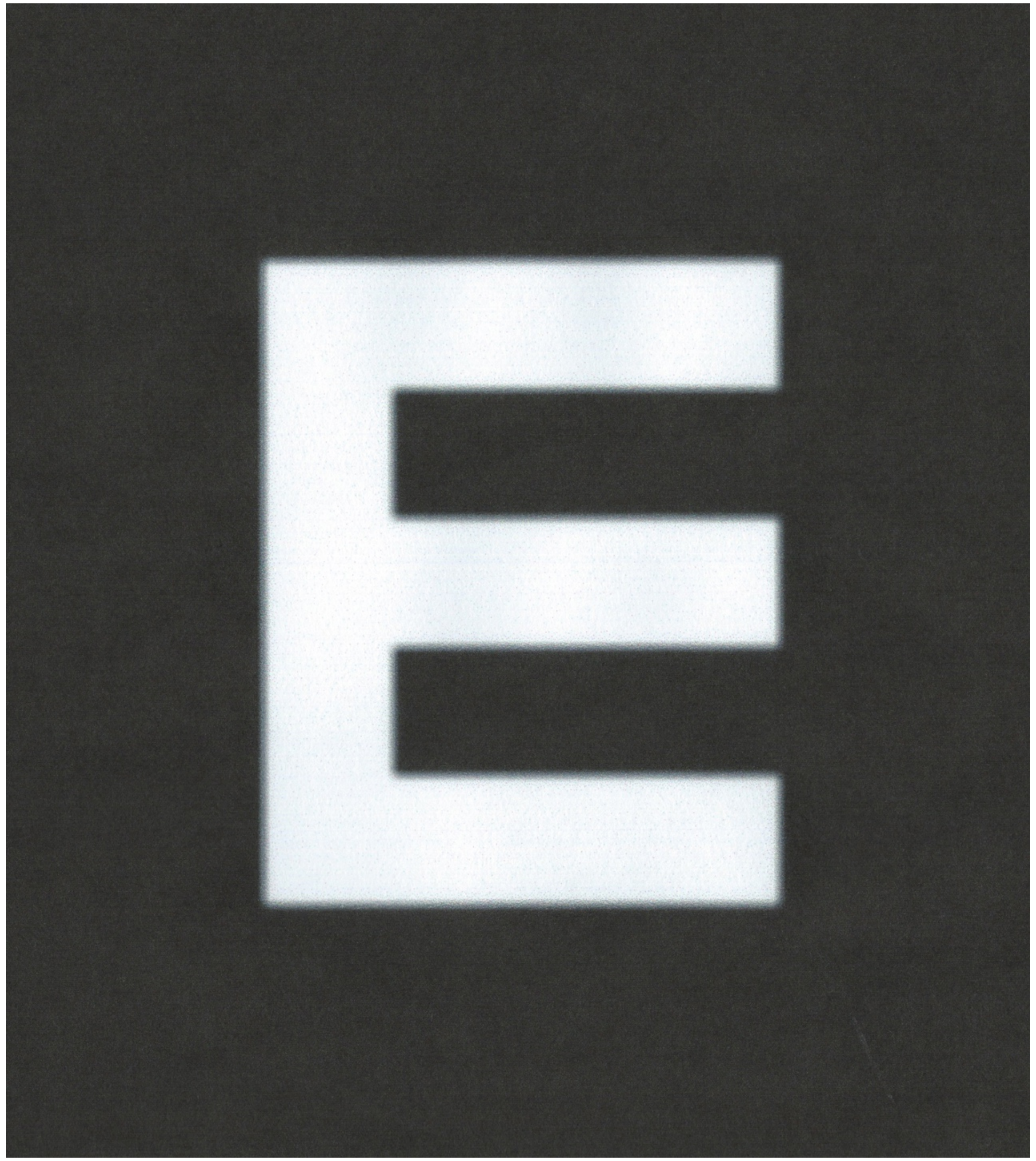
Near normal corneal center.

4 RK incisions.

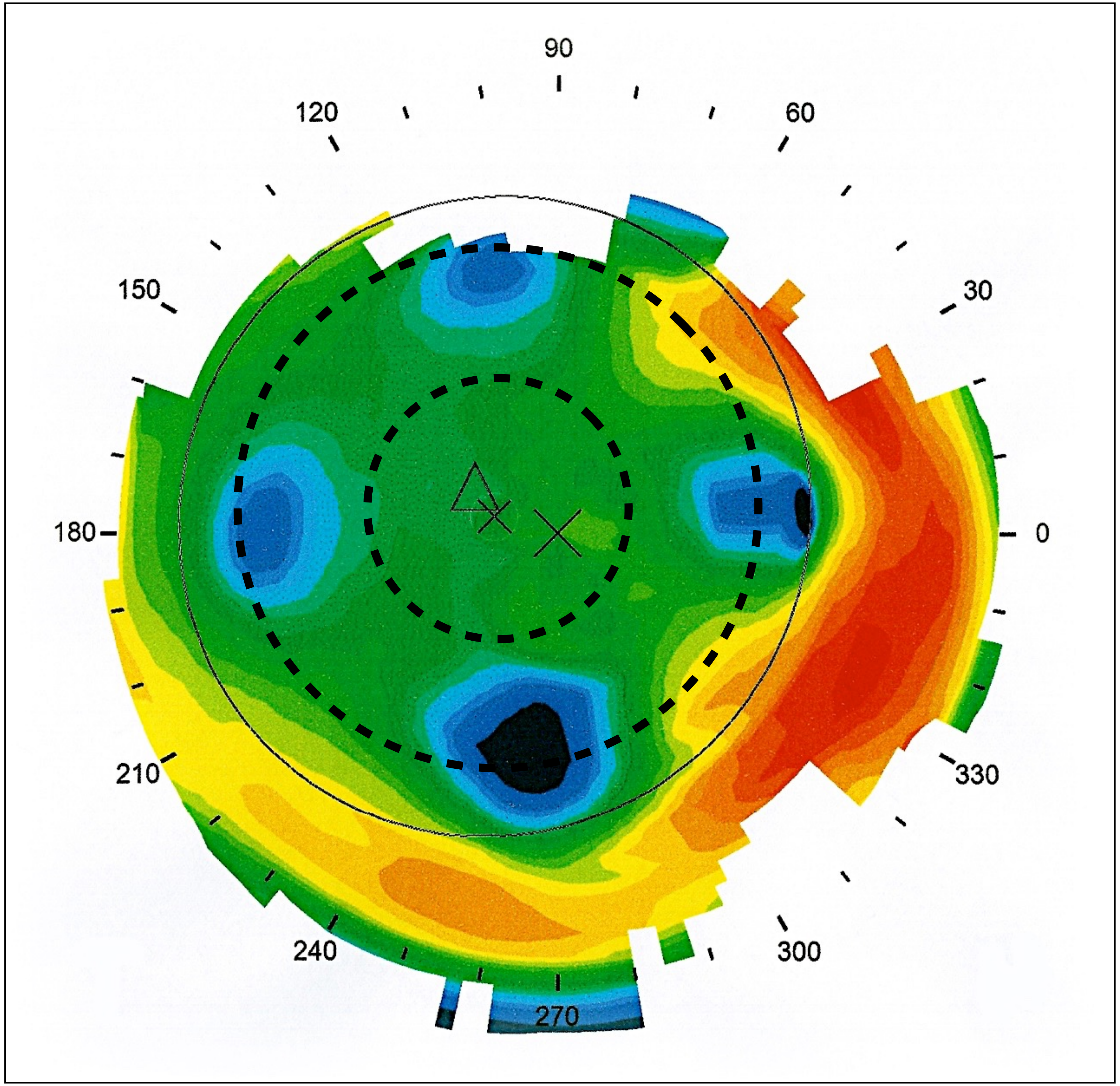


Quatrefoil

Why am I not seeing any better after cataract surgery?



Photopic pupil



Aberrations

MTF plot - Modulation Transfer Function

Snellen Acuity

Smallest perceptible target, high contrast detail.

Contrast Sensitivity

Same size target with **lowest perceptible contrast.**

Image contrast.

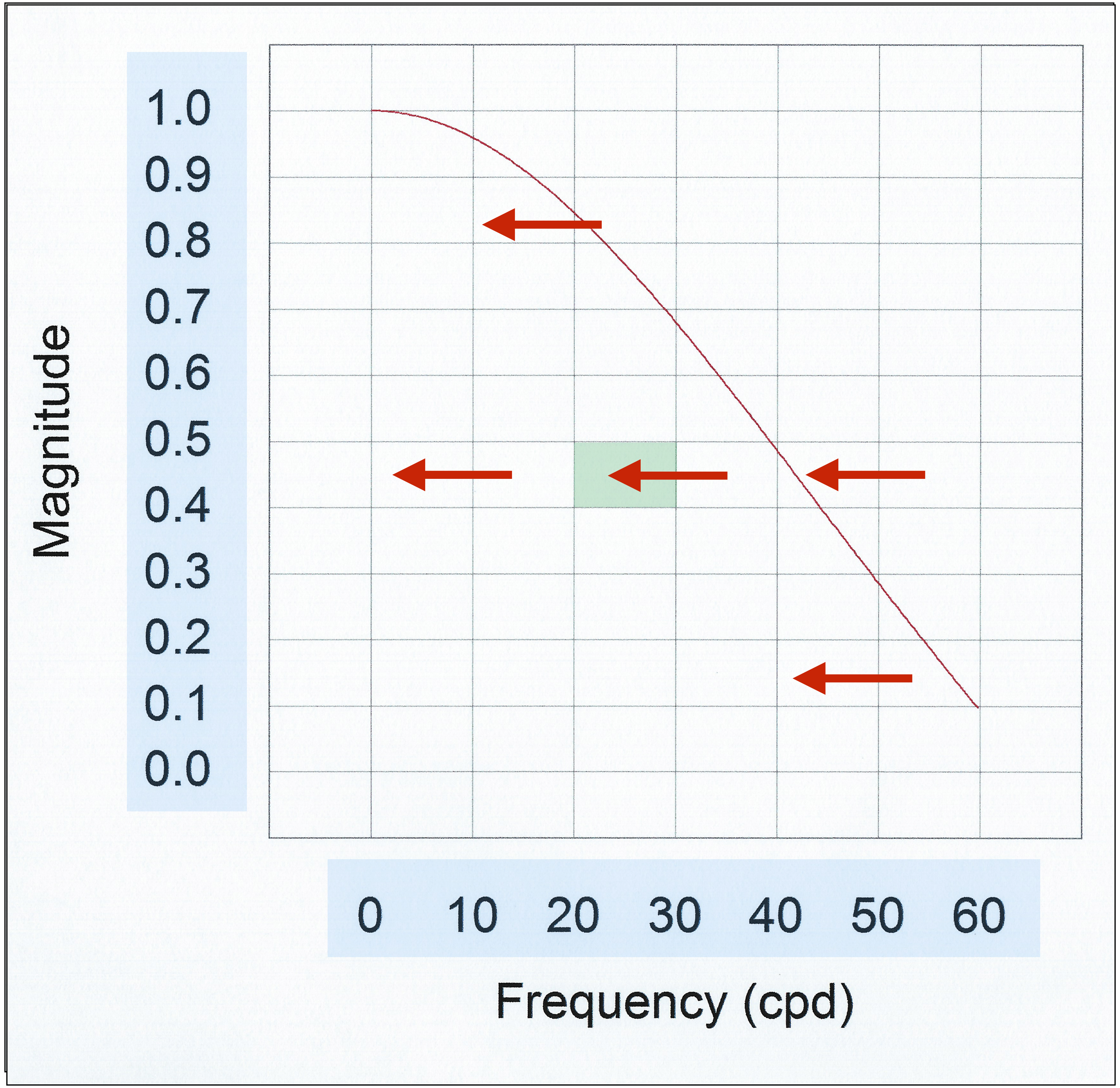
Spatial frequency.

Visual performance.

Normal visual function.

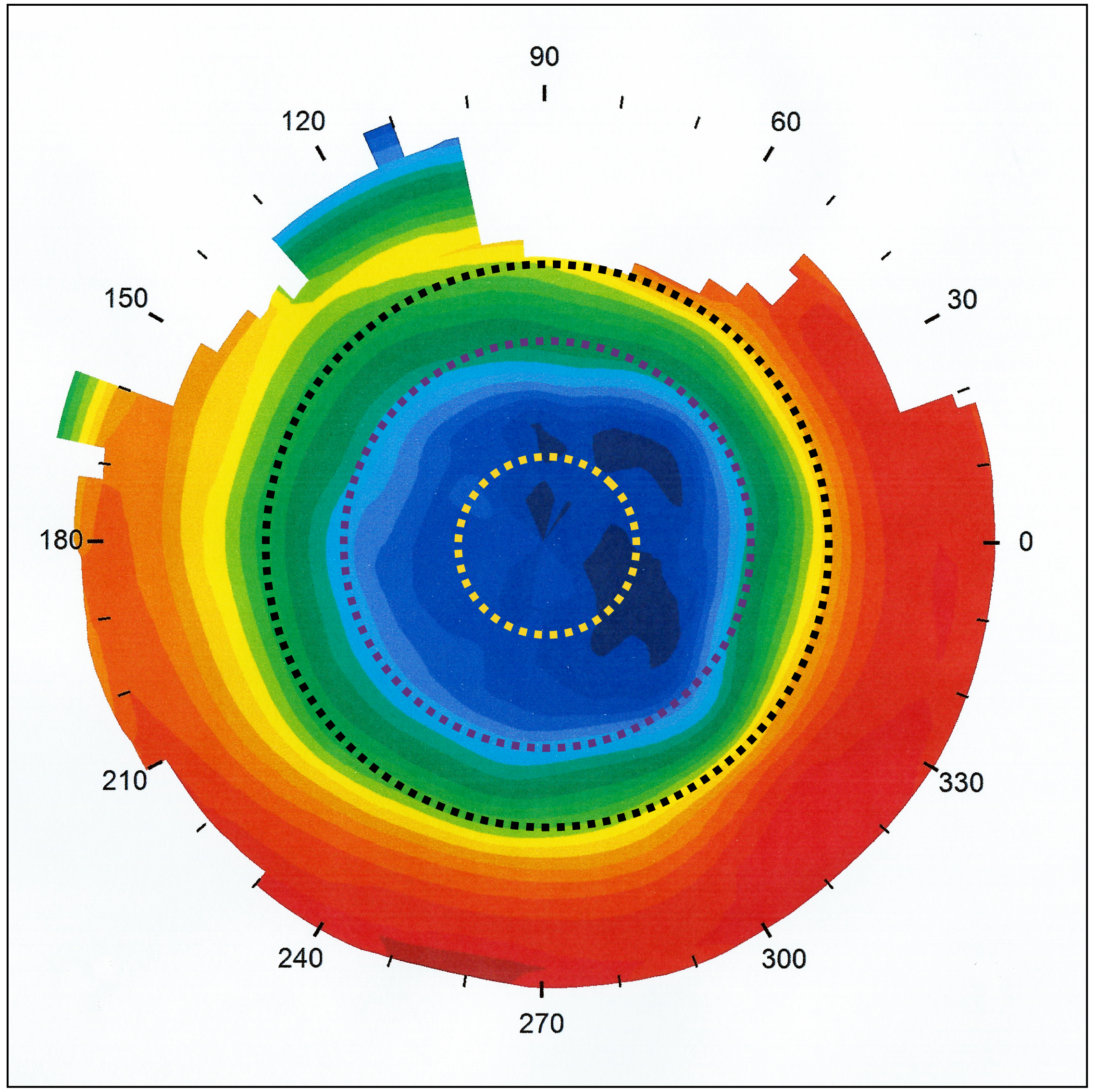
Typical normal eye
with photopic pupil.

-9.00 D myopic LASIK.

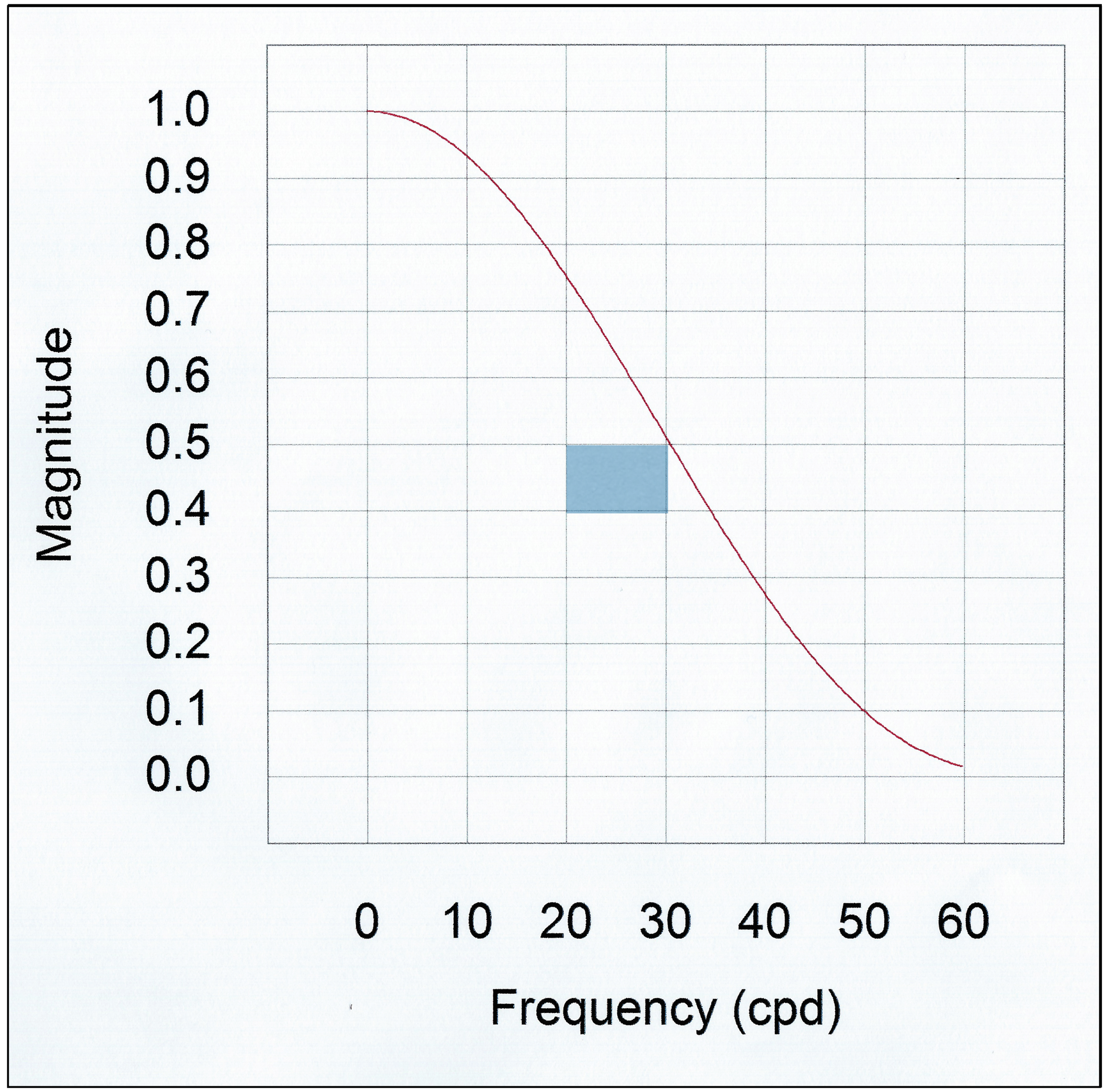


Aberrations

Pupil size - Impact on contrast sensitivity



Axial Power Map 4 mm Pupil



MTF Plot

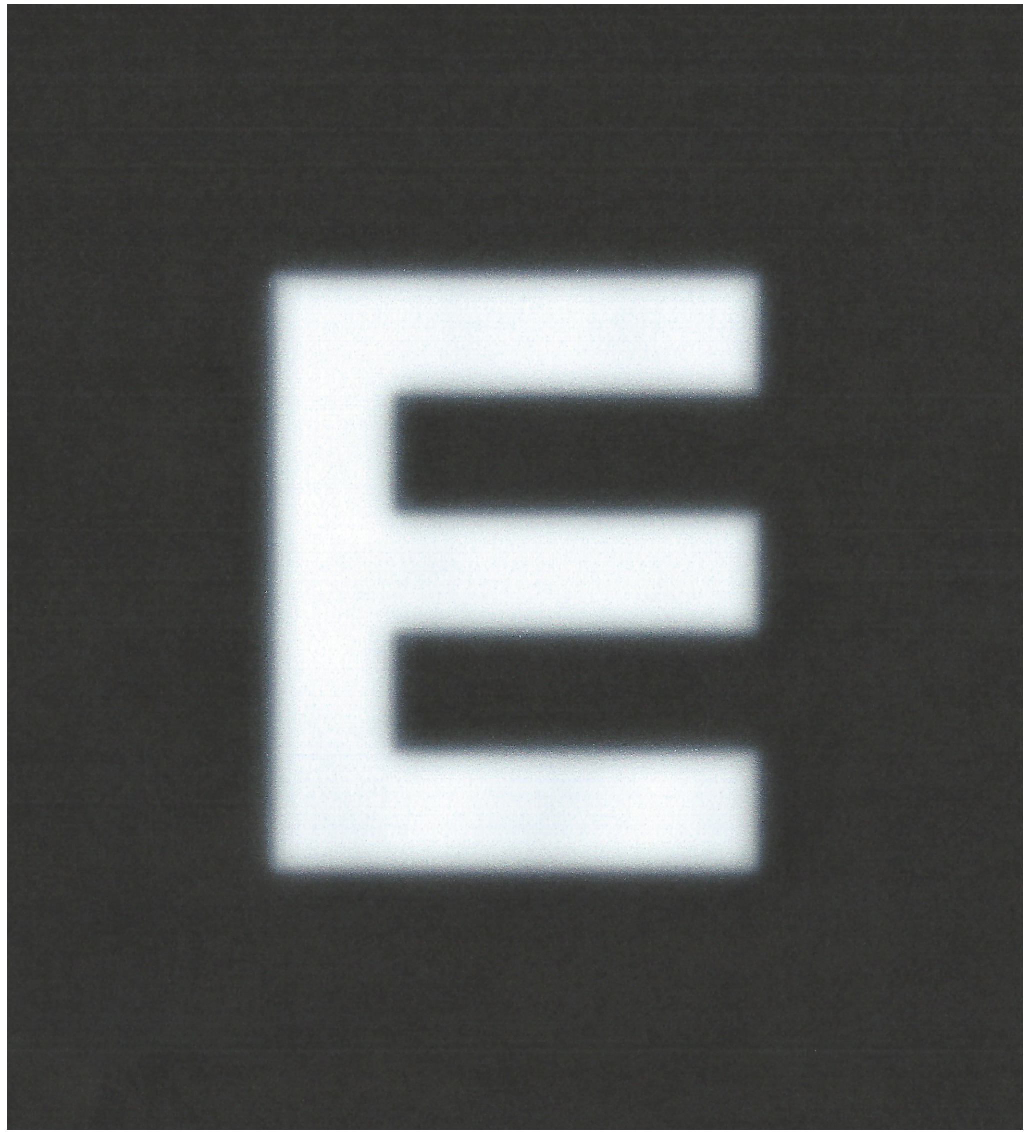


Image Simulation

Aberrations

How can this be shown to patients?

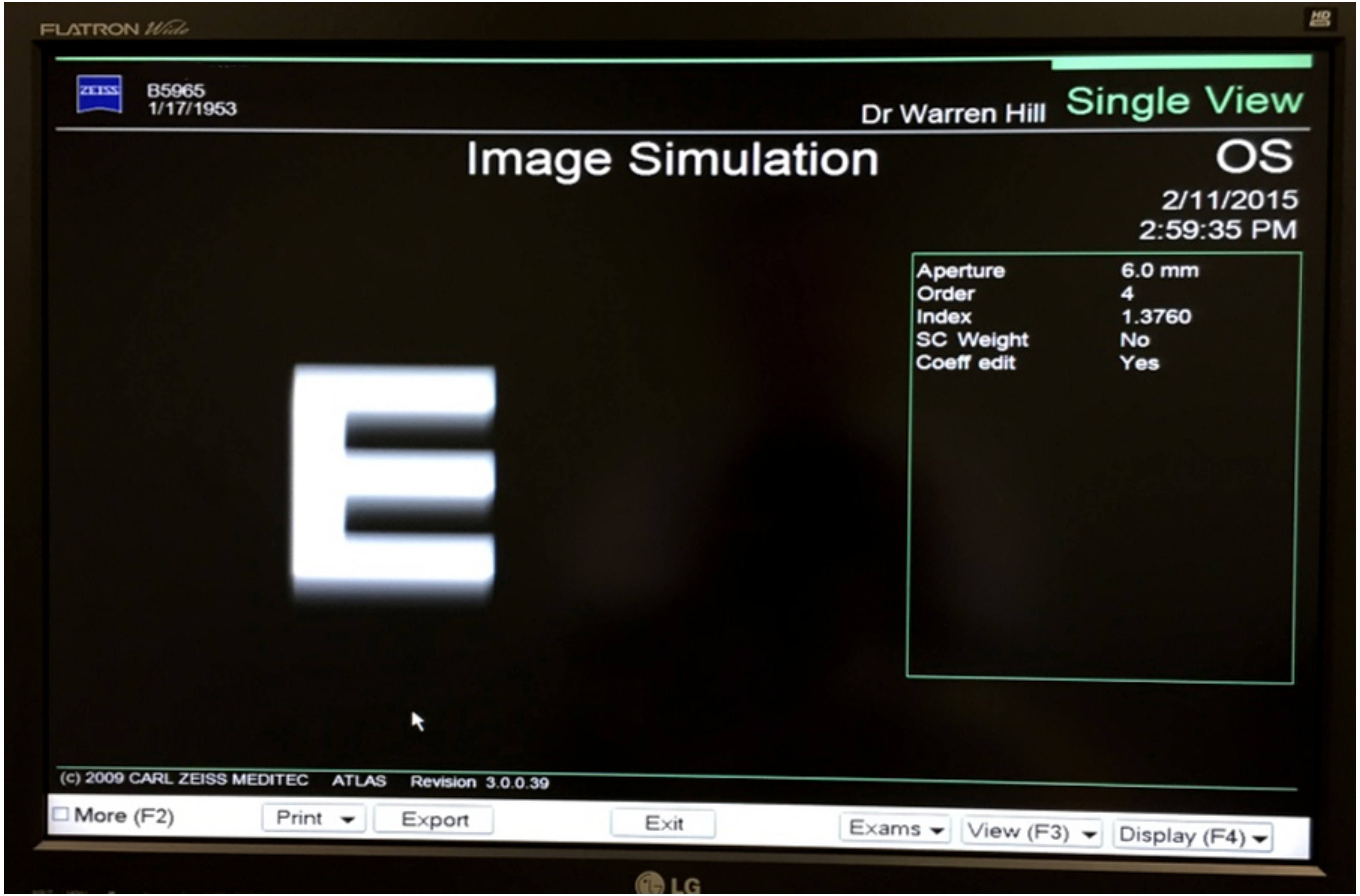
Large LED screen on the wall in diagnostic area.

Direct VGA video output from Atlas topographer.

Aberrations added & subtracted, pupil size changed.

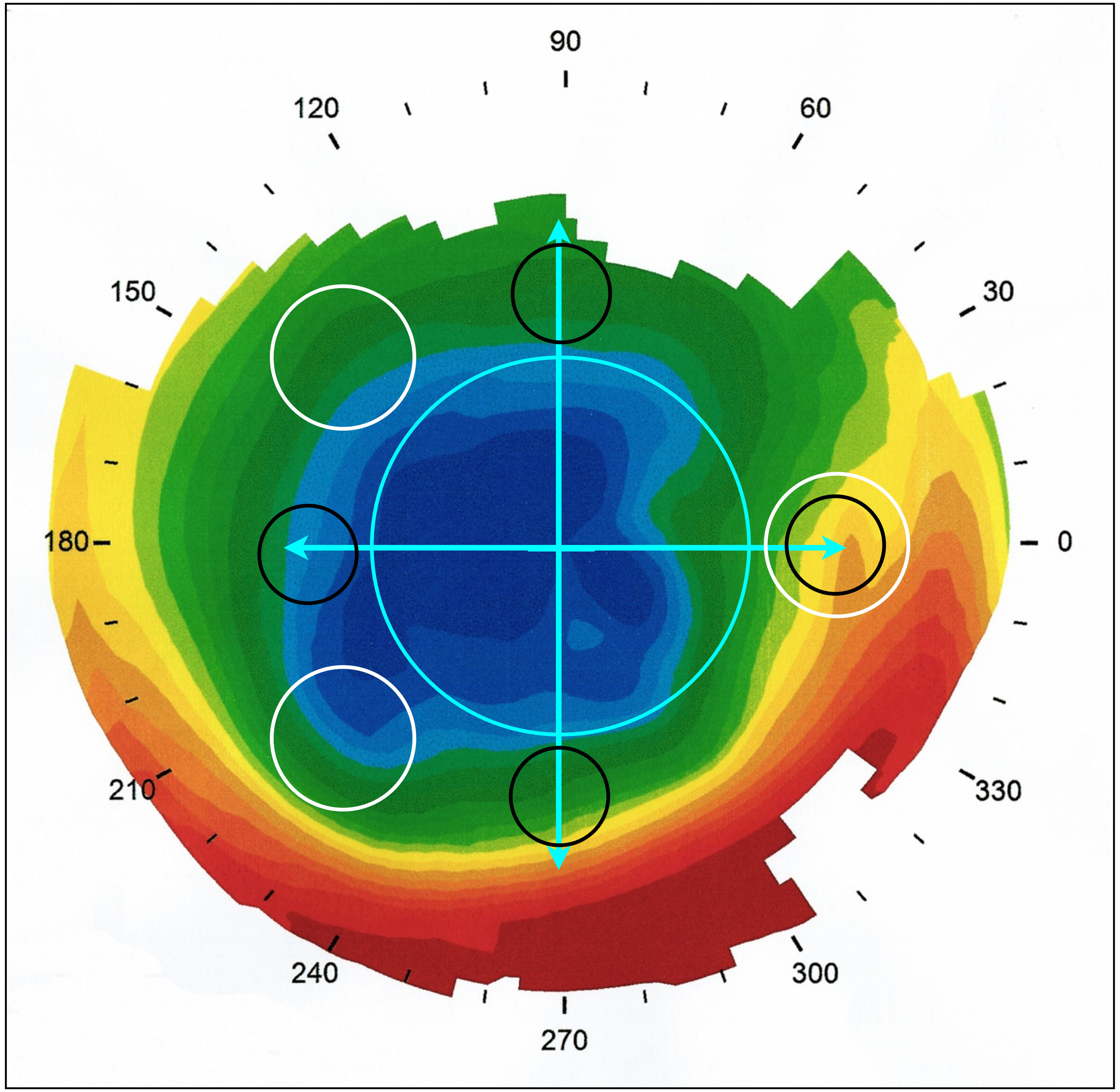
Patient-physician discussion of findings.

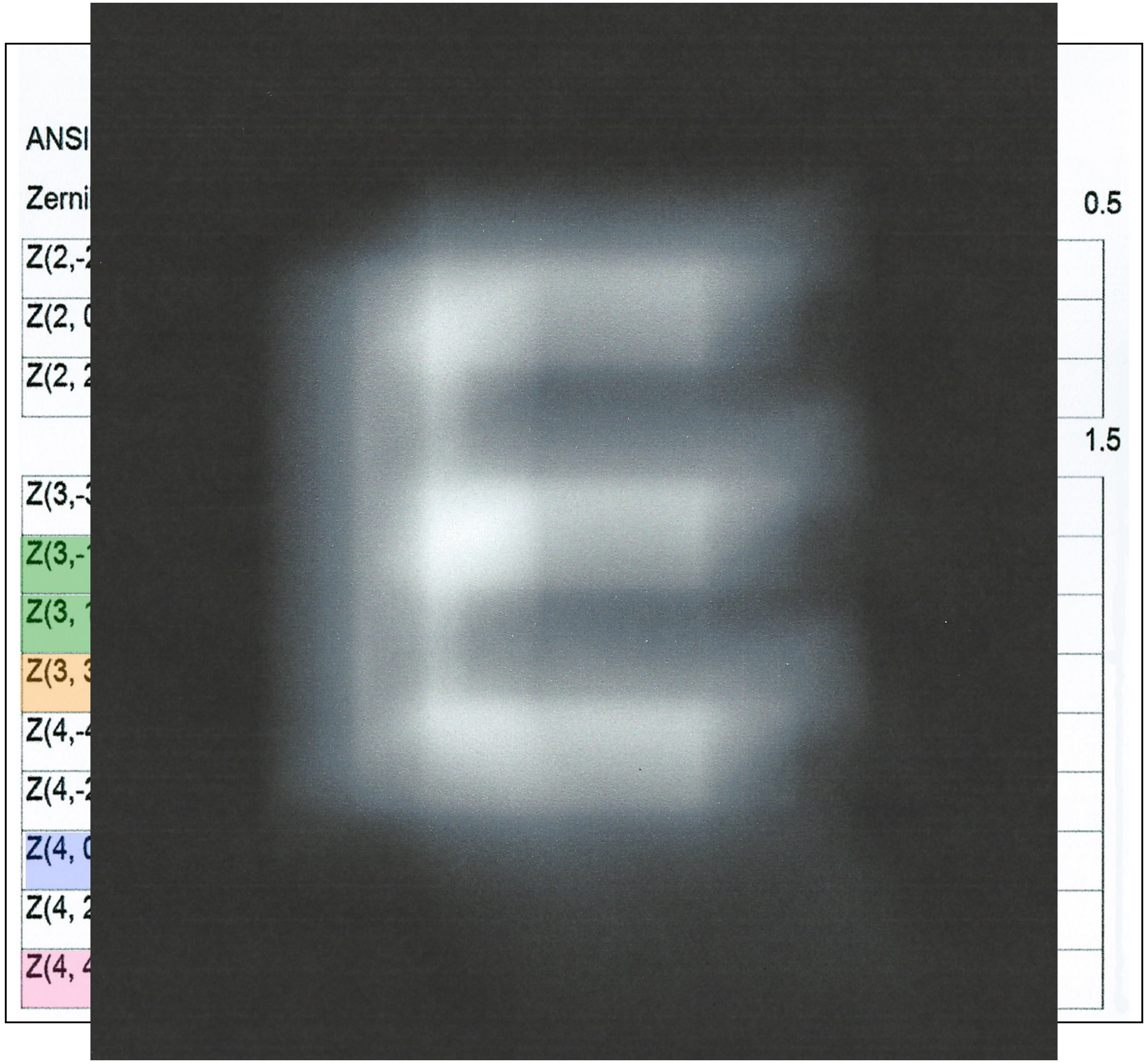
- Axial Map.
- MTF plot.
- Image simulation.



Aberrations

Post-lecture test



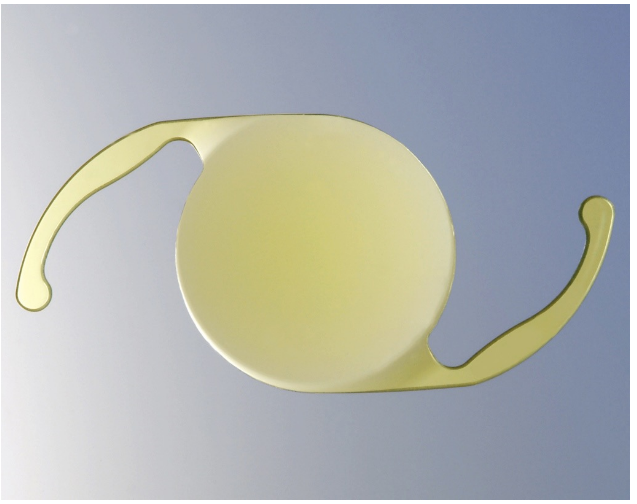


Prior LASIK / PRK and RK

IOL selection

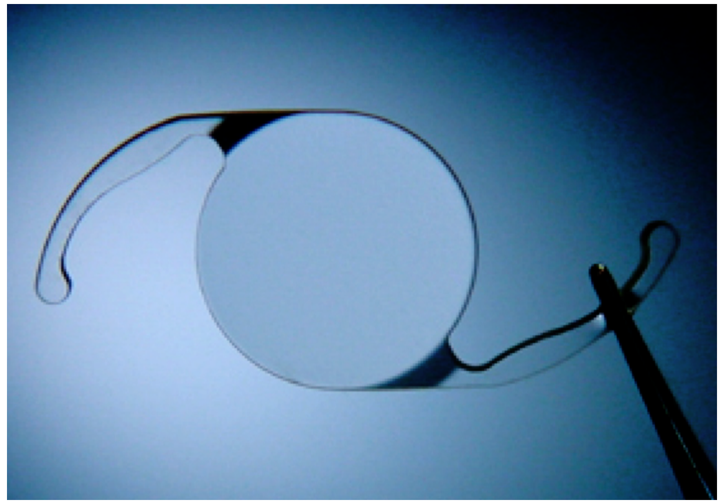
Ideally, the anterior corneal spherical aberration should be measured prior to cataract surgery. If it is not possible to do so, select an aspheric IOL that does not worsen the anterior corneal spherical aberration profile.

AMO Tecnis (-0.275 µm)



Alcon IQ Lens (-0.20 µm)

Bausch & Lomb LI61AO (0.00 µm)



Alcon SN60AT (+0.198 µm)

Myopic LASIK	Aspheric IOL with negative spherical aberration.
Hyperopic LASIK	Aberration neutral, or spherical IOL (negative corneal spherical aberration).
Radial Keratotomy	Aspheric IOL with negative spherical aberration.

We should be mindful of what our plans for surgery will do to contrast sensitivity.

Summary

Aberrations reduce contrast,
each in a specific way.

Visual quality, and patient satisfaction,
are directly related to image contrast.

Summary

Anyone who tells you differently
is selling something.

- ☑ An elegant tool with many more features than just an axial power map.
- ☑ An instrument is only as good as the person using it.
- ☑ Knowing how to use Placido topography greatly increases its usefulness.
- ☑ Very useful for… Toric IOL pre-operative evaluation.
  Evaluating the ocular surface.
  Generating an aberration profile & image simulation.
  Patient education.
- ☑ Remains a diagnostic modality that's not utilized to its full extent.


Thank You