


ASCRS ANNUAL MEETING
23-27 JULY 2021 | LAS VEGAS, NV

# Corneal OCT for Refractive & Cataract Surgeons

**David Huang, MD, PhD**
Peterson Professor of Ophthalmology
Professor of Biomedical Engineering
Casey Eye Institute, Oregon Health & Science University
Portland, Oregon

CASEY EYE Institute OHSU

Financial Interests:
OHSU and Dr. D. Huang have a significant financial interest in Optovue, a company that may have a commercial interest in the results of this research and technology. These potential conflicts of interest have been reviewed and managed by OHSU.
Optovue, Inc.: patent royalty, equipment loan, stock ownership.

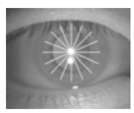
1

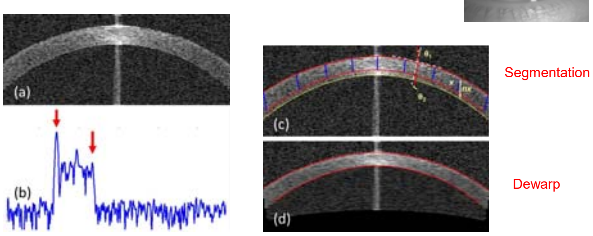
Corneal OCT Applications

## CORNEAL PACHYMETRY AND EPITHELIUM MAPPING

2

## Pachymetry Mapping with OCT






Li Y, et al. (Huang D) *Ophthalmology* 2006;113(5):792-9

3

## OCT Pachymetry Agreement with Other Modalities

| N | OCT | OCT CCT (µm) | OCT- Other modalities (µm) | | |
|---|---|---|---|---|---|
| | | | Scheimpflug (Pentacam[A] or Galilei[B]) | Slit-scanning (Orbscan II) | Ultrasound (Sonogage[C] or Sonomed[D]) |
| 50 | RTVue[1] | 536.9 | -- | -0.3±12.1 | -19.7±10.5[C] |
| 66 | RTVue[2] | 532.8 | -6.0±4.8[A] | -- | -- |
| 50 | Casia[3] | 547.2 | -11.7±6.0[B] | -7.2 | -9.2[D] |

CCT = central corneal thickness

1. Li Y, et al. (Huang D) *J Cataract Refract Surg* 2010;36(5):826-831.
2. Huang J, et al. (Wang Q) *PLoS* One 2014;9(5):e98316.
3. Lee YW, et al. (Choi CY) *J Cataract Refract Surg* 2015;41(5):1018-1029.

4

## OCT Pachymetry Repeatability and Reproducibility

| | OCT | Central D<2mm | D=2~5mm |
|---|---|---|---|
| | RTVue[1] | 1.3 µm | 1.8~3.8 µm |
| Repeatability | RTVue[2] | 2.1 µm | 2.9~5.5 µm |
| | Avanti[3] | 1.3 µm | 3.1~6.7 µm |
| | Casia[4] | 2.5 µm | 3.8~6.1 µm |
| Reproducibility | RTVue[5] | 2.1 µm | 3.6 µm |

1. Li Y, et al. (Huang D) *J Cataract Refract Surg* 2010;36(5):826-831.
2. Huang J, et al. (Wang Q) Ophthalmology 2013;120(10):1951-1958.
3. Unpublished data.
4. Neri A, et al. (Neri A) Acta Ophthalmol 2012; 90:e452-e457.
4. Prakash G, et al. (Agarwal A). *Am J Ophthalmol* 2009;148(2):282-290 e282.

5

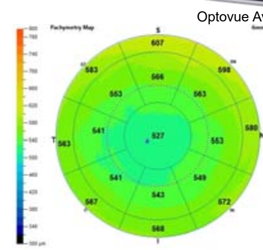
## Pachymetry Mapping with OCT

Optovue Avanti

Avanti OCT 6-mm Pachymetry Map
"Pachymetry+CPwr" scan pattern

Pachymetry

SN-IT(2-5mm): 22 S-I(2-5mm): 23
Min: 522 Location Y: -159
Min-Median: -23 Min-Max: -72
Min thickness at(-0.312mm, -0.159mm) indicated as *



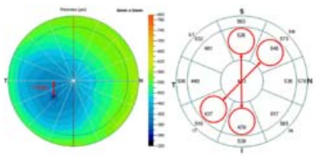
**Normal cornea** is:
- Mostly green on the pachymetry map
- Thinnest cornea locates inside the central D=2 mm circle

David Huang, MD, PhD www.COOLLab.net

6

## OCT Keratoconus Pachymetric Parameters

| Parameter | Explanation |
|---|---|
| IT-SN | Average thickness of the IT octant minus that of the SN octant |
| I-S | Average thickness of the inferior (I) octant minus that of the superior (S) octant |
| Min | Minimum corneal thickness |
| Min - Med | Minimum corneal thickness-median corneal thickness |
| Y Min | Y coordinate of minimum corneal thickness |



1. Li Y, et al. (Huang D) *Ophthalmology* 2008;115(12):2159-2166.
2. Qin B, et al. (Huang D) *J Cataract Refract Surg* 2013;39(12):1864-1871.

7

## OCT Pachymetry Based Keratoconus Risk Score

Keratoconus Risk Score Table

Available for downloading @ http://www.coollab.net/resources

**Patient Name**

| Variables (µm) | 0 | 1 | 2 | 3 | OD | OS |
|---|---|---|---|---|---|---|
| SN-IT | <33 | 33-42 | 43~51 | >51 | | |
| Minimum | >499 | 499 ~ 476 | 475 ~ 455 | <455 | | |
| Minimum-Median | >-21 | -21 ~ -25 | -26 ~ -29 | <-29 | | |
| S-I | <30 | 30-40 | 41~49 | >49 | | |
| Ymin | >-734 | -734 ~ -1069 | -1070 ~ -1353 | <-1353 | | |
| **Keratoconus Risk Score** | | | | | | |

Summation

Keratoconus risk:

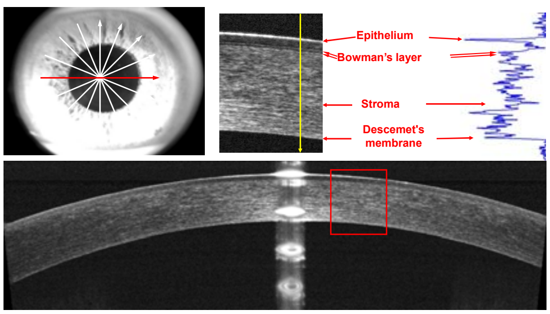
Keratoconus risk score 0~3: low risk, ≥4: high risk.

- Each variable will be assigned a score of 1, 2, 3 if it exceeds 20, 5, 1 percentile thresholds.
- The keratoconus risk score of the eye is the summation of all scores.

Qin B, et al. (Huang D). *J Cataract Refract Surg* 2013;39(12):1864-71.

8

## Corneal Epithelial Imaging with FD-OCT



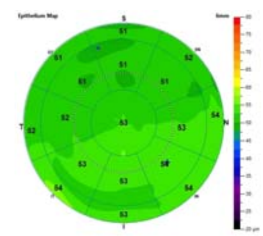

Li Y, et al. (Huang D) *Ophthalmology* 2012; 119(12):2425-33.

9

## OCT Epithelial Thickness Map

iVue OCT 6-mm Epithelial Thickness Map
"Cornea Pachymetry" scan pattern

**Epithelium**
Epithelium statistics within central 5 mm
S (2-5mm): 51 I (2-5mm): 53
Min: 50 Max: 55
Std Dev: 1.4 Min-Max: -5
Min/Max thickness indicated as */+



**Normal cornea** is:
- Mostly green on the epithelial map
- Superior slightly thinner than the inferior
- Epithelial Std Dev < 3.6

David Huang, MD, PhD www.COOLLab.net

10

## OCT Epithelial Map Repeatability

| OCT Device | Central D<2mm | D=2~5mm |
|---|---|---|
| RTVue[1] | 0.7 µm | 0.7~1.1 µm |
| RTVue[2] | 0.7 µm | 0.6~0.9 µm |
| Avanti[3] | 1.6 µm | 1.2~1.7 µm |
| Cirrus HD[4] | 1.5 µm | 1.3~1.5 µm |

1. Li Y, et al. (Huang D) *Ophthalmology* 2012;119(12):2425-2433.
2. Ma XJ, et al. (Koch DD) *Cornea* 2013;32(12):1544-1548.
3. Hashmani N, et al. (Hashmani S) ) *Invest Opthalmol Vis Sci* 2018; 59(3):1652-1658.
4. Sha P, et al. (Durbin M) ) *Invest Opthalmol Vis Sci* 2017; 58:3510

11

## Commercially Available Anterior Eye OCT


Optovue Avanti


Zeiss Cirrus HD


Optovue Solix *


Heidelberg Anterion *


Tomey CASIA2 *


Optopol SOCT Copernicus REVO *


Topcon DRI OCT Triton *

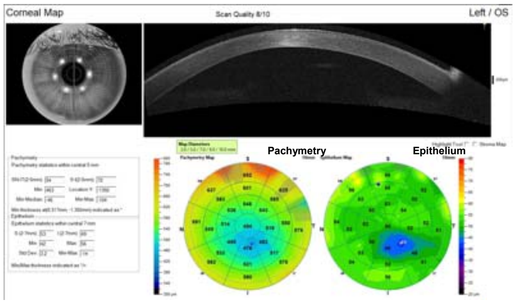

Cylite Hyperparallel OCT *

David Huang, MD, PhD www.COOLLab.net

* Pending FDA clearance for anterior eye imaging

12

## 10-mm Diameter Corneal Maps




**Solix OCT**
Optovue, Inc
**Maps:**
- **Epithelium**
- **Pachymetry**
- **Stroma**

FDA clearance pending

David Huang, MD, PhD www.COOLLab.net

13

Yan Li, PhD

Elias Pavlatos, PhD

Corneal OCT Applications

## CORNEAL TOPOGRAPHY WITH OCT

14

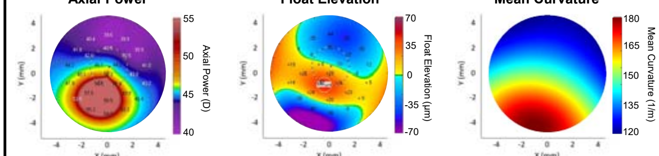
## Standard Corneal Topographers

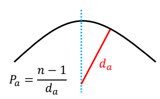
**Placido disc**

**Scheimpflug Imaging**

15

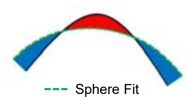
## Corneal Topography Representations



$P_a = \frac{n-1}{d_a}$

$n = index\ of\ refraction$




$C_m(x,y) = \frac{1}{2}[K_1(x,y) + K_2(x,y)]$

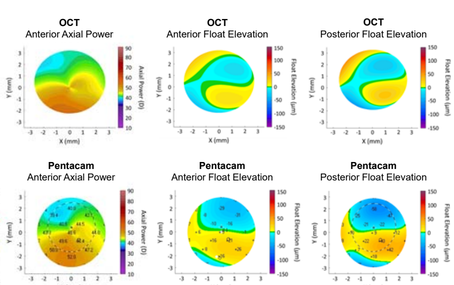
$K_1 and\ K_2 = principal\ curvatures$

www.COOLLab.net

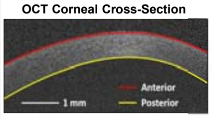
16

## Our Group Developed an OCT Topography Algorithm

**Avanti**
*Optovue, Inc.*




**OCT Corneal Cross-Section**




Pavlatos E, et al. (Li Y) *Biomed Opt Express* 2020; 11(12):7343-7356

17

## Motion Detection Improves Repeatability

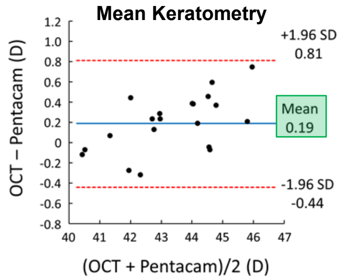
| Diopters | No Motion Detection | Motion Detection |
|---|---|---|
| Anterior Mean Power | 0.28 | 0.14 |
| Anterior Astigmatism - Cardinal | 0.92 | 0.28 |
| Anterior Astigmatism - Oblique | 1.16 | 0.24 |
| Posterior Mean Power | 0.04 | 0.03 |
| Posterior Astigmatism - Cardinal | 0.13 | 0.05 |
| Posterior Astigmatism - Oblique | 0.15 | 0.05 |

Pooled standard deviations for 20 eyes from 10 participants, 5 Repeated OCT Scans

Pavlatos E et al, *Biomed Opt Express*, 2020; 11(12):7343-7356

18

## OCT-Based Keratometry Agreement with Pentacam




Pavlatos E, et al. (Li Y) *Biomed Opt Express* 2020; 11(12):7343-7356

19

## Commercial OCT Systems with Corneal Topography

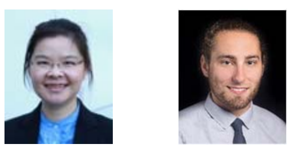
**Anterion**
*Heidelberg Engineering*

**Casia 2**
*Tomey Corporation*

**Revo NX 130**
*Optopol Technology*

**Devices not FDA cleared**

20



**Yan Li, PhD** **Elias Pavlatos, PhD**

Corneal OCT Applications

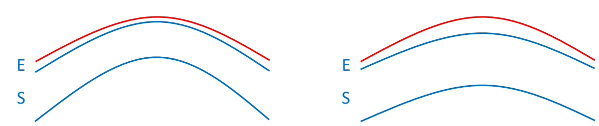
# DIFFERENTIATING KERATOCONUS FROM WARPAGE, DRY EYE, AND OTHER IRREGULARITIES

21

## Keratoconus vs. Warpage

S = stroma
E = epithelium

Thickening of epithelium can also produce focal steepening



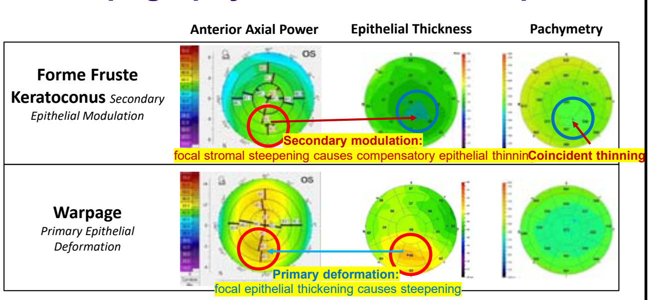

Cornea with Keratoconus

Cornea With Contact Lens Warpage

www.COOLLab.net

22

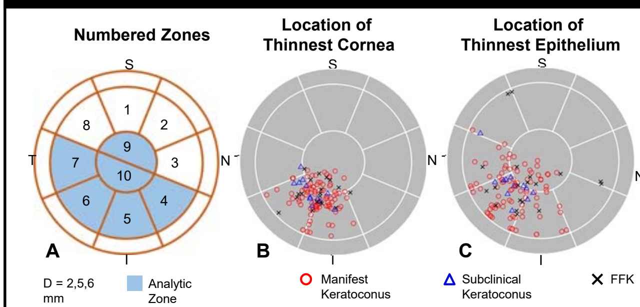
## Topography and Thickness Maps




Schallhorn J et al. (Huang D) *J Cataract Refract Surg.* 2017; 43(1):60-66

23

## Coincident Pachymetric & Epithelial Thinning

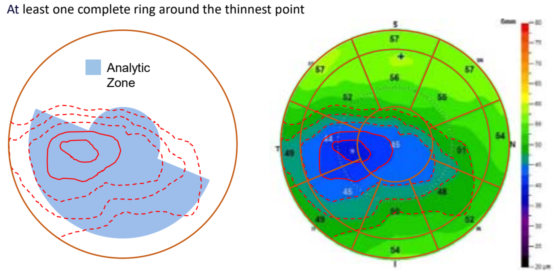



Yang Y, et al. (Li Y) *J Cataract Refract Surg* 2021;47(6):759-766

24

## Epithelial Concentric Thinning

- Epithelial thickness map has more than two color-scale step changes (>5 µm) inside the analytic zone
- At least one complete ring around the thinnest point

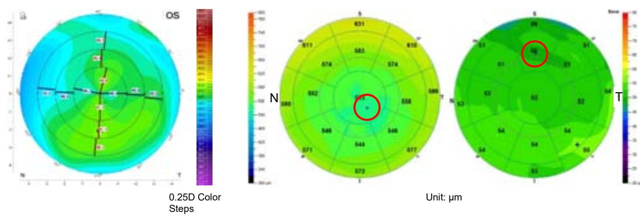



Yang Y, et al. (Li Y) *J Cataract Refract Surg* 2021;47(6):759-766

25

## Case 1 – Normal

**Axial Power** **Pachymetry** **Epithelial Thickness**

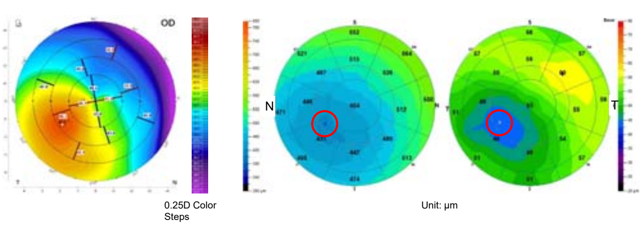



Yang Y, et al. (Li Y) *J Cataract Refract Surg* 2021;47(6):759-766

26

## Case 2 – Subclinical Keratoconus

**Axial Power** **Pachymetry** **Epithelial Thickness**

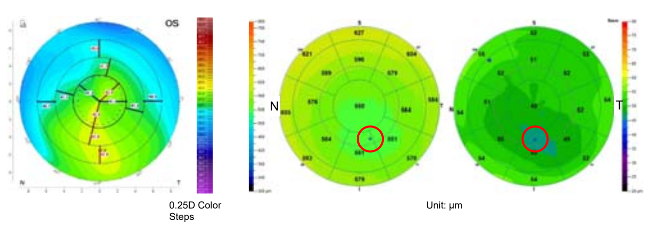



Yang Y, et al. (Li Y) *J Cataract Refract Surg* 2021;47(6):759-766

27

## Case 3 – Forme Fruste Keratoconus

**Axial Power** **Pachymetry** **Epithelial Thickness**




Yang Y, et al. (Li Y) *J Cataract Refract Surg* 2021;47(6):759-766

28

## Coincident Concentric Thinning Decision

**Step 1**
Map parameters

Pachymetric Min < 515 µm **OR,**
Pachymetric Min-Max < -71 µm **OR,**
Pachymetric SN-IT > 28 µm **OR,**
Epithelial Std Dev > 1.9 µm

YES → **Step 2** Map patterns: Coincident **AND** concentric epithelial thinning?
- YES → Keratoconus
- NO → Not keratoconus

NO → Not keratoconus

Yang Y, et al. (Li Y) *J Cataract Refract Surg* 2021;47(6):759-766

29

## Classification Accuracy of Decision Tree

- **Manifest keratoconus** – abnormal topography and CDVA < 20/20
- **Subclinical keratoconus** – abnormal topography and CDVA ≥ 20/20
- **Forme Fruste keratoconus (FFK)** – fellow eye of asymmetric keratoconus with normal or borderline topography and CDVA ≥ 20/20

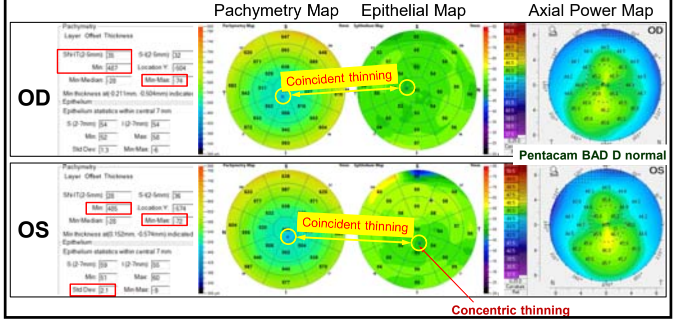
| Normal (54 eyes) | Manifest Keratoconus (91 eyes) | Subclinical Keratoconus (12 eyes) | Forme Fruste Keratoconus (19 eyes) |
|---|---|---|---|
| 100% | 97.8% | 100% | 73.7% |

Yang Y, et al. (Li Y) *J Cataract Refract Surg* 2021;47(6):759-766

30

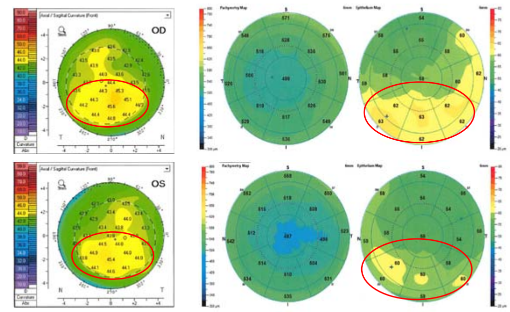
## Refractive Surgery Candidate, Family Hx Keratoconus

Pachymetry Map Epithelial Map Axial Power Map




31

## Refractive Surgery Candidate w/o CL Wear




32

Yan Li, PhD

Elias Pavlatos, PhD

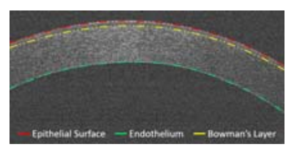
Corneal OCT Applications

**QUANTITATIVE INDICES TO SEPARATE PRIMARY AND SECONDARY EPITHELIAL CHANGES**

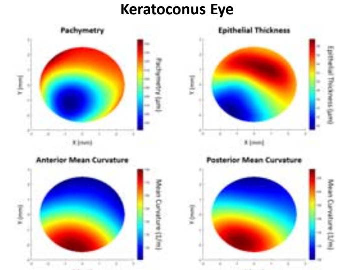
33

## OCT Mapping of the Cornea

OCT Cross-Section of Cornea




Keratoconus Eye




Li Y et al. (Huang D) *Ophthalmology* 2012; 119:2425
Pavlatos E et al. (Li Y) *J Refract Surg* 2020; 36:757
Pavlatos E et al. (Li Y) *Biomed Opt Express* 2020; 11:7343

34

## Epithelial Pattern Standard Deviation

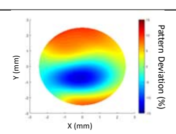
**Epi PSD**

$$\sqrt{\frac{\sum_x\sum_y (\mathrm{PD}_E(x,y))^2}{N}}$$

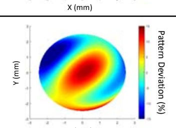
Normal < 4.1%

Epithelial Thickness Pattern Deviation

**Forme Fruste Keratoconus**
*Epi PSD = 5.9%*




**Warpage**
*Epi PSD = 7.2%*




Li Y et al. (Huang D) *J Cataract Refract Surg* 2016; 42:284

35

## Epithelial PSD is a very sensitive detector of keratoconus

| | Keratoconus N= 35 eyes 150 control | 20/20 Keratoconus N=50 eyes 150 control | *Forme fruste* keratoconus N=8 150 control |
|---|---|---|---|
| Sensitivity | 100% | 96.0% | 87.5% |
| Specificity | 100% | 100% | 100% |

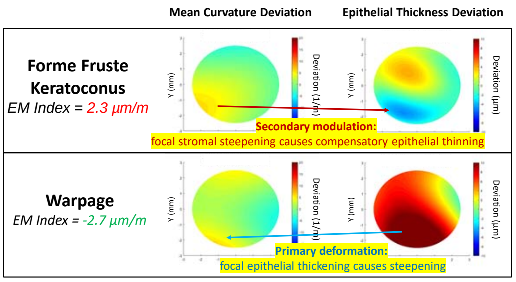
1. Li Y, et al. (Huang D) *Ophthalmology* 2012; 119:2425-33.
2. Li Y, et al. (Huang D) *J Cataract Refract Surg* 2016; 42(2):284-95.

36

## Epithelial Modulation (EM) Index

**EM Index**
-Cov(ΔET, ΔMC)

**Normal < 1.4 µm/m**




www.COOLLab.net

37

## Patient Groups

**Keratoconus Groups**

1) **Manifest Keratoconus (n = 89)**
   - Topographic signs of keratoconus
   - Corrected visual acuity < 20/20
2) **Subclinical Keratoconus (n = 16)**
   - Topographic signs of keratoconus
   - Corrected visual acuity ≥ 20/20
3) **Forme Fruste Keratoconus (n = 26)**
   - Normal topography
   - Corrected visual acuity ≥ 20/20
   - Keratoconus in fellow eye

**Non-Keratoconus Groups**

1) **Contact Lens Warpage (n = 18)**
   - Suspicious topographic steepening
   - Reduction in corrected visual acuity
2) **Normal (n = 32)**
   - Normal topography
   - Corrected visual acuity ≥ 20/20

www.COOLLab.net

38

## Classification Accuracy of EM Index

**Binary classification**
- Class 1 = non-keratoconus (normal and warpage)
- Class 2 = keratoconus (manifest, subclinical, forme fruste)

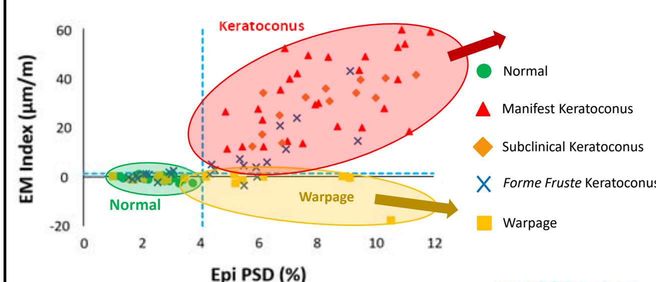
| EM Index | Classification Accuracy (%) | | | | |
|---|---|---|---|---|---|
| Cutoff | Normal | Warpage | Manifest Keratoconus | Subclinical Keratoconus | FF Keratoconus |
| 1.39 ± 0.01 | 100 ± 0 | 98.9 ± 2.2 | 100 ± 0 | 100 ± 0 | 51.5 ± 1.9 |

- Cutoff determined at 50% probability by logistic regression
- 5-fold cross-validation repeated 5 times

www.COOLLab.net

39

## Epi PSD & EM Index Diagnostic Space




www.COOLLab.net

40

## Concept Applies to Other Conditions

**Primary Deformation**
- Warpage
- Dry Eye
- EBMD

**Secondary Modulation**
- Keratoconus/ectasia
- Post-LASIK/PRK
- Stromal scars
- Stromal/Bowman dystrophies

www.COOLLab.net

41

**Yan Li, PhD**

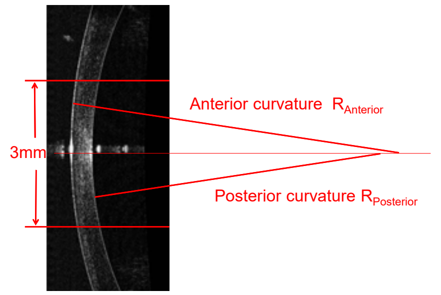
**Clara Llorens Quintana, PhD**

Corneal OCT Applications

## TOTAL (NET) CORNEAL POWER AND ASTIGMATISM

42

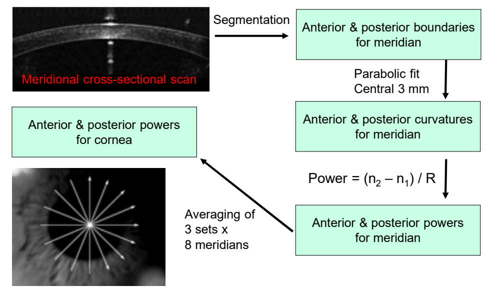
## OCT Measures Anterior and Posterior Corneal Power




David Huang, MD, PhD www.COOLLab.net

43

## OCT Total Corneal Power Algorithm




David Huang, MD, PhD www.COOLLab.net

44

## OCT Corneal Power Repeatability: Published Results

| | | RTVue[1] | RTVue[2] |
|---|---|---|---|
| Corneal power (D) | Total (Net) | 0.19 | 0.10 |
| | Anterior | 0.19 | 0.11 |
| | Posterior | 0.02 | 0.02 |

1. Tang M, et al. (Huang D) *J Cataract Refract Surg.* 2010;36(12):2115-2122.
2. Wang Q, et al. (Huang J) *Cornea.* 2015;34(10):1266-1271.

45

## Repeatability: RTVue vs Avanti

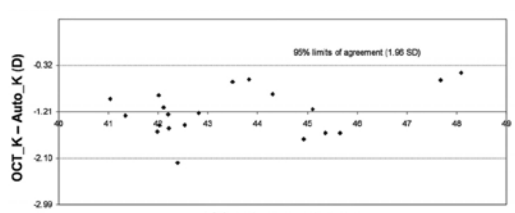
| | | RTVue | Avanti |
|---|---|---|---|
| Corneal power (D) | Total (Net) | 0.18 | 0.14 |
| | Anterior | 0.20 | 0.15 |
| | Posterior | 0.04 | 0.04 |

n = 24 eyes of 12 normal subjects

David Huang, MD, PhD www.COOLLab.net

46

## OCT Net Corneal Power Is Lower Than Conventional Keratometry in Normal Eyes

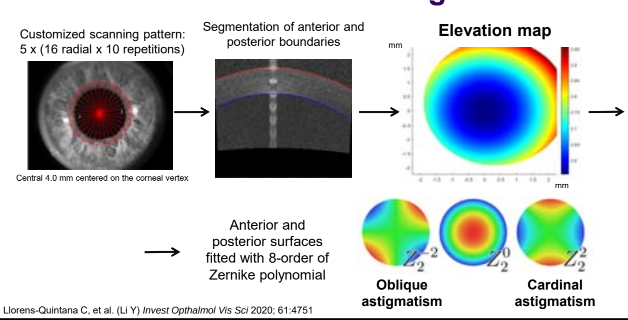



**Special IOL formula should be used with OCT net corneal power**

Tang M, et al. (Huang D) *J Cataract Refract Surg.* 2010;36(12):2115-2122.

47

## OCT derived net corneal astigmatism




Llorens-Quintana C, et al. (Li Y) *Invest Opthalmol Vis Sci* 2020; 61:4751

48

## Subjects

60 pseudophakic eyes (39 patients)

- With non-toric monofocal IOL
- Post Laser visual correction

⬇

Manifest refraction astigmatism = ground truth

Llorens-Quintana C, et al. (Li Y) *Invest Opthalmol Vis Sci* 2021;62:2026

49

## Net Corneal Astigmatism Repeatability

**Coefficient of repeatability**
Pooled standard deviation* 1.96 * sqrt(2)

| | Avanti* | Pentacam | Significance** |
|---|---|---|---|
| Cardinal (D) | 0.22 | 0.50** | $p < 0.05$ |
| Oblique (D) | 0.19 | 0.44** | $p < 0.05$ |
| Vector (D) | 0.29 | 0.67** | $p < 0.05$ |

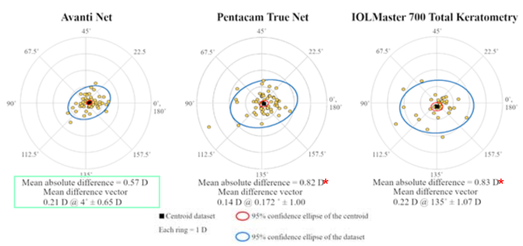
* Experimental software, not FDA-cleared
** F test comparison with OCT Net astigmatism

Llorens-Quintana C, et al. (Li Y) *Invest Opthalmol Vis Sci* 2021;62:2026

50

## OCT More Accurately Measures Net Corneal Astigmatism

**Difference between corneal astigmatism and manifest refraction astigmatism**




* Significantly higher compared to Avanti (GMME, **p<0.05**)

Llorens-Quintana C, et al. (Li Y) *Invest Opthalmol Vis Sci* 2021;62:2026

51

## OCT Corneal Mapping

- Four maps
  - Epithelial thickness
  - Pachymetry
  - Anterior topography
  - Posterior topography
- Distinguish ectasia from warpage
- May provide more accurate net corneal astigmatism measurement in aberrated corneas
- Advanced features still FDA pending

52

## Grants & Material Supports

**NIH Grant R01 EY029023, R01 EY028755, P30 EY010572**

**Unrestricted grant from Research to Prevent Blindness**

**Material support from Optovue, Inc.**

53

CASEY EYE Institute
OHSU

www.COOLLab.net

CENTER FOR OPHTHALMIC OPTICS & LASERS



54

# Measuring the cornea for IOL power calculations

Li Wang, MD, PhD,
Cullen Eye Institute
Baylor College of Medicine,
Houston, Texas, USA

Consultant:
Alcon
Carl Zeiss Meditec

1

## Corneal power measurements

- Range of devices:
  - 4 points: keratometer
  - 6-32 points: ocular biometers
  - >500 points: topographic / tomographic values averaged over the central 3-4 mm zone

2

## Corneal power measurements

- Most of the commonly used devices measure only the anterior corneal curvature
- Total corneal power calculated
  - Assume constant ratio of posterior to anterior corneal curvature
  - Standard index of refraction 1.3375 (USA) or 1.332 (Europe)

3

## Ratio of posterior/anterior radii of curvature from Galilei*

| | Ratio | "Standardized" index of refraction |
|---|---|---|
| Gullstrand's schematic eye | 0.883 | 1.3315 |
| Normal (n=94) | 0.816 | 1.3278 |
| Myopic-LASIK/PRK (n=61) | 0.765 | 1.3246 |
| Hyperopic-LASIK/PRK (n=9) | 0.857 | 1.3302 |

Ratio in RK eyes (n=114) with Avanti OCT

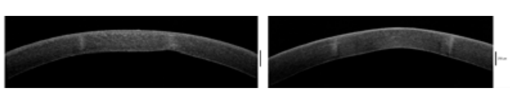
Mean: 0.94
Range: 0.66 – 1.30

* Wang L, Mahmoud AM, Anderson BL, Koch DD and Roberts CJ. IOVS 2011; 52:1716-22

4

## Ratio of posterior/anterior radii of curvature

- Effect on calculation of total corneal power
  - Small in normal eyes
  - Key issue in post-refractive eyes



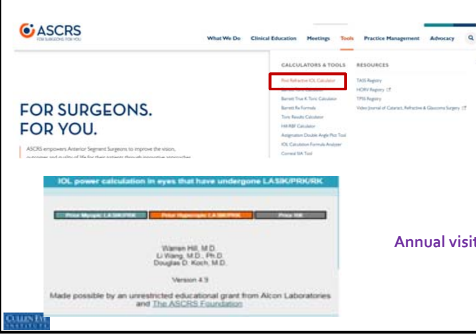
Posterior corneal power: -3.5 D

5

## IOL power calculation in post-refractive eyes

- Traditionally using corneal power based on anterior corneal surface
- Formulas/methods using data from both anterior and posterior corneal surfaces emerging
  - OCT-based IOL calculation formula
  - Galilei TCP formula
  - Potvin-Hill Pentacam
  - Ray-tracing

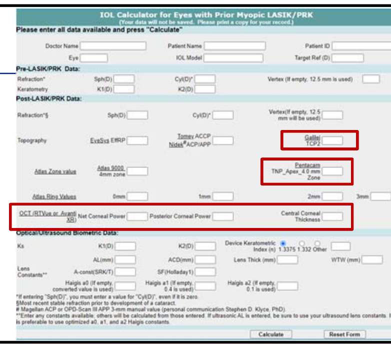
6




ascrs.org

Annual visits > 1 million

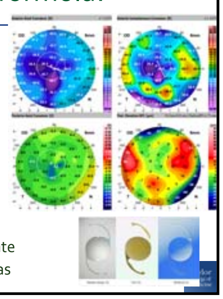
7




8

## What is ideally the best IOL formula?

- Ray tracing:
  - Incorporates all surfaces and aberrations
    - Cornea
    - IOL
  - Major limitation
    - Does not provide a solution to ELP
    - Outcomes with ray tracing formulas to date are not better than our other best formulas



9

## Outcomes reported in literature: recent large studies including newer formulas

| | % ± 0.5 D |
|---|---|
| Myopic LASIK/PRK eyes | 40% - 85% |
| Hyperopic LASIK/PRK eyes | 38% - 73% |
| RK eyes | 29% - 62% |

- Reported more accurate formulas:
  - Average IOL power, OCT-based, Barrett True K, Haigis-L, Masket

10

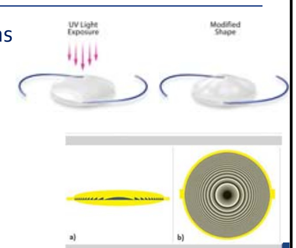
## Current best practices

- Use as many formulas as possible
- Rely more on
  - Average IOL power
  - OCT-based, Barrett True K No History, and Haigis-L
- Warn patients of inaccuracy and possible additional surgeries and costs

11

## "Holy Grail": postop adjustable IOL?

- RxSight: light adjustable lens
  - Curvature change
- Perfect Lens and Clerio
  - Localized refractive index change




12

## Posterior corneal astigmatism

13

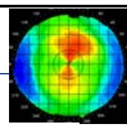
## Magnitude of posterior corneal astigmatism

- Our paper: 0.30 ± 0.15 (0 – 1.10) (n = 715)
- Tonn...Kohnen: 0.33 ± 0.18 (0 – 1.35) (n = 3818)

*Koch et al. JCRS 2012; 38:2080-2087*
*Tonn B, Klaproth OK, Kohnen T. IOVS 2014;56:291-8*

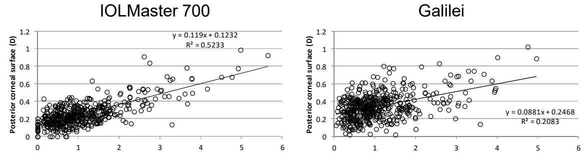
14

## Relationship of anterior & posterior corneal astigmatism: WTR anteriorly



n=496

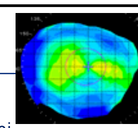
IOLMaster 700 | Galilei




**Up to 1.0 D!**

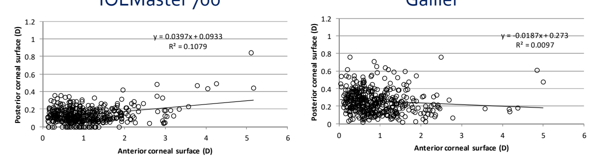
15

## Relationship of anterior & posterior corneal astigmatism: ATR anteriorly



n=417

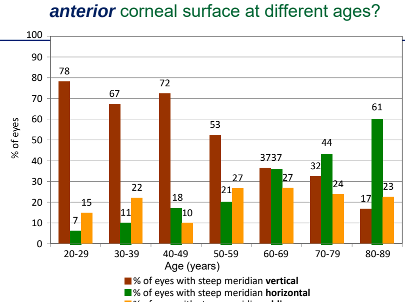
IOLMaster 700 | Galilei




**Up to 0.6 D!**

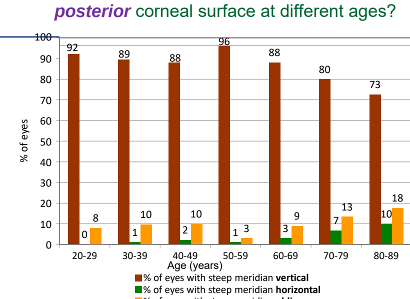
16

## Where is the steep meridian on the *anterior* corneal surface at different ages?




17

## Where is the steep meridian on the *posterior* corneal surface at different ages?




18

## Toric IOL calculation: how do we incorporate posterior corneal astigmatism (PCA)?

- Use regression/theoretical models
  - Baylor nomogram
  - Abulafia-Koch: Vector version of Baylor nomogram + clinical data
  - J&J (AMO): J&J clinical trial data + Baylor nomogram
  - Barrett toric calculator (standard, predicted PCA)
- Measure the posterior cornea
  - Barrett toric calculator (new, measured PCA)

19

## Baylor Toric IOL Nomogram, Version 2

Temporal clear corneal incision and target for postop astigmatism of 0.4 D WTR to account for ATR shift with age

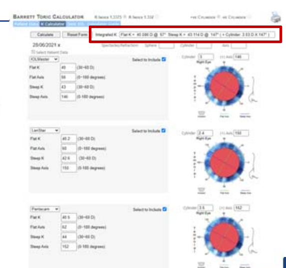
| Effective IOL cylinder power at corneal plane (D) | WTR (D) | ATR (D) |
|---|---|---|
| 0 | ≤ 1.69 (>1.0: PCRI) | ≤ 0.39 |
| 1.00 | 1.70 – 2.19 | 0.40* – 0.79 |
| 1.50 | 2.20 – 2.69 | 0.80 – 1.29 |
| 2.00 | 2.70 – 3.19 | 1.30 – 1.79 |
| 2.50 | 3.20 – 3.79 | 1.80 – 2.29 |
| 3.00 | 3.80 – 4.39 | 2.30 – 2.79 |
| 3.50 | 4.40 – 4.99 | 2.80 – 3.29 |
| 4.00 | 5.00 – | 3.30 – 3.79 |

0.7 D (WTR) — 0.7 D (ATR)

*Especially if specs have more ATR

20

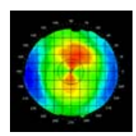
## Barrett toric calculator (apacrs.org)

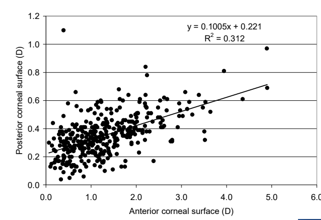


21

## Problem with regression approaches for selecting toric IOLs: Scatter

- Wide individual variation
  - Even "normal" corneas






22

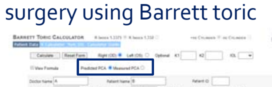
## Does measuring the posterior cornea improve toric outcomes?

- Prior Scheimpflug studies:
  - No benefit to direct measurement
- Studies:
  - Regression models vs. direct measurements
  - More accurate with regression models

23

## Our study

- To compare the accuracy of predicting residual astigmatism after cataract surgery using Barrett toric calculator with:
  - Predicted PCA
  - Measured PCA from IOLMaster 700
- Dataset from VERACITY surgical database
  - Included eyes with monofocal non-toric IOLs



24

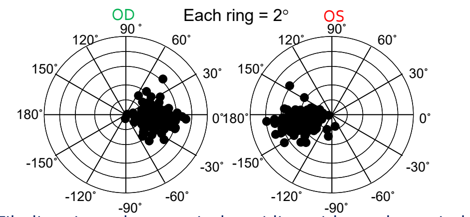
## Results: % residual astigmatism prediction error (PE) (n=602)

| | Scalar PE magnitude | | Vector PE magnitude | |
|---|---|---|---|---|
| | Predicted PCA | Measured PCA | Predicted PCA | Measured PCA |
| ≤0.25 D | 41.2% | 43.9% | 16.8% | 19.8% |
| ≤0.50 D | 72.6%* | 76.1%* | 52.5%** | 57.6%** |
| ≤0.75 D | 88.2% | 89.05% | 77.1% | 78.6% |
| ≤1.00 D | 94.9% | 95.5% | 88.0% | 89.2% |

* **: significant differences between predicted and measured PCA

25

## What about crystalline lens and IOL tilt?

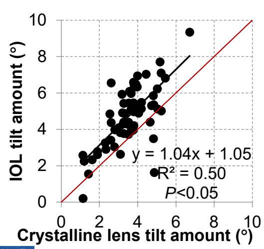



Tilt direction: along vertical meridian with nasal anteriorly

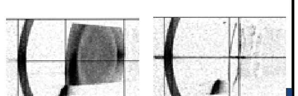
*Wang L, Guimaraes de Souza R, Weikert MP, Koch DD. JCRS 2019;45:35-40*

26

## Pre-op crystalline lens vs. post-op IOL (n=65 eyes)




- Significantly correlated
- Tilt direction & magnitude:
  - Preop predicts postop



27

## IOL tilt

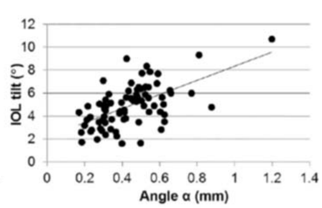
- Average magnitude:
  - 4.9 ° our study
  - 6.2° by Hirnschall
  - Range 1.6 to 10.7 °
- Induces net + power along the horizontal meridian
  - "ATR" refractive astigmatism

*Hirnschall N....Findl O JCRS 2017: 43:732-736*
**Wang L, Guimaraes de Souza R, Weikert MP, Koch DD. JCRS 2019;45:35-40*

28

## Can we predict eyes with large IOL tilt?

- Angle alpha
  - ↑ angle alpha, ↑ IOL tilt

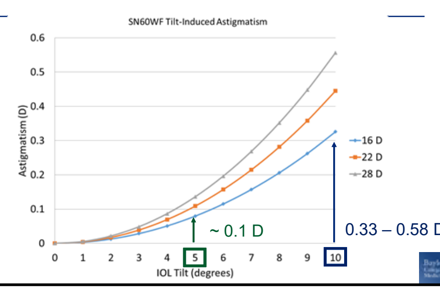



*Wang L, Guimaraes de Souza R, Weikert MP, Koch DD. JCRS 2019;45:35-40*

29

## Astigmatism induced by IOL tilt: aspheric IOL

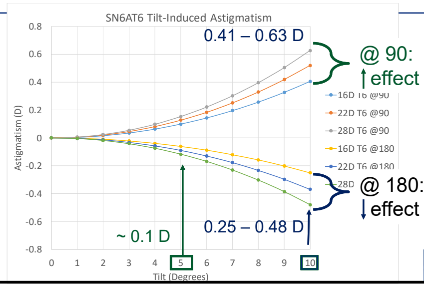
*Weikert MP, Golla A, Wang L. JCRS 2018;44:745-749*




30

## Astigmatism induced by IOL tilt: SN6AT6 toric IOL

*Weikert MP, Golla A, Wang L. JCRS 2018;44:745-749*




31

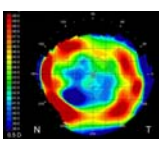
## Toric IOL in LASIK/PRK/RK eyes

- High expectations following cataract surgery
  - Good uncorrected visual acuity
  - Spectacle independence
- Corneal astigmatism common
  - LASIK/PRK performed to eliminate ocular refractive error including astigmatism
  - Residual or induced to compensate for lenticular astigmatism

32

## Corneal astigmatism in LASIK/PRK/RK eyes

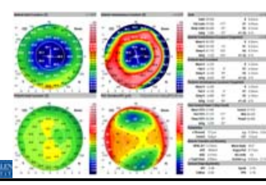
- Challenge to correct
  - Due to presence of varying amounts of irregular astigmatism
  - Difficult to estimate posterior corneal astigmatism based on anterior corneal data

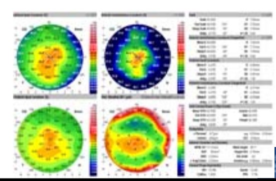


33

## When to use toric IOLs?

- Criterion #1:
  - Regular bow-tie corneal astigmatism within central 3-mm zone





34

## When to use toric IOLs?

- Criterion #2:
  - Difference in corneal astigmatism magnitude between IOLMaster and Lenstar ≤0.75 D
- Criterion #3:
  - Difference in astigmatism meridian between IOLMaster and Lenstar ≤15°

| | | | |
|---|---|---|---|
| Lenstar | 1.27 | @ | 008 |
| IOLM | 1.63 | @ | 021 |

≤ 0.75 D

≤ 15°

35

## IOL toricity selection

- Posterior corneal astigmatism
  - Difficult to estimate
    - Estimate 0.3 D of against-the-rule refractive effect
- Target for corneal astigmatism correction
  - 0.3 D WTR
  - Be conservative and not over-correct!

36

## IOL spherical power selection: ascrs.org

- Post-refractive IOL calculator

37

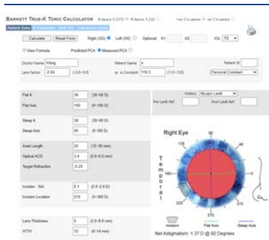
## When corneas met all 3 criteria:

- % of eyes with refractive astigmatism ≤ 0.5 D
  - Post-myopic LASIK (n = 56): 80%
  - Post-hyperopic LASIK (n = 19): 84%
  - Post-RK (n = 41): 76%

*Cao D, Wang L, Koch DD. JCRS . 46(4):534-539, 2020.*

38

## Barrett True-K toric calculator

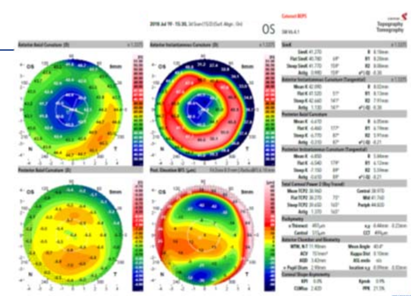


Myopic LASIK
2D @ 90
Net astigmatism: 1.39D@92

39

## Case #1

- 75 yo male
- s/p LASIK
- Cataract OS



40

Preop corneal astigmatism

| MR | -0.75 + 1.0 x 175 |
|---|---|
| Lenstar | 1.29 @ 169 |
| IOLMaster 700 | 1.30 @ 169 |
| Galilei<br>SimK<br>TCP | <br>0.99 @ 159<br>1.37 @ 165 |

- 19.0 D ZCT225@172
- POM#1
  - UCVA = 20/20
  - MR: plano

18.56 to 20.04 D

41

## Case #2: previous RK

- 60 yrs male cataract surgery OS
  - MR: + 1.75 + 0.75 x 166
  - 8 radial cuts and one superior T cut
  - Target for D

42

## Corneal astigmatism

- MR: +1.75+ 0.75 x 166
- IOLMaster: 0.93 D @150˚
- Lenstar: 1.04 D @149˚
- Galilei SimK: 1.01 D @157˚
- Galilei TCP: 1.19 D @173˚
- Atlas: 0.76 D @177˚

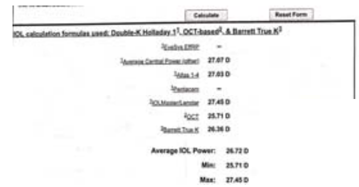
**Toric or nontoric IOL? ZCT150 @160˚**

43

## IOL spherical power: which would you choose??

Calculator formulas for target -0.5 D:

25.71 to 27.45 D




44

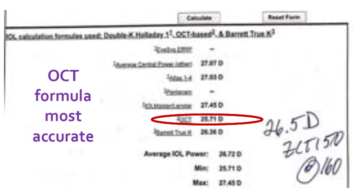
## 26.5D ZCT150 @160 implanted targeting **-0.50**

POM #1:
- UCVA = 20/100
- -1.75Sph= 20/20

POM#2:
- UCVA = 20/50
- -1.25 Sph= 20/20

POM#3:
- UCVA = 20/70
- -1.75 Sph= 20/25

**OCT formula most accurate**




What would you do now?

45

## Fit with -1.25 D CL

- Realized how nice a little near vision is
- Wants perfect distance vision OD!
  - It has 12 radial and 8 T cuts....

46

## Summary

- Accurate total corneal power estimation is crucial
  - Posterior corneal power measurements improve accuracy, especially in un-usual eyes
- IOL power calculation in post-refractive eyes still a ways to go
  - Especially in RK eyes
  - More accurate corneal power measurements and IOL power formulas are needed

47

## Summary

- Considering posterior corneal astigmatism in toric IOL selection improves accuracy
- Toric IOLs can work well in post-refractive eyes
  - Corneas met all 3 criteria
- Postop IOL power adjustment is very promising

48