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

Corneal Tomography and Topography for Refractive and Cataract Surgeons

Session # IC-101
Saturday July 24, 2021: 8:00 AM - 9:30 AM,
Madalay Bay Convention Center, Level 2, Lagoon KL

Program

1. Renato Ambrósio Jr., MD, PhD
   Scheimpflug Imaging
2. David Huang, MD, PhD
   Corneal OCT
3. Li Wang, MD, PhD
   Measuring the cornea for IOL calculations

Scheimpflug Imaging for Enhanced Refractive Diagnosis

Renato Ambrósio Jr., MD, PhD

Instituto de Olhos Renato Ambrósio

visareRIO
Clínica de Olhos
Prof. Renato Ambrósio Jr.

Financial Disclosures

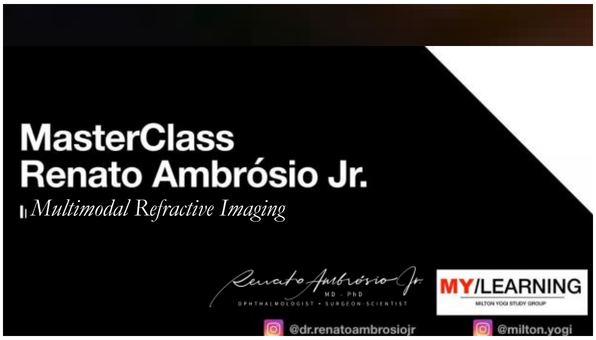
Oculus
Alcon/Wavelight
Allergan
Essilor
Genom / União Química
Ofta Vision Health
Mediphacos
ZEISS

brain 10 ANOS

PROF. DR. AYDANO MACHADO
PROF. DR. JOÃO MARCELO LYRA
PROF. DR. RENATO AMBRÓSIO

Edileuza V. Leão, PhD

Bernardo T. Lopes, MD MPhil PhD



MasterClass
Renato Ambrósio Jr.

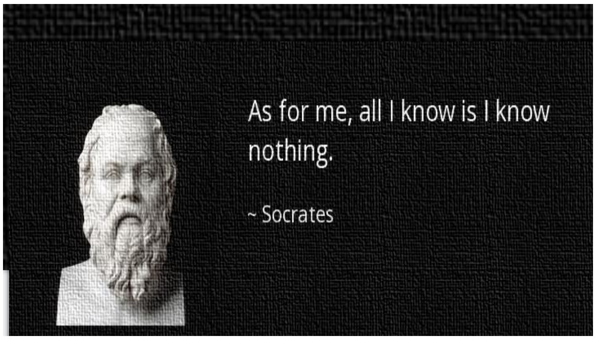
Multimodal Refractive Imaging

Renato Ambrósio Jr.
MD - PhD
OPHTHALMOLOGIST • SURGEON-SCIENTIST

MY/LEARNING
MILTON YOGI STUDY GROUP

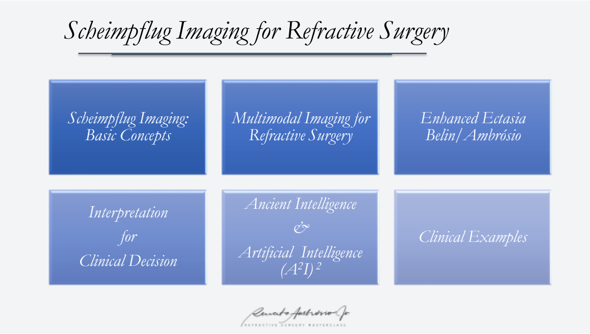
@dr.renatoambrosiojr

@milton.yogi



As for me, all I know is I know nothing.

~ Socrates



Scheimpflug Imaging for Refractive Surgery

- *Scheimpflug Imaging: Basic Concepts*
- *Multimodal Imaging for Refractive Surgery*
- *Enhanced Ectasia Belin/Ambrósio*
- *Interpretation for Clinical Decision*
- *Ancient Intelligence & Artificial Intelligence $(A^2I)^2$*
- *Clinical Examples*

A little of History…

- Geometric principle was first described by Jules Carpentier (1901)

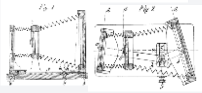
Jules Carpentier
(1851 – 1921)

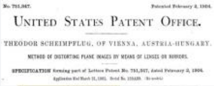
No 1139 A.D. 1901

Date of Application, 17th Jan., 1901
Complete Specification Left, 26th Sept., 1901 – Accepted, 2nd Nov., 1901

PROVISIONAL SPECIFICATION.

"Improvements in Enlarging or like Cameras".





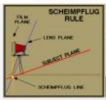
No. 751,347. Patented February 2, 1904.

UNITED STATES PATENT OFFICE.

THEODOR SCHEIMPFLUG, OF VIENNA, AUSTRIA-HUNGARY.

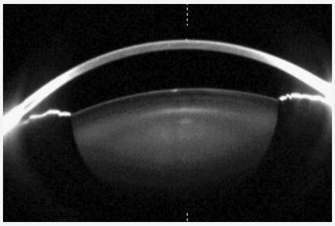
METHOD OF DISTORTING PLANE IMAGES BY MEANS OF LENSES OR MIRRORS.

SPECIFICATION forming part of Letters Patent No. 751,347, dated February 2, 1904.

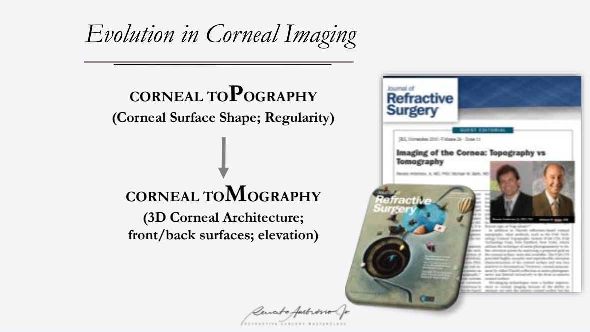


Theodor Scheimpflug
(1865-1911)

Scheimpflug Imaging



Slit Lamp Scheimpflug



Evolution in Corneal Imaging

CORNEAL TOPOGRAPHY
(Corneal Surface Shape; Regularity)

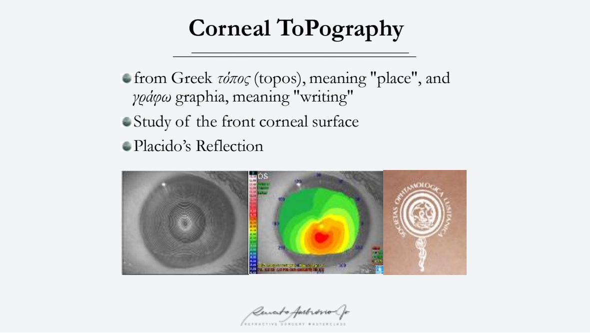
↓

CORNEAL TOMOGRAPHY
(3D Corneal Architecture;
front/back surfaces; elevation)

Journal of Refractive Surgery

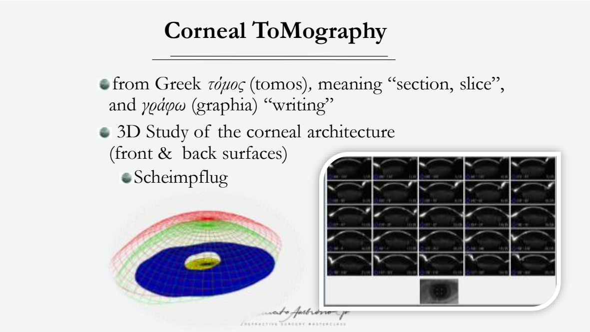
GUEST EDITORIAL

Imaging of the Cornea: Topography vs Tomography



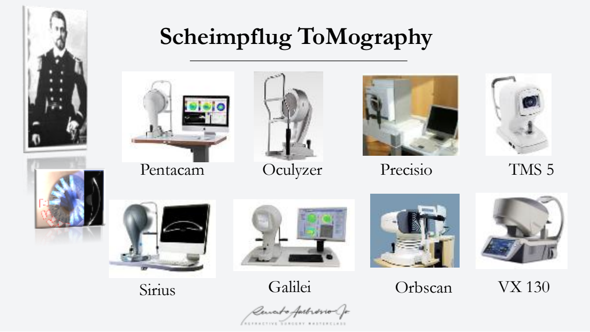
Corneal ToPography

- from Greek *τόπος* (topos), meaning "place", and *γράφω* graphia, meaning "writing"
- Study of the front corneal surface
- Placido's Reflection



Corneal ToMography

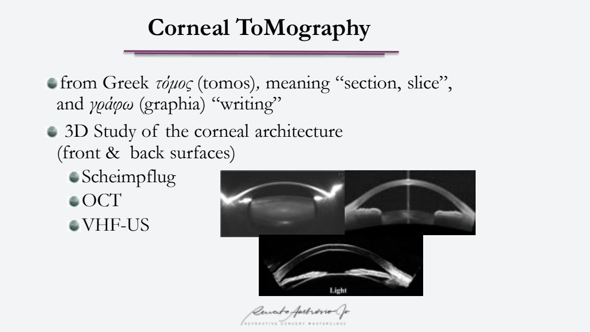
- from Greek *τόμος* (tomos), meaning "section, slice", and *γράφω* (graphia) "writing"
- 3D Study of the corneal architecture (front & back surfaces)
  - Scheimpflug



Scheimpflug ToMography

Pentacam Oculyzer Precisio TMS 5

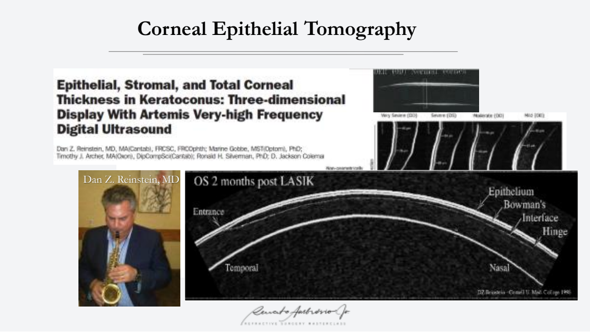
Sirius Galilei Orbscan VX 130



Corneal ToMography

- from Greek *τόμος* (tomos), meaning "section, slice", and *γράφω* (graphia) "writing"
- 3D Study of the corneal architecture (front & back surfaces)
  - Scheimpflug
  - OCT
  - VHF-US

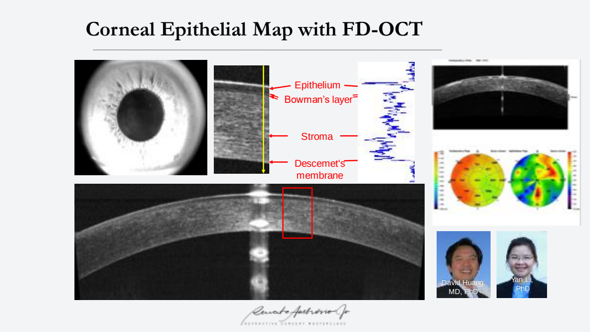
Segmental or Layered ToMography



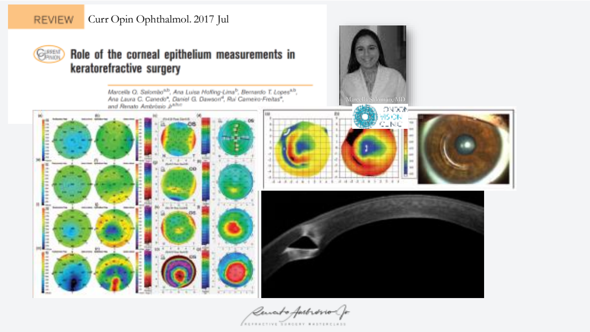
Corneal Epithelial Tomography

Epithelial, Stromal, and Total Corneal Thickness in Keratoconus: Three-dimensional Display With Artemis Very-high Frequency Digital Ultrasound

Dan Z. Reinstein, MD, MA(Cantab), FRCSC, FRCOphth; Marine Gobbe, MST(Optom), PhD; Timothy J. Archer, MA(Oxon), DipCompSci(Cantab); Ronald H. Silverman, PhD; D. Jackson Colema



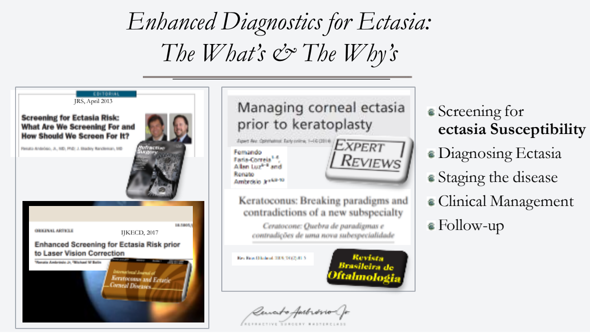
Corneal Epithelial Map with FD-OCT



REVIEW Curr Opin Ophthalmol. 2017 Jul

Role of the corneal epithelium measurements in keratorefractive surgery

Marcella Q. Salomão[a,b], Ana Luisa Hofling-Lima[b], Bernardo T. Lopes[a,b], Ana Laura C. Canedo[a], Daniel G. Dawson[d], Rui Carneiro-Freitas[a], and Renato Ambrósio Jr[a,b,c]



Enhanced Diagnostics for Ectasia: The What's & The Why's

EDITORIAL

JRS, April 2013

Screening for Ectasia Risk: What Are We Screening For and How Should We Screen For It?

Renato Ambrósio, Jr, MD, PhD; J. Bradley Randleman, MD

ORIGINAL ARTICLE

IJKECD, 2017

Enhanced Screening for Ectasia Risk prior to Laser Vision Correction

Renato Ambrósio Jr, Michael W Belin

Managing corneal ectasia prior to keratoplasty

Expert Rev. Ophthalmol. Early online, 1–16 (2016)

Fernando Faria-Correia[1-6], Allan Luz[6-8] and Renato Ambrósio Jr[6,8-10]

Keratoconus: Breaking paradigms and contradictions of a new subspecialty

Ceratocone: Quebra de paradigmas e contradições de uma nova subespecialidade

- Screening for **ectasia Susceptibility**
- Diagnosing Ectasia
- Staging the disease
- Clinical Management
- Follow-up

22

International English Edition

Highlights of Ophthalmology

SERIES 2020 • VOLUME 48 • NUMBER 4

Multimodal Imaging in Refractive Surgery

Louise Pellegrino Gomes Esporcatte, MD
Marcella Q. Salomão, MD
Nelson Batista Sena Jr., MD
Jorge Haddad, MD
(Brazil)
Daniel G. Dawson, MD
(USA)
Fernando Faria-Correia, MD, PhD, FEBOS-CR
(Portugal)
Renato Ambrósio Jr, MD, PhD
(Brazil)

INDIAN JOURNAL OF OPHTHALMOLOGY Volume 68 Issue 12

Guest Editorial

Multimodal imaging for refractive surgery: *Quo vadis?*

Prof. Renato Ambrósio Jr, MD, PhD

23

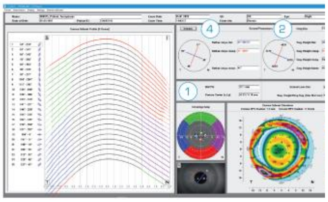
The Pentacam® Family

24

Diagnostics with the Pentacam

25

Pentacam CSP Report
Scheimpflug Imaging for Scleral Lens



① **Select scleral lens diameter**
Select scleral lens diameter based on HWTW value:
a. 11.8 mm or greater ❯ select Zenlens 17 mm or Zen RC 15.4 mm
b. 11.7 mm or less ❯ select Zenlens 16 mm or Zen RC 14.8 mm

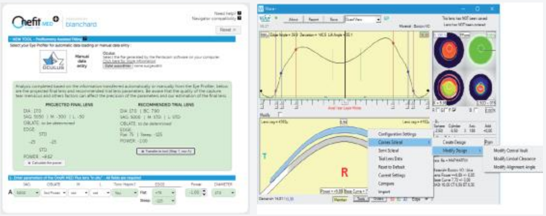
② **Adapt ring diameter**
Set Ring Dia to lens diameter as determined in step 1

③ **Select sagittal height**
Select Sag. Height Mean and add 300 microns for initial clearance

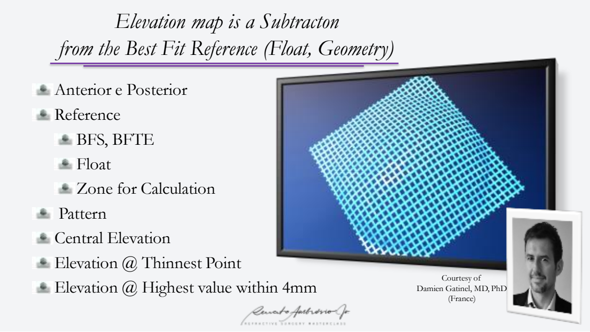
④ **Select APS (Advanced Peripheral System)**
Use bulbar slope values to select APS from the table on the right:
❯ e.g. when Bulbar slope flat = 38 and Bulbar slope steep = 42, select APS of Standard and Steep 4
When the steep and flat slopes differ by less than 3 degrees, select a spherical APS using slope mean:
❯ e.g. when slope flat = 37 and slope steep = 39, select APS of Standard

26

Pentacam CSP Report
Scheimpflug Imaging for Scleral Lens



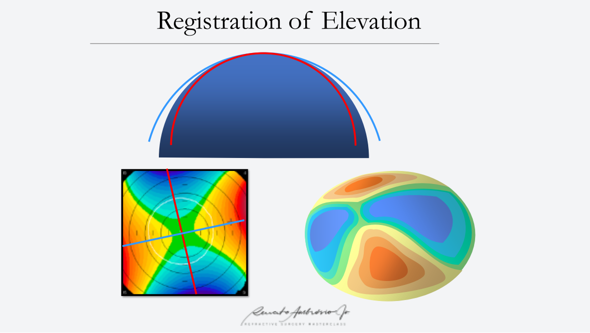
27



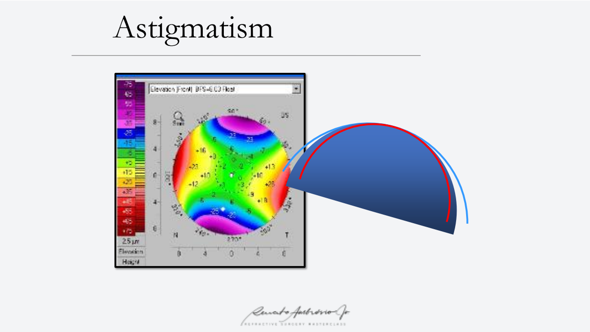
Elevation map is a Subtracton from the Best Fit Reference (Float, Geometry)

- Anterior e Posterior
- Reference
  - BFS, BFTE
  - Float
  - Zone for Calculation
- Pattern
- Central Elevation
- Elevation @ Thinnest Point
- Elevation @ Highest value within 4mm

Courtesy of
Damien Gatinel, MD, PhD
(France)

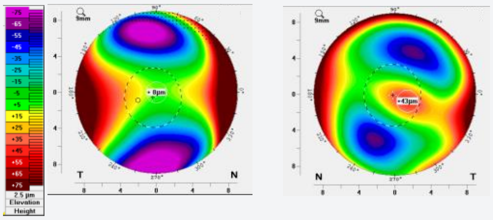


Registration of Elevation



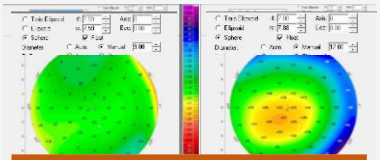
Astigmatism

Astigmatism vs. Ectasia



31

Corneal Zone Diameter
For Calculating the Reference



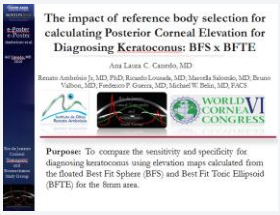
○ Toric Ellipsoid r: 7.59 Axis: 0
○ Ellipsoid rv: 7.58 Ecc: 0.00
● Sphere ☑ Float
Diameter ○ Auto ● Manual 8.00

○ Toric Ellipsoid r: 7.00 Axis: 0
○ Ellipsoid rv: 7.88 Ecc: 0.00
● Sphere ☑ Float
Diameter: ○ Auto ● Manual 12.00

Recommend BFS 8mm *Float*

32

Best-Fit-Sphere (BFS) x
Best-Fit Toric-Ellipsoid (BFTE)



The impact of reference body selection for calculating Posterior Corneal Elevation for Diagnosing Keratoconus: BFS x BFTE

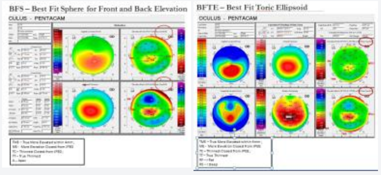
Ana Laura C. Canedo, MD

Renato Ambrósio Jr, MD, PhD; Ricardo Lousada, MD; Marcella Salomão, MD; Bruno Valbon, MD; Frederico P. Guerra, MD; Michael W. Belin, MD, FACS

Purpose: To compare the sensitivity and specificity for diagnosing keratoconus using elevation maps calculated from the floated Best Fit Sphere (BFS) and Best Fit Toric Ellipsoid (BFTE) for the 8mm area.

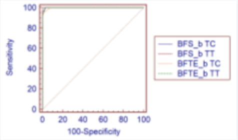
33

Best-Fit-Sphere (BFS) x *Best-Fit Toric-Ellipsoid* (BFTE)



Corneal Elevation Back : Thinnest

- 98 normal corneas from 49 patients and 56 keratoconic corneas from 28 patients
- Pentacam HR rotating Scheimpflug camera (Oculus, Wetzlar, Germany).

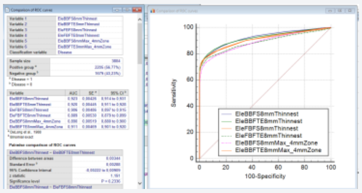


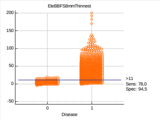
P-value

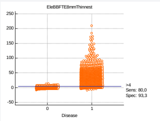
	BFS b TC	BFS b TT	BFTE b TC	BFTE b TT
BFS b TC	1	0,436	0,094	0,145
BFS b TT		1	0,087	0,131
BFTE b TC			1	0,093
BFTE b TT				1

	Sensitivity	Specificity	Criterion	AUC	Standard Error
BFS b TC	**100**	96,9	>17	0,999	0,0007
BFS b TT	100	100	>19	1	0
BFTE b TC	94,6	100	>16	0,998	0,00166
BFTE b TT	100	98	12	0,999	0,000911

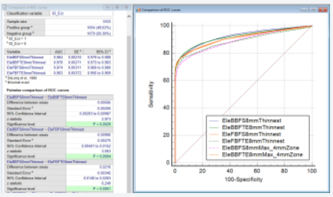
"Big Study" Data: No difference for All (N x [KC+VA-E+VAE-NT])

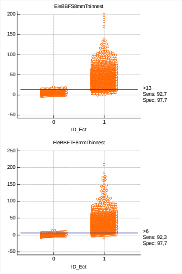




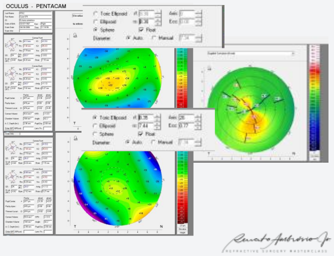


Better AUC for Clin. Ectasia (N x [KC+VA-E])



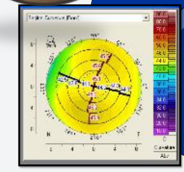


Reference Based Subtraction Maps: Best Fit Toric Elipsoid



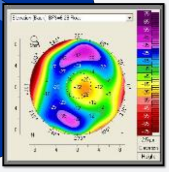
- Same Accuracy
- BFS facilitates visualization; BFTE enhance HOA
- Cut off for Keratoconus are different
- Posterior elevation at the thinnest:
- BFS : 19 μm
- BFTE: 12 μm

Anterior & Posterior Corneal Surface Measurement

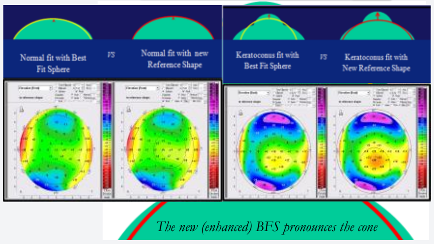


"Looking at only the Anterior Surface is Half an Exam"

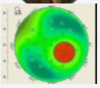
M. Belin, MD



Enhanced BFS Elevation Concept (Belin)



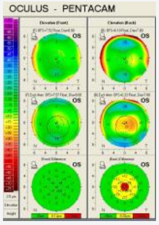

Michael W. Belin, MD



Renato Ambrósio Jr

40

Enhanced BFS (Belin)



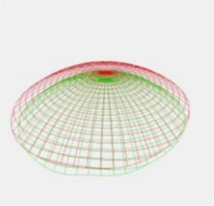
- Anterior - green is <6, yellow is between 6 - 12, red is > 12
- Posterior: green is < 8, yellow is between 8 - 20, red is > 20

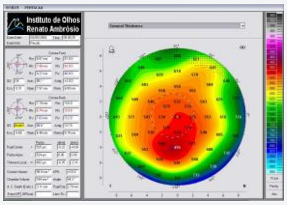
Renato Ambrósio Jr

41

CORNEAL TOMOGRAPHY

3D Architecture

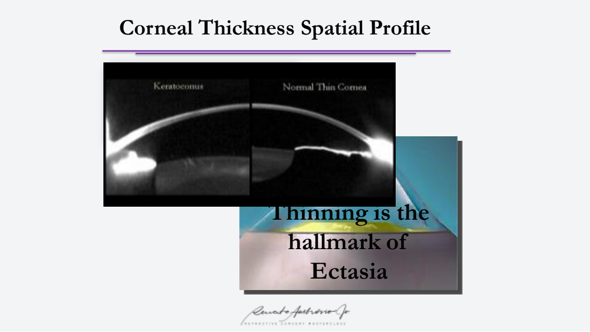




Front and Back Elevation = Pachymetry

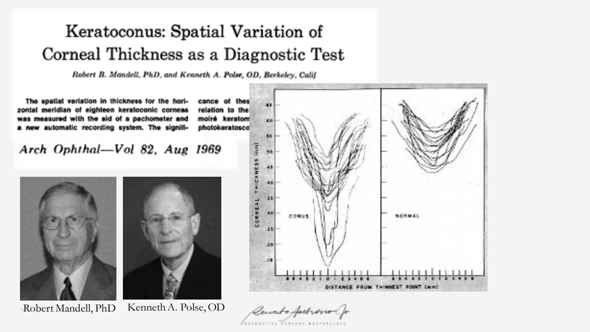
Renato Ambrósio Jr

42



Corneal Thickness Spatial Profile

Thinning is the hallmark of Ectasia



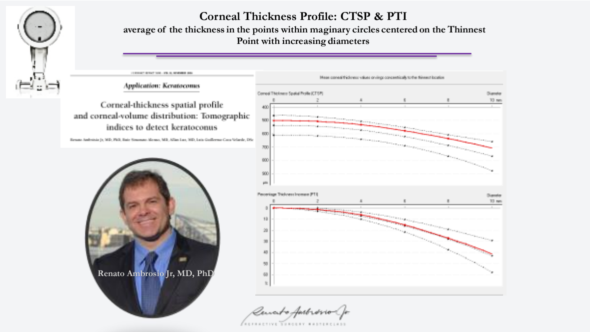
Keratoconus: Spatial Variation of Corneal Thickness as a Diagnostic Test

Robert B. Mandell, PhD, and Kenneth A. Polse, OD, Berkeley, Calif

The spatial variation in thickness for the horizontal meridian of eighteen keratoconic corneas was measured with the aid of a pachometer and a new automatic recording system. The signifi- cance of thes relation to the moiré keratom photokeratosco

Arch Ophthal—Vol 82, Aug 1969

Robert Mandell, PhD Kenneth A. Polse, OD



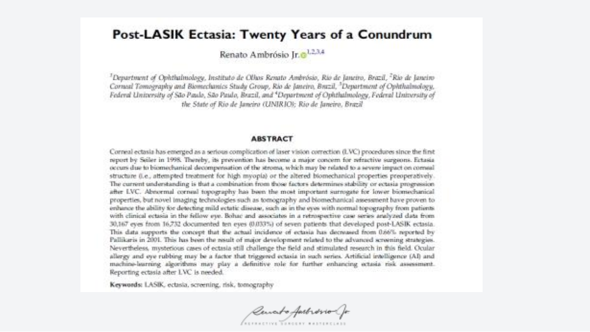
Corneal Thickness Profile: CTSP & PTI

average of the thickness in the points within maginary circles centered on the Thinnest Point with increasing diameters

Application: Keratoconus

Corneal-thickness spatial profile and corneal-volume distribution: Tomographic indices to detect keratoconus

Renato Ambrosio Jr, MD, PhD



Post-LASIK Ectasia: Twenty Years of a Conundrum

Renato Ambrósio Jr.[1,2,3,4]

[1]Department of Ophthalmology, Instituto de Olhos Renato Ambrósio, Rio de Janeiro, Brazil, [2]Rio de Janeiro Corneal Tomography and Biomechanics Study Group, Rio de Janeiro, Brazil, [3]Department of Ophthalmology, Federal University of São Paulo, São Paulo, Brazil, and [4]Department of Ophthalmology, Federal University of the State of Rio de Janeiro (UNIRIO); Rio de Janeiro, Brazil

ABSTRACT

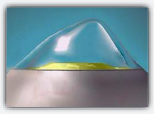
Corneal ectasia has emerged as a serious complication of laser vision correction (LVC) procedures since the first report by Seiler in 1998. Thereby, its prevention has become a major concern for refractive surgeons. Ectasia occurs due to biomechanical decompensation of the stroma, which may be related to a severe impact on corneal structure (i.e., attempted treatment for high myopia) or the altered biomechanical properties preoperatively. The current understanding is that a combination from those factors determines stability or ectasia progression after LVC. Abnormal corneal topography has been the most important surrogate for lower biomechanical properties, but novel imaging technologies such as tomography and biomechanical assessment have proven to enhance the ability for detecting mild ectatic disease, such as in the eyes with normal topography from patients with clinical ectasia in the fellow eye. Bohac and associates in a retrospective case series analyzed data from 30,167 eyes from 16,732 documented ten eyes (0.033%) of seven patients that developed post-LASIK ectasia. This data supports the concept that the actual incidence of ectasia has decreased from 0.66% reported by Pallikaris in 2001. This has been the result of major development related to the advanced screening strategies. Nevertheless, mysterious cases of ectasia still challenge the field and stimulated research in this field. Ocular allergy and eye rubbing may be a factor that triggered ectasia in such series. Artificial intelligence (AI) and machine-learning algorithms may play a definitive role for further enhancing ectasia risk assessment. Reporting ectasia after LVC is needed.

Keywords: LASIK, ectasia, screening, risk, tomography

Pathophysiology of Ectasia

Biomechanical Decompensation of the Cornea

- Corneal Resistance (innate biomechanical properties)
- Impact from the environment
  - LVC procedures
  - Eye Rubbing



Any cornea may develop ectasia!

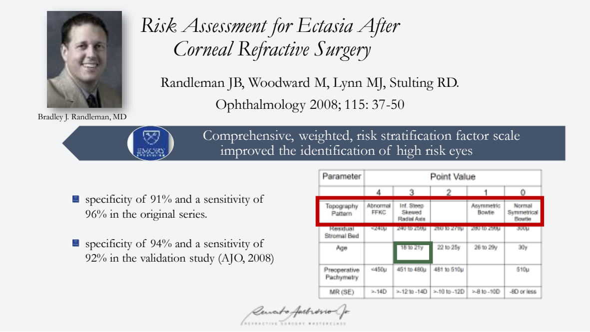
Violet June

THE KERATOCONUS

"Rubbing or scratching the eyes ***aggravates*** *Keratoconus &*
may also ***cause*** *Corneal Ectasia!*

The misinformation makes the patient suffer more than the disease."

Renato Ambrósio Jr, MD, PhD
Rio de Janeiro, Brazil



Risk Assessment for Ectasia After Corneal Refractive Surgery

Randleman JB, Woodward M, Lynn MJ, Stulting RD.
Ophthalmology 2008; 115: 37-50

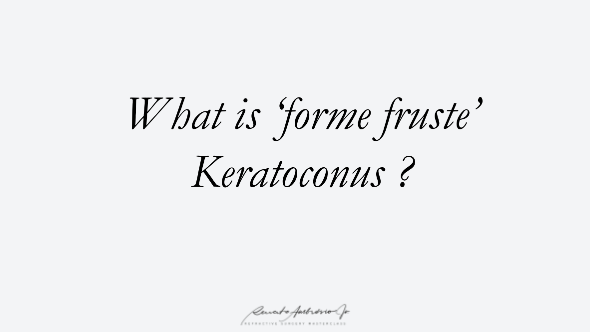
Bradley J. Randleman, MD

Comprehensive, weighted, risk stratification factor scale improved the identification of high risk eyes

- specificity of 91% and a sensitivity of 96% in the original series.
- specificity of 94% and a sensitivity of 92% in the validation study (AJO, 2008)

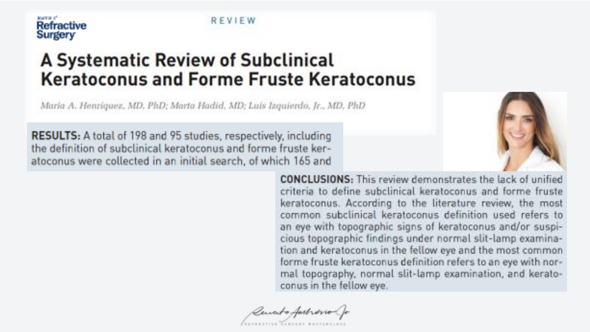
Parameter	Point Value				
	4	3	2	1	0
Topography Pattern	Abnormal FFKC	Inf. Steep Skewed Radial Axis		Asymmetric Bowtie	Normal Symmetrical Bowtie
Residual Stromal Bed	<240μ	240 to 259μ	260 to 279μ	280 to 299μ	300μ
Age		18 to 21y	22 to 25y	26 to 29y	30y
Preoperative Pachymetry	<450μ	451 to 480μ	481 to 510μ		510μ
MR (SE)	>-14D	>-12 to -14D	>-10 to -12D	>-8 to -10D	-8D or less

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS



What is 'forme fruste' Keratoconus ?

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS



Journal of Refractive Surgery

REVIEW

A Systematic Review of Subclinical Keratoconus and Forme Fruste Keratoconus

Maria A. Henriquez, MD, PhD; Marta Hadid, MD; Luis Izquierdo, Jr., MD, PhD

RESULTS: A total of 198 and 95 studies, respectively, including the definition of subclinical keratoconus and forme fruste keratoconus were collected in an initial search, of which 165 and

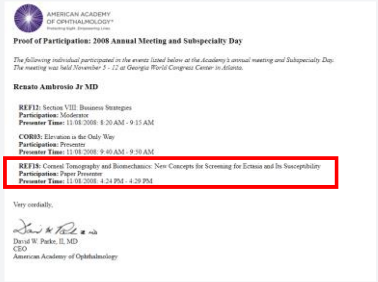
CONCLUSIONS: This review demonstrates the lack of unified criteria to define subclinical keratoconus and forme fruste keratoconus. According to the literature review, the most common subclinical keratoconus definition used refers to an eye with topographic signs of keratoconus and/or suspicious topographic findings under normal slit-lamp examination and keratoconus in the fellow eye and the most common forme fruste keratoconus definition refers to an eye with normal topography, normal slit-lamp examination, and keratoconus in the fellow eye.

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS

What is Forme Fruste Keratoconus?

- Incomplete or abortive form of keratoconus (Amsler)
- "Mild" keratoconus (Krachmer)
- Fellow eye with no clinical sings from patients with very asymmetric (?unilateral?; Klyce, 2009)
- Fact: There is no consensus!
- Forme Fruste Keratoconus is defined as with **very high susceptibility** for ectasia progression (Ambrósio, 2009)

52



AMERICAN ACADEMY OF OPHTHALMOLOGY®

Proof of Participation: 2008 Annual Meeting and Subspecialty Day

The following individual participated in the events listed below at the Academy's annual meeting and Subspecialty Day. The meeting was held November 5 - 12 at Georgia World Congress Center in Atlanta.

Renato Ambrosio Jr MD

REF12: Section VIII: Business Strategies
Participation: Moderator
Presenter Time: 11/08/2008: 8:20 AM - 9:15 AM

COR03: Elevation is the Only Way
Participation: Presenter
Presenter Time: 11/08/2008: 9:40 AM - 9:50 AM

REF18: Corneal Tomography and Biomechanics: New Concepts for Screening for Ectasia and Its Susceptibility
Participation: Paper Presenter
Presenter Time: 11/08/2008: 4:24 PM - 4:29 PM

Very cordially,

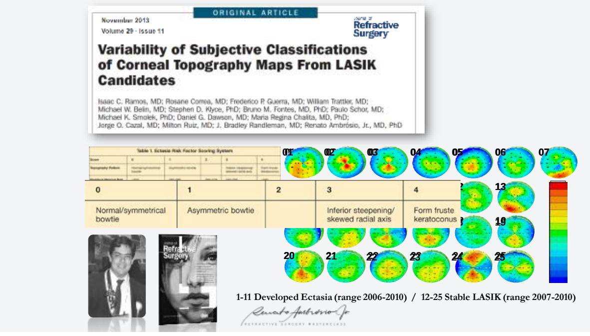
David W. Parke, II, MD
CEO
American Academy of Ophthalmology

53

Ectasia Case Presentation

- Custom SBK-LASIK in 2008
- RSB=304µm; PTA=0.36
- Good vision in early postop, but developed progressive ectasia, confirmed at 14 months after LASIK

54



ORIGINAL ARTICLE

November 2013
Volume 29 · Issue 11

Journal of Refractive Surgery

Variability of Subjective Classifications of Corneal Topography Maps From LASIK Candidates

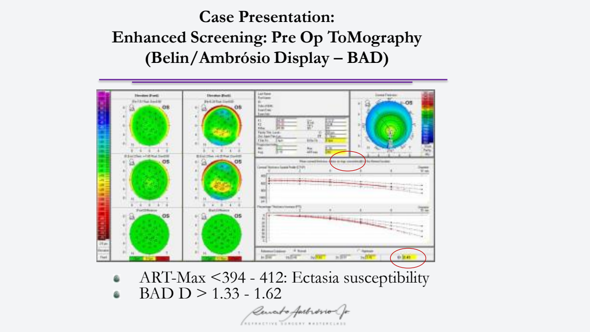
Isaac C. Ramos, MD; Rosane Correa, MD; Frederico P. Guerra, MD; William Trattler, MD; Michael W. Belin, MD; Stephen D. Klyce, PhD; Bruno M. Fontes, MD, PhD; Paulo Schor, MD; Michael K. Smolek, PhD; Daniel G. Dawson, MD; Maria Regina Chalita, MD, PhD; Jorge O. Cazal, MD; Milton Ruiz, MD; J. Bradley Randleman, MD; Renato Ambrósio, Jr., MD, PhD

Table 1. Ectasia Risk Factor Scoring System

0	1	2	3	4
Normal/symmetrical bowtie	Asymmetric bowtie		Inferior steepening/ skewed radial axis	Form fruste keratoconus

1-11 Developed Ectasia (range 2006-2010) / 12-25 Stable LASIK (range 2007-2010)

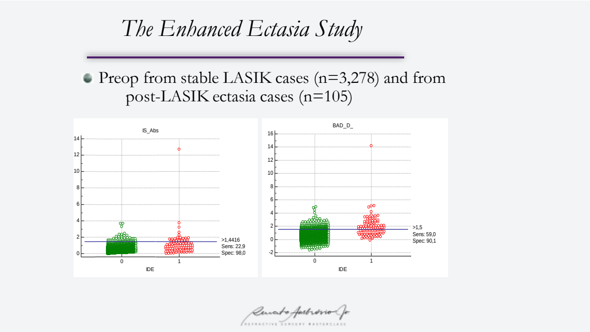
Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS



Case Presentation:
Enhanced Screening: Pre Op ToMography
(Belin/Ambrósio Display – BAD)

- ART-Max <394 - 412: Ectasia susceptibility
- BAD D > 1.33 - 1.62

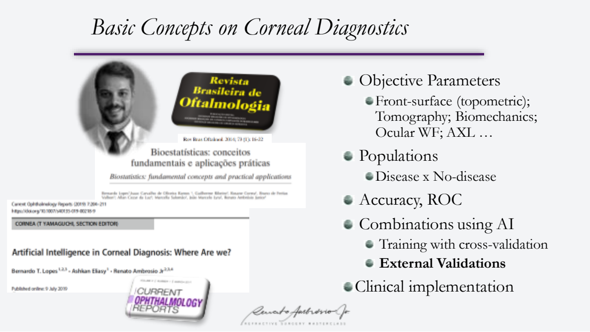
Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS



The Enhanced Ectasia Study

- Preop from stable LASIK cases (n=3,278) and from post-LASIK ectasia cases (n=105)

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS



Basic Concepts on Corneal Diagnostics

Revista Brasileira de Oftalmologia

Rev Bras Oftalmol. 2014; 73 (1): 16-22

Bioestatísticas: conceitos fundamentais e aplicações práticas

Biostatistics: fundamental concepts and practical applications

Current Ophthalmology Reports (2019) 7:204–211

https://doi.org/10.1007/s40135-019-00218-9

CORNEA (T YAMAGUCHI, SECTION EDITOR)

Artificial Intelligence in Corneal Diagnosis: Where Are we?

Bernardo T. Lopes[1,2,3] · Ashkan Eliasy[1] · Renato Ambrosio Jr[2,3,4]

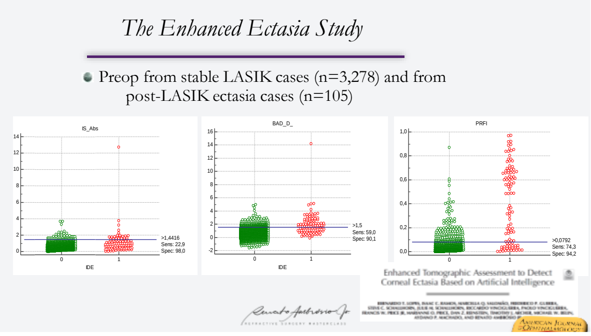
Published online: 9 July 2019

CURRENT OPHTHALMOLOGY REPORTS

- Objective Parameters
  - Front-surface (topometric); Tomography; Biomechanics; Ocular WF; AXL …
- Populations
  - Disease x No-disease
- Accuracy, ROC
- Combinations using AI
  - Training with cross-validation
  - **External Validations**
- Clinical implementation

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS

58



The Enhanced Ectasia Study

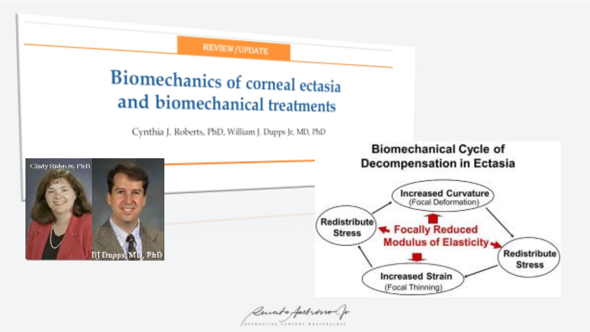
- Preop from stable LASIK cases (n=3,278) and from post-LASIK ectasia cases (n=105)

Enhanced Tomographic Assessment to Detect Corneal Ectasia Based on Artificial Intelligence

AMERICAN JOURNAL OF OPHTHALMOLOGY

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS

59



REVIEW/UPDATE

Biomechanics of corneal ectasia and biomechanical treatments

Cynthia J. Roberts, PhD, William J. Dupps Jr, MD, PhD

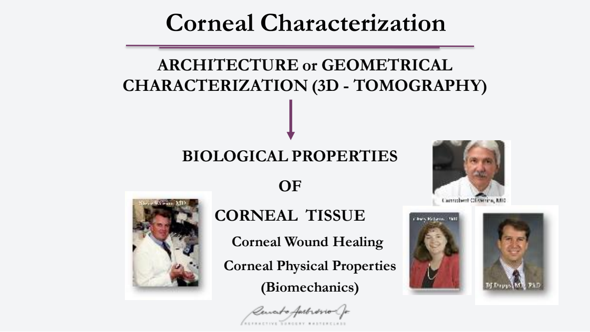
Cindy Roberts, PhD

BJ Dupps, MD, PhD

Biomechanical Cycle of Decompensation in Ectasia

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS

60



Corneal Characterization

ARCHITECTURE or GEOMETRICAL CHARACTERIZATION (3D - TOMOGRAPHY)

BIOLOGICAL PROPERTIES

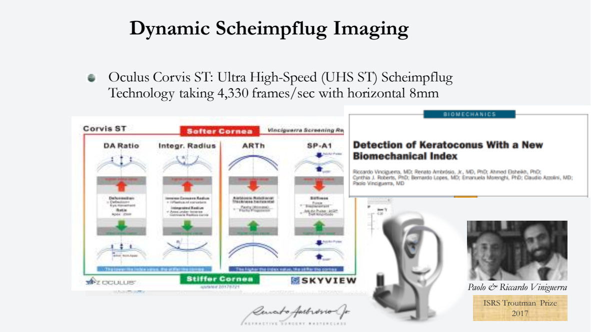
OF

CORNEAL TISSUE

Corneal Wound Healing

Corneal Physical Properties

(Biomechanics)



Dynamic Scheimpflug Imaging

- Oculus Corvis ST: Ultra High-Speed (UHS ST) Scheimpflug Technology taking 4,330 frames/sec with horizontal 8mm

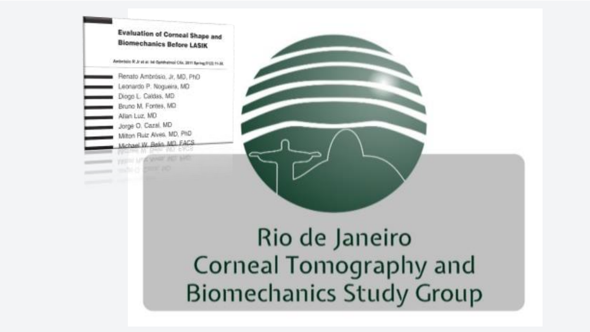
BIOMECHANICS

Detection of Keratoconus With a New Biomechanical Index

Riccardo Vinciguerra, MD; Renato Ambrósio, Jr., MD, PhD; Ahmed Elsheikh, PhD; Cynthia J. Roberts, PhD; Bernardo Lopes, MD; Emanuela Morenghi, PhD; Claudio Azzolini, MD; Paolo Vinciguerra, MD

Paolo & Riccardo Viniguerra

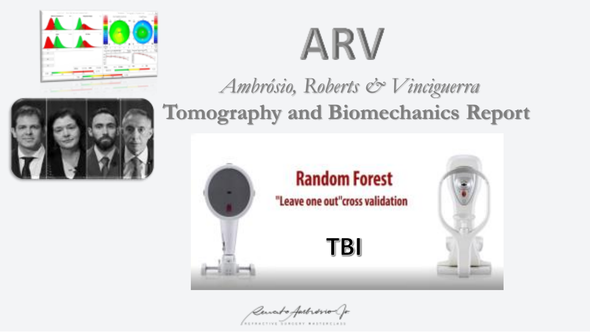
ISRS Troutman Prize 2017



Evaluation of Corneal Shape and Biomechanics Before LASIK

Renato Ambrósio, Jr, MD, PhD
Leonardo P. Nogueira, MD
Diogo L. Caldas, MD
Bruno M. Fontes, MD
Allan Luz, MD
Jorge O. Cazal, MD
Milton Ruiz Alves, MD, PhD
Michael W. Belin, MD, FACS

Rio de Janeiro
Corneal Tomography and
Biomechanics Study Group



ARV

Ambrósio, Roberts & Vinciguerra

Tomography and Biomechanics Report

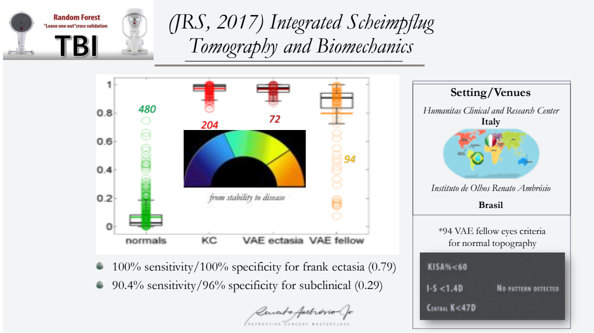
Random Forest

"Leave one out"cross validation

TBI

Renato Ambrósio Jr

REFRACTIVE SURGERY MASTERCLASS



(JRS, 2017) Integrated Scheimpflug Tomography and Biomechanics

- 100% sensitivity/100% specificity for frank ectasia (0.79)
- 90.4% sensitivity/96% specificity for subclinical (0.29)

Setting/Venues

Humanitas Clinical and Research Center

Italy

Instituto de Olhos Renato Ambrósio

Brasil

*94 VAE fellow eyes criteria for normal topography

KISA%<60

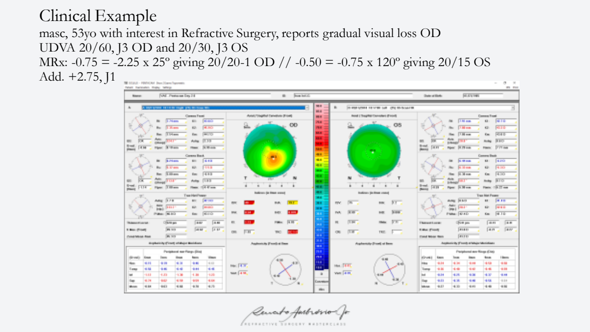
I-S <1.4D

No pattern detected

Central K<47D

Renato Ambrósio Jr

REFRACTIVE SURGERY MASTERCLASS



Clinical Example

masc, 53yo with interest in Refractive Surgery, reports gradual visual loss OD

UDVA 20/60, J3 OD and 20/30, J3 OS

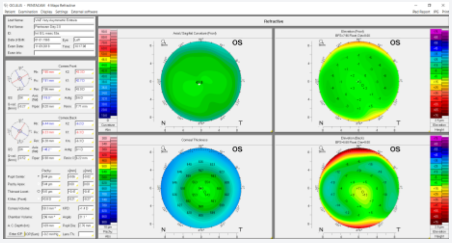
MRx: -0.75 = -2.25 x 25º giving 20/20-1 OD // -0.50 = -0.75 x 120º giving 20/15 OS

Add. +2.75, J1

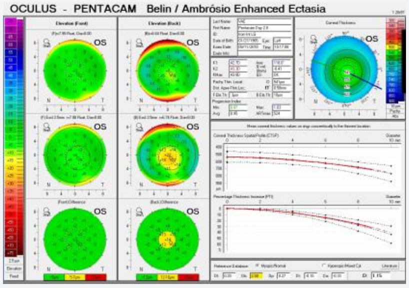
Renato Ambrósio Jr

REFRACTIVE SURGERY MASTERCLASS

Quad. Refractive Map



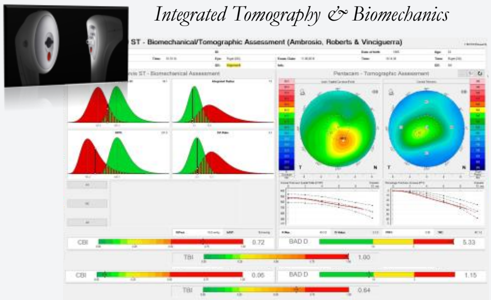
67



OCULUS - PENTACAM Belin / Ambrósio Enhanced Ectasia

68

Integrated Tomography & Biomechanics

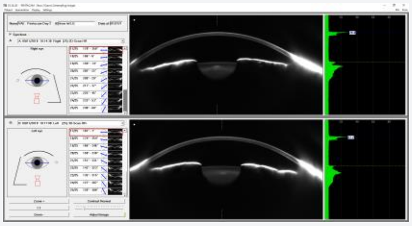


ST - Biomechanical/Tomographic Assessment (Ambrosio, Roberts & Vinciguerra)

Pentacam - Tomographic Assessment

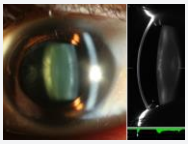
69

Lens Dysfunction Grade 2-3



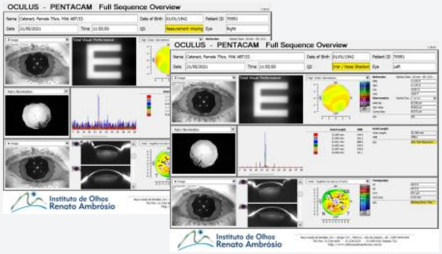
Lens Dysfunction Staging

- Stage I: early presbyopic (add up to +2.00D)
- Stage II: severe loss of accommodation (add >2.25D)
- Stage III: "mild cataract": loss of quality of vision *need for objective documentation
- Stage IV: loss of high contrast DCVA (Snellen <20/30)
- Stage V: moderate cataract with more significant loss of DCVA (Snellen <20/50)

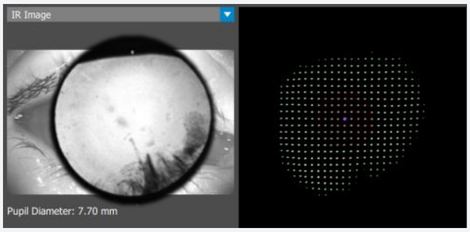


Female. 72 yo DCVA 20/30- OU

Pentacam AXL-Wave

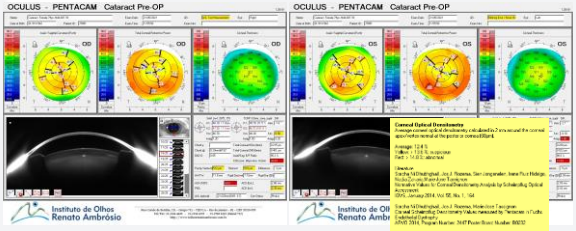


Wavefront Sensor & Retroillumination



73

Female. 72 yo DCVA 20/30- OU



Corneal Optical Densitometry
Average corneal optical densitometry calculated in 2 mm around the corneal apex/vertex normal at the posterior cornea (50µm).

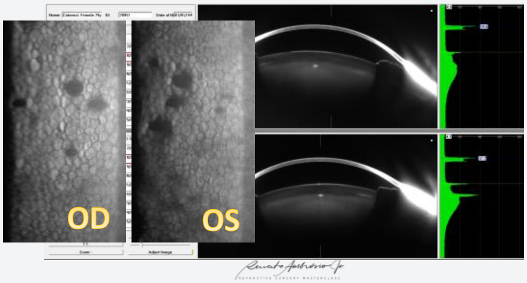
Average: 12.4 %
Yellow: > 13.6 %: suspicious
Red: > 14.8 %: abnormal

Literature
Sorcha Ní Dhubhghaill, Jos J. Rozema, Sien Jongenelen, Irene Ruiz Hidalgo, Nadia Zakaria, Marie-José Tassignon
Normative Values for Corneal Densitometry Analysis by Scheimpflug Optical Assessment
IOVS, January 2014, Vol 55, No. 1, 164

Sorcha Ní Dhubhghaill, Jos J. Rozema, Marie-José Tassignon
Corneal Scheimpflug Densitometry Values measured by Pentacam in Fuchs Endothelial Dystrophy
ARVO 2014, Program Number: 2447 Poster Board Number: B0032

74

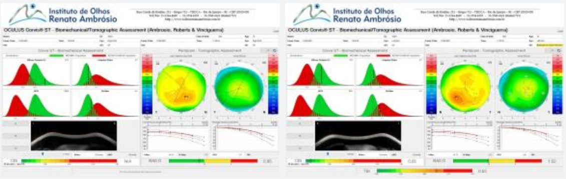
Female. 72 yo DCVA 20/30- OU



75

Female. 72 yo DCVA 20/30- OU

Integrated Tomography and Biomechanics

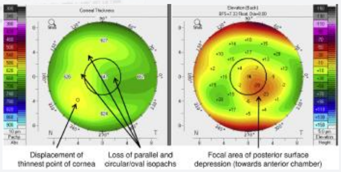


AMERICAN ACADEMY OF OPHTHALMOLOGY

Determining Subclinical Edema in Fuchs Endothelial Corneal Dystrophy: Revised Classification using Scheimpflug Tomography for Preoperative Assessment

Susan Y. Sun, MS,[1] Karim Wacker, MD,[1,2] Keith H. Baratz, MD,[1] Sanjay V. Patel, MD, FRCOphth[1]

Three signs of subclinical edema



Displacement of thinnest point of cornea

Loss of parallel and circular/oval isopachs

Focal area of posterior surface depression (towards anterior chamber)

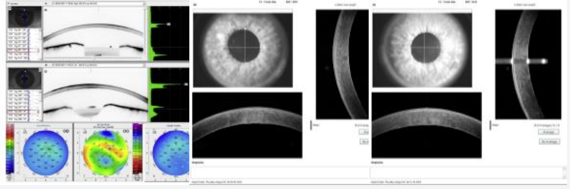
AMERICAN ACADEMY OF OPHTHALMOLOGY

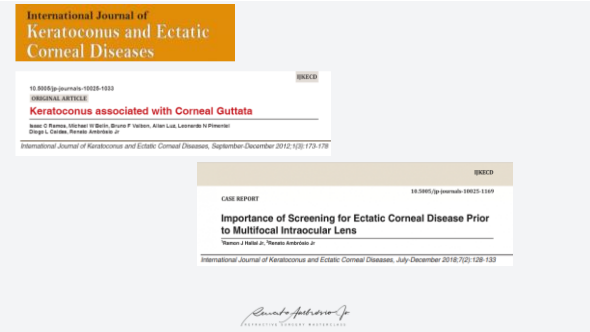
Commentary

Advanced Corneal Imaging for Fuchs Endothelial Corneal Dystrophy

Renato Ambrósio Jr., MD, PhD - *Rio de Janeiro, Brazil*
Frederico P. Guerra, MD - *Rio de Janeiro, Brazil*

Ophthalmology Volume 126, Number 2, February 2019





International Journal of
Keratoconus and Ectatic
Corneal Diseases

IJKECD

10.5005/jp-journals-10025-1033

ORIGINAL ARTICLE

Keratoconus associated with Corneal Guttata

Isaac C Ramos, Michael W Belin, Bruno F Valbon, Allan Luz, Leonardo N Pimentel
Diogo L Caldas, Renato Ambrósio Jr

International Journal of Keratoconus and Ectatic Corneal Diseases, September-December 2012;1(3):173-178

IJKECD

10.5005/jp-journals-10025-1169

CASE REPORT

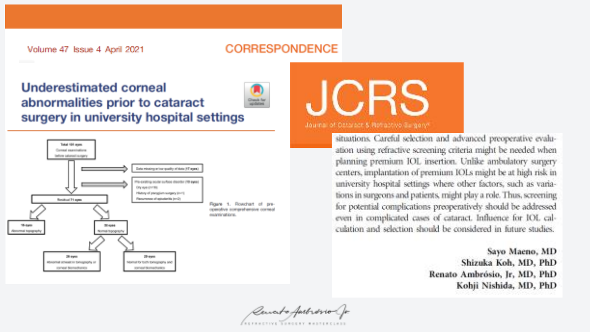
Importance of Screening for Ectatic Corneal Disease Prior to Multifocal Intraocular Lens

[1]Ramon J Hallal Jr, [2]Renato Ambrósio Jr

International Journal of Keratoconus and Ectatic Corneal Diseases, July-December 2018;7(2):128-133

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS

79



Volume 47 Issue 4 April 2021

CORRESPONDENCE

Underestimated corneal abnormalities prior to cataract surgery in university hospital settings

Figure 1. Flowchart of preoperative comprehensive corneal examinations.

JCRS
Journal of Cataract & Refractive Surgery

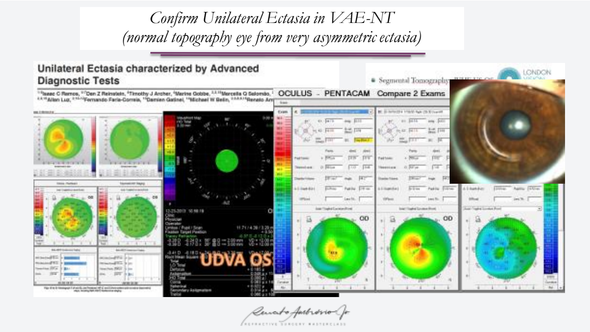
situations. Careful selection and advanced preoperative evaluation using refractive screening criteria might be needed when planning premium IOL insertion. Unlike ambulatory surgery centers, implantation of premium IOLs might be at high risk in university hospital settings where other factors, such as variations in surgeons and patients, might play a role. Thus, screening for potential complications preoperatively should be addressed even in complicated cases of cataract. Influence for IOL calculation and selection should be considered in future studies.

Sayo Maeno, MD
Shizuka Koh, MD, PhD
Renato Ambrósio, Jr, MD, PhD
Kohji Nishida, MD, PhD

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS

80

Confirm Unilateral Ectasia in VAE-NT
(normal topography eye from very asymmetric ectasia)

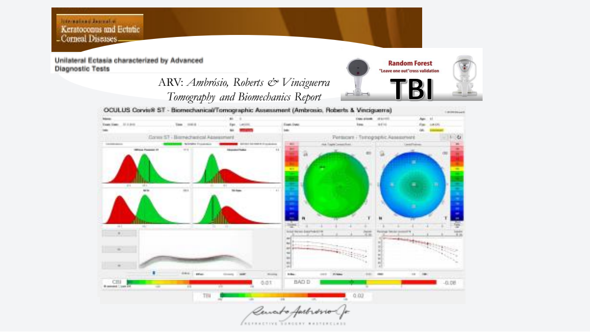


Unilateral Ectasia characterized by Advanced Diagnostic Tests

Isaac C Ramos, Dan Z Reinstein, Timothy J Archer, Marine Gobbe, Marcella Q Salomão,
Allan Luz, Fernando Faria-Correia, Damien Gatinel, Michael W Belin, Renato Am

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS

81



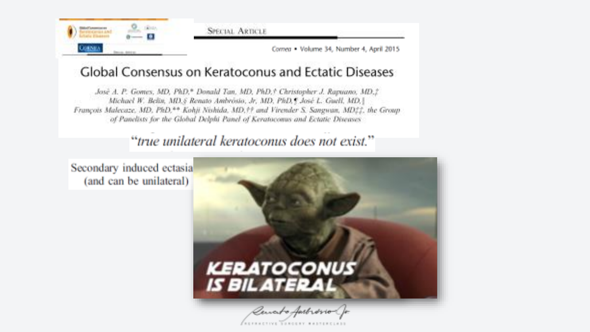
International Journal of Keratoconus and Ectatic Corneal Diseases

Unilateral Ectasia characterized by Advanced Diagnostic Tests

ARV: *Ambrósio, Roberts & Vinciguerra Tomography and Biomechanics Report*

Random Forest
"Leave one out" cross validation
TBI

OCULUS Corvis® ST - Biomechanical/Tomographic Assessment (Ambrosio, Roberts & Vinciguerra)



SPECIAL ARTICLE

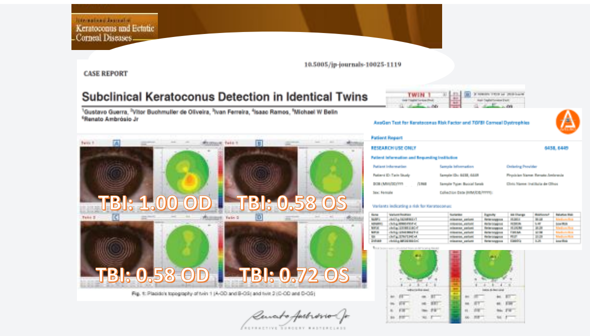
Cornea • Volume 34, Number 4, April 2015

Global Consensus on Keratoconus and Ectatic Diseases

José A. P. Gomes, MD, PhD, Donald Tan, MD, PhD,† Christopher J. Rapuano, MD,‡ Michael W. Belin, MD,§ Renato Ambrósio, Jr, MD, PhD,¶ José L. Guell, MD,‖ François Malecaze, MD, PhD,** Kohji Nishida, MD,†† and Virender S. Sangwan, MD‡‡, the Group of Panelists for the Global Delphi Panel of Keratoconus and Ectatic Diseases*

"true unilateral keratoconus does not exist."

Secondary induced ectasia
(and can be unilateral)



International Journal of Keratoconus and Ectatic Corneal Diseases

10.5005/jp-journals-10025-1119

CASE REPORT

Subclinical Keratoconus Detection in Identical Twins

[1]Gustavo Guerra, [2]Vitor Buchmuller de Oliveira, [3]Ivan Ferreira, [4]Isaac Ramos, [5]Michael W Belin
[6]Renato Ambrósio Jr

Fig. 1: Placido's topography of twin 1 (A-OD and B-OS) and twin 2 (C-OD and D-OS)

AvaGen Test for Keratoconus Risk Factor and TGFBI Corneal Dystrophies

Patient Report

RESEARCH USE ONLY 6438, 6449

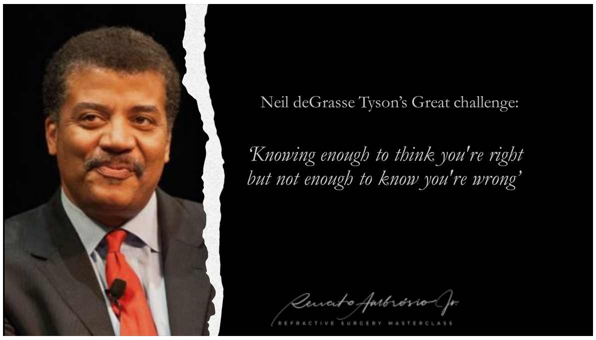
Patient Information and Requesting Institution

Patient Information
Patient ID: Twin Study
DOB (MM/DD/YY) /1968
Sex: Female

Sample Information
Sample IDs: 6438, 6449
Sample Type: Buccal Swab
Collection Date (MM/DD/YYYY):

Ordering Provider
Physician Name: Renato Ambrosio
Clinic Name: Instituto de Olhos

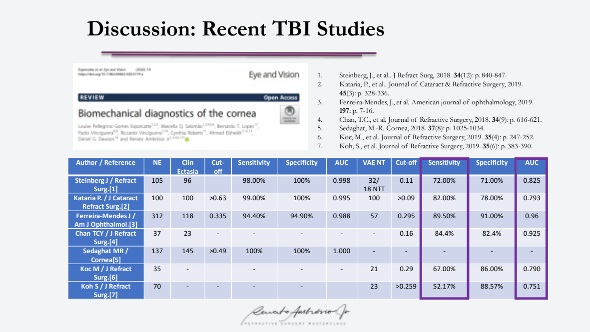
Variants indicating a risk for Keratoconus



Neil deGrasse Tyson's Great challenge:

'Knowing enough to think you're right but not enough to know you're wrong'

Renato Ambrósio Jr.
REFRACTIVE SURGERY MASTERCLASS



Discussion: Recent TBI Studies

Eye and Vision

REVIEW Open Access

Biomechanical diagnostics of the cornea

1. Steinberg, J., et al.. J Refract Surg, 2018. **34**(12): p. 840-847.
2. Kataria, P., et al.. Journal of Cataract & Refractive Surgery, 2019. **45**(3): p. 328-336.
3. Ferreira-Mendes, J., et al. American journal of ophthalmology, 2019. **197**: p. 7-16.
4. Chan, T.C., et al. Journal of Refractive Surgery, 2018. **34**(9): p. 616-621.
5. Sedaghat, M.-R. Cornea, 2018. **37**(8): p. 1025-1034.
6. Koc, M., et al. Journal of Refractive Surgery, 2019. **35**(4): p. 247-252.
7. Koh, S., et al. Journal of Refractive Surgery, 2019. **35**(6): p. 383-390.

Author / Reference	NE	Clin Ectasia	Cut-off	Sensitivity	Specificity	AUC	VAE NT	Cut-off	Sensitivity	Specificity	AUC
Steinberg J / Refract Surg.[1]	105	96		98.00%	100%	0.998	32/ 18 NTT	0.11	72.00%	71.00%	0.825
Kataria P. / J Cataract Refract Surg.[2]	100	100	>0.63	99.00%	100%	0.995	100	>0.09	82.00%	78.00%	0.793
Ferreira-Mendes J / Am J Ophthalmol.[3]	312	118	0.335	94.40%	94.90%	0.988	57	0.295	89.50%	91.00%	0.96
Chan TCY / J Refract Surg.[4]	37	23	-	-	-	-	-	0.16	84.4%	82.4%	0.925
Sedaghat MR / Cornea[5]	137	145	>0.49	100%	100%	1.000	-	-	-	-	-
Koc M / J Refract Surg.[6]	35	-		-	-	-	21	0.29	67.00%	86.00%	0.790
Koh S / J Refract Surg.[7]	70	-	-	-	-		23	>0.259	52.17%	88.57%	0.751

Renato Ambrósio Jr.
REFRACTIVE SURGERY MASTERCLASS

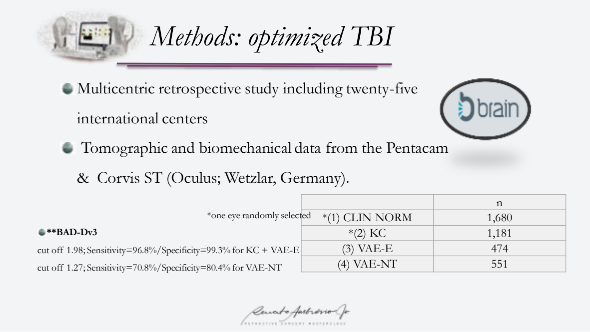
ESCRS
EURO TIMES
September 2020 | Vol 25 Issue 9

Artificial intelligence for
KERATOCONUS DIAGNOSIS

Deep learning improves detection of mild ectasia.
Howard Larkin reports

A revolution, in evolution…

Renato Ambrósio Jr.
REFRACTIVE SURGERY MASTERCLASS



Methods: optimized TBI

- Multicentric retrospective study including twenty-five international centers
- Tomographic and biomechanical data from the Pentacam & Corvis ST (Oculus; Wetzlar, Germany).

*one eye randomly selected

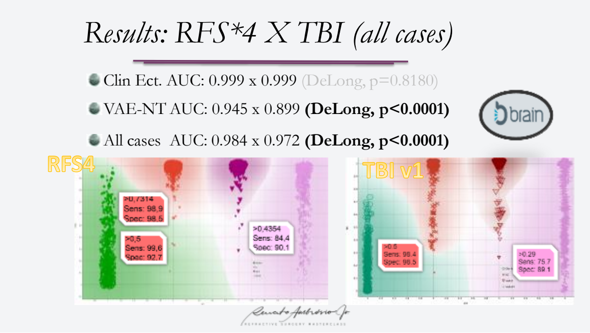
	n
*(1) CLIN NORM	1,680
*(2) KC	1,181
(3) VAE-E	474
(4) VAE-NT	551

- ****BAD-Dv3**

cut off 1.98; Sensitivity=96.8%/Specificity=99.3% for KC + VAE-E

cut off 1.27; Sensitivity=70.8%/Specificity=80.4% for VAE-NT

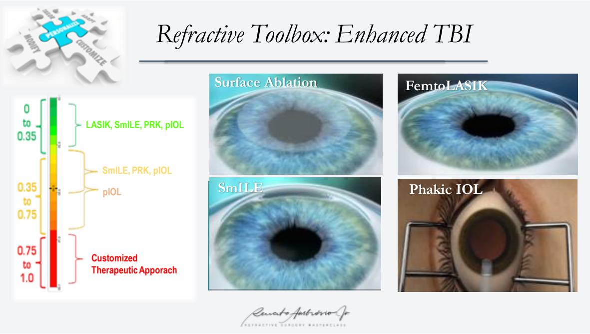
Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS



*Results: RFS*4 X TBI (all cases)*

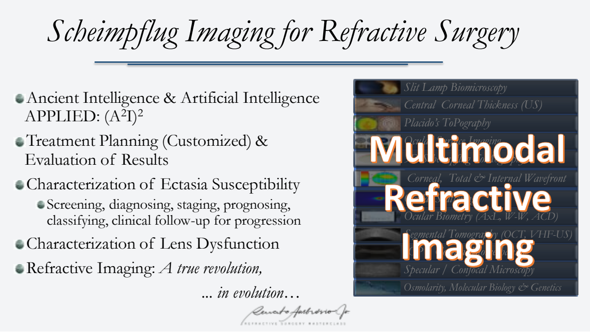
- Clin Ect. AUC: 0.999 x 0.999 (DeLong, p=0.8180)
- VAE-NT AUC: 0.945 x 0.899 **(DeLong, p<0.0001)**
- All cases AUC: 0.984 x 0.972 **(DeLong, p<0.0001)**

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS



Refractive Toolbox: Enhanced TBI

Renato Ambrósio Jr
REFRACTIVE SURGERY MASTERCLASS



Scheimpflug Imaging for Refractive Surgery

- Ancient Intelligence & Artificial Intelligence APPLIED: $(A^2I)^2$
- Treatment Planning (Customized) & Evaluation of Results
- Characterization of Ectasia Susceptibility
  - Screening, diagnosing, staging, prognosing, classifying, clinical follow-up for progression
- Characterization of Lens Dysfunction
- Refractive Imaging: *A true revolution,*

… in evolution…

Thank you, Obrigado!

dr.renatoambrosio@gmail.com

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

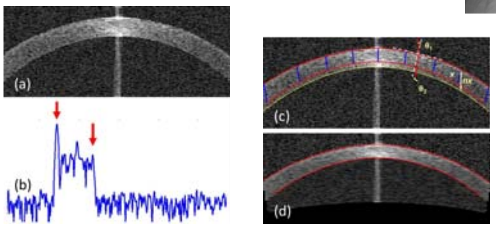
CASEY EYE Institute
OHSU

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.

Corneal OCT Applications

CORNEAL PACHYMETRY AND EPITHELIUM MAPPING

Pachymetry Mapping with OCT



Segmentation

Dewarp

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

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.

OCT Pachymetry Repeatability and Reproducibility

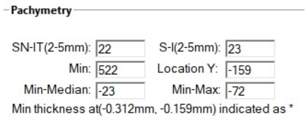
	OCT	Central D<2mm	D=2~5mm
	RTVue[1]	1.3 µm	1.8~3.8 µm
Repeatability	RTVue[2]	2.1 µm	2.9~5.5 µm
	Avanti[3]	1.3 µm	3.1~6.7 µm
	Casia[4]	2.5 µm	3.8~6.1 µm
Reproducibility	RTVue[5]	2.1 µm	3.6 µm

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.

Pachymetry Mapping with OCT

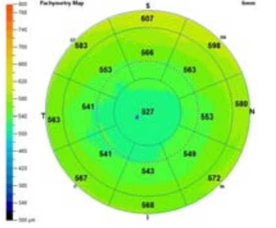
Optovue Avanti

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 *

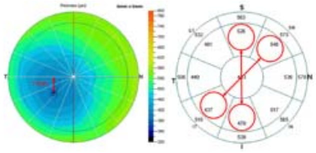


Normal cornea is:
- Mostly green on the pachymetry map
- Thinnest cornea locates inside the central D=2 mm circle

David Huang, MD, PhD www.COOLLab.net

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

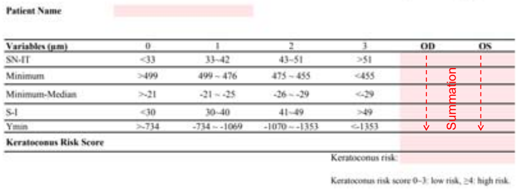


1. Li Y, et al. (Huang D) *Ophthalmology* 2008;115(12):2159-2166.
2. Qin B, et al. (Huang D) *J Cataract Refract Surg* 2013;39(12):1864-1871.

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						

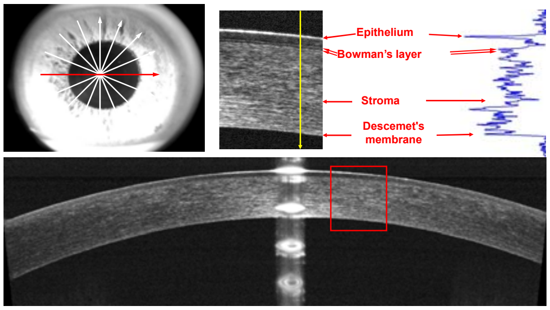
Keratoconus risk:

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.

Corneal Epithelial Imaging with FD-OCT

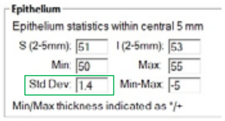


Li Y, et al. (Huang D) *Ophthalmology* 2012; 119(12):2425-33.

OCT Epithelial Thickness Map

iVue OCT 6-mm Epithelial Thickness Map

"Cornea Pachymetry" scan pattern



Epithelium

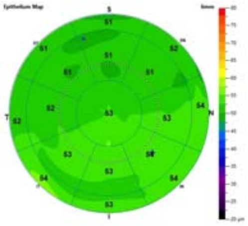
Epithelium statistics within central 5 mm

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

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

Commercially Available Anterior Eye OCT


Optovue Avanti


Zeiss Cirrus HD


Optovue Solix *


Heidelberg Anterion *


Tomey CASIA2 *


Optopol SOCT Copernicus REVO *

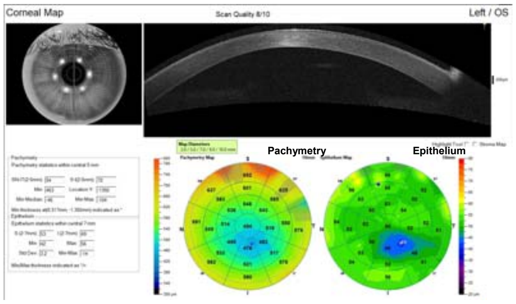

Topcon DRI OCT Triton *


Cylite Hyperparallel OCT *

David Huang, MD, PhD www.COOLLab.net

* Pending FDA clearance for anterior eye imaging

10-mm Diameter Corneal Maps



Solix OCT

Optovue, Inc

Maps:

- **Epithelium**
- **Pachymetry**
- **Stroma**

FDA clearance pending

David Huang, MD, PhD www.COOLLab.net

Yan Li, PhD

Elias Pavlatos, PhD

Corneal OCT Applications

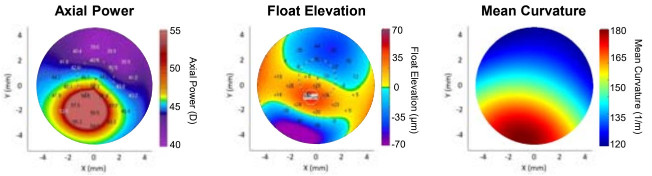
CORNEAL TOPOGRAPHY WITH OCT

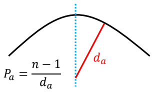
Standard Corneal Topographers

Placido disc

Scheimpflug Imaging

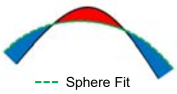
Corneal Topography Representations





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

$n = index\ of\ refraction$



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

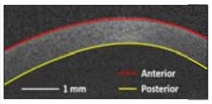
$K_1 and\ K_2 = principal\ curvatures$

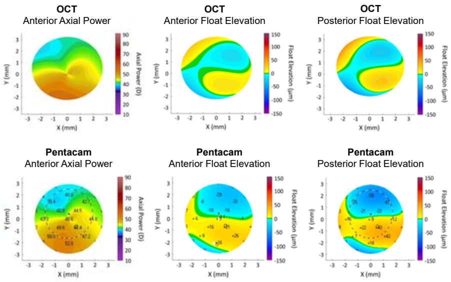
www.COOLLab.net

Our Group Developed an OCT Topography Algorithm

Avanti
Optovue, Inc.

OCT Corneal Cross-Section





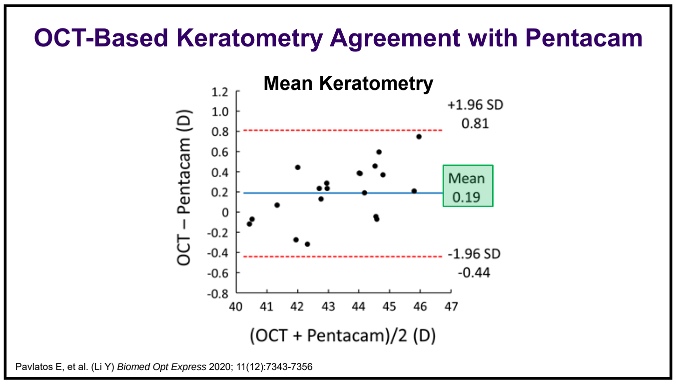
Pavlatos E, et al. (Li Y) *Biomed Opt Express* 2020; 11(12):7343-7356

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

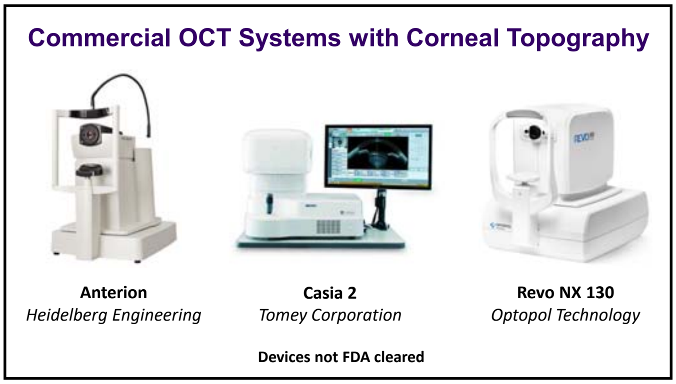
Pooled standard deviations for 20 eyes from 10 participants, 5 Repeated OCT Scans

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



OCT-Based Keratometry Agreement with Pentacam

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



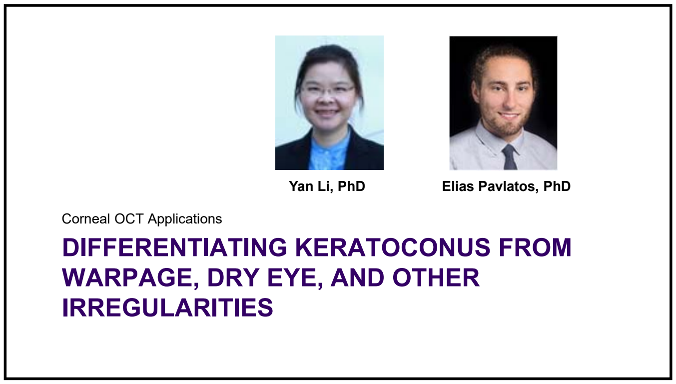
Commercial OCT Systems with Corneal Topography

Anterion
Heidelberg Engineering

Casia 2
Tomey Corporation

Revo NX 130
Optopol Technology

Devices not FDA cleared

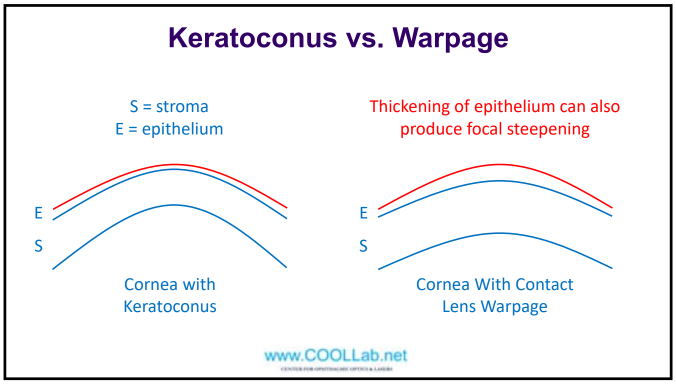


Yan Li, PhD

Elias Pavlatos, PhD

Corneal OCT Applications

DIFFERENTIATING KERATOCONUS FROM WARPAGE, DRY EYE, AND OTHER IRREGULARITIES



Keratoconus vs. Warpage

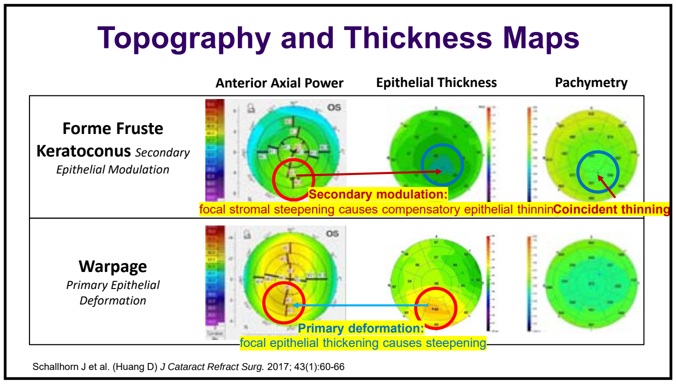
S = stroma
E = epithelium

Thickening of epithelium can also produce focal steepening

Cornea with Keratoconus

Cornea With Contact Lens Warpage

www.COOLLab.net



Topography and Thickness Maps

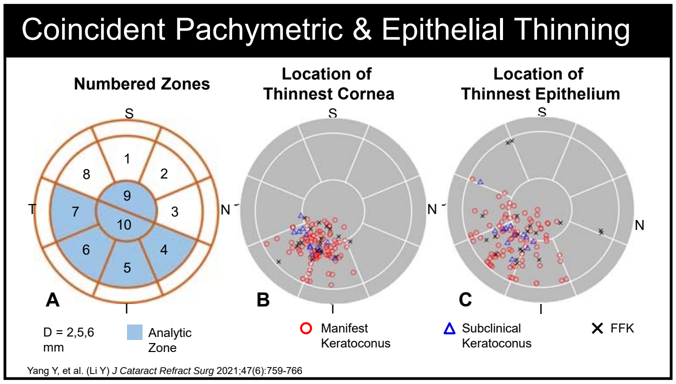
Forme Fruste Keratoconus *Secondary Epithelial Modulation*

Secondary modulation:
focal stromal steepening causes compensatory epithelial thinnin**Coincident thinning**

Warpage
Primary Epithelial Deformation

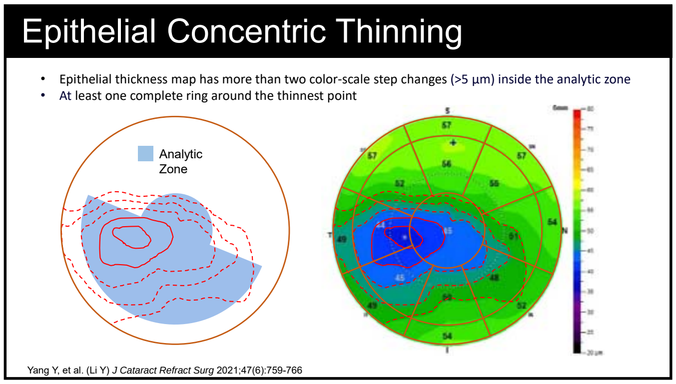
Primary deformation:
focal epithelial thickening causes steepening

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



Coincident Pachymetric & Epithelial Thinning

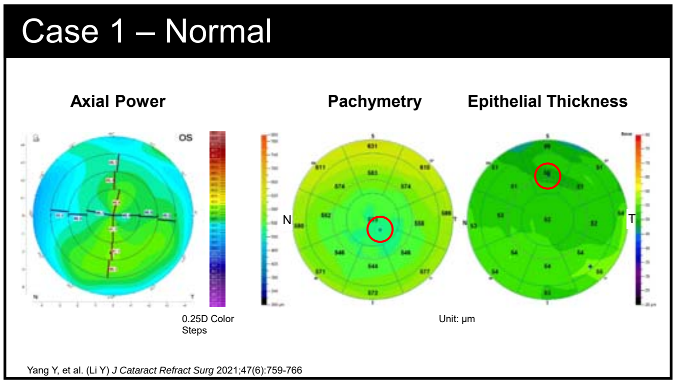
Yang Y, et al. (Li Y) *J Cataract Refract Surg* 2021;47(6):759-766



Epithelial Concentric Thinning

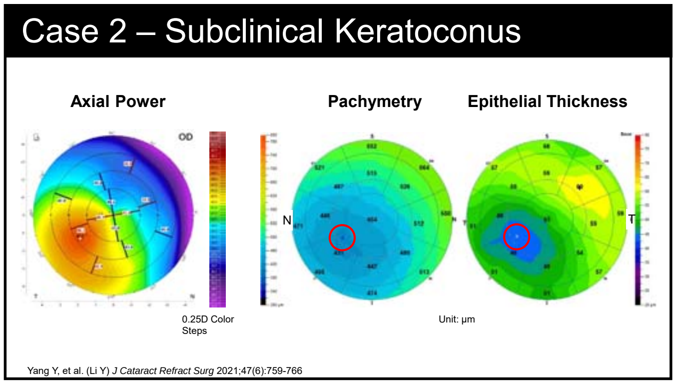
- Epithelial thickness map has more than two color-scale step changes (>5 µm) inside the analytic zone
- At least one complete ring around the thinnest point

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



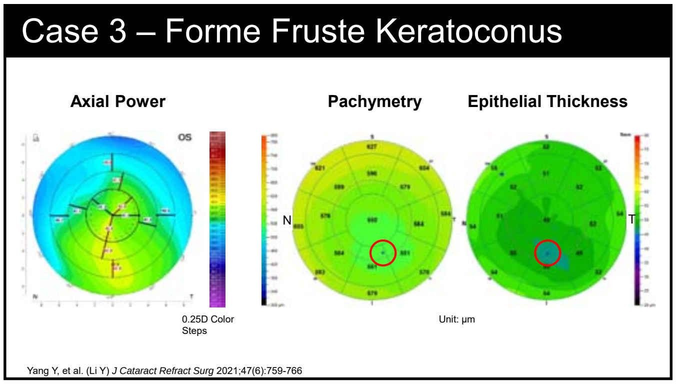
Case 1 – Normal

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



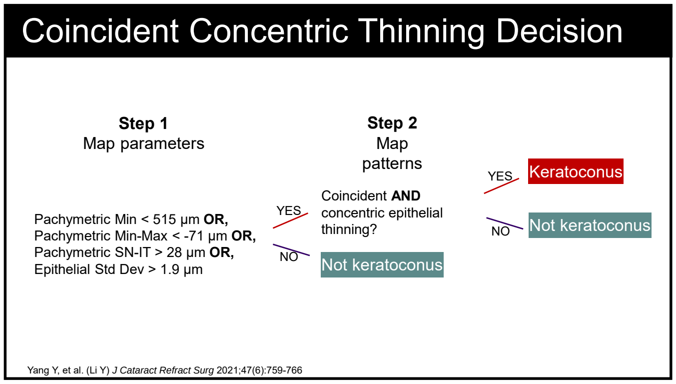
Case 2 – Subclinical Keratoconus

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



Case 3 – Forme Fruste Keratoconus

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



Coincident Concentric Thinning Decision

Step 1
Map parameters

Step 2
Map patterns

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

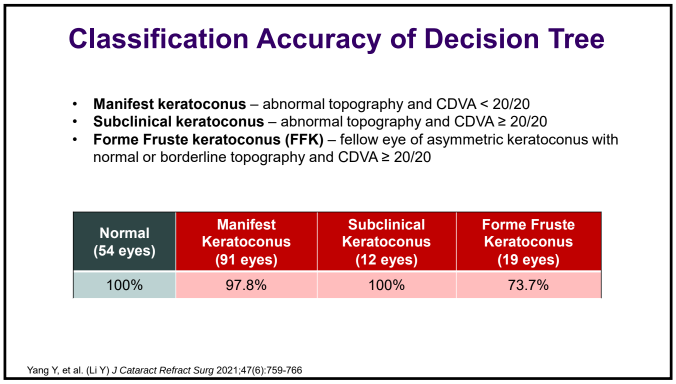
Not keratoconus

Coincident **AND** concentric epithelial thinning?

Keratoconus

Not keratoconus

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



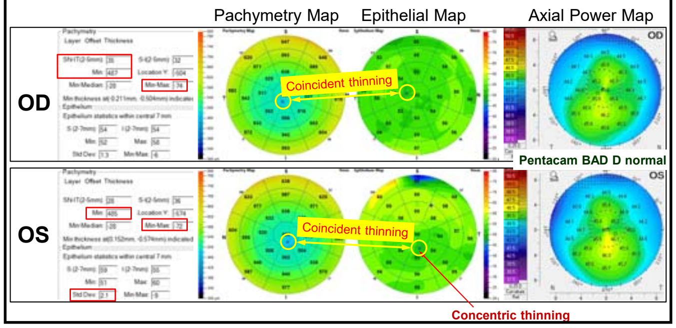
Classification Accuracy of Decision Tree

- **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

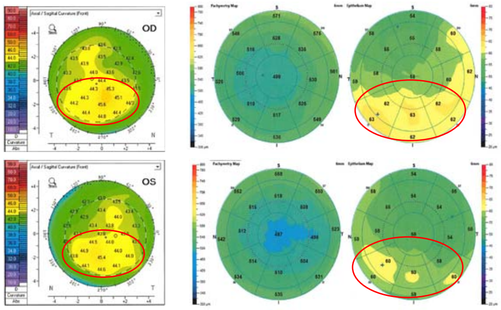
Normal (54 eyes)	Manifest Keratoconus (91 eyes)	Subclinical Keratoconus (12 eyes)	Forme Fruste Keratoconus (19 eyes)
100%	97.8%	100%	73.7%

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

Refractive Surgery Candidate, Family Hx Keratoconus



Refractive Surgery Candidate w/o CL Wear



Yan Li, PhD

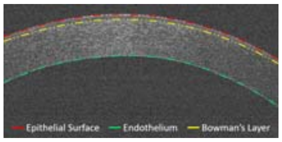
Elias Pavlatos, PhD

Corneal OCT Applications

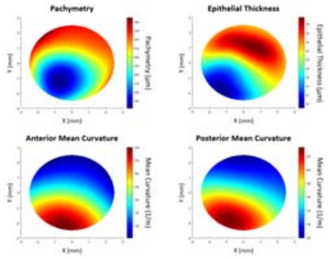
QUANTITATIVE INDICES TO SEPARATE PRIMARY AND SECONDARY EPITHELIAL CHANGES

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

Epithelial Pattern Standard Deviation

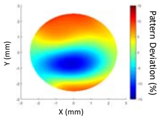
Epi PSD

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

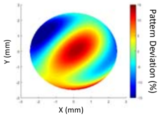
Normal < 4.1%

Epithelial Thickness Pattern Deviation

Forme Fruste Keratoconus
Epi PSD = 5.9%



Warpage
Epi PSD = 7.2%

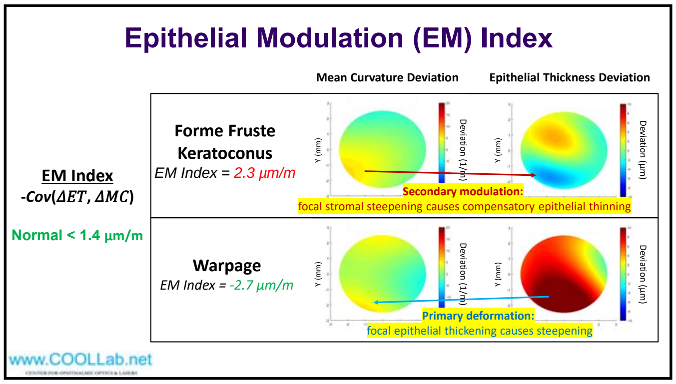


Li Y et al. (Huang D) *J Cataract Refract Surg* 2016; 42:284

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.



Epithelial Modulation (EM) Index

EM Index

-Cov(ΔET, ΔMC)

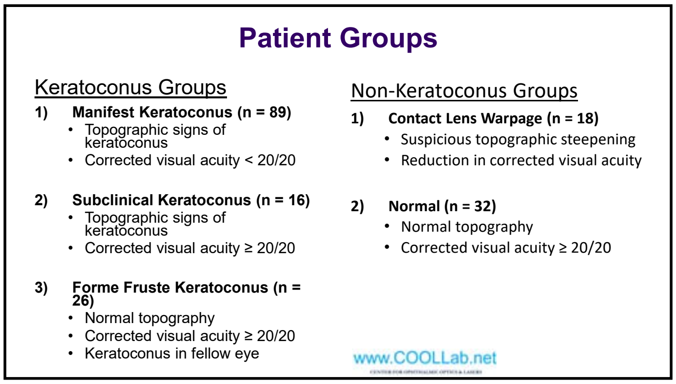
Normal < 1.4 μm/m

	Mean Curvature Deviation	Epithelial Thickness Deviation
Forme Fruste Keratoconus *EM Index = 2.3 μm/m*		
Warpage *EM Index = -2.7 μm/m*		

Secondary modulation: focal stromal steepening causes compensatory epithelial thinning

Primary deformation: focal epithelial thickening causes steepening

www.COOLLab.net



Patient Groups

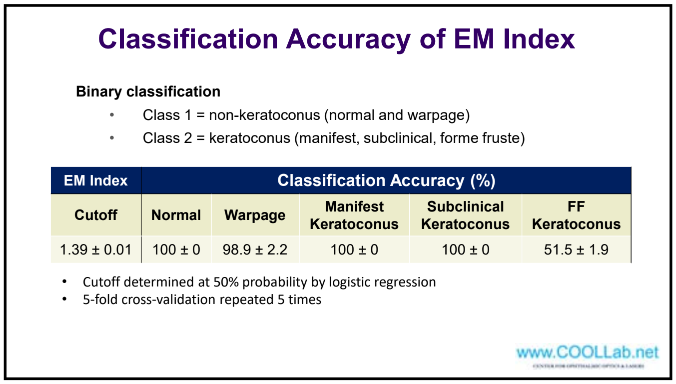
Keratoconus Groups

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



Classification Accuracy of EM Index

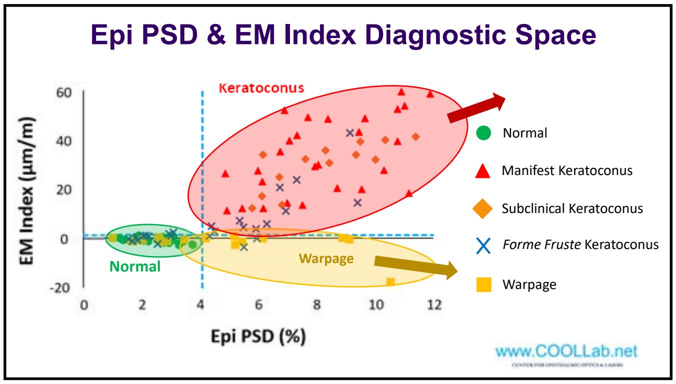
Binary classification

- 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

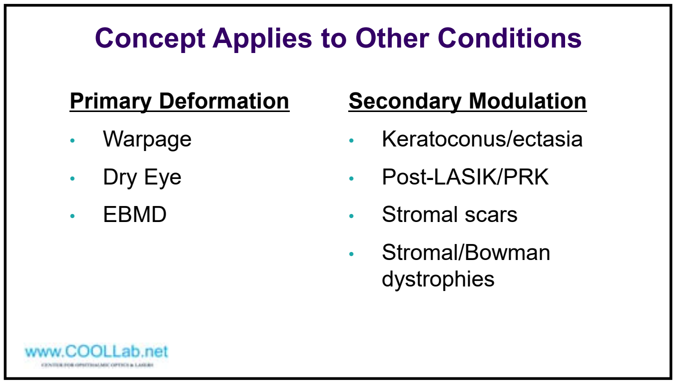
- Cutoff determined at 50% probability by logistic regression
- 5-fold cross-validation repeated 5 times

www.COOLLab.net



Epi PSD & EM Index Diagnostic Space

www.COOLLab.net



Concept Applies to Other Conditions

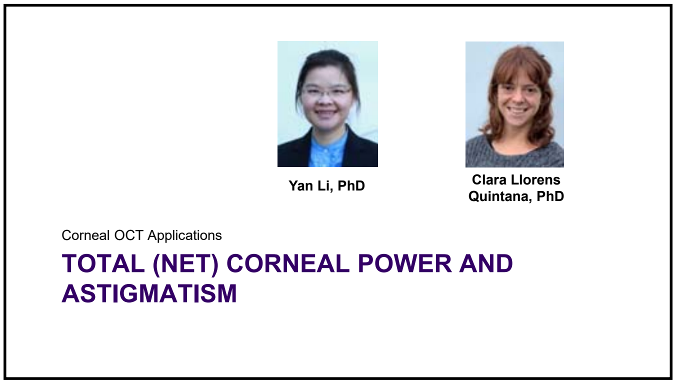
Primary Deformation

- Warpage
- Dry Eye
- EBMD

Secondary Modulation

- Keratoconus/ectasia
- Post-LASIK/PRK
- Stromal scars
- Stromal/Bowman dystrophies

www.COOLLab.net

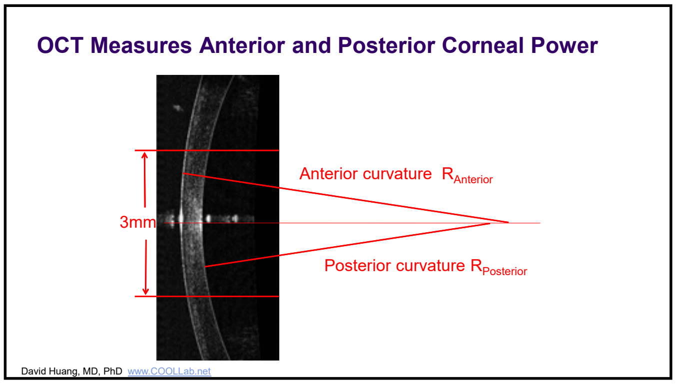


Yan Li, PhD

Clara Llorens Quintana, PhD

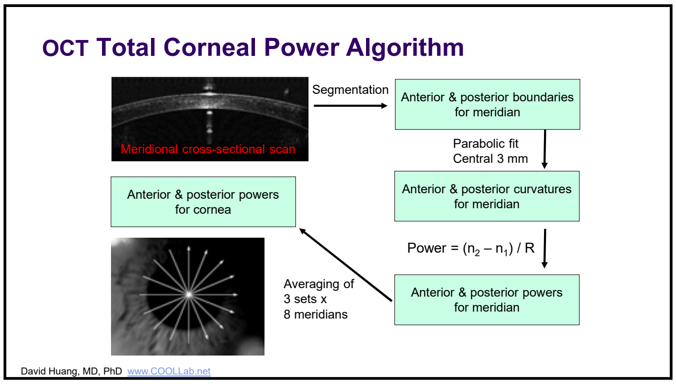
Corneal OCT Applications

TOTAL (NET) CORNEAL POWER AND ASTIGMATISM



OCT Measures Anterior and Posterior Corneal Power

David Huang, MD, PhD www.COOLLab.net



OCT Total Corneal Power Algorithm

Meridional cross-sectional scan

Segmentation → Anterior & posterior boundaries for meridian

Parabolic fit Central 3 mm → Anterior & posterior curvatures for meridian

Power = $(n_2 – n_1) / R$ → Anterior & posterior powers for meridian

Averaging of 3 sets x 8 meridians → Anterior & posterior powers for cornea

David Huang, MD, PhD www.COOLLab.net

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

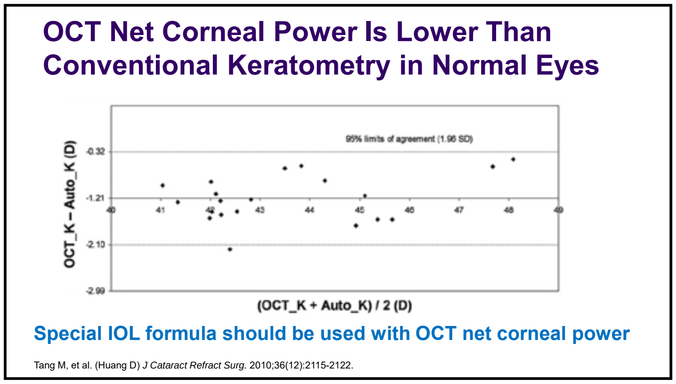
1. Tang M, et al. (Huang D) *J Cataract Refract Surg.* 2010;36(12):2115-2122.
2. Wang Q, et al. (Huang J) *Cornea.* 2015;34(10):1266-1271.

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

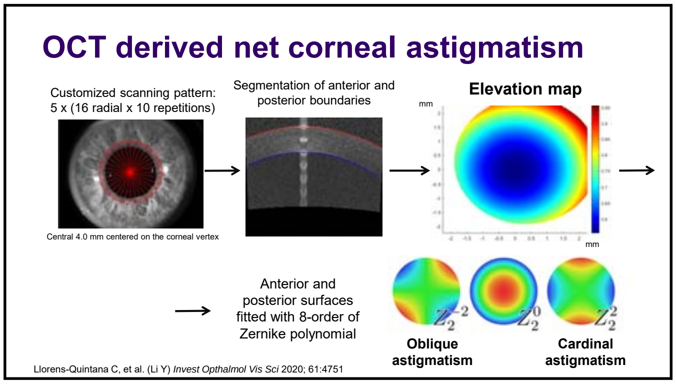
David Huang, MD, PhD www.COOLLab.net



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.



OCT derived net corneal astigmatism

Customized scanning pattern: 5 x (16 radial x 10 repetitions)

Central 4.0 mm centered on the corneal vertex

Segmentation of anterior and posterior boundaries

Anterior and posterior surfaces fitted with 8-order of Zernike polynomial

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

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

Net Corneal Astigmatism Repeatability

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

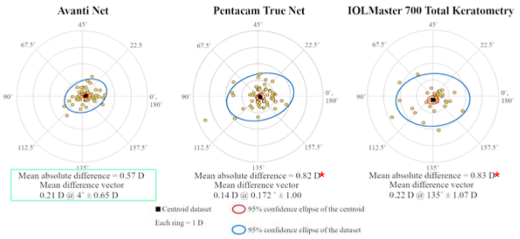
	Avanti*	Pentacam	Significance**
Cardinal (D)	0.22	0.50**	*p* < 0.05
Oblique (D)	0.19	0.44**	*p* < 0.05
Vector (D)	0.29	0.67**	*p* < 0.05

* 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

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

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

Grants & Material Supports

NIH Grant R01 EY029023, R01 EY028755, P30 EY010572

Unrestricted grant from Research to Prevent Blindness

Material support from Optovue, Inc.

CASEY EYE Institute
OHSU

www.COOLLab.net

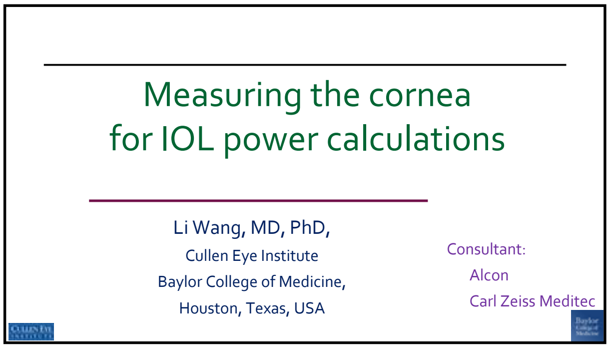
CENTER FOR OPHTHALMIC OPTICS & LASERS

Jessica Mahlum, Lab Manager
Loki Mahlum, Events Mascot

David Huang, MD, PhD
Yali Jia, PhD
Yan Li, PhD
Ou Tan, PhD
Yifan Jian, PhD
Karine Bojikian, MD
Liang Liu, MD
Elias Pavlatos, PhD
Tristan Hormel, PhD
Kevin Lathrop

Shaohua Pi, PhD
Clara Llorens Quintana, PhD
Kotaro Tsuboi, MD
Qisheng You, MD, PhD
Bingjie Wang, PhD
Ping Wei, MD
Keke Liu, BS
Yukun Guo, MS
Denny Romfh, OD
Shanjida Khan, BS

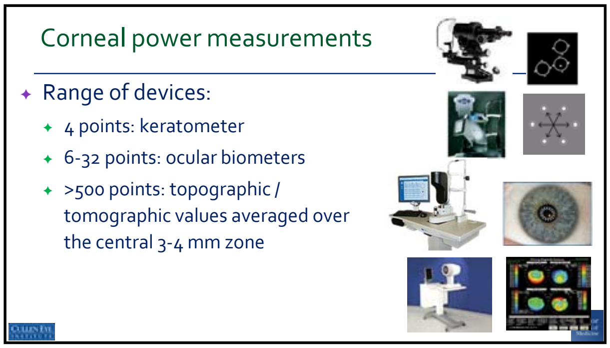
Humberto Martinez, COT
George Pacheco, COA, BS
Chinmay Deshpande M. Optom
Jie Wang, MS
Xiang Wei, MS
PengXiao Zang, MS
Omkar Thaware, MS
Min Gao, MS
Shuibin Ni, MS
Priscilla Vu, MD, MS



Measuring the cornea for IOL power calculations

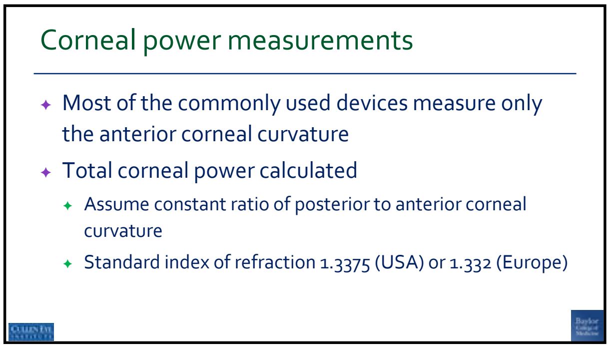
Li Wang, MD, PhD,
Cullen Eye Institute
Baylor College of Medicine,
Houston, Texas, USA

Consultant:
Alcon
Carl Zeiss Meditec



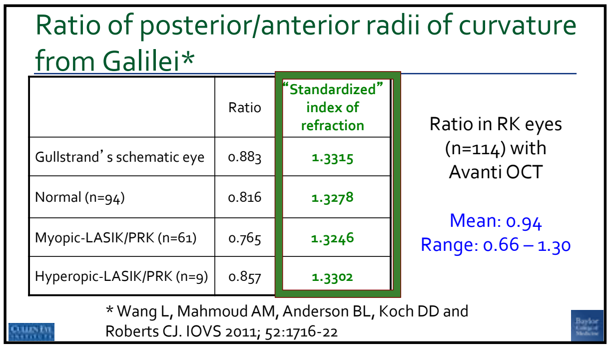
Corneal power measurements

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



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)



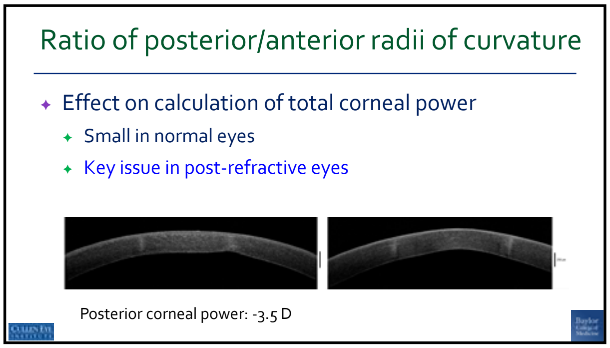
Ratio of posterior/anterior radii of curvature from Galilei*

	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

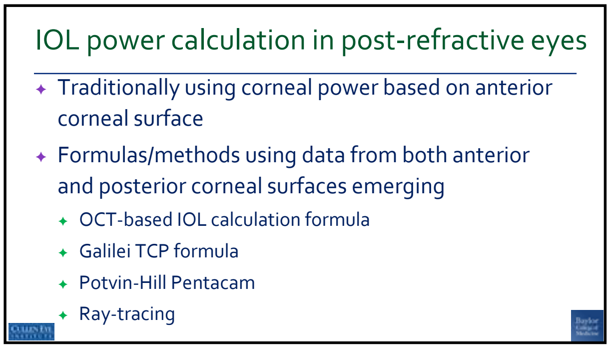
* Wang L, Mahmoud AM, Anderson BL, Koch DD and Roberts CJ. IOVS 2011; 52:1716-22



Ratio of posterior/anterior radii of curvature

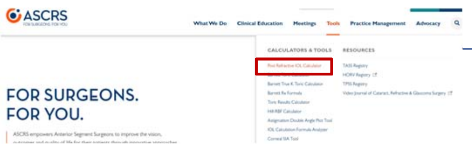
- Effect on calculation of total corneal power
  - Small in normal eyes
  - Key issue in post-refractive eyes

Posterior corneal power: -3.5 D



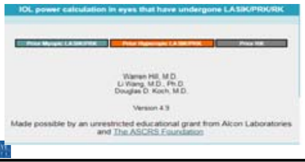
IOL power calculation in post-refractive eyes

- 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



FOR SURGEONS.
FOR YOU.

ascrs.org



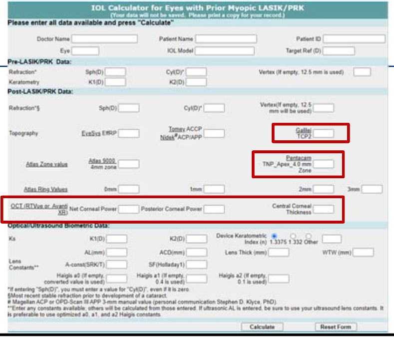
IOL power calculation in eyes that have undergone LASIK/PRK/RK

Warren Hill, M.D.
Li Wang, M.D., Ph.D.
Douglas D. Koch, M.D.

Version 4.9

Made possible by an unrestricted educational grant from Alcon Laboratories and The ASCRS Foundation

Annual visits > 1 million



IOL Calculator for Eyes with Prior Myopic LASIK/PRK
(Your data will not be saved. Please print a copy for your record.)

Please enter all data available and press "Calculate"

Doctor Name ☐ Patient Name ☐ Patient ID ☐
Eye ☐ IOL Model ☐ Target Ref (D) ☐

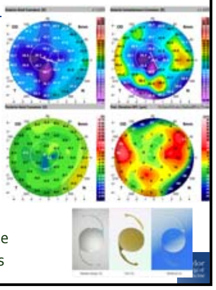
Pre-LASIK/PRK Data:
Refraction* Sph(D) ☐ Cyl(D)* ☐ Vertex (If empty, 12.5 mm is used) ☐
Keratometry K1(D) ☐ K2(D) ☐

Post-LASIK/PRK Data:
Refraction*§ Sph(D) ☐ Cyl(D)* ☐ Vertex(If empty, 12.5 mm will be used) ☐
Topography EyeSys EffRP ☐ Tomey ACCP Nidek#ACP/APP ☐ Galilei TCP2 ☐
Atlas Zone value Atlas 9000 4mm zone ☐ Pentacam TNP_Apex_4.0 mm Zone ☐
Atlas Ring Values 0mm ☐ 1mm ☐ 2mm ☐ 3mm ☐
OCT (RTVue or Avanti XR) Net Corneal Power ☐ Posterior Corneal Power ☐ Central Corneal Thickness ☐

Optical/Ultrasound Biometric Data:
Ks K1(D) ☐ K2(D) ☐ Device Keratometric Index (n) ● 1.3375 ○ 1.332 ○ Other ☐
AL(mm) ☐ ACD(mm) ☐ Lens Thick (mm) ☐ WTW (mm) ☐
Lens Constants** A-const(SRK/T) ☐ SF(Holladay1) ☐
Haigis a0 (If empty, converted value is used) ☐ Haigis a1 (If empty, 0.4 is used) ☐ Haigis a2 (If empty, 0.1 is used) ☐

*If entering "Sph(D)", you must enter a value for "Cyl(D)", even if it is zero.
§Most recent stable refraction prior to development of a cataract.
Magellan ACP or OPD-Scan III APP 3-mm manual value (personal communication Stephen D. Klyce, PhD).
**Enter any constants available; others will be calculated from those entered. If ultrasonic AL is entered, be sure to use your ultrasound lens constants. It is preferable to use optimized a0, a1, and a2 Haigis constants.

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

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

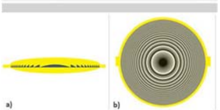
Current best practices

- 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

"Holy Grail": postop adjustable IOL?

- RxSight: light adjustable lens
  - Curvature change

- Perfect Lens and Clerio
  - Localized refractive index change



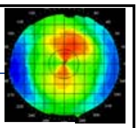
Posterior corneal astigmatism

Magnitude of posterior corneal astigmatism

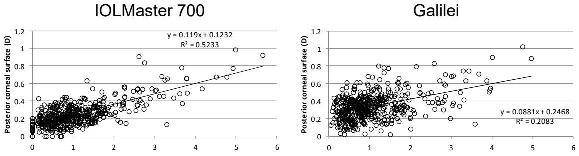
- Our paper: 0.30 ± 0.15 (0 – 1.10) (n = 715)
- Tonn…Kohnen: 0.33 ± 0.18 (0 – 1.35) (n = 3818)

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

Relationship of anterior & posterior corneal astigmatism: WTR anteriorly



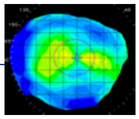
n=496



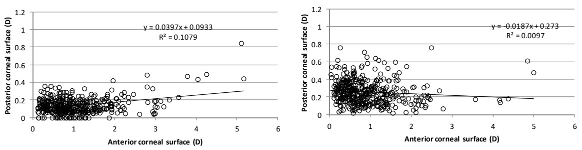
IOLMaster 700 Galilei

Up to 1.0 D!

Relationship of anterior & posterior corneal astigmatism: ATR anteriorly



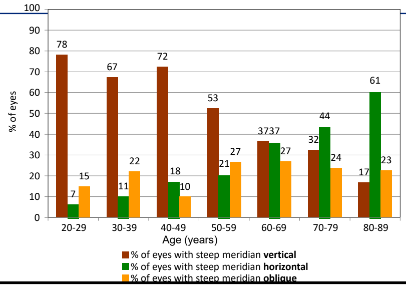
n=417



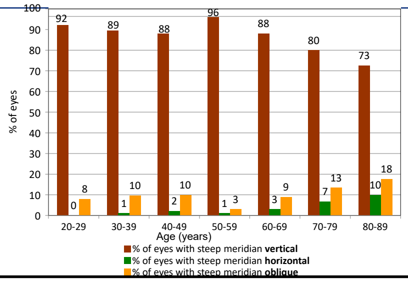
IOLMaster 700 Galilei

Up to 0.6 D!

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



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



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)

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

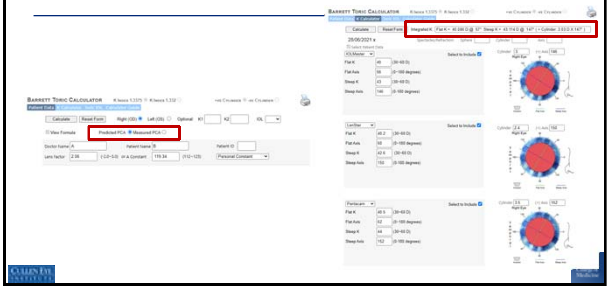
Effective IOL cylinder power at corneal plane (D)	WTR (D)	ATR (D)
0	≤ 1.69 (>1.0: PCRI)	≤ 0.39
1.00	1.70 – 2.19	0.40* – 0.79
1.50	2.20 – 2.69	0.80 – 1.29
2.00	2.70 – 3.19	1.30 – 1.79
2.50	3.20 – 3.79	1.80 – 2.29
3.00	3.80 – 4.39	2.30 – 2.79
3.50	4.40 – 4.99	2.80 – 3.29
4.00	5.00 –	3.30 – 3.79

0.7 D ↑

0.7 D ↓

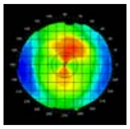
*Especially if specs have more ATR

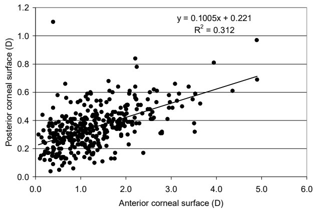
Barrett toric calculator (apacrs.org)



Problem with regression approaches for selecting toric IOLs: Scatter

- Wide individual variation
  - Even "normal" corneas



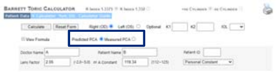


Does measuring the posterior cornea improve toric outcomes?

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

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

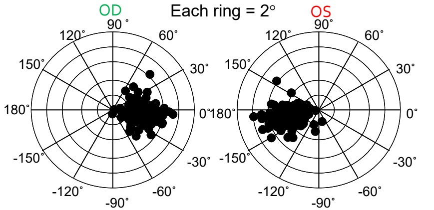


Results: % residual astigmatism prediction error (PE) (n=602)

	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

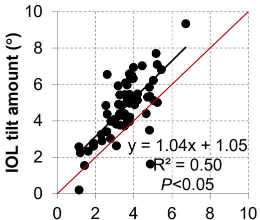
What about crystalline lens and IOL tilt?



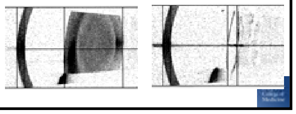
Tilt direction: along vertical meridian with nasal anteriorly

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

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



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



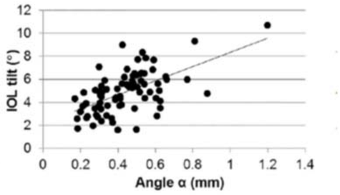
IOL tilt

- 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*

Can we predict eyes with large IOL tilt?

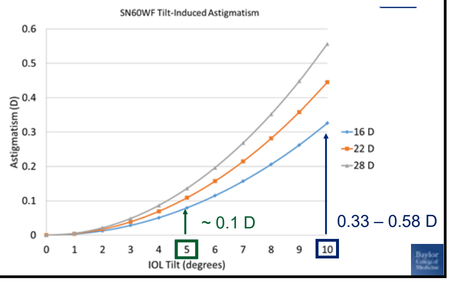
- Angle alpha
  - ↑ angle alpha, ↑ IOL tilt

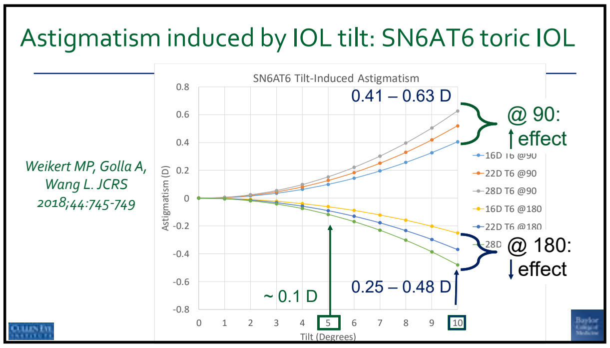


Wang L, Guimaraes de Souza R, Weikert MP, Koch DD. JCRS 2019;45:35-40

Astigmatism induced by IOL tilt: aspheric IOL

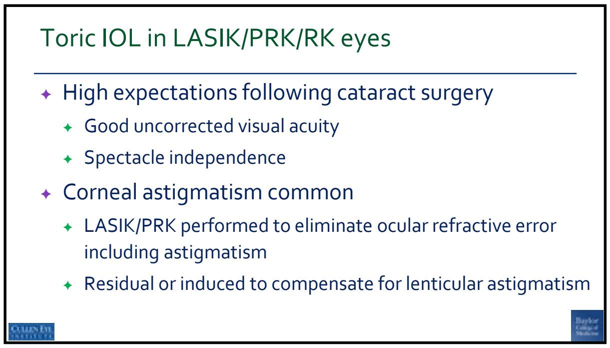
Weikert MP, Golla A, Wang L. JCRS 2018;44:745-749





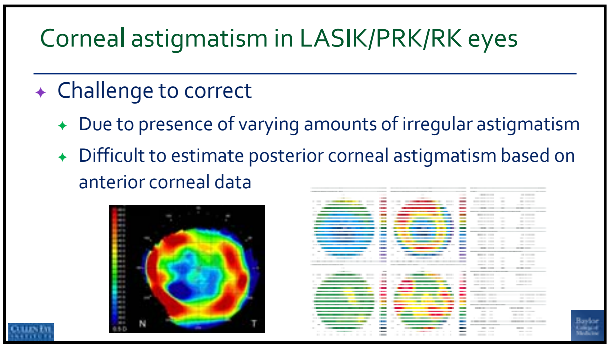
Astigmatism induced by IOL tilt: SN6AT6 toric IOL

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



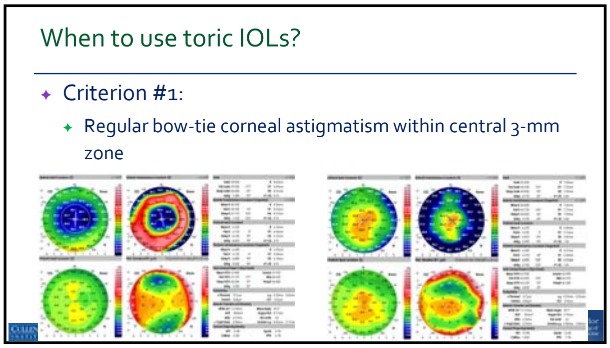
Toric IOL in LASIK/PRK/RK eyes

- 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



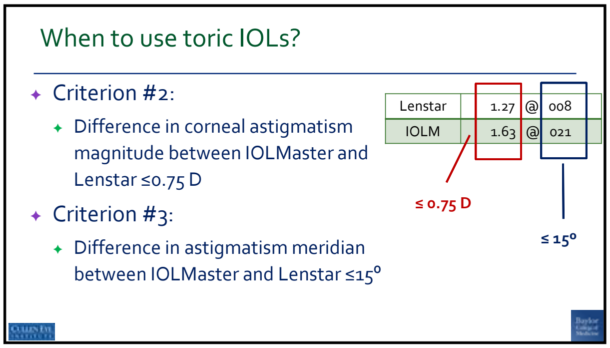
Corneal astigmatism in LASIK/PRK/RK eyes

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



When to use toric IOLs?

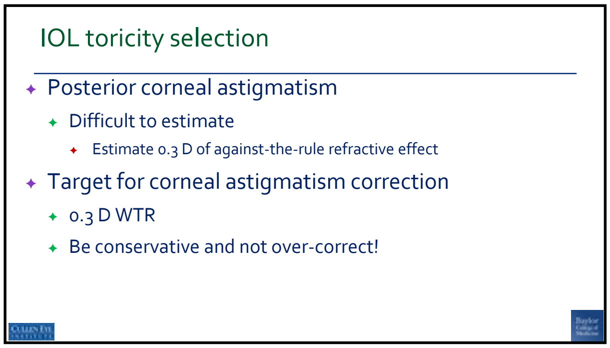
- Criterion #1:
  - Regular bow-tie corneal astigmatism within central 3-mm zone



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



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!

IOL spherical power selection: ascrs.org

- Post-refractive IOL calculator


FOR SURGEONS. FOR YOU.

IOL power calculation in eyes that have undergone LASIK/PRK/RK

Warren Hill, M.D.
Li Wang, M.D., Ph.D.
Douglas D. Koch, M.D.

Version 4.9

Made possible by an unrestricted educational grant from Alcon Laboratories and The ASCRS Foundation

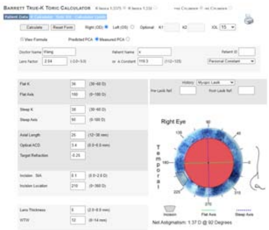
When corneas met all 3 criteria:

- % 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.

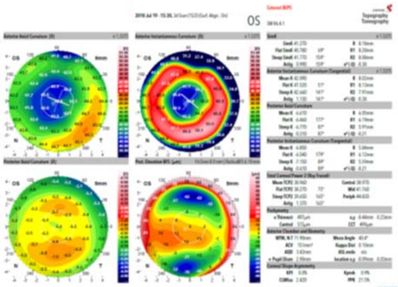
Barrett True-K toric calculator



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

Case #1

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



Preop corneal astigmatism

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

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

18.56 to 20.04 D

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

Corneal astigmatism

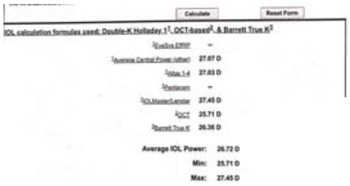
MR:	+1.75+ 0.75 x 166
IOLMaster:	0.93 D @150°
Lenstar:	1.04 D @149°
Galilei SimK:	1.01 D @157°
Galilei TCP:	1.19 D @173°
Atlas:	0.76 D @177°

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

IOL spherical power: which would you choose??

Calculator formulas for target -0.5 D:

25.71 to 27.45 D



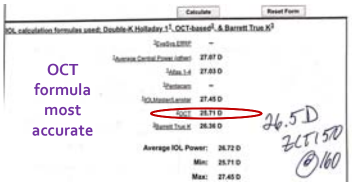
IOL calculation formulas used: Double-K Holladay 1[1], OCT-based[2], & Barrett True K[3]

[1]EyeSys EffRP –
[1]Average Central Power (other) 27.07 D
[1]Atlas 1-4 27.03 D
[1]Pentacam –
[1]IOLMaster/Lenstar 27.45 D
[2]OCT 25.71 D
[3]Barrett True K 26.36 D

Average IOL Power: 26.72 D
Min: 25.71 D
Max: 27.45 D

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

IOL calculation formulas used: Double-K Holladay 1[1], OCT-based[2], & Barrett True K[3]

[1]EyeSys EffRP –
[1]Average Central Power (other) 27.07 D
[1]Atlas 1-4 27.03 D
[1]Pentacam –
[1]IOLMaster/Lenstar 27.45 D
[2]OCT 25.71 D
[3]Barrett True K 26.36 D

Average IOL Power: 26.72 D
Min: 25.71 D
Max: 27.45 D

26.5 D
ZCT150
@160

What would you do now?

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….

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

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