ADVANCED IOL POWER CALCULATIONS

Jack T. Holladay, MD, MSEE, FACS

I. Formulas and Measurements
   A. Variables Used to Predict ACD
      1. Binkhorst 2 - 1981 - AL
      2. Holladay 1 - 1988 - AL, K
      3. SRK/T - 1990 - AL, K
      4. Hoffer Q - 1993 - AL, K
      5. Olsen - 1995 - AL, K, ACD
      6. Clarke- 1996 - AL, K1, K2 ACD, LT
      7. Holladay 2 - 1996 - AL, K, HWTW, REF, ACD, LT, AG
      8. Barrett, Hill RBF, Kane
   B. Normal Values for required Measurements
      1. Axial Length: mean = 23.5 mm, SD = 1.25 mm
      2. Keratometry: mean = 43.81 D, SD = 1.6 D
      3. Horizontal White-to-White (Corneal diameter): mean = 11.7 mm, SD = 0.46 mm
      4. Preoperative Refraction: mean = plano
      5. Anterior Chamber Depth (ultrasonic): mean = 3.1 mm, SD = 0.30 mm
      6. Crystalline Lens Thickness (ultrasonic): mean = 4.7 mm, SD = 0.41 mm
      7. Age: mean = 72, SD = 12 years

II. Axial length Measurements in Aphakic and Pseudophakic eyes
   A. Aphakia - 1532 M/sec
   B. Pseudophakia
      1. PMMA - 2718 M/sec
      2. Silicone - 980 M/sec
      3. Acrylic- 2120 M/sec

III. Determination of corneal power following Keratorefrative Sx (PRK, LASIK, RK)
   A. Manual Keratometry
   B. Automated Keratometry
   C. Corneal Topography
   D. Calculation from pre- keratorefractive surgery K's
   E. Determination from hard contact lens trial

IV. Data Screening Techniques on Preoperative Measurements
   A. Probability of unusual measurements (one eye only)
   B. Probability of asymmetrical measurements (both eyes)

V. IOL Calculations requiring Axial Length Measurements
   A. Standard Cataract Removal with IOL
      1. Piggy-Back IOL's: Use 34 D IOL posterior in bag
      2. Multifocal IOL's: Target distance plano, near for -3.00 D.
      3. Toric IOL's: IOL Cylinder to Corneal Cylinder ~ 1.46, but not exact for low (1.75) and high (1.20) power IOLs
      a. Optimization of Cataract Incision Location: Normal 4 locations for zero residual astigmatism
      b. Back calculation for surprise: 1) P.O. Refraction &, 2) P.O. Ks OR Current IOL axis

B. Cataract Removal with IOL and Silicone in Vitreous: use convexplano ~ 3 D more, for biconvex ~ from 5 - 6 D more in IOL.

VI. IOL Calculations not requiring Axial Length
- A. Secondary Implant for Aphakia: in sulcus or anterior chamber angle
- B. AC IOL in phakic patient: High myopia (- IOL) & High hyperopia (+ IOL)
- C. Secondary Piggy-Back IOL for high hyperopia (or myopia within 1 year)

VII. Pediatric IOL calculations
- A. Ideal Postoperative Target Refraction: plano to -1.00 D.
- B. Expected Myopic Shift with age: 4 D from age 2 to age 21.

VIII. Minimizing Prediction Error
- A. Personalizing Formula Constants (A-const, ACD or Surgeon Factor)
- B. Prediction Error vs. IOL Power
- C. Creating personalized constants for subgroups
  1. Axial Length (< 22 mm or > 26 mm)
  2. Keratometry (< 40 D or > 48 D)
  3. Preoperative Refraction (< -4 D or > +4 D)

IX. Calculating SIRC (Surgically induced refractive change)
- A. From pre and post operative keratometry
- B. From pre and post operative refraction

X. Outcomes Analysis
- A. Prediction Error Analysis: Mean absolute prediction error should be < 0.50 D.
- B. Formula Comparisons: more predictors, better results in unusual eyes
- C. SIRC Results: Astigmatic Analysis
- D. Visual Acuity Results
  1. Best corrected
  2. Uncorrected

XI. Back-calculations
- A. For determining source of error with refractive surprise
- B. Comparison of back-calculated lens constant and actual lens constant

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Financial Disclosure

- I have the following financial interests or relationships to disclose:
  - Abbott Medical Optics: C;
  - AcuFocus, Inc.: C,O;
  - Alcon Laboratories, Inc.: C;
  - ArcScan: C,O;
  - Carl Zeiss Inc: C;
  - Clerio Vision: C,O;
  - Oculus, Inc.: C;
  - OcuPhire: C,O;
  - RX Vision: C,O;
  - M & S Technologies: C;
  - Visiometrics: C,O;

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IOL Calculation Software for Ophthalmologists - Jack T. Holladay, MD, MSEE, FACS

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2. Holladay Report 2018 - Interpretation Guidelines - 2018 (1,100 KB)
3. TORIC IOL CALCULATIONS: Minimizing & Managing Residual Astig - 2018 (2,043 KB)
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5. Phakic IOL Calcs 16x9 - 2016 (288 KB)
6. Analyzing Individual & Aggregate Astigmatism - 2006 (375 KB)
7. New Automated CSF Testing - 2006 (2.6 MB)
8. Advanced IOL Calcs with Outline 16x9 2018 (7,856 KB)
9. EDOF Pinhole Trifocal Promise no glasses and How to Deliver 16x9 – 2017 (1,316 KB)
10. HOLLADAY IOL Outcomes Optics We K to Know – 2018 (1,820 KB)
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14. Optics and Clinical of Mono IC8 EDOF Bif Tri - 2018 (1,309 KB)

#8

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Vergence Formula

- Theoretical Formula has not changed in 173 years
- Physiologic Assumptions may be slightly different
  - Retinal thickness
  - Corneal Index of Refraction

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Vergence Formula

$$IOL = \frac{1336}{AL - ELP} - \frac{1336}{\frac{1336}{\frac{1000}{\frac{1000}{DPostRx.} - V} + K} - ELP}$$

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E L P

Effective Lens Position

- Distance from corneal vertex to principal plane of thin IOL (no thickness)
- Same as ACD, but avoids confusion with anatomy

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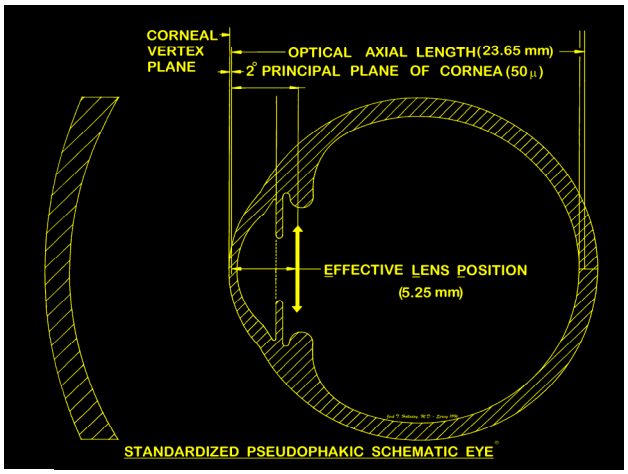

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Prediction of E L P

1. <1980 Constant (0) 4.5
2. 1981 Binkhorst 2 (1) AL
3. 1988 Holladay 1 (2) AL, K
4. 1995 Olsen (4) AL, K, ACD, LT

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Prediction of E L P

6. 1996 Holladay2 (7) AL, K, ACD, LT, HWTW, REF, AGE
6. 2012 Olsen II (5) AL, K, ACD, LT, C constant
7. 2015 Barrett Universal II (7) AL, K, ACD, LT, HWTW, REF, Lens Factor

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Measurements taken for Predictors of ELP

1. Axial Length
2. Average K
3. Horizontal WTW
4. ACD
5. LT
6. Pre-opRefraction
7. Age

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HWTW Gauge

Horizontal Corneal Diameter

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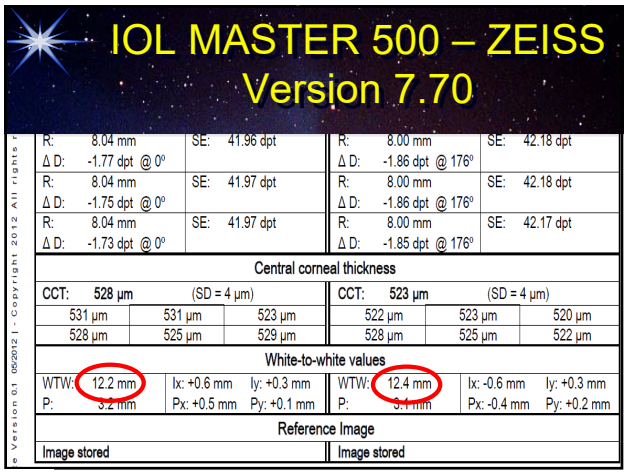

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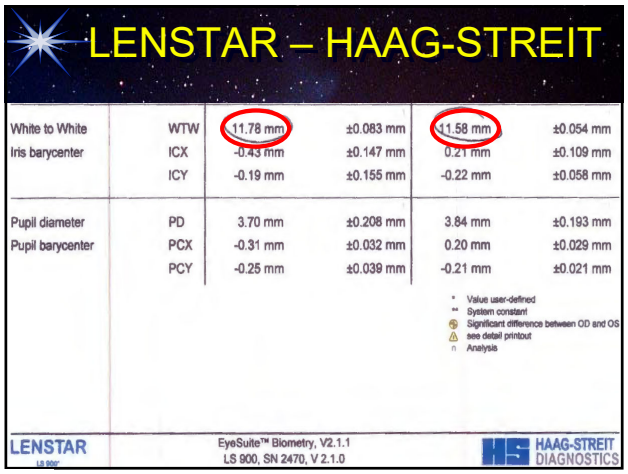

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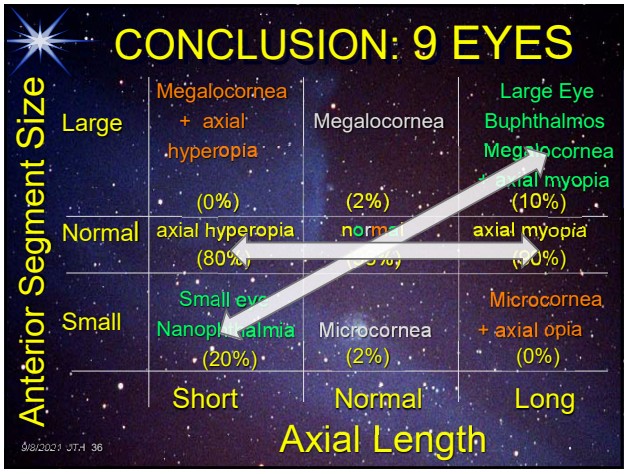

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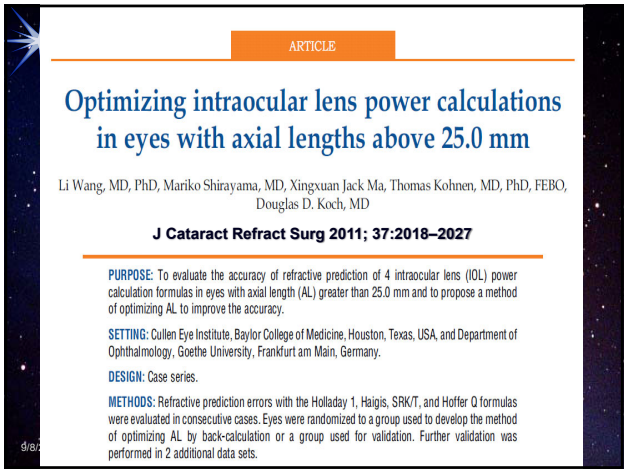

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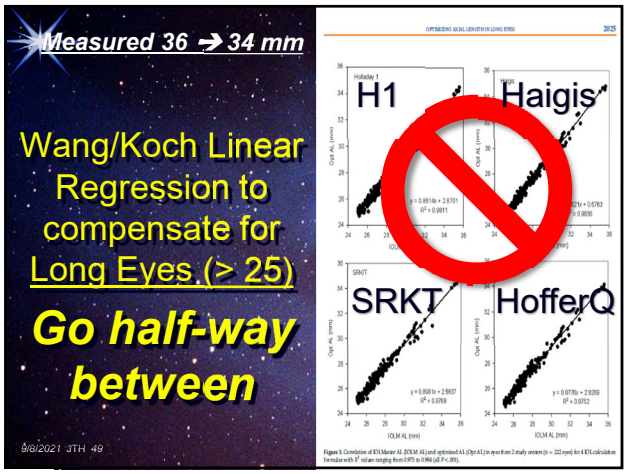

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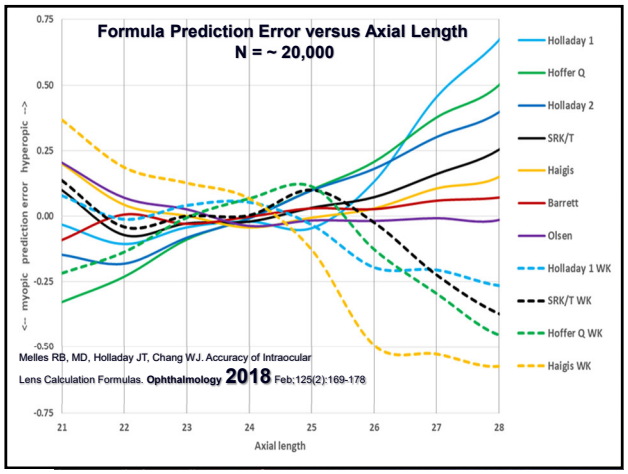

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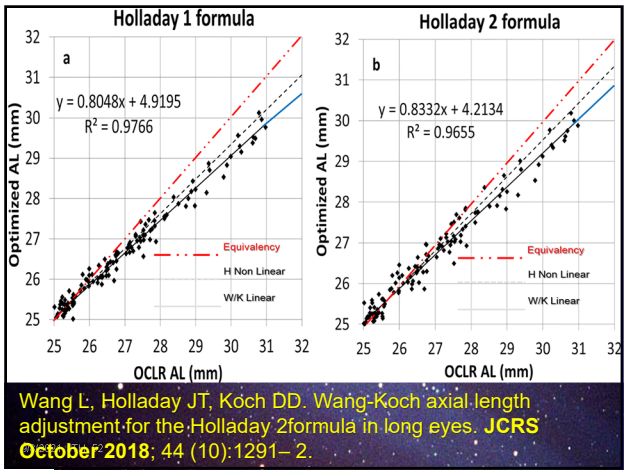

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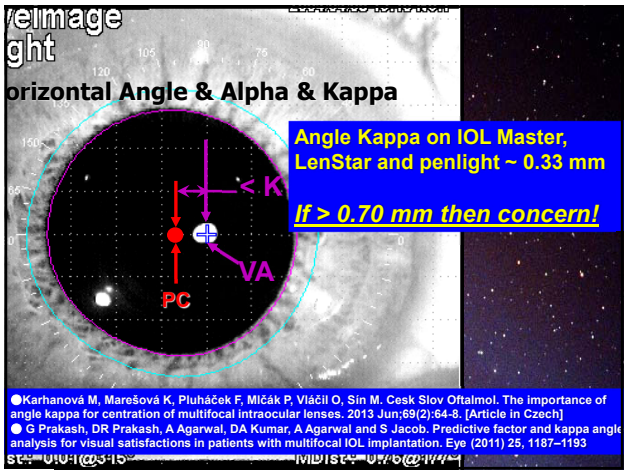

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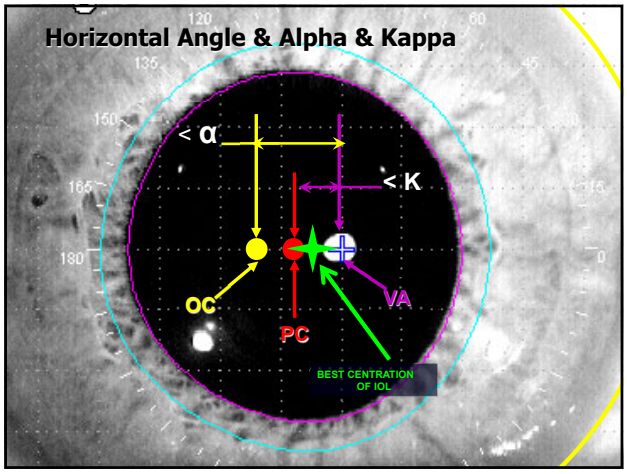

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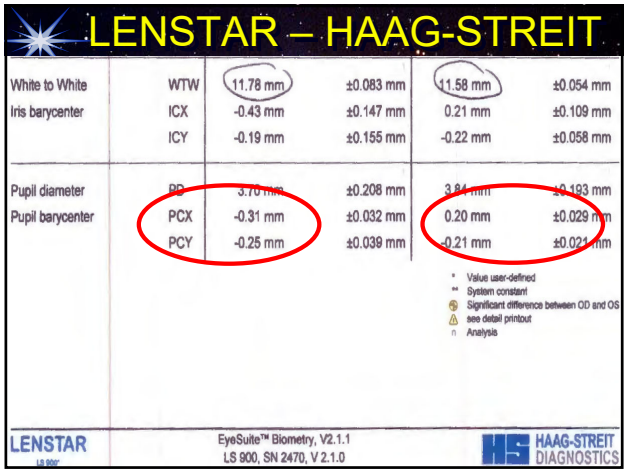

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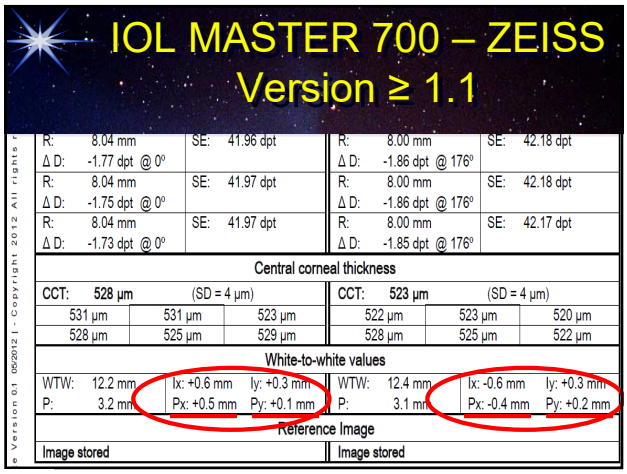

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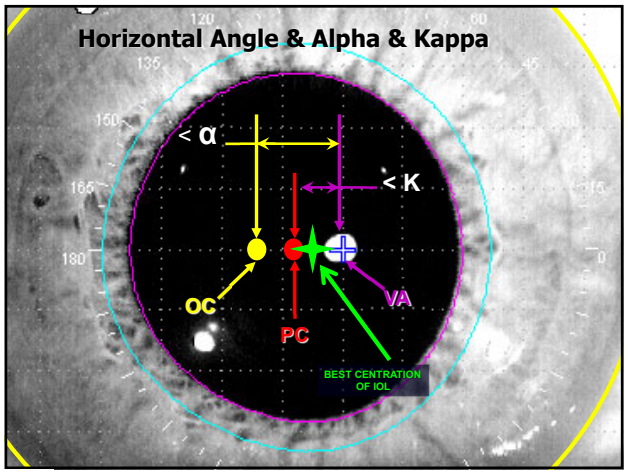

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Data Screening *Identifies* Measurement Error - *Repeat*

- Binocular
  - AL difference > 0.3 mm
  - K difference > 1.0 D
  - IOL power difference > 1.0 D
- Monocular
  - AL Signal/Noise (S/N) Ratio < 2.0
  - K Std Dev (σ) > 0.20 D (0.030 mm) or 30 μ

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Cataract Surgery … IOL Power Calculations Following Refractive Surgery

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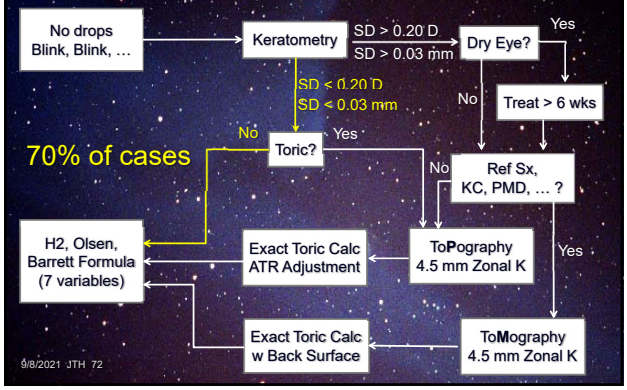
Corneal Power Decision Tree



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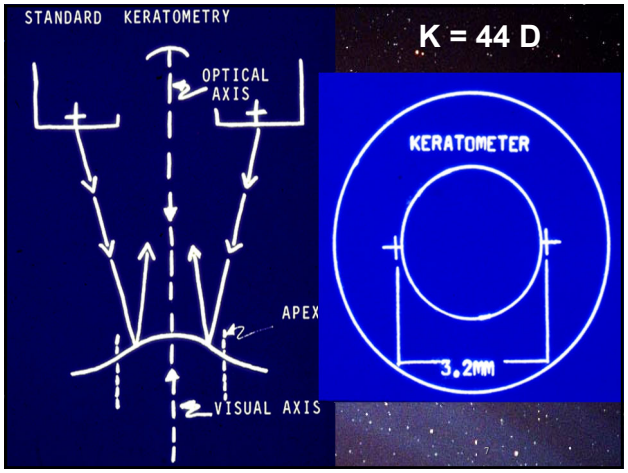

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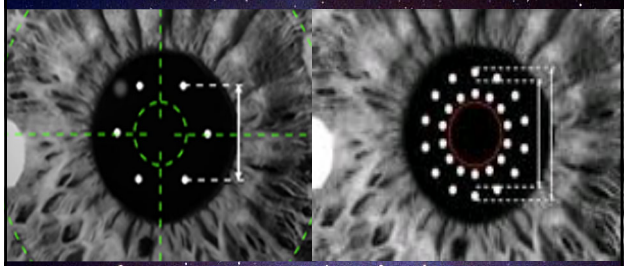
IOL Master 2.5 mm LenStar 1.7 & 2.3 mm



K = 44 D

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Astigmatism Measurement for a 44 D Cornea

- **Manual** Keratometer
  - **3.2 mm** Diameter
- **IOL Master*** Keratometer
  - **2.5 mm** Diameter
- **LenStar†** Keratometer
  - **2.35 & 1.65** mm Diameters
  - (Average 2.0 mm Diameter)

* **Carl Zeiss Meditec AG**, Goeschwitzer Str. 51-52, 07745 Jena, Deutschland
† **Haag-Streit AG,** Gartenstadtstrasse 10,3098 Koeniz, Switzerland

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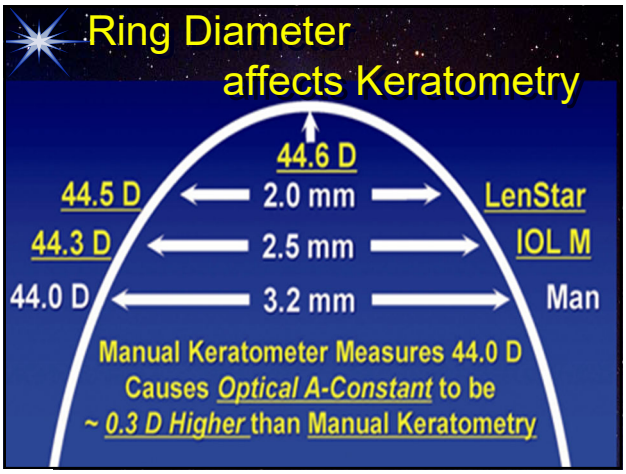

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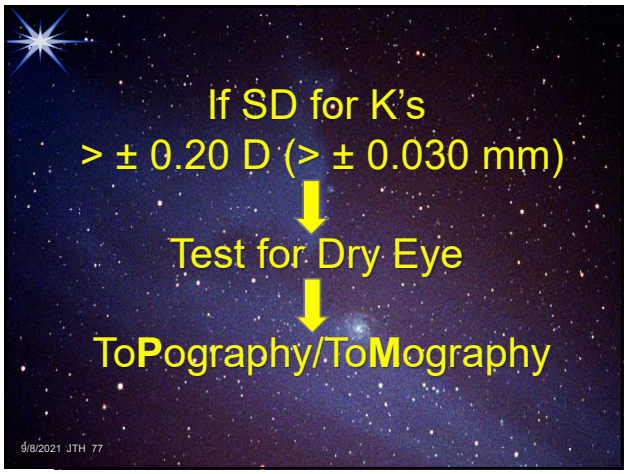

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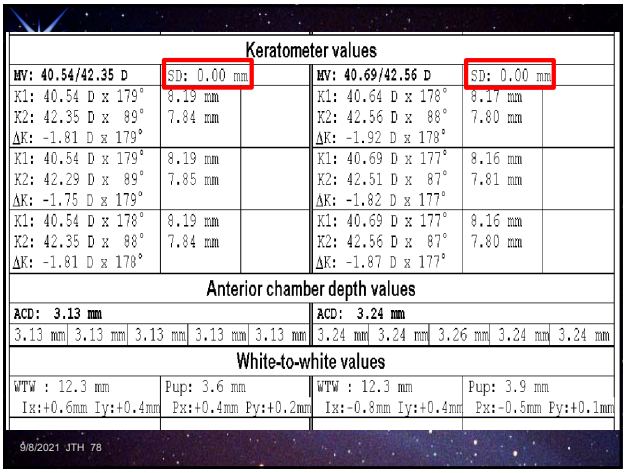

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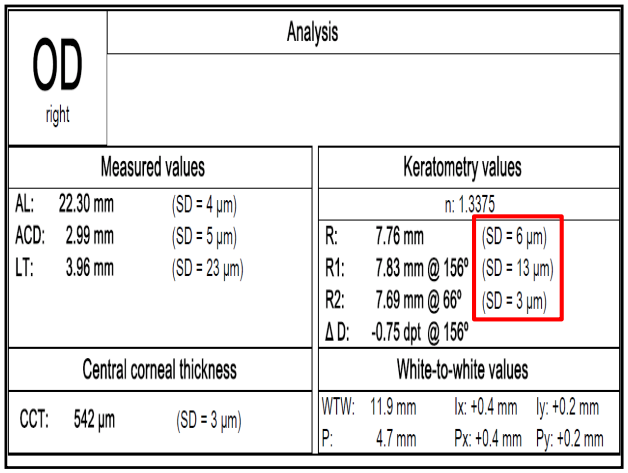

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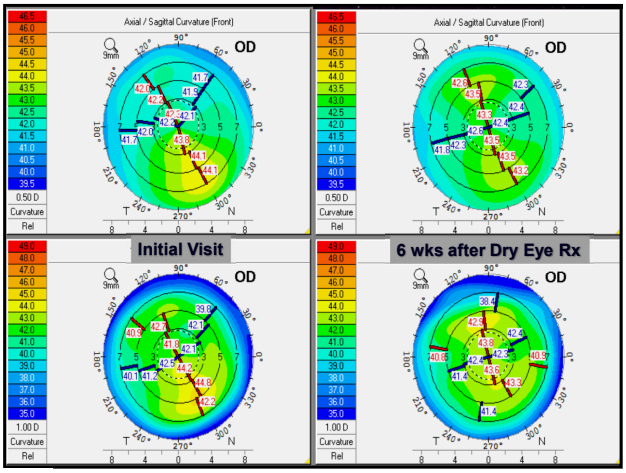

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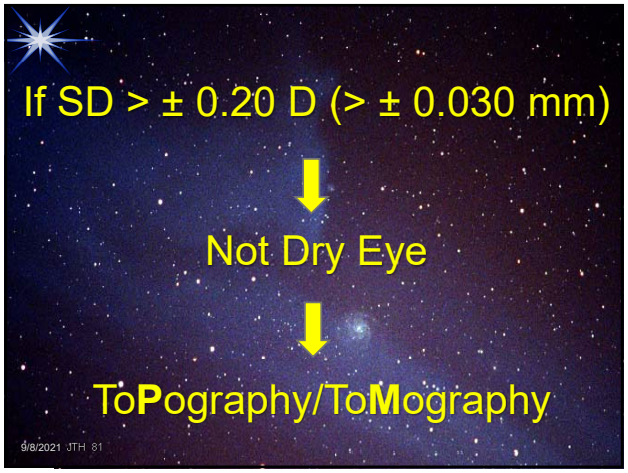

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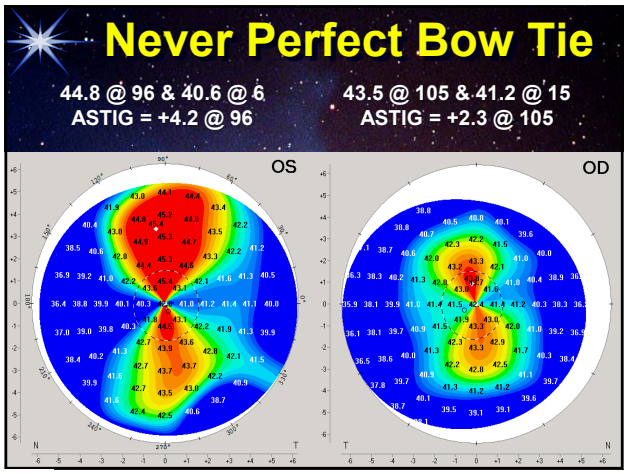

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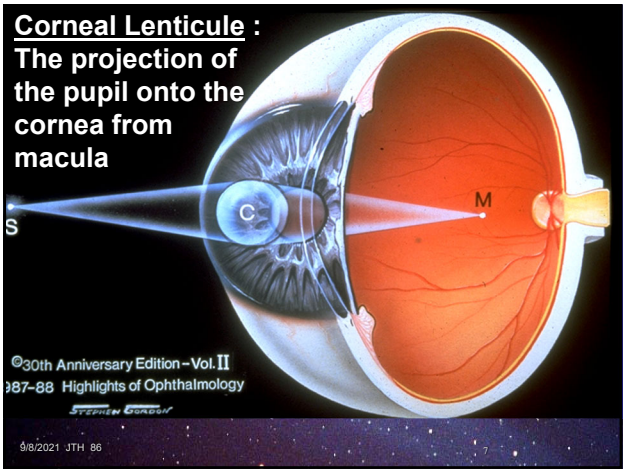

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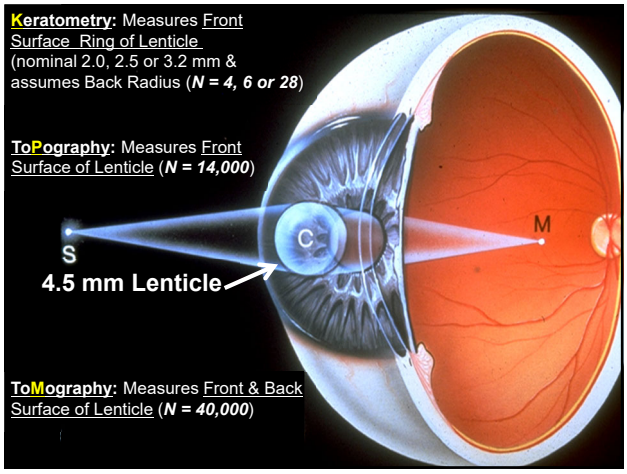

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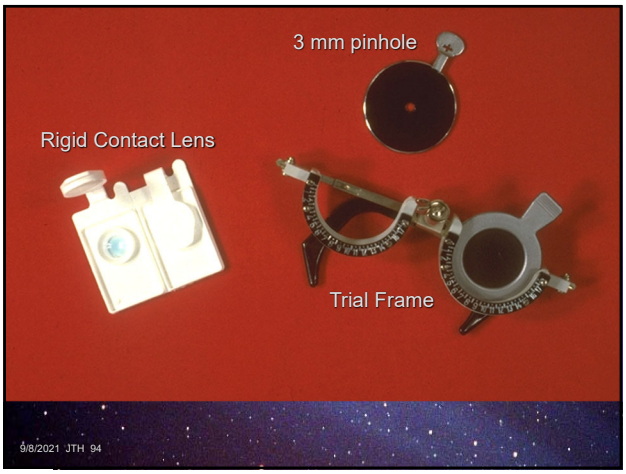

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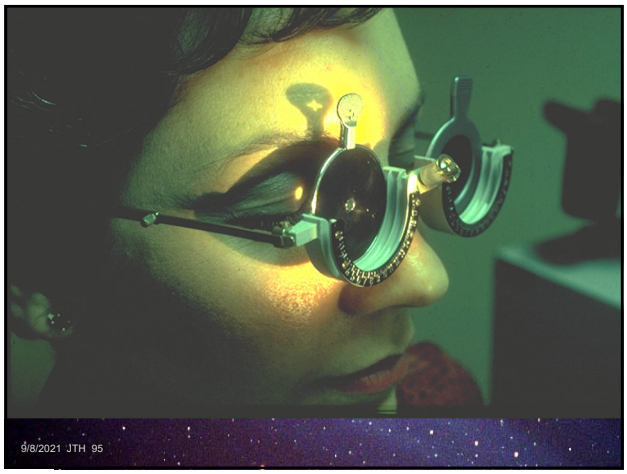

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1. Calculation from Prior Data (Pre K & Δ MR known)

Pre KR Mean K = 44.00 D

Change in SEQ Ref = -4.50 D

Calc Mean K = 39.50 D

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4. Trial Hard Contact Lens (Rigid Contact lens only)

Plano HCL Base Curve = 41.50 D

SEQ Ref without CL = +0.50 D

SEQ Ref with CL = -1.00 D

Front K = 41.50 - 1.50 = 40.00 D

40.00 D – 10% (4.50) = 39.50 D

Mean K = 39.50 D

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5. Multiple K-readings

- Right Eye
  - Topcon: 35.13 @ 90° 37.02 @ 180° -1.89D ax90°
  - Galilei: 34.16 @ 94 36.80 @ 4 2.64 D @4
  - JAVAL: 35@80° 37@180° // IRREGULAR
- Left Eye
  - Topcon: 35.06 @ 50° 37.11 @ 140° -2.05D ax50
  - Galilei: 34.99 @50 37.44 @ 140 2.46 @140
  - JAVAL: 35.25@45° 38@155° // IRREGULAR

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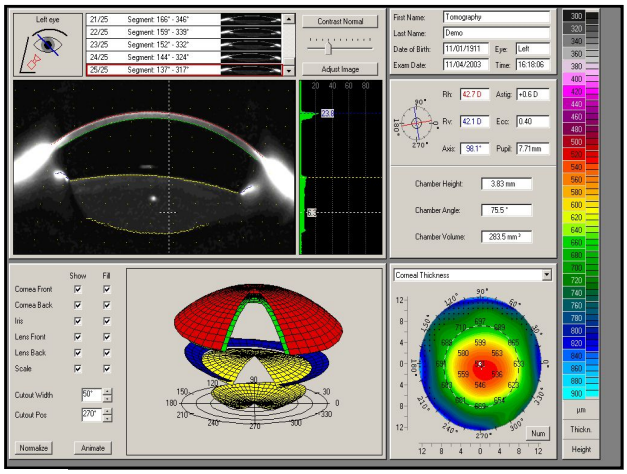

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Accuracy of EKR

Prior Sx	STD 4.5 (D)
LASIK	0.56
RK	0.94

Holladay JT, Hill WE, Steinmueller A. Corneal Power Measurements Using Scheimpfl ug Imaging in Eyes With Prior Corneal Refractive Surgery. J Refractive Surgery 2009:25:862-868. (October 2009 Issue of J Refr Surgery)

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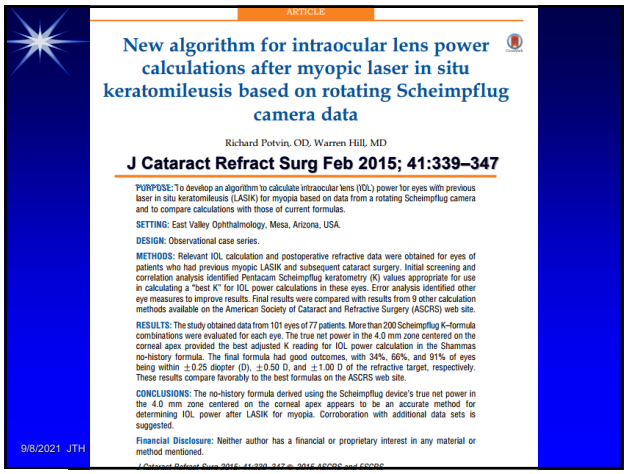

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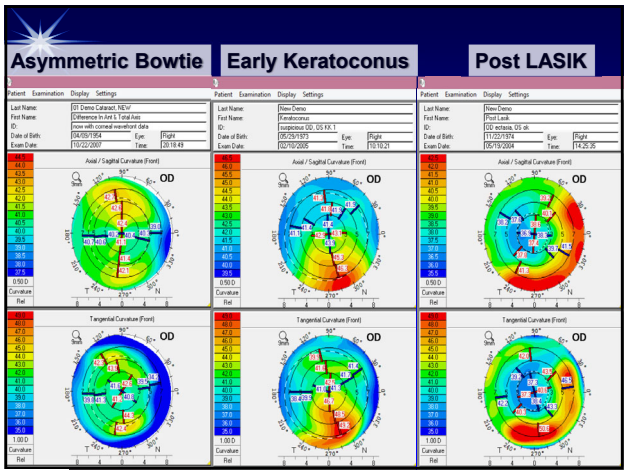

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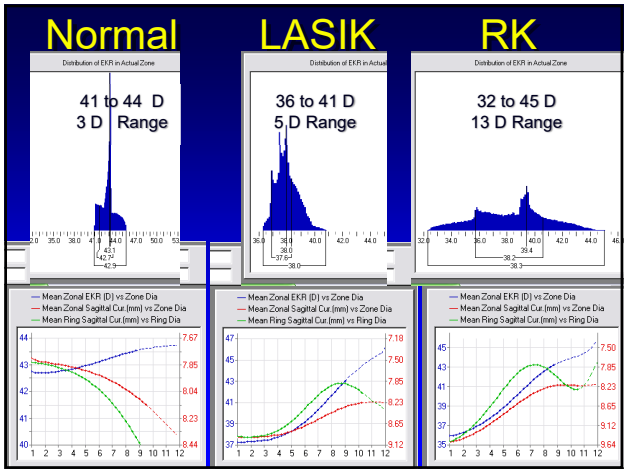

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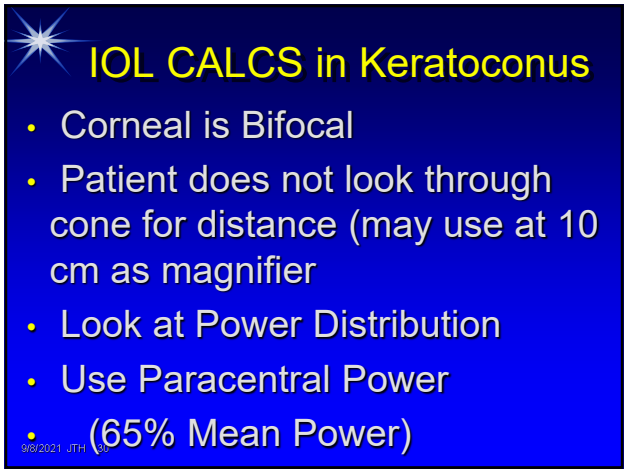

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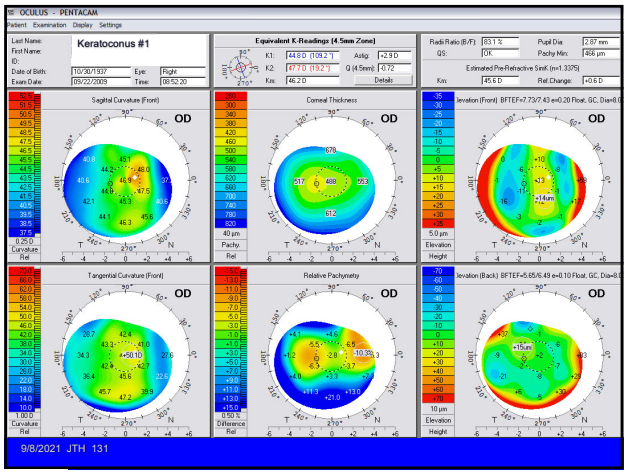

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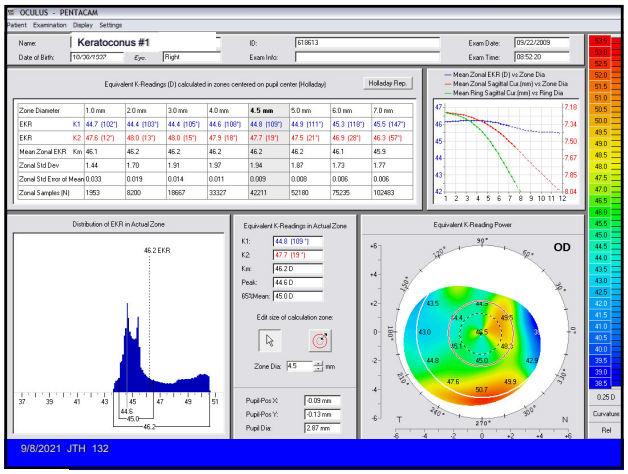

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Toric IOL's

- Calculate IOL power for steep and flat meridian using same ELP
- Difference in IOL powers is the toricity necessary to completely correct corneal astigmatism

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Ideal Toric IOL Calcs

- Accurate corneal power and astigmatism … repeat if SD > 0.020 D (0.030 mm)
- Exact Toric Calculator (not a constant ratio of corneal astigmatism to toricity (1.46)
- Proper Surgically Induced Astigmatism (SIA) for incision location and magnitude and axis of PreOp astigmatism … must account for ATR over 3 to 6 months PostOp
- Results will be greater than 80% within 0.50 D

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Toric IOL's

- Always choose toricity to undercorrect corneal astigmatism – WRONG!
- LEAVE MIN RESIDUAL CYL!
- *Eg:* Steep calc yields 24.0 D
  Flat calc yields 27.0 D
- Ideal Toricity is 3.0 D
- (Use 24.0 D with < 3.0 D of toricity)

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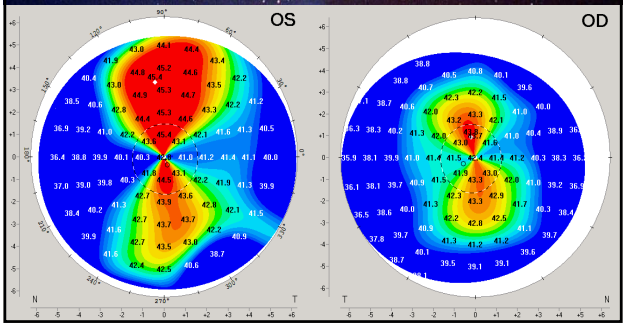
Never Perfect Bow Tie

44.8 @ 96 & 40.6 @ 6
ASTIG = +4.2 @ 96

43.5 @ 105 & 41.2 @ 15
ASTIG = +2.3 @ 105



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Total Surgically Induced Astigmatism in Toric IOL Calculations

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❶ Use Exact Vergence Calculator (not Constant)

❷ Change from Keratometric SIA + Posterior Corneal Astig to Total SIA

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TORIC IOL Calculators - 2 Types

- ***Constant*** Ratio Calculator uses a constant ratio (1.46) for the corneal cylinder to the IOL cylinder

K = 43 x 45 = 2 D astig

IOL SEQ = 10D → **3.0 D** Ideal Toricity
IOL SEQ = 22D → **3.0 D** Ideal Toricity
IOL SEQ = 34D → **3.0 D** Ideal Toricity

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TORIC IOL Calculators - 2 Types

- ***Exact*** Vergence Calculator depends on IOL SEQ Power and ELP

K = 43 x 45 = 2 D astig

IOL SEQ = 10D → **3.5 D** Ideal Toricity
IOL SEQ = 22D → **3.0 D** Ideal Toricity
IOL SEQ = 34D → **2.4 D** Ideal Toricity

A *1.1 D* toricity difference between a 10 and 34 D IOL !

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Toric Calculators

Exact Verg	Constant Ratio
• AMO Express On-line	• B & L On-line
• Holladay On-line Open Access (**docholladay.com**)	
• Alcon On-line	
• Barrett Calculator	
• Holladay AAO	

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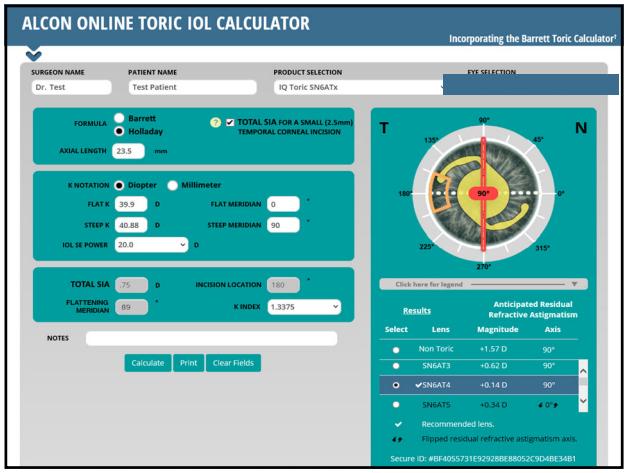

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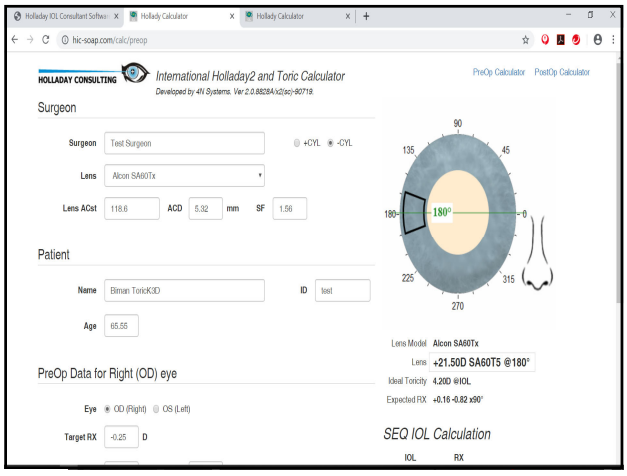

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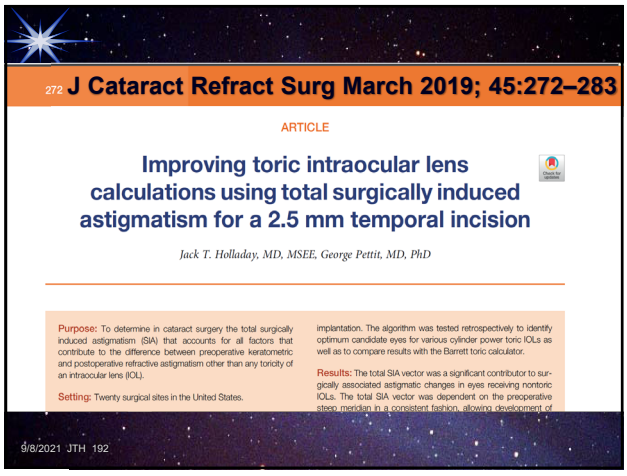

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Total SIA - 2019

IF

Before Sx Ks: + 0.50 WTR

After Sx Ref: + 0.50 ATR

What is Total SIA?

1 D ATR

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Total SIA - 2019

K_{pre} + Total SIA = REF $Astig_{post}$

Total SIA = REF $Astig_{post}$ - K_{pre}

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Total SIA – 2019

Cornea

1. Systematic difference in measured keratometric versus actual corneal refractive astigmatism
2. Δ Anterior Corneal Astig
3. Posterior Corneal Astig (PCA)
4. Δ PCA

IOL

5. Systematic IOL Tilt (~ 0.06 D ATR)
6. Systematic IOL Decentration (ATR)

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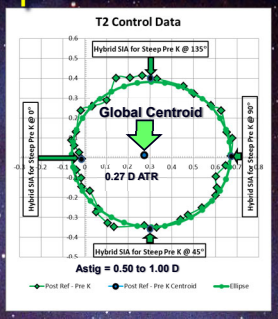
2.5 mm Temp Cataract Incision

Total SIA



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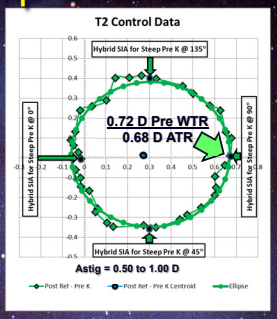
2.5 mm Temp Cataract Incision

Total SIA



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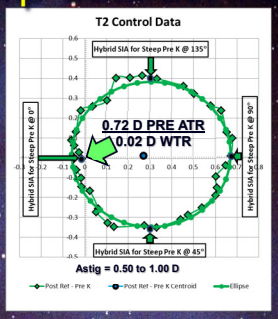
2.5 mm Temp Cataract Incision

Total SIA



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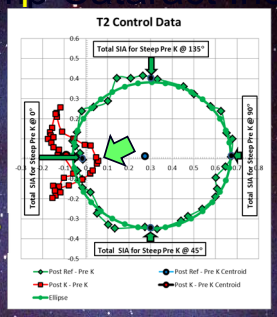
2.5 mm Temp Cataract Incision

SIA_K

Pre K 0.75 WTR → 0.05 @ ATR



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2.5 mm Temp Cataract Incision

- For 0.72 D of astigmatism @
  - WTR: Total SIA = 0.68 ATR
  - ATR: Total SIA = 0.02 WTR
  - @ 45°: Total SIA = 0.42 @ 152°
  - @ 135°: Total SIA = 0.42 @ 28°

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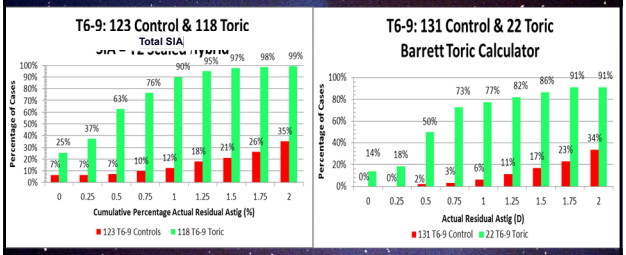
2.25 to 4.50 D Toric IOLs



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Toric Formula Comparisons Must Use

- Preoperative K's (D) (not postoperative)
- Toric IOL implanted
  - SEQ Power (D)
  - Toric Power (D)
  - Observed Axis of IOL (not intended)

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Summary

- Total SIA using post op refraction @ corneal plane accounts for all factors
- Minimum long term residual astigmatism is goal
- 0.25 D ATR drift per decade means slight WTR (< 0.25 D) immediately after surgery desirable (not ATR)

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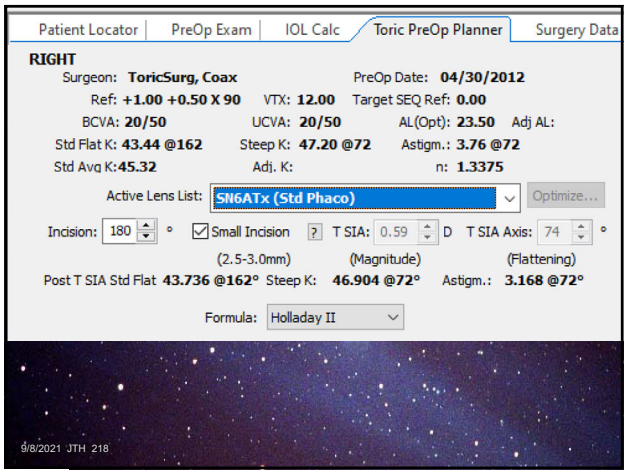

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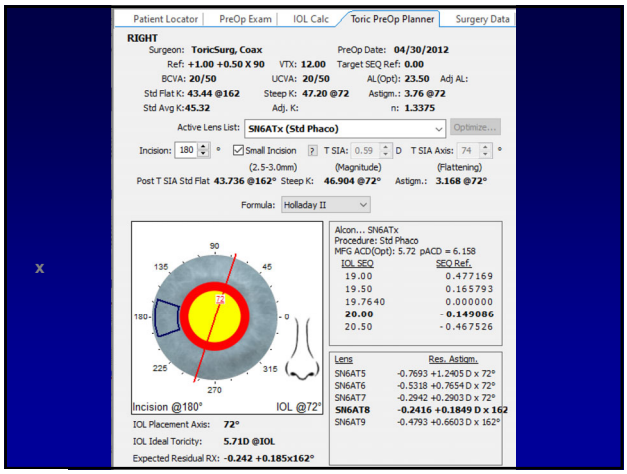

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Post Op Toric Calculators

- Holladay IOL Consultant
  - www.hicsoap.com (exact)
- Berdahl & Hardten Toric IOL Calculator
  - www.astigmatismfix.com (approximate)

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Two Sources of Error

- IOL misaligned (wrong axis)
- IOL Toricity wrong (over/under)
  - Or
- Both
  - ***Measuring Current Axis***

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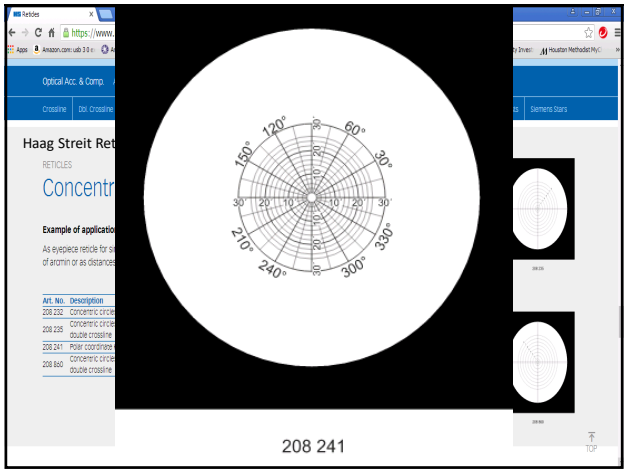

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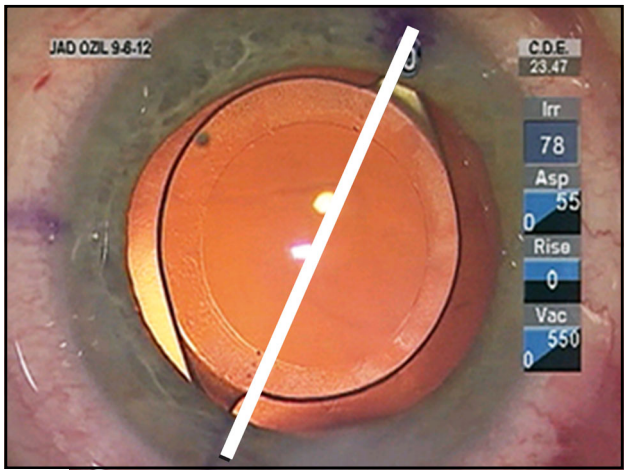

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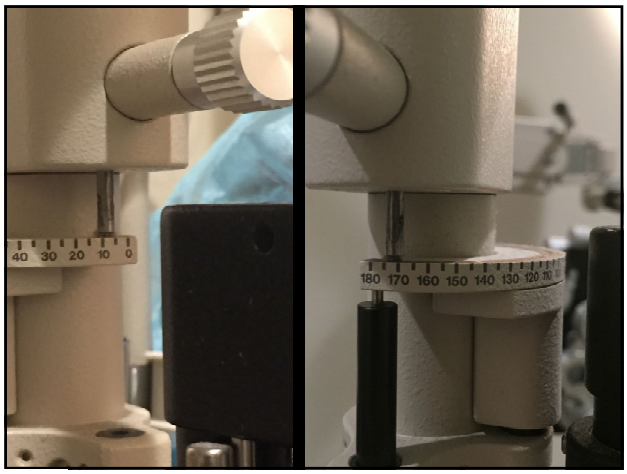

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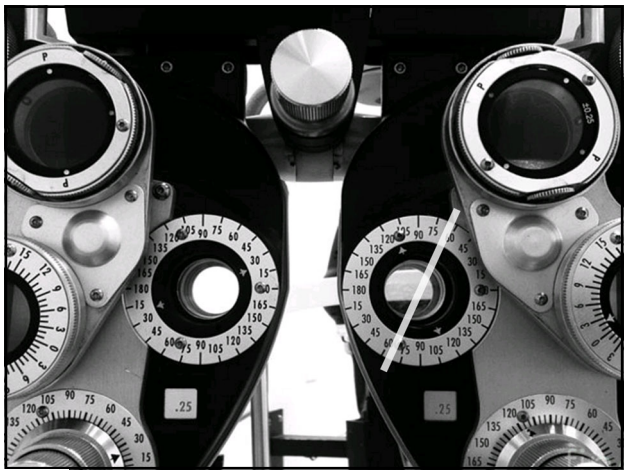

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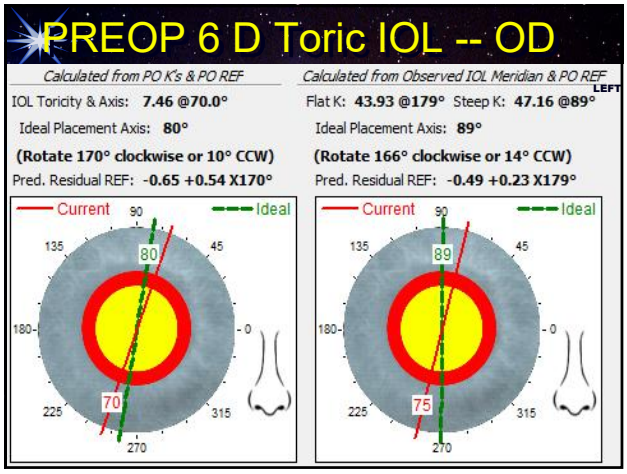

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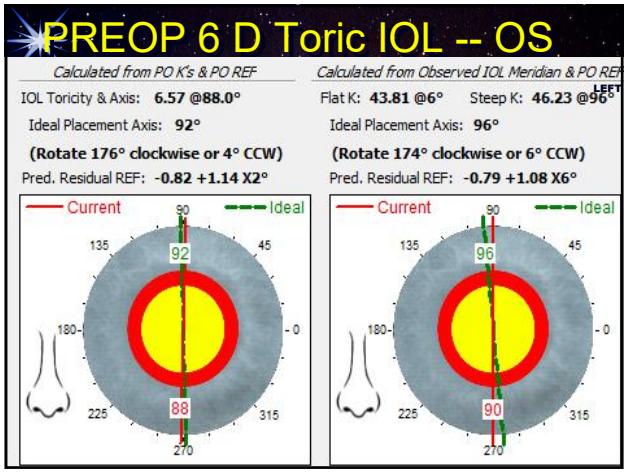

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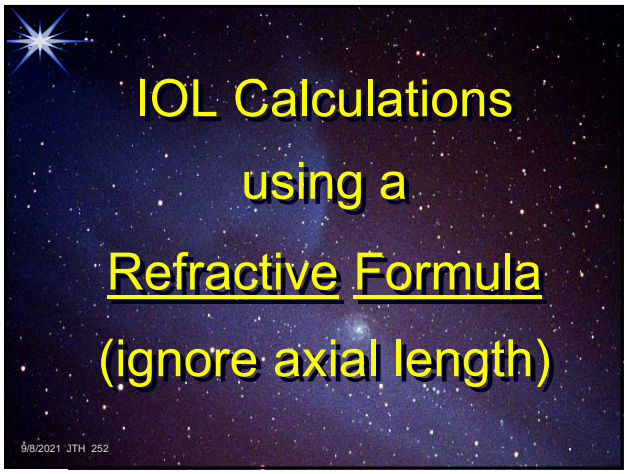

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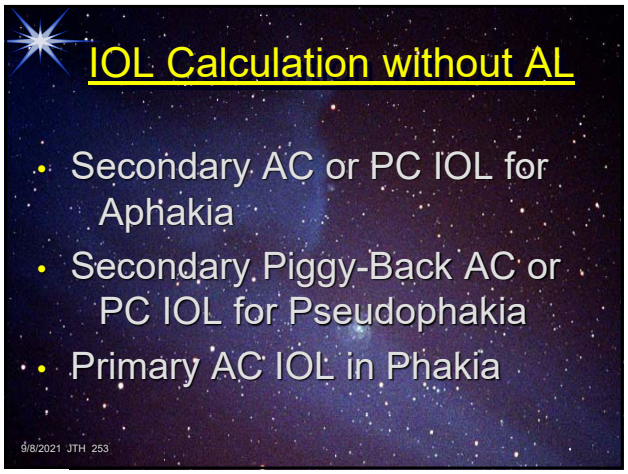

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REFRACTION FORMULA

$$IOL = \frac{1336}{\frac{1336}{\frac{1000}{PreRx} - V} + K} - ELP - \frac{1336}{\frac{1336}{\frac{1000}{DPostRx} - V} + K} - ELP$$

Holladay JT. Refractive power calculations for intraocular lenses in the phakic eye. Am J Ophthalmol. 1993; 116: 63-6.

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Refractive Surprises

1. Previous RK, PRK, LASIK
2. Bad axial length - short/long
3. Mislabeled IOL
4. Axially displaced
5. Misc.

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Secondary Piggy-Back Calc Advantages over Exchange

1. Mislabeled IOL irrelevant
2. Less risk to capsule or zonules
3. Mismeasured AL irrelevant
4. No AP shift of existing IOL
5. Fewer unknown variables

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