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, AGE
- 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)

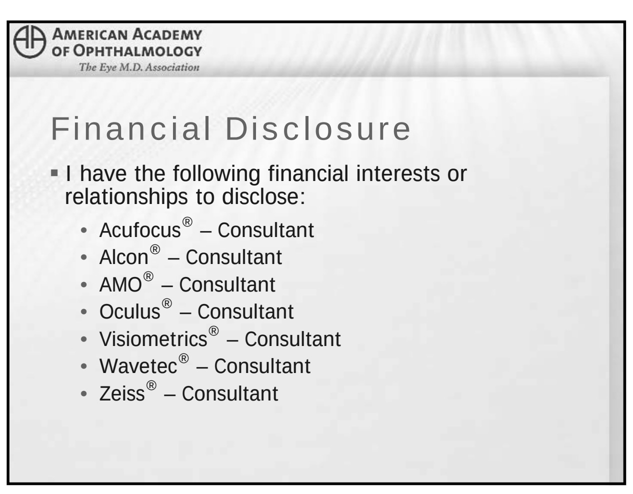
VII. Pediatric IOL calculations
- A. Ideal Postoperative Target Refraction: plano to -1.00 D.
- B. Expected Myopic Shift with age: 4 D from age 2 to age 21.

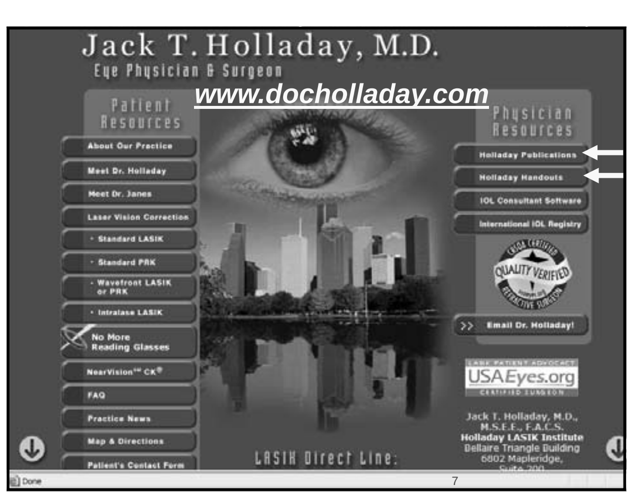
VIII. Minimizing Prediction Error
- A. Personalizing Formula Constants (A-const, ACD or Surgeon Factor)
- B. Prediction Error vs. IOL Power
- C. Creating personalized constants for subgroups
  1. Axial Length (< 22 mm or > 26 mm)
  2. Keratometry (< 40 D or > 48 D)
  3. Preoperative Refraction (< -4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

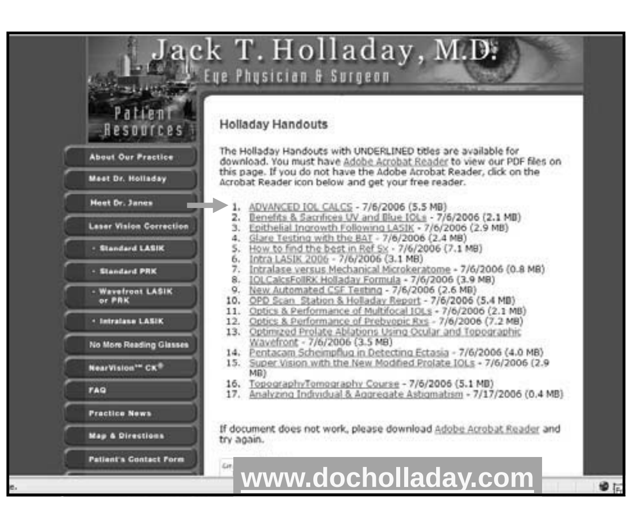
IX. Calculating SIRC (Surgically induced refractive change)
- A. From pre and post operative keratometry
- B. From pre and post operative refraction

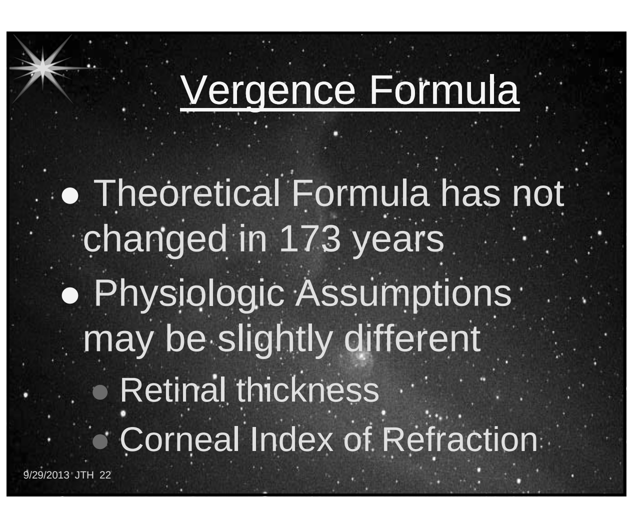
X. Outcomes Analysis
- A. Prediction Error Analysis: Mean absolute prediction error should be < 0.50 D.
- B. Formula Comparisons: more predictors, better results in unusual eyes
- C. SIRC Results: Astigmatic Analysis
- D. Visual Acuity Results
  1. Best corrected
  2. Uncorrected

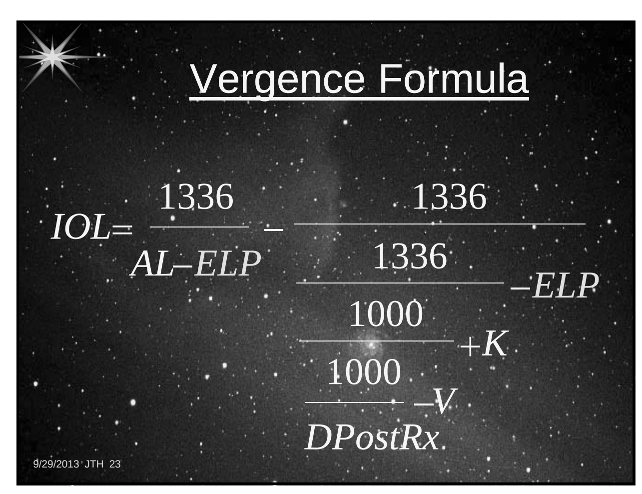
XI. Back-calculations
- A. For determining source of error with refractive surprise
- B. Comparison of back-calculated lens constant and actual lens constant

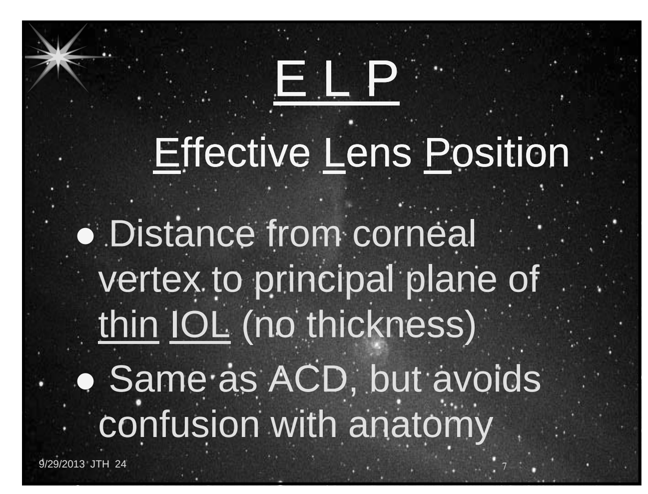


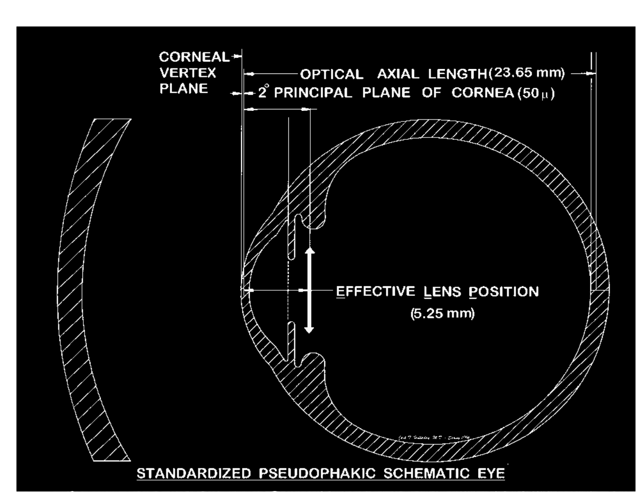


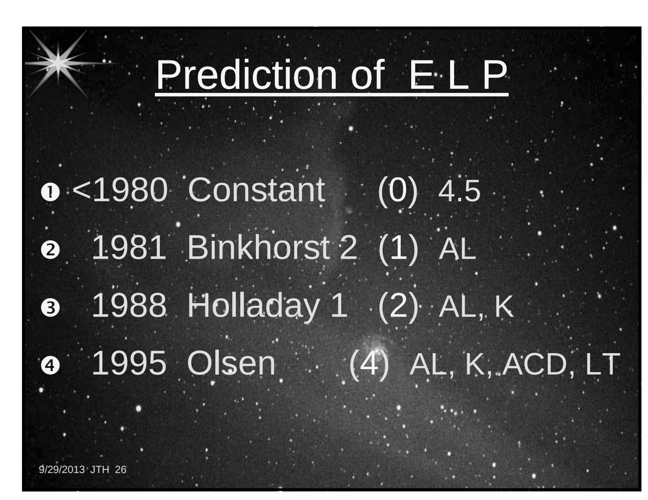


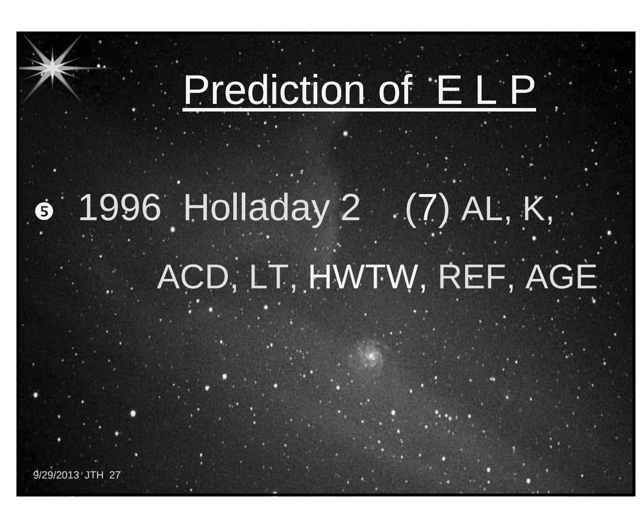


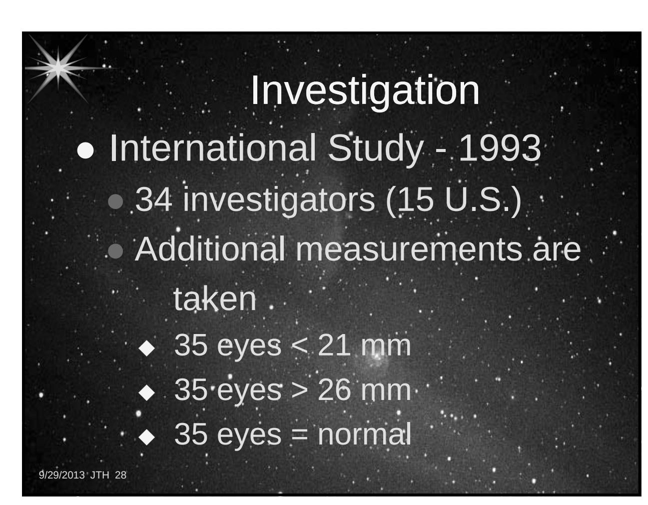


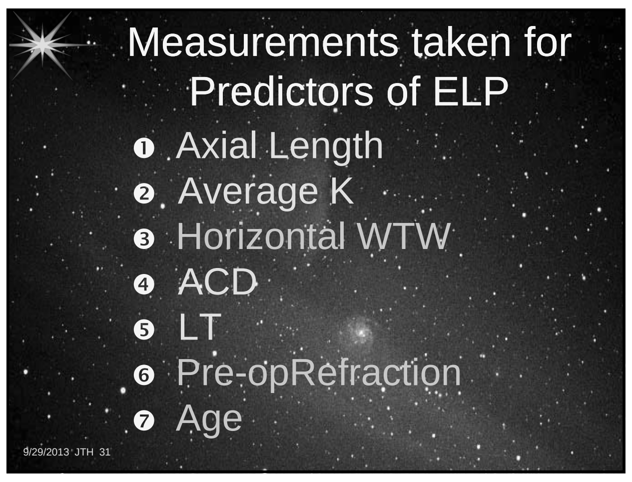


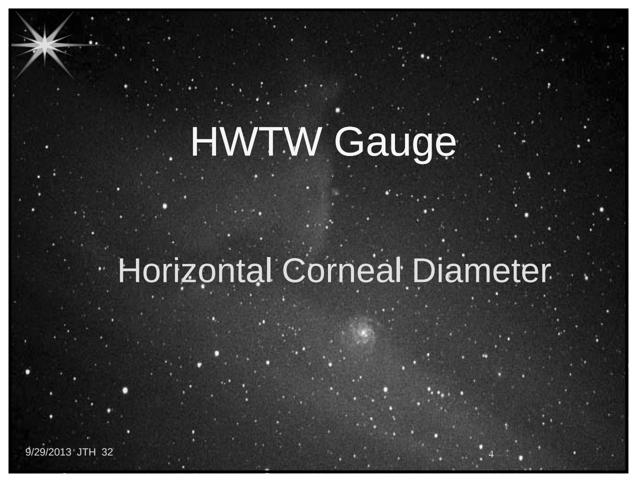




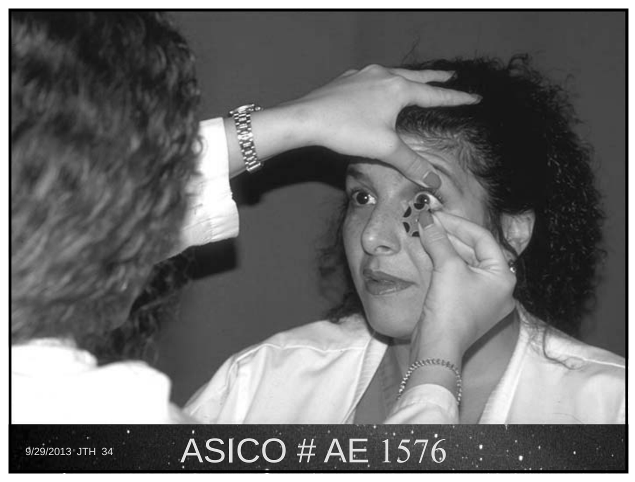


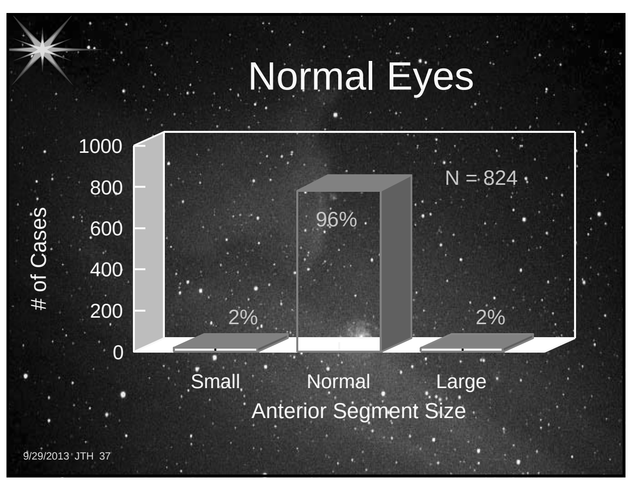


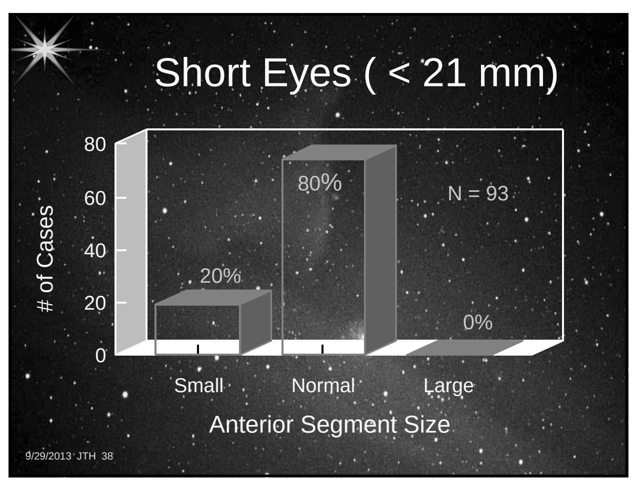

Measurements taken for Predictors of ELP
❶ Axial Length
❷ Average K
❸ Horizontal WTW
❹ ACD
❺ LT
❻ Pre-opRefraction
❼ Age

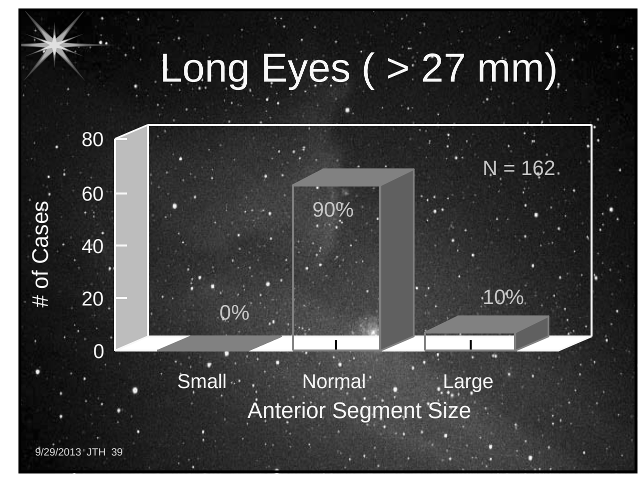

HWTW Gauge
Horizontal Corneal Diameter

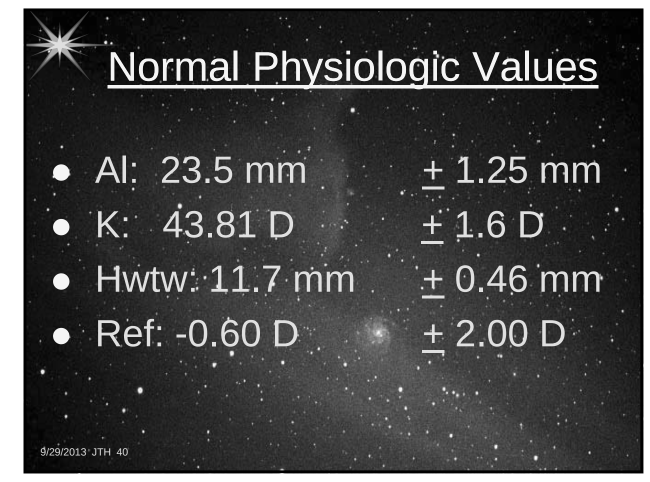

ASICO # AE 1576

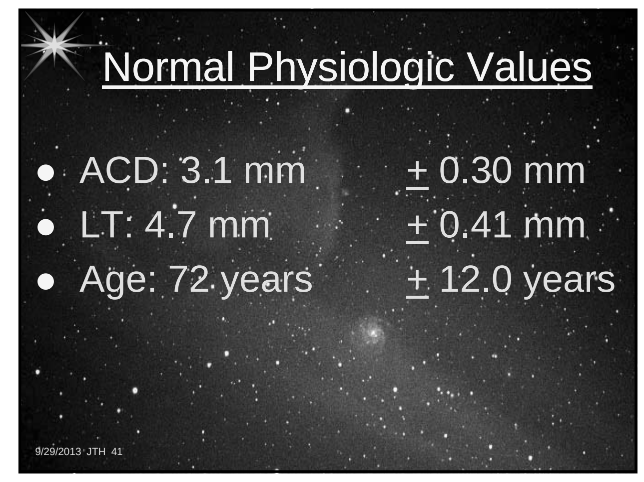

ASICO # AE 1576

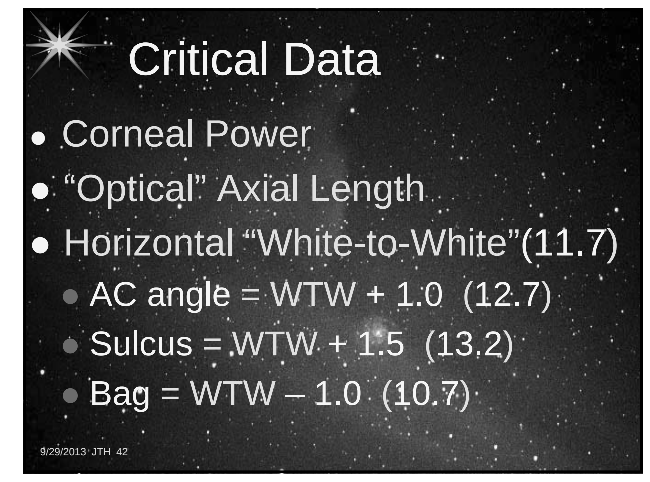

Normal Eyes
N = 824
96%
2%
2%
# of Cases
Small
Normal
Large
Anterior Segment Size

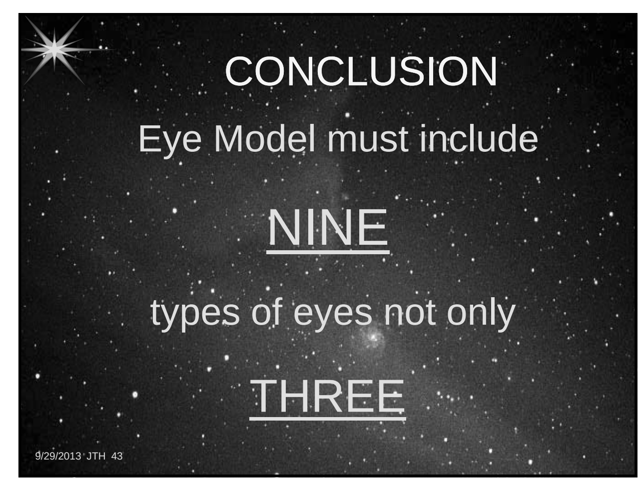

Short Eyes (< 21 mm)
N = 93
80%
20%
0%
# of Cases
Small
Normal
Large
Anterior Segment Size

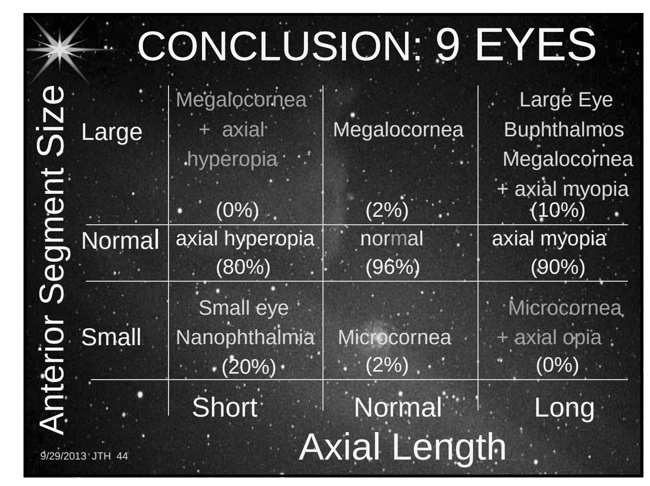

Long Eyes (> 27 mm)
N = 162
90%
0%
10%
# of Cases
Small
Normal
Large
Anterior Segment Size

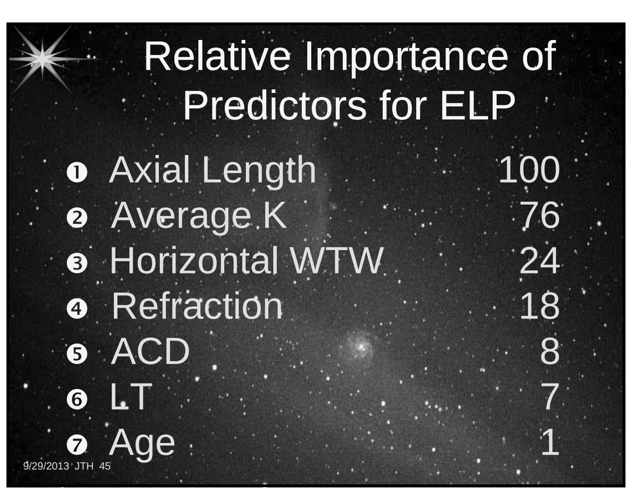

Normal Physiologic Values
Al: 23.5 mm ± 1.25 mm
K: 43.81 D ± 1.6 D
Hwtw: 11.7 mm ± 0.46 mm
Ref: -0.60 D ± 2.00 D

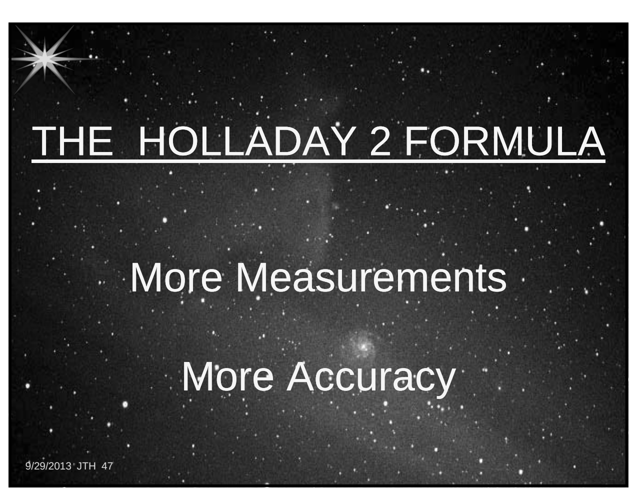

Normal Physiologic Values
ACD: 3.1 mm ± 0.30 mm
LT: 4.7 mm ± 0.41 mm
Age: 72 years ± 12.0 years

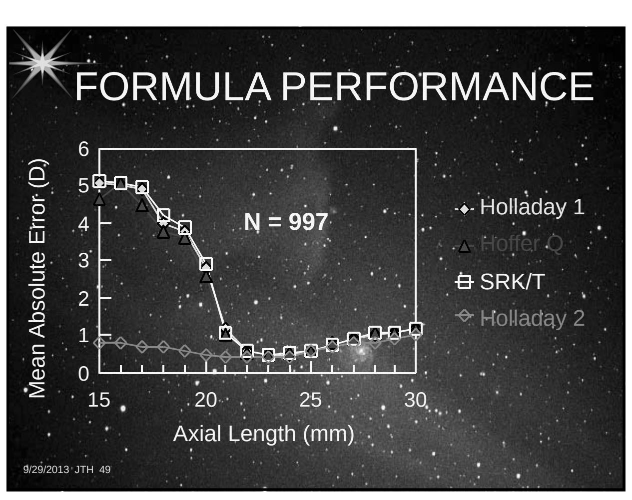

Critical Data
Corneal Power
"Optical" Axial Length
Horizontal "White-to-White"(11.7)
AC angle = WTW + 1.0 (12.7)
Sulcus = WTW + 1.5 (13.2)
Bag = WTW – 1.0 (10.7)

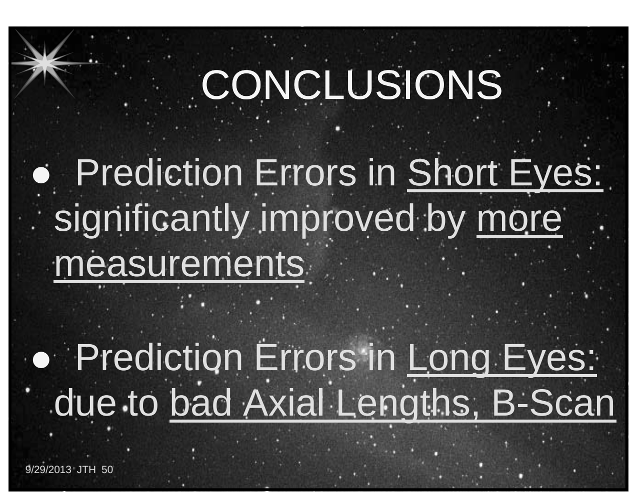

CONCLUSION
Eye Model must include
NINE
types of eyes not only
THREE

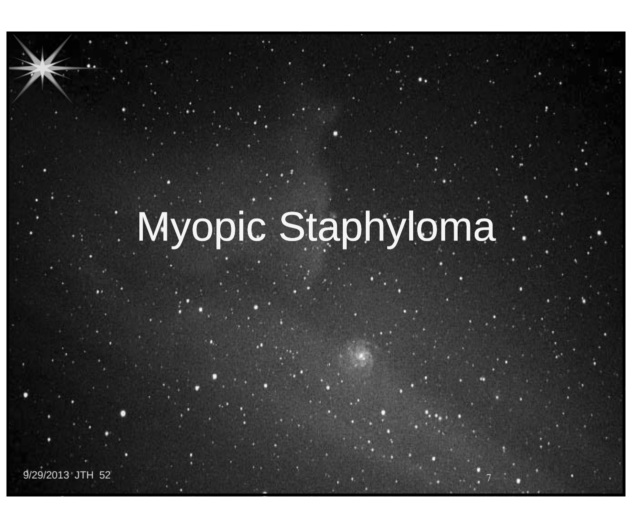

CONCLUSION: 9 EYES
Anterior Segment Size
Large
Megalocornea + axial hyperopia (0%)
Megalocornea (2%)
Large Eye Buphthalmos Megalocornea + axial myopia (10%)
Normal
axial hyperopia (80%)
normal (96%)
axial myopia (90%)
Small
Small eye Nanophthalmia (20%)
Microcornea (2%)
Microcornea + axial opia (0%)
Short
Normal
Long
Axial Length


Relative Importance of Predictors for ELP
❶ Axial Length 100
❷ Average K 76
❸ Horizontal WTW 24
❹ Refraction 18
❺ ACD 8
❻ LT 7
❼ Age 1


THE HOLLADAY 2 FORMULA
More Measurements
More Accuracy


FORMULA PERFORMANCE
N = 997
Mean Absolute Error (D)
Axial Length (mm)
Holladay 1
SRK/T
Holladay 2


CONCLUSIONS
Prediction Errors in Short Eyes: significantly improved by more measurements
Prediction Errors in Long Eyes: due to bad Axial Lengths, B-Scan


Myopic Staphyloma

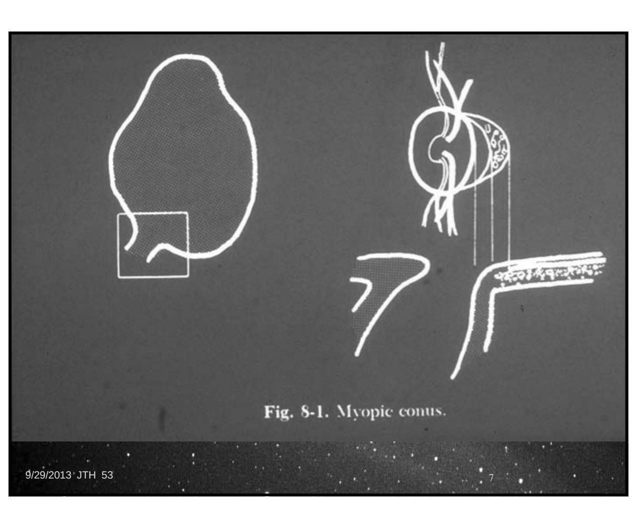
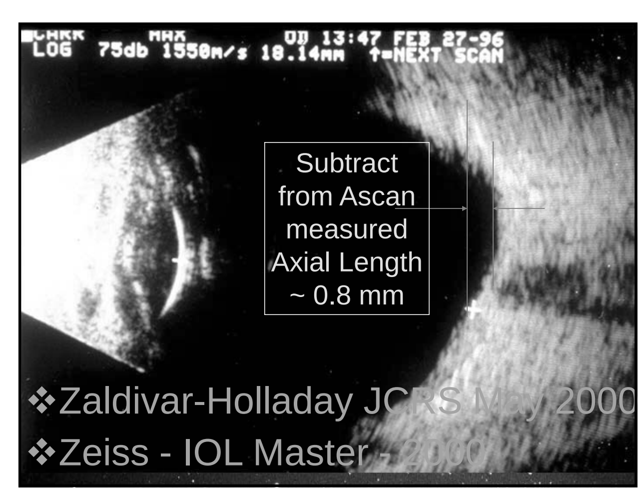
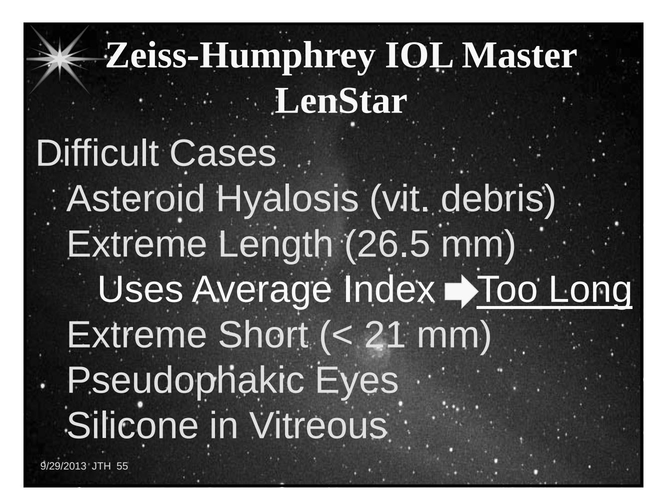
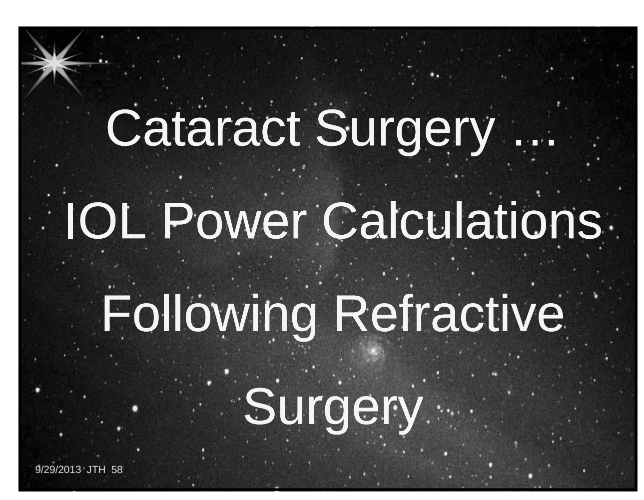
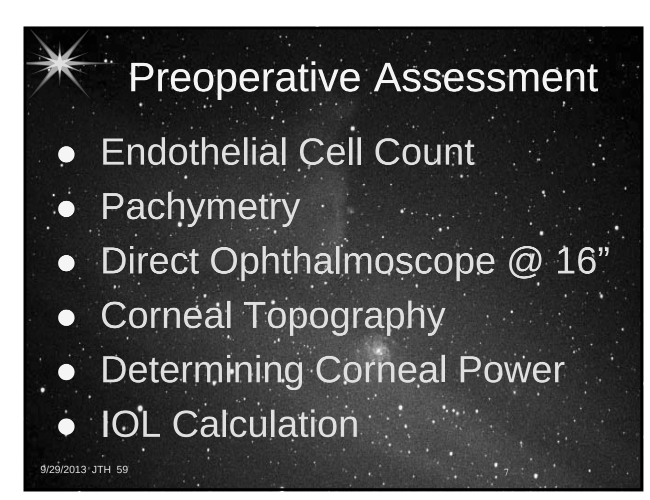


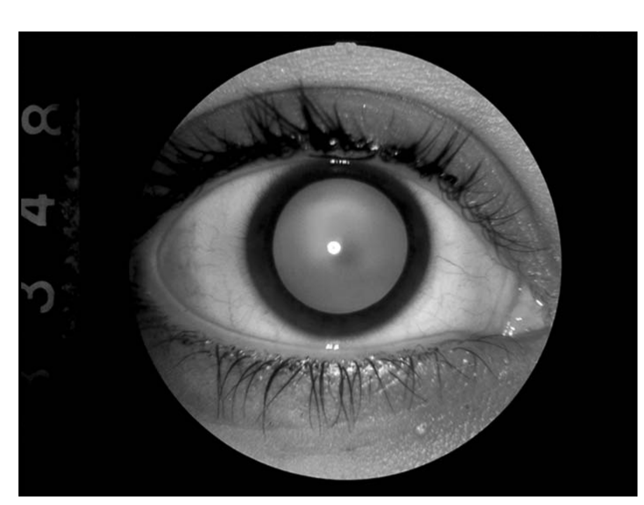
Fig. 8-1. Myopic conus

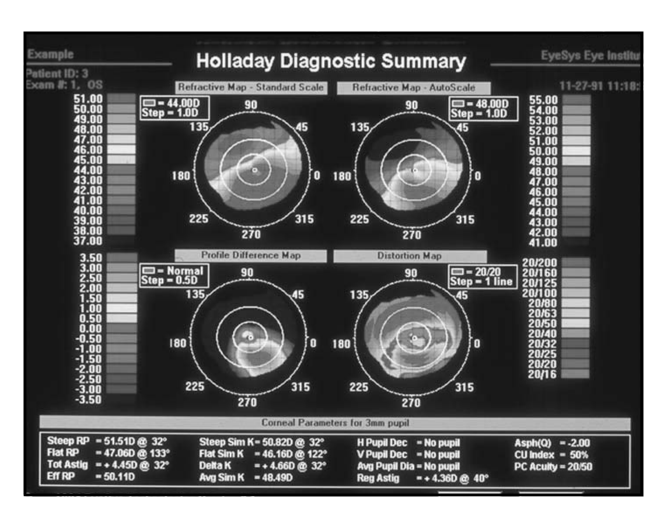

Subtract from Ascan measured Axial Length ~ 0.8 mm
❖Zaldivar-Holladay JC
❖Zeiss - IOL Master


Zeiss-Humphrey IOL Master LenStar
Difficult Cases
Asteroid Hyalosis (vit. debris)
Extreme Length (26.5 mm)
Uses Average Index ➡Too Long
Extreme Short (< 21 mm)
Pseudophakic Eyes
Silicone in Vitreous


Cataract Surgery …
IOL Power Calculations
Following Refractive
Surgery


Preoperative Assessment
Endothelial Cell Count
Pachymetry
Direct Ophthalmoscope @ 16"
Corneal Topography
Determining Corneal Power
IOL Calculation



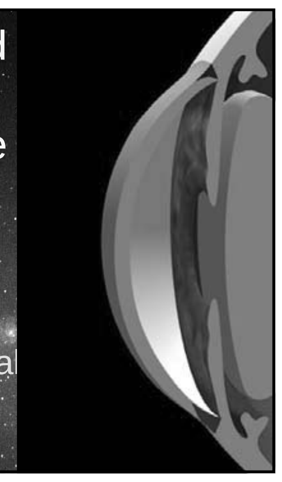

Holladay Diagnostic Summary

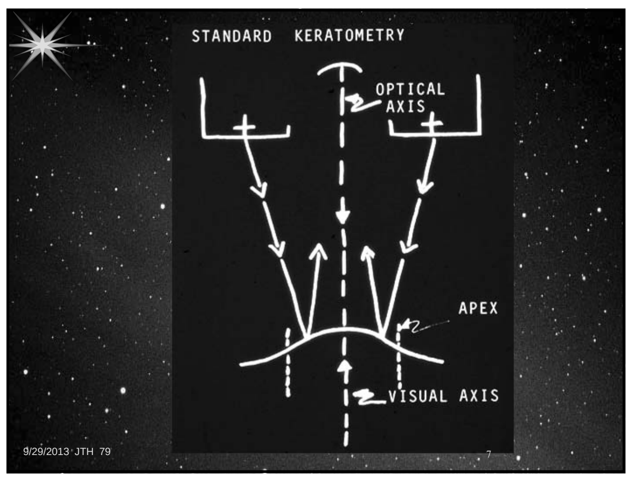
Corneal Power after LASIK, PRK, RK

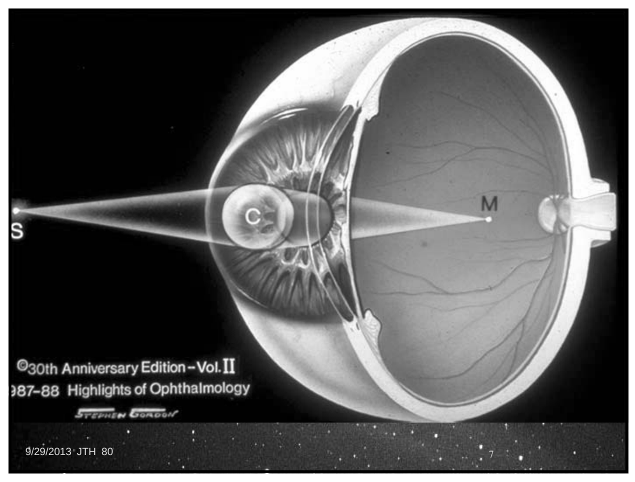
1. Ideally, Calculation from both surfaces …
2. Calculation from Prior Data Trial
3. Hard Contact Lens
4. Corneal Topography
5. Automated Keratometry
6. Manual Keratometry

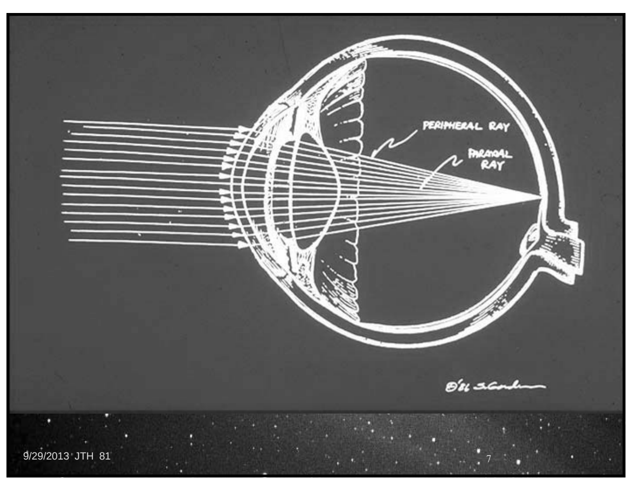
Pachymetry and Posterior Corneal Surface

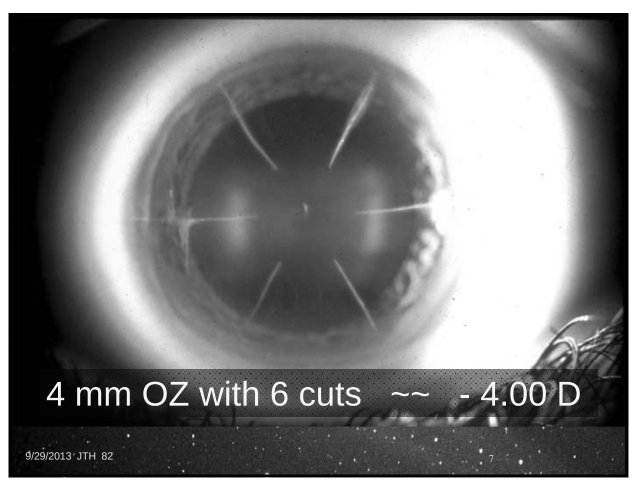
New patented laser cross for measurement of posterior corneal surface and optical pachymentry

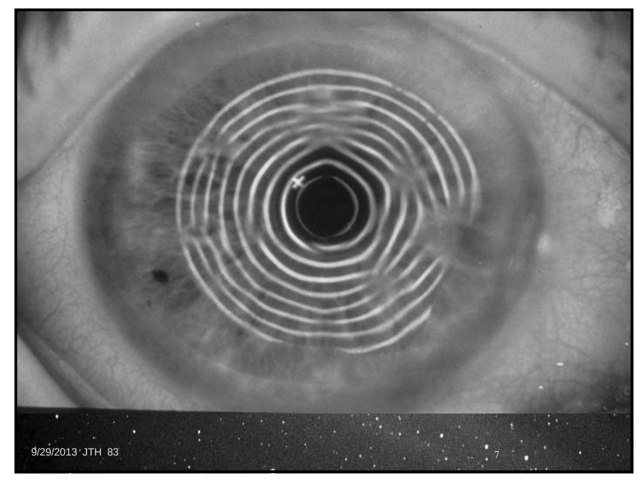


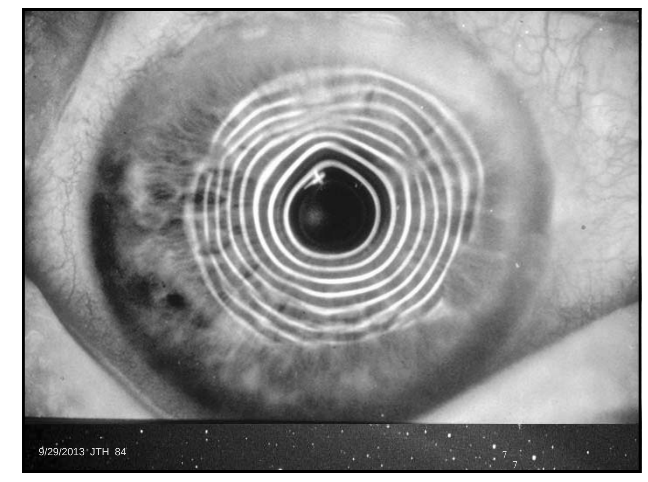


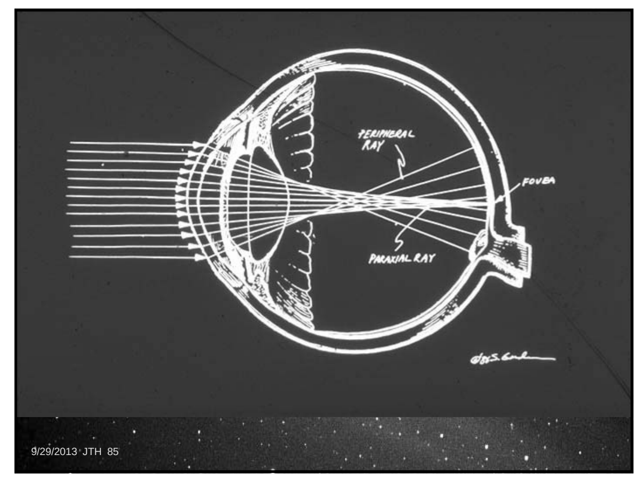


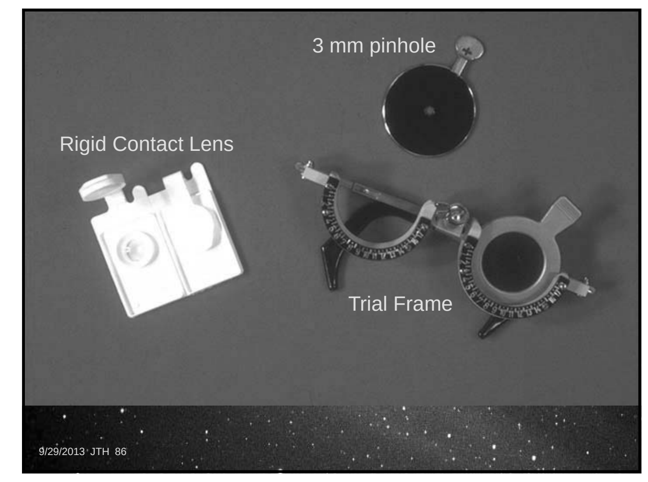












1. Calculation from Prior Data (Pre K & Δ MR known)

Pre KR Mean K = 44.00 D

Change in SEQ Ref = -4.50 D

<u>Calc Mean K</u> = <u>39.50 D</u>

2. Calculation from Prior Data (Post Std. K's & Δ MR only)

Post Mean K = 40.58 D

Change in SEQ Ref = -4.50 D

STD K's: -0.24 * SEQ = -1.08

<u>Calc Mean K</u> = <u>39.50 D</u>

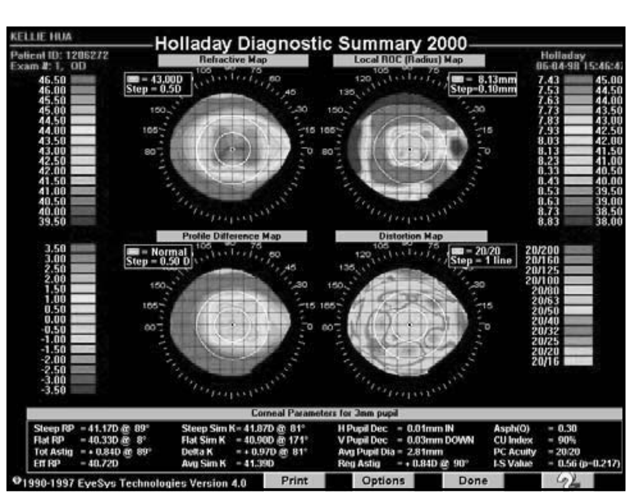
3. Calculation from Prior Data (Post Ctr Top Power & Δ MR only)

Post Mean K = 40.27 D

Change in SEQ Ref = -4.50 D

Ctr Top: -0.15 * SEQ = -0.77

<u>Calc Mean K</u> = <u>39.50 D</u>

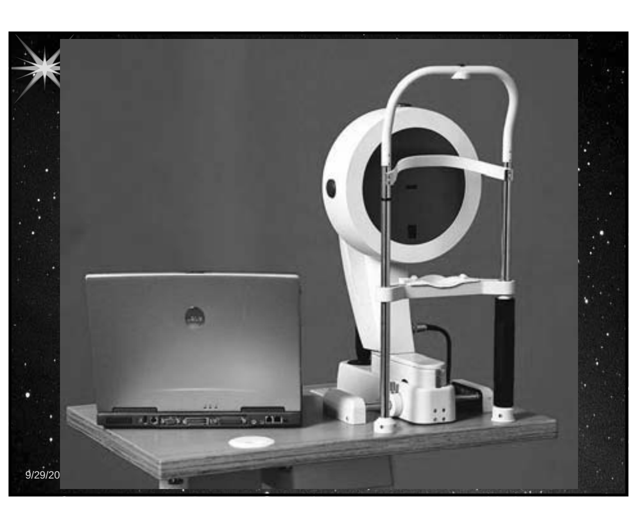


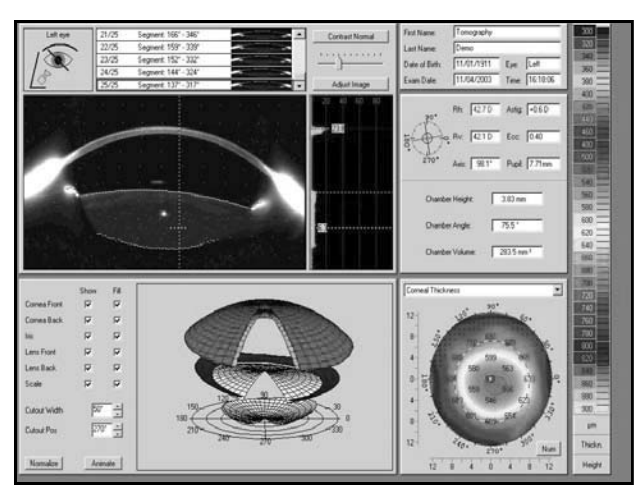
4. Trial Hard Contact Lens (Rigid Contact lens only)

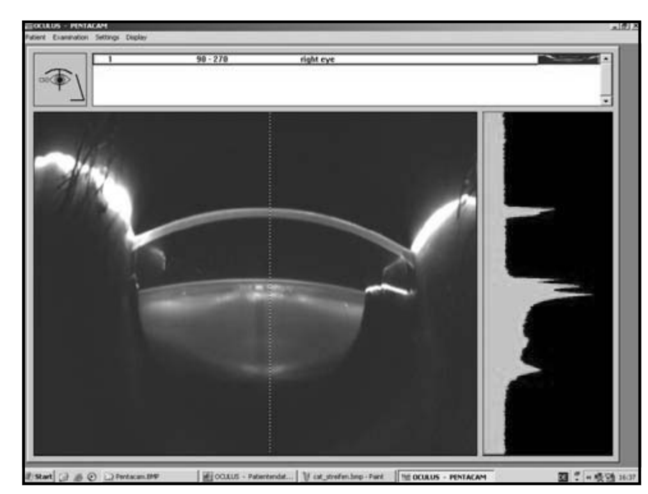
Plano HCL Base Curve = 41.50 D
SEQ Ref <u>without</u> CL = +0.50 D
SEQ Ref <u>with</u> CL = -1.00 D
Front <u>K</u> = 41.50 - 1.50 = 40.00 D
40.00 D – 10% (4.50) = 39.50 D
<u>Mean K</u> = <u>39.50 D</u>

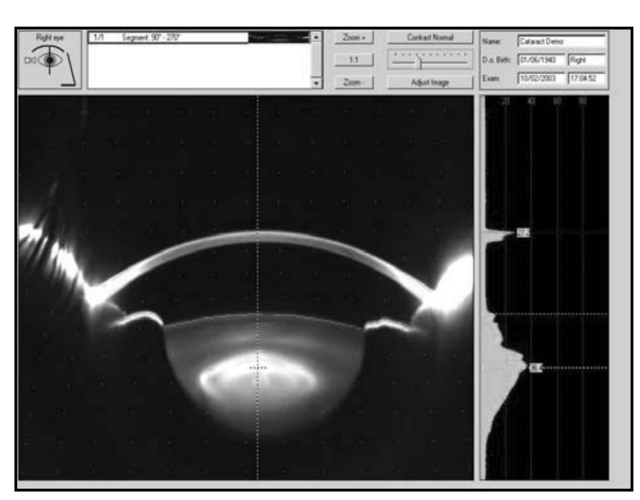
Post-operative

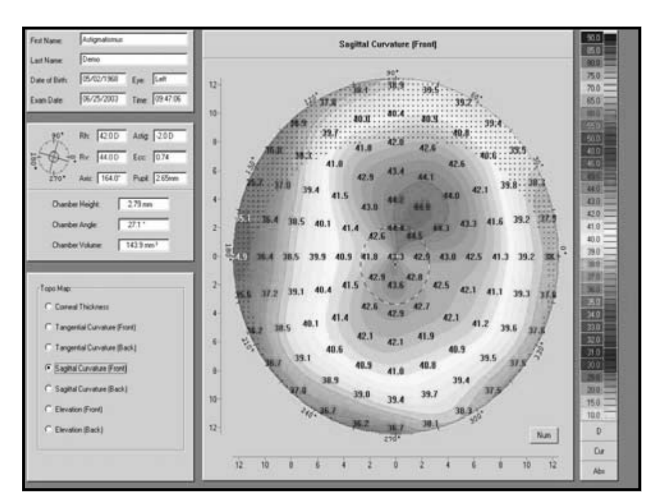
- Initial Hyperopic Shift
- Long Term Hyperopic Drift
- ATR Astigmatism Drift

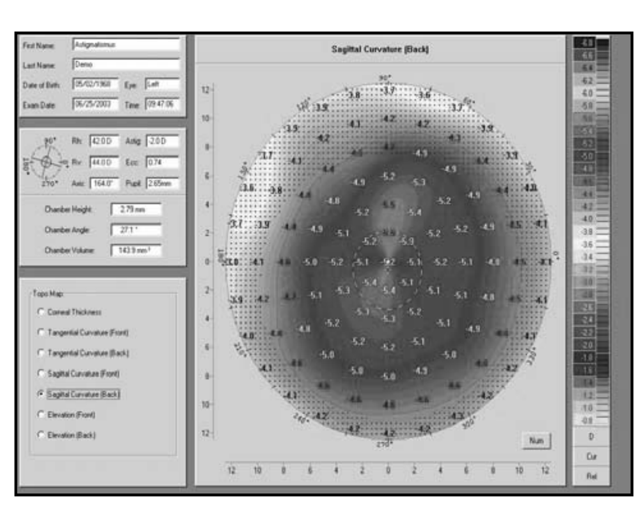








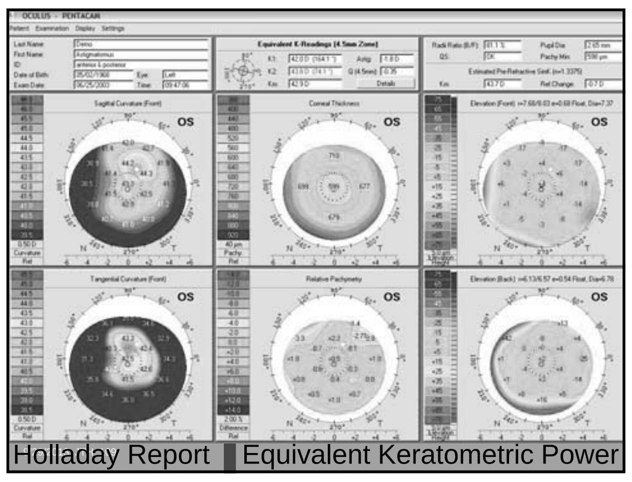


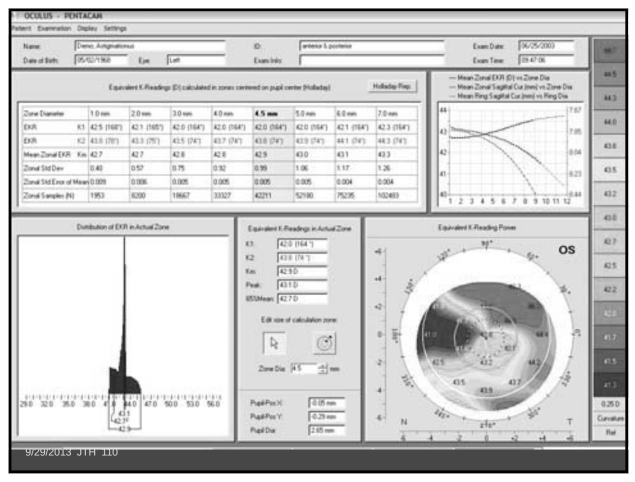


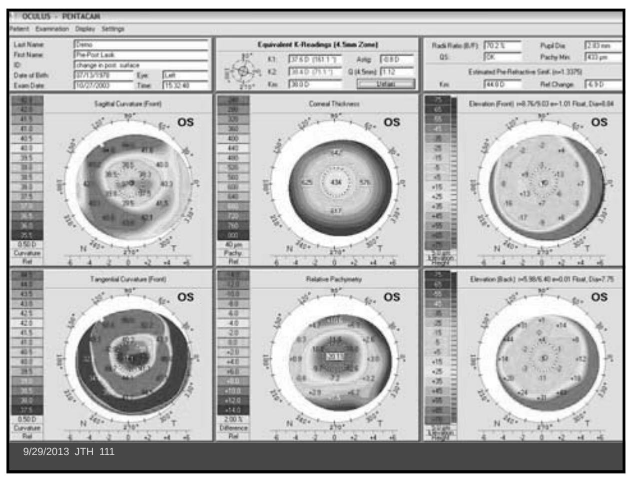
Accuracy of EKR

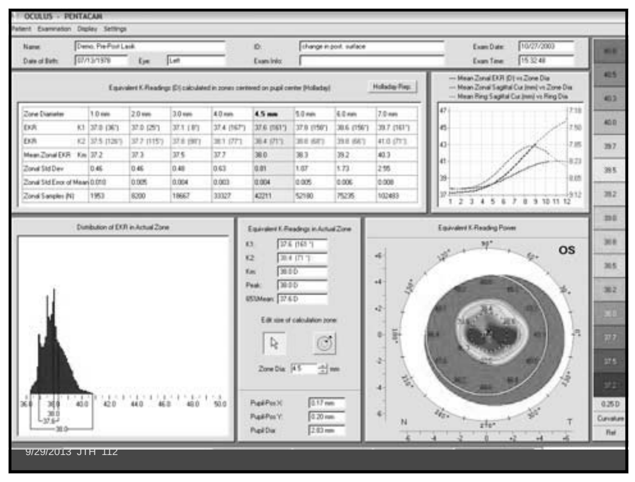
Prior Sx	STD 4.5 (D)
LASIK	0.56
RK	0.94

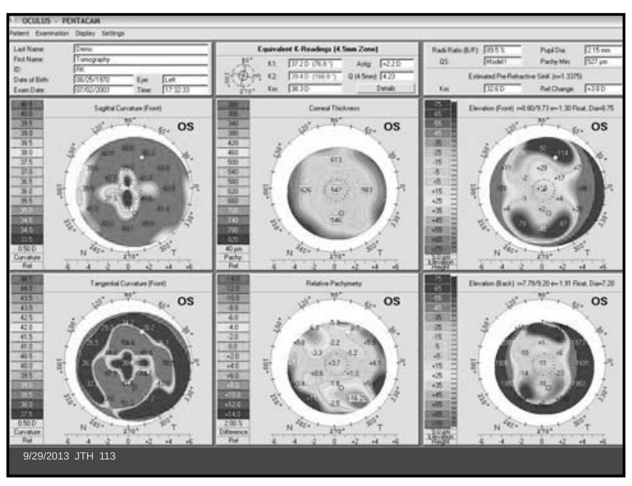
Holladay JT, Hill WE, Steinmueller A. Corneal Power Measurements Using Scheimpfl ug Imaging in Eyes With Prior Corneal Refractive Surgery. J Refractive Surgery 2009:25:862-868. (October 2009 Issue of J Refr Surgery)

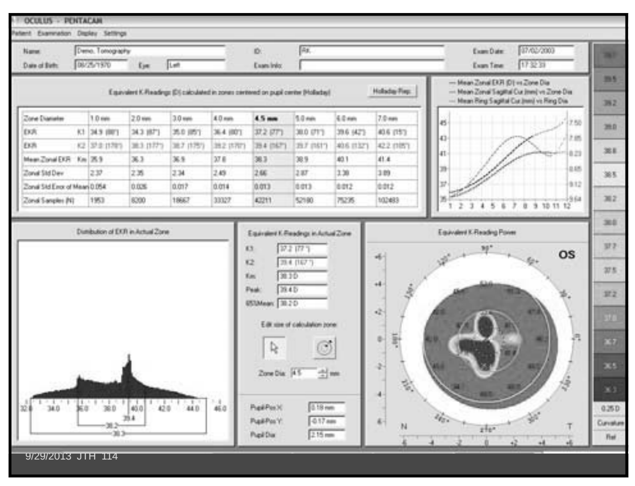


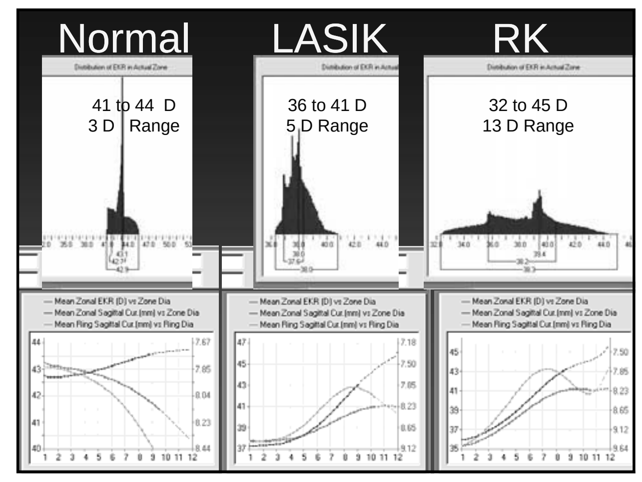












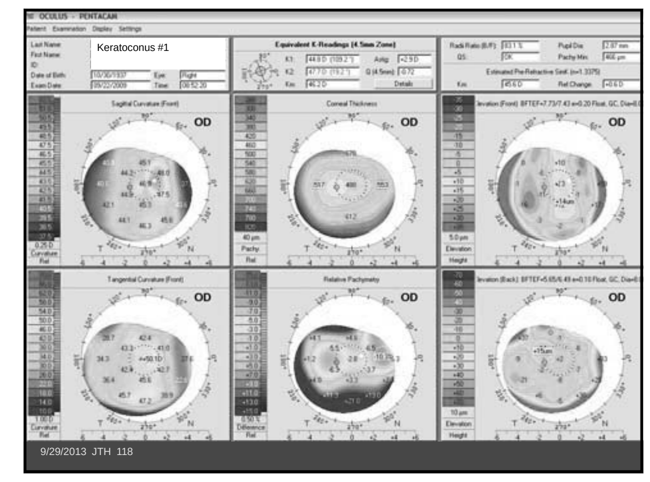
Summary

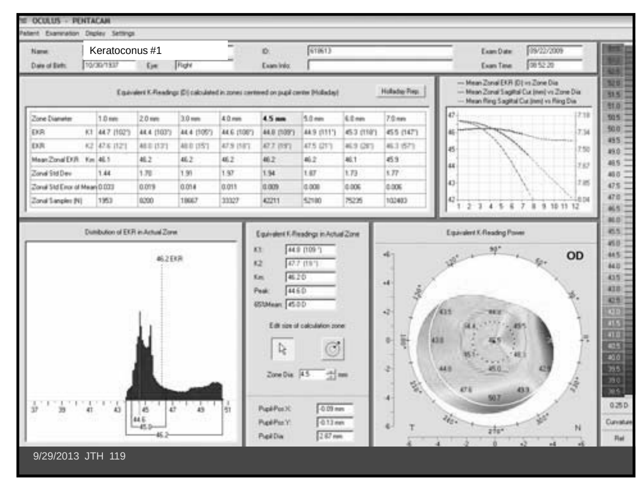
- Optimal Zone
  - LASIK: 4.5 mm
  - RK: 5.0 mm
  - Customize for small/large pupils
- Accuracy
  - LASIK: ± 0.56 D
  - RK: ± 0.94 D
- Error on MYOPIC side

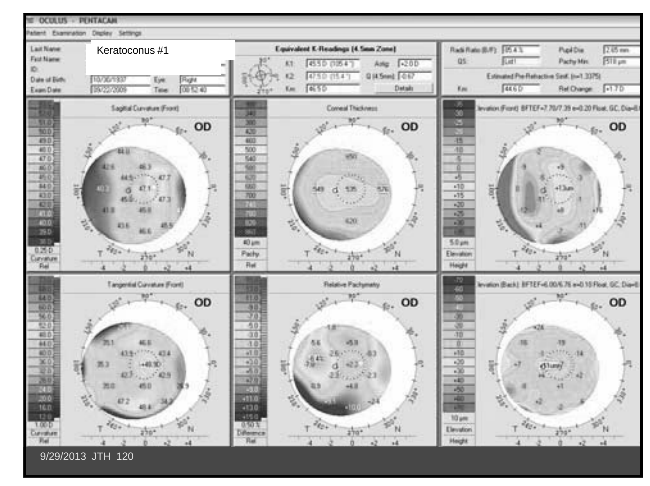
9/29/2013 JTH 116

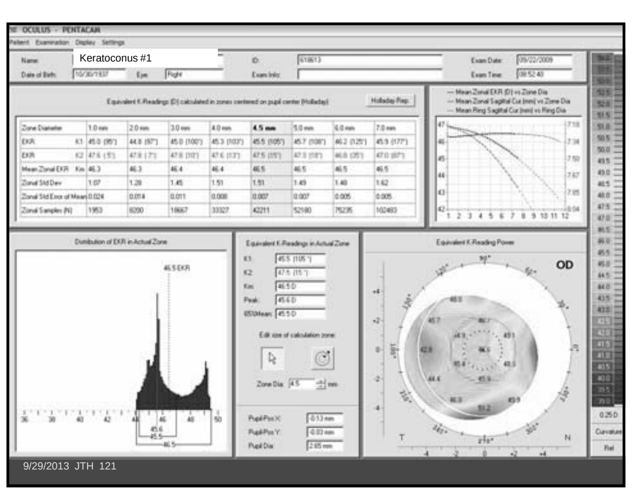
IOL CALCS in Keratoconus

- Corneal is Bifocal
- Patient does not look through cone for distance (may use at 10 cm as magnifier
- Look at Power Distribution
- Use Paracentral Power (65% Mean Power)









Keratoconus Calculation #1 OS

- Used Km = 46.5 D => +1.00 D
- Should have used 65% Mean
  - 45.5 D => plano
  - should have targeted -0.50 D (-0.50 always better than +0.50)

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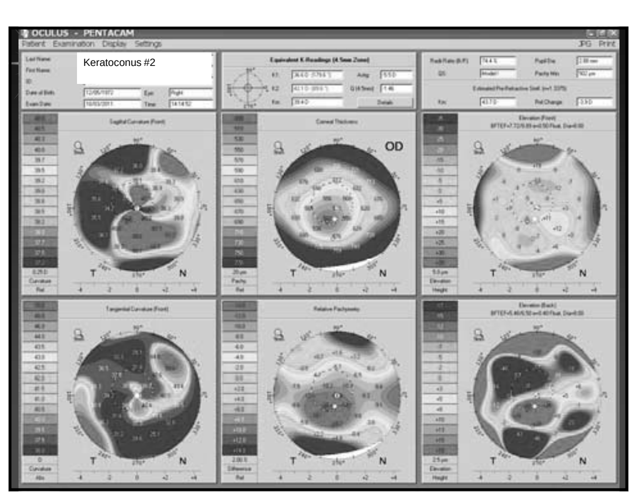
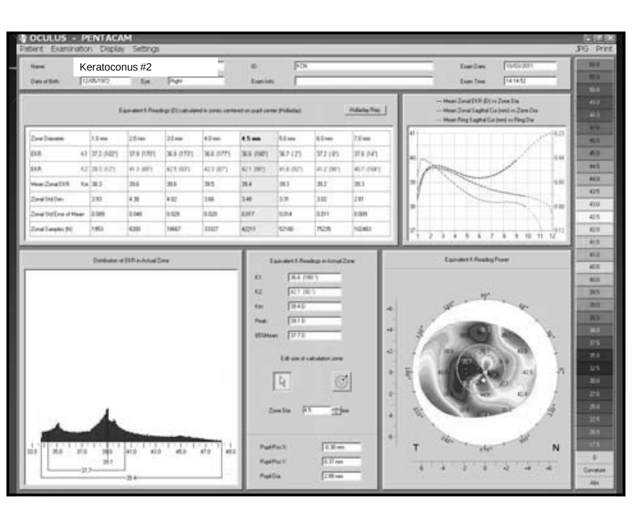
Keratoconus Calculation #2

Dear Dr. Holladay,
> Will you please review this case and give me some insight. A KKC with Intacs patient undewent ECCE/IOL the doc targeted -4.OO so as to not make him anisometropic. I used the Pentacam 3.0mm zone EKR and the Holladay ll formula. The patient came out Pl -0.75x 135= 20/30! UCVA = 20/40. Patient is very very happy. But, this was an unintended outcome. How does one measure the central corneal power in an Intacs pt?. Can you determine the cause of this outcome?. It appears that the cornea must be flatter than what the instruments measured? Is that a correct assumption. The suggested IOL power was 26.0D. for a target 0f -4.00. When I click the keratoconous box (after the fact) for the same target the suggested IOL power was 27.50.?????? What should I have done differently!
>
> Please Advise! THANK YOU 1000x
> Yvonne

9/29/2013 JTH 123





Keratoconus Calculation #2

- Used Km = 39.60 D => Plano, but targeted for -4.00 D
- Should have used 65% Mean
  - 37.7 D => +2.00 D
  - If had ✓ KKC => +0.50 D

(not ✓ will use steeper K to size eye)

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Keratoconus Case #3

- Dear Dr. Holladay,
  I am so pleased and excited to tell you about a very successful outcome involving IOL calcs on KCN patient and the assistance Holladay distribution scale on the Pentacam. I thought you might find this case interesting and gratifying at the least.

  Pre Op Refraction: +5.75 -8.00x 075= 20/40 IOLM ks 47/54.17 x 91

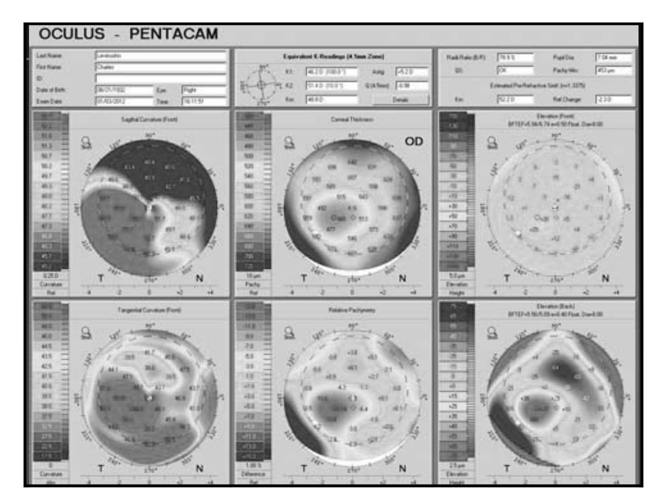
  1wk Post-Op Refraction : -0.50-3.25X65 = 20/50 The surgeon placed a temporal suture. Will this 1 suture significantly impact the astigmatism?

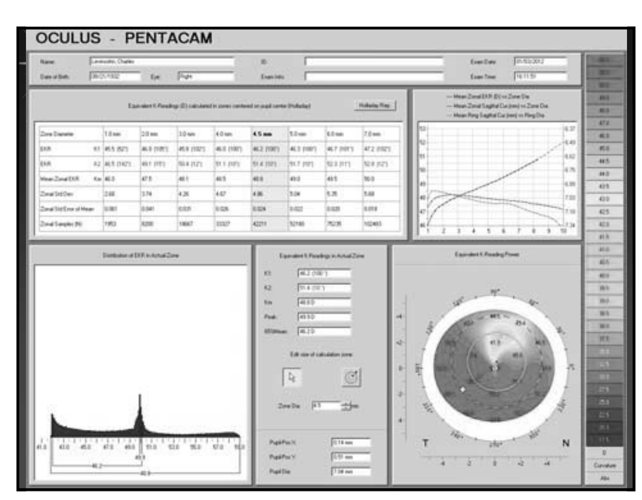
  I ran IOL calcs based on instructions you gave me on a similar case ,previously. You instructed me to use the Ks from a paracentral region derived from the EKR Distribution scale on Holladay report. I used the Ks from the smaller peak which I approximated to be about 44D. With those Ks and Holladay consultant we obtained the above results. I think this case demonstrates the invaluable utility of the Holldaday report when calculating IOL power in pts with KCN.

  I attached the screenshots of Pentacam and IOL calcs. The technician who perfromed the IOL Master was unable to get ACD with IOLM and failed to get ACD with Immersion ultrasound- thats the reason that field is blank.

  Yvonne

9/29/2013 JTH 127





Keratoconus Calculation

- K_{mean} = 48.8 D
- Used 44 D => SEQ = -2.12 D (-0.50-3.25X65 = 20/50)
- 65% mean = 46.2 D => +0.08 D
- Always ✓ KKC
- Use 65% mean K

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IOL Calcs Using Axial Length

- Cataract or Clear Lens Removal
  - Primary Piggy-Back IOL's
  - Multifocal IOL's
  - Toric IOL's
  - Silicone in Vitreous Compartment

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Axial Length Measurements

- Phakia AL_{1555}
- Aphakia AL_{1532}
- Pseudophakia
  - PMMA AL_{1532} + 0.4
  - Silicone AL_{1532} - 0.6
  - Acrylic AL_{1532} + 0.2

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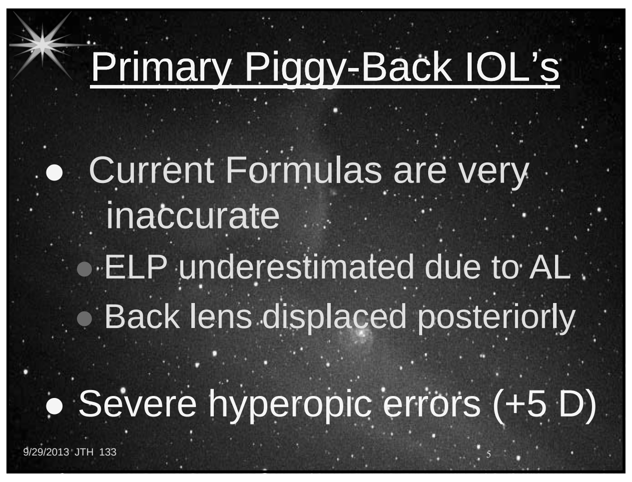
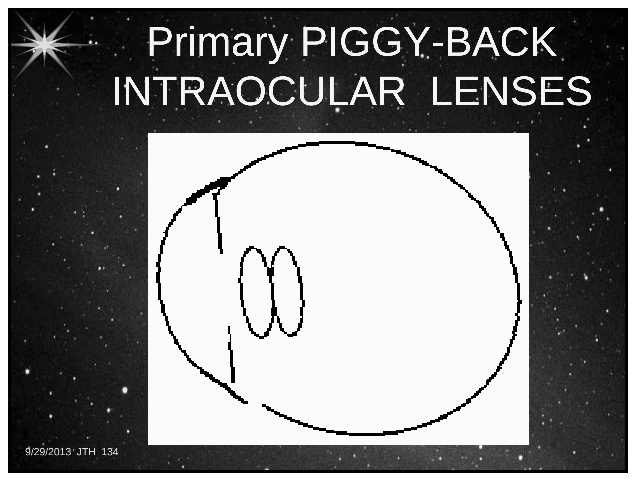
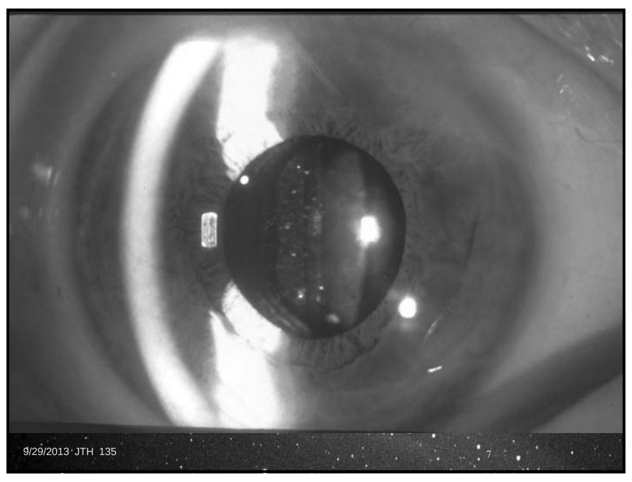
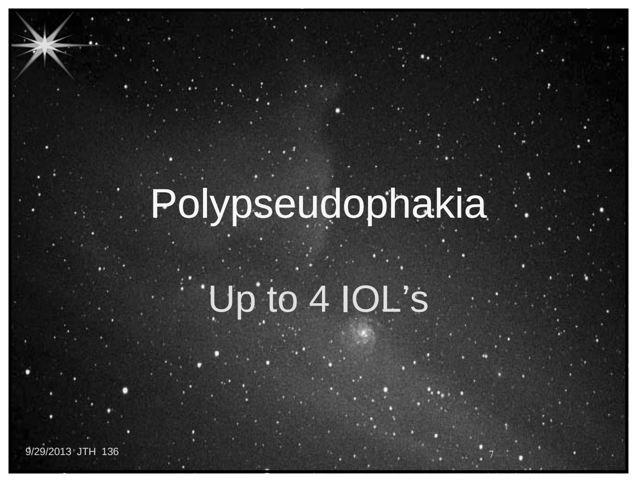
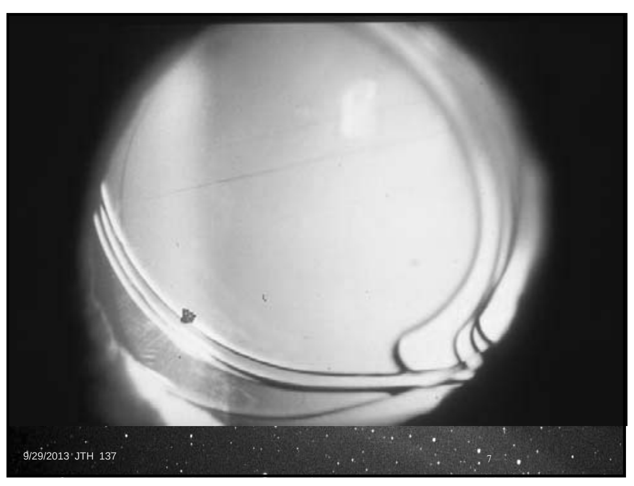
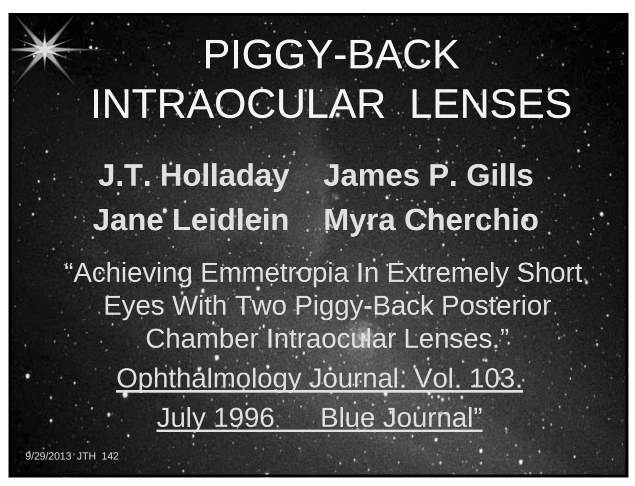


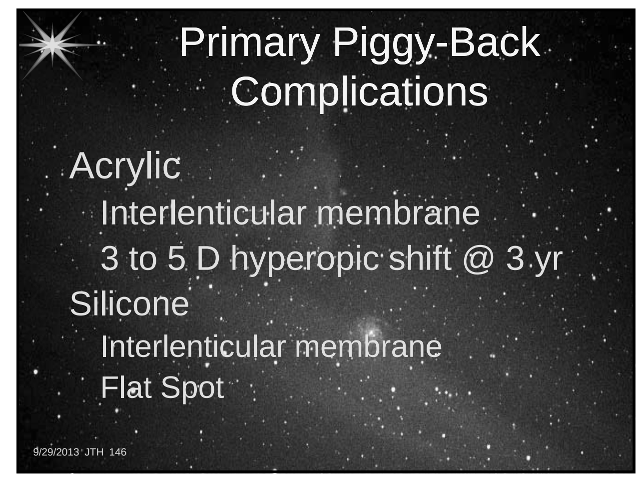


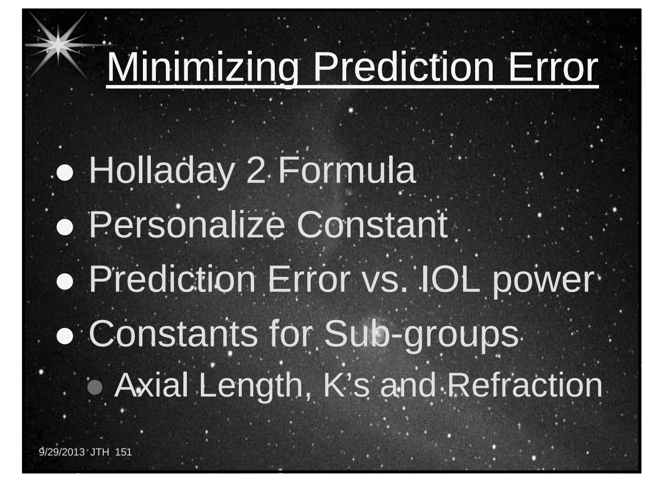


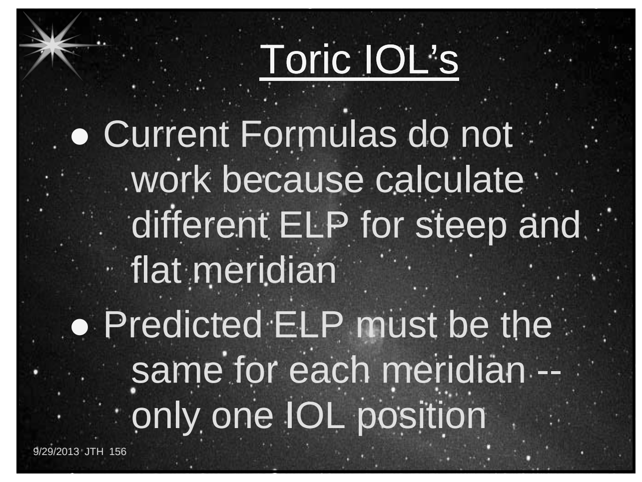


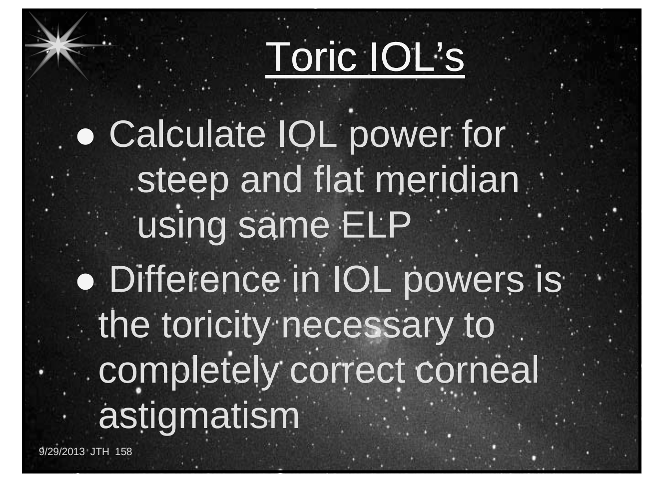


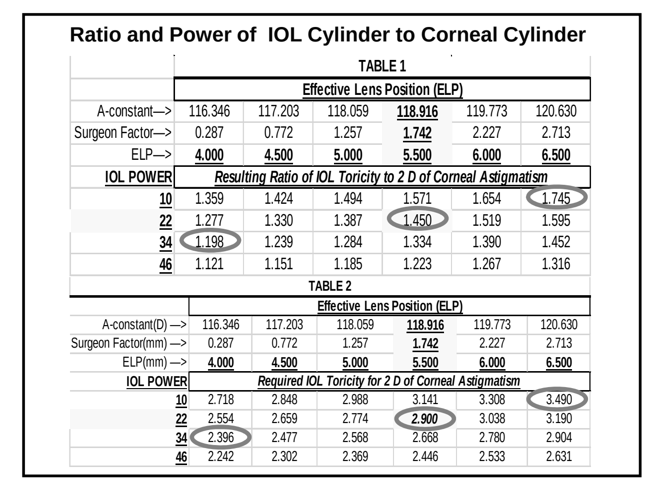












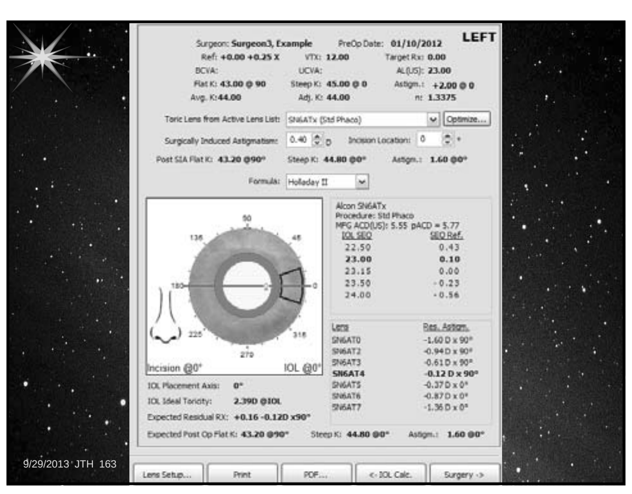
Ratio and Power of IOL Cylinder to Corneal Cylinder

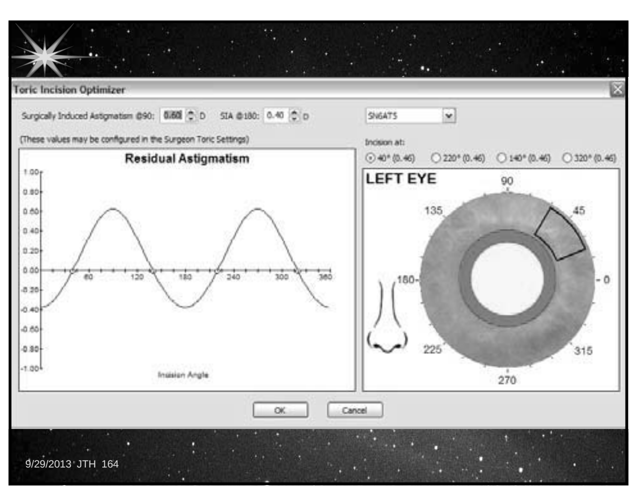
TABLE 1

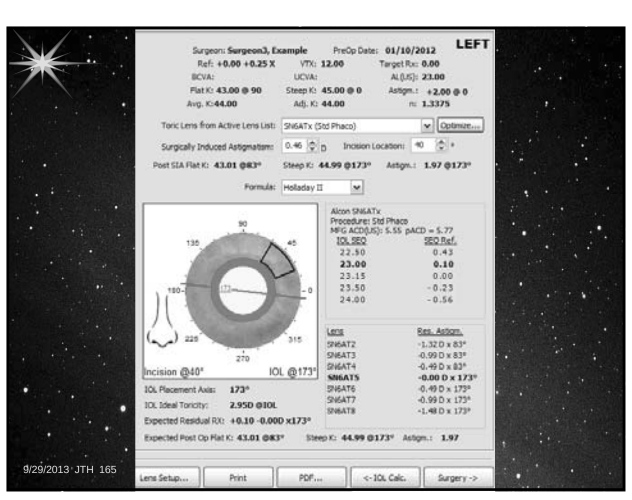
	Effective Lens Position (ELP)					
A-constant—>	116.346	117.203	118.059	118.916	119.773	120.630
Surgeon Factor—>	0.287	0.772	1.257	1.742	2.227	2.713
ELP—>	4.000	4.500	5.000	5.500	6.000	6.500
IOL POWER	Resulting Ratio of IOL Toricity to 2 D of Corneal Astigmatism					
10	1.359	1.424	1.494	1.571	1.654	1.745
22	1.277	1.330	1.387	1.450	1.519	1.595
34	1.198	1.239	1.284	1.334	1.390	1.452
46	1.121	1.151	1.185	1.223	1.267	1.316

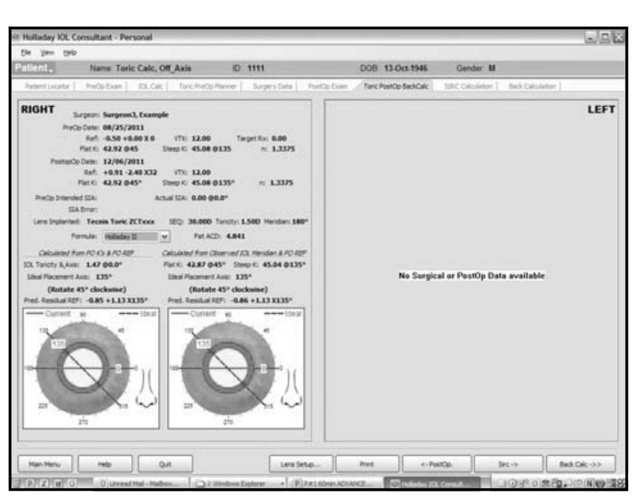
TABLE 2

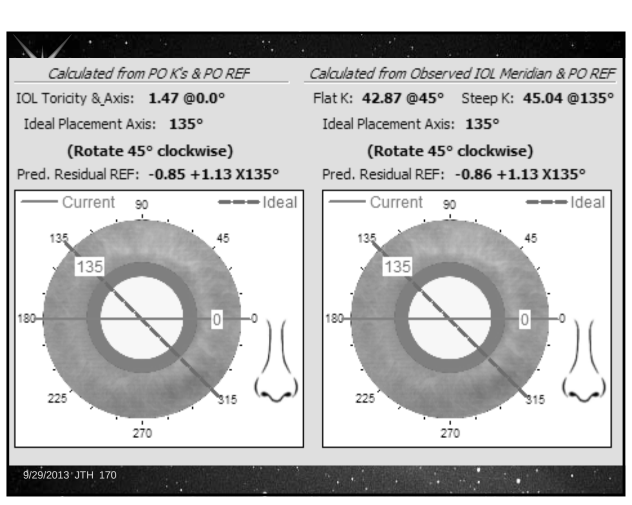
	Effective Lens Position (ELP)					
A-constant(D) —>	116.346	117.203	118.059	118.916	119.773	120.630
Surgeon Factor(mm) —>	0.287	0.772	1.257	1.742	2.227	2.713
ELP(mm) —>	4.000	4.500	5.000	5.500	6.000	6.500
IOL POWER	Required IOL Toricity for 2 D of Corneal Astigmatism					
10	2.718	2.848	2.988	3.141	3.308	3.490
22	2.554	2.659	2.774	2.900	3.038	3.190
34	2.396	2.477	2.568	2.668	2.780	2.904
46	2.242	2.302	2.369	2.446	2.533	2.631

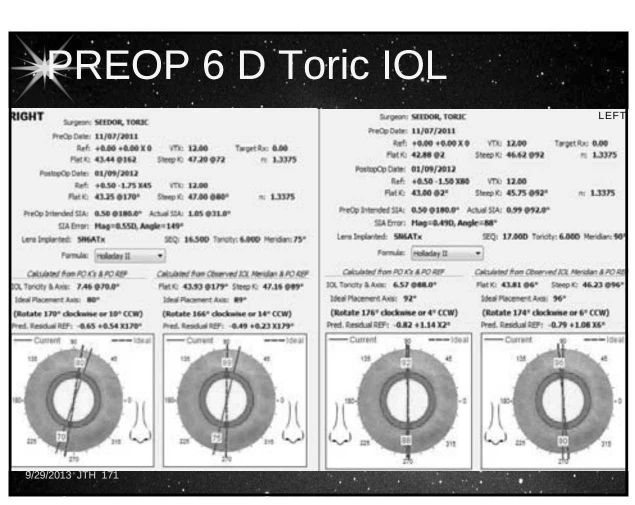


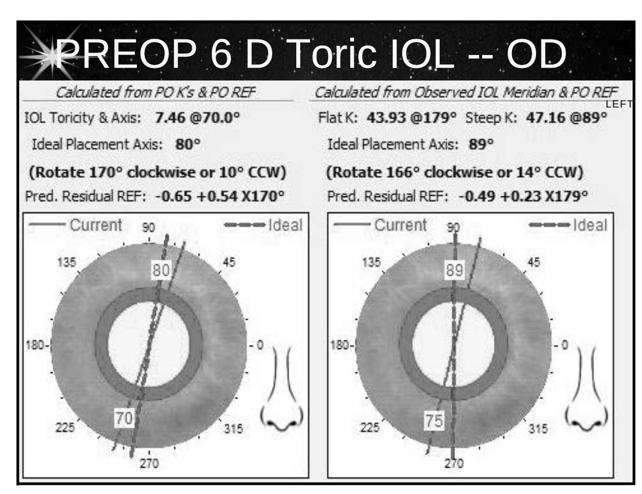


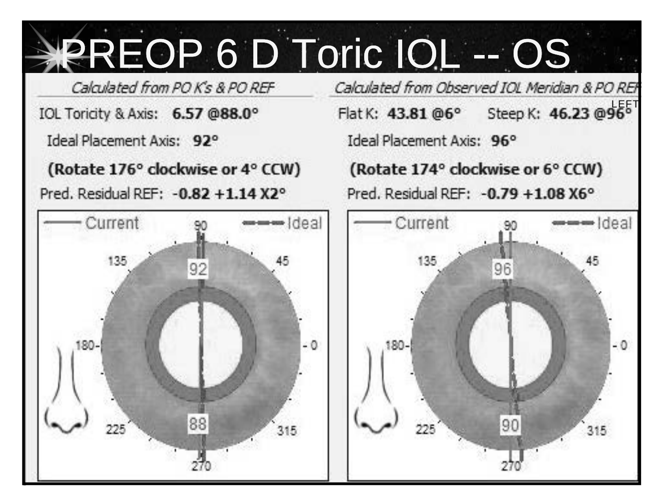


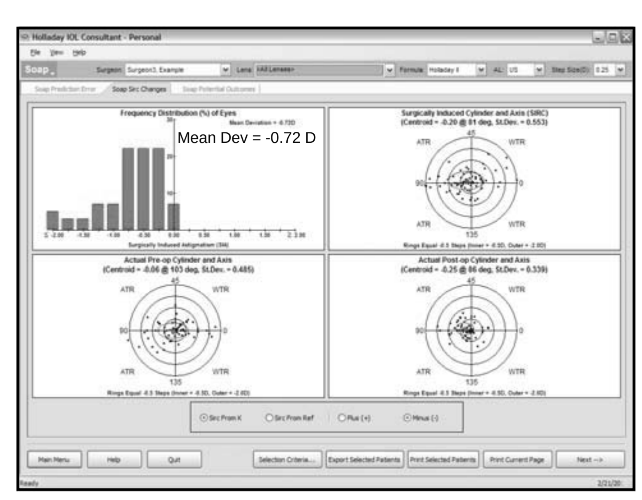


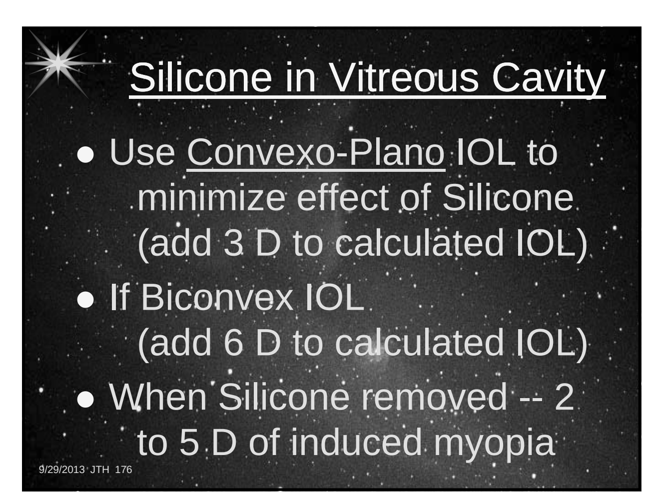


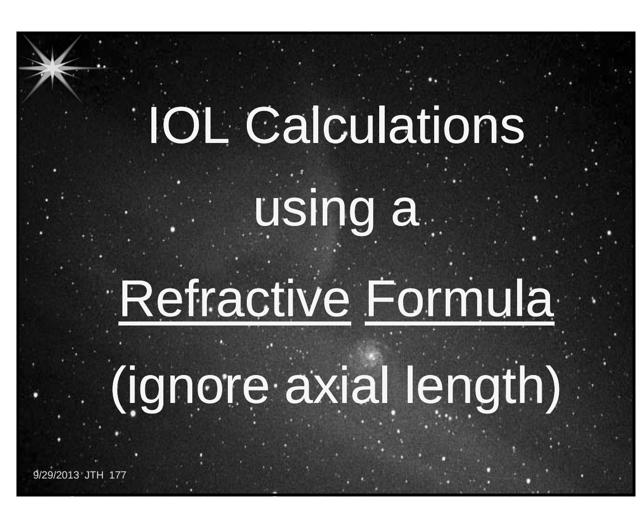


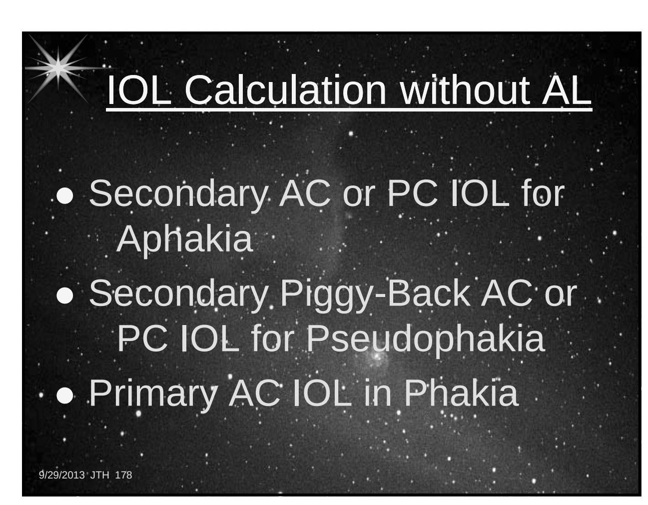












REFRACTION FORMULA

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

Secondary Piggy-Back IOL's Indications

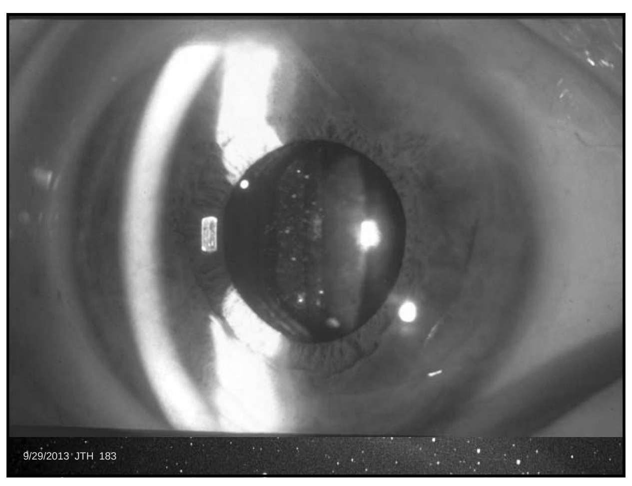
Intolerable Pseudophakic Refractive Error

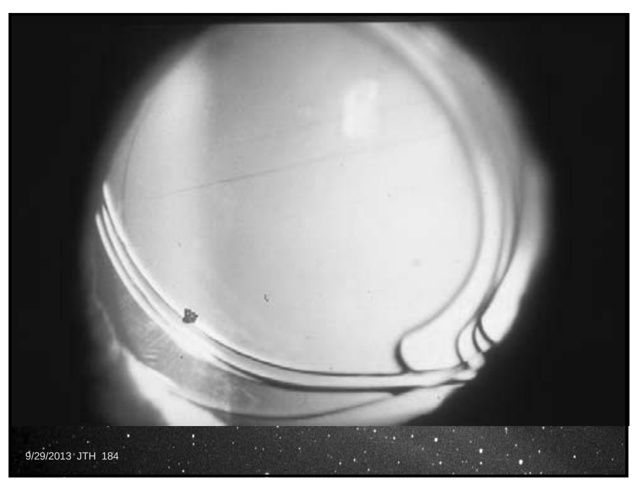
Refractive Surprises

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

Secondary Piggy-Back Calc Advantages over Exchange

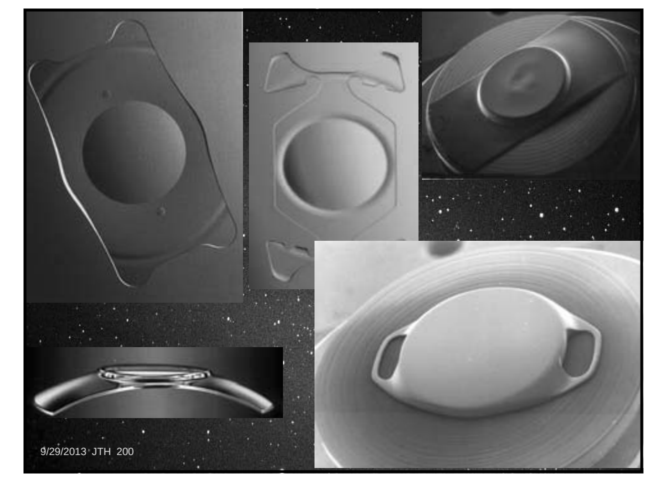
1. Mislabeled IOL irrelevant
2. Less risk to capsule or zonules
3. Mismeasured AL irrelevant
4. No AP shift of existing IOL
5. Fewer unknown variables





Phakic IOL's

- Compete with corneal refractive procedures for high myopia and med & high hyperopia
- ACL, ICL or Iris Clip ?



Phakic IOL's (Secondary Piggy Back IOL's)

Refraction Formula

Phakic IOL Calculation Input Variables

- Refraction and Vertex
- Keratometry
- Desired Refraction
- Predict ELP (ACD) Effective Lens Position

REFRACTION FORMULA

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

Holladay, J.T.: "Refractive Power Calculations for Intraocular Lenses in the Phakic Eye." *American Journal of Ophthalmology*. Volume 116:63-66, July 1993.

Phakic IOL Calculation Input Variables

Refraction and Vertex

Soft Contact Lens @ Vtx = 0 w Small Over-Refraction (< ± 2 D) is most accurate.

Effective Lens Position (ELP) OLD ACD

- Verisye Avg ELP = 4.27 mm
- AACD (20 y/o) = 3.60 mm

AACD + 0.67 mm = ELPx

Effective Lens Position (ELP) OLD ACD

- Visian ICL Avg ELP = 4.00 mm
- AACD (20 y/o) = 3.60 mm

AACD + 0.40 mm = ELPx

Effective Lens Position (ELP) OLD ACD

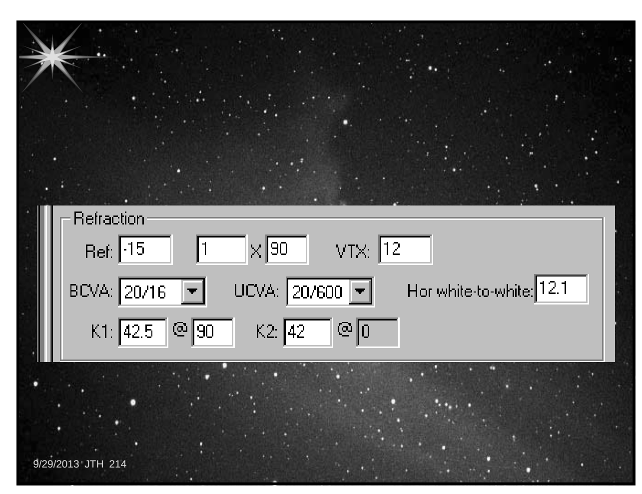
- Visian ICL Avg ELP = 4.00

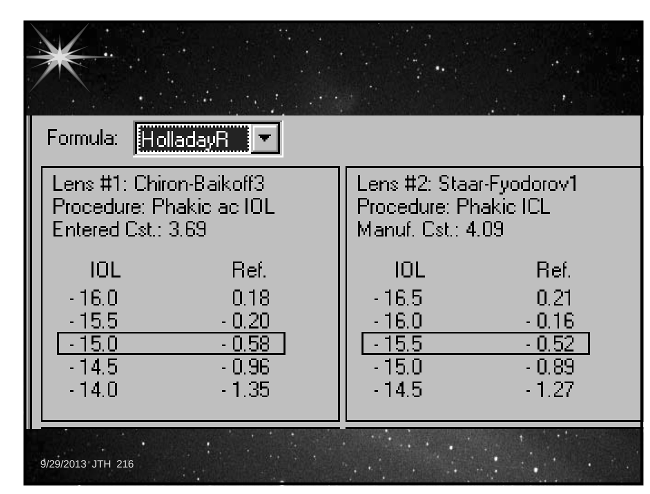
Table of Recommended Visian ICL Overall Diameter by White to White and ACD Measurements

White to White (mm)	ACD (mm)	Recommended ICL Length
<10.5	All	Not Recommended
10.5-10.6	<=3.5	Not Recommended
10.5-10.6	>3.5	12.1
10.7-11.0	All	12.1
11.1	<=3.5	12.1
11.1	>3.5	12.6
11.2-11.4	All	12.6
11.5-11.6	<=3.5	12.6
11.5-11.6	>3.5	13.2
11.7-12.1	All	13.2
12.2	<=3.5	13.2
12.2	>3.5	13.7
12.3-12.9	All	13.7
>=13	All	Not Recommended

Phakic IOL Calculations

- \+ IOL's to Specs ~ 1.5 to 1
- \- IOL's to Specs ~ 1.0 to 1
- Approximation only





Pediatric IOL Calculations

- Ideal Refraction: plano to -1 D
- Expect average of 4 D myopic shift from age 2 to 20
- Much easier to correct myopia at age 20 than amblyopia

Minimizing Prediction Error

- Holladay 2 Formula
- Personalize Constant
- Prediction Error vs. IOL power
- Constants for Sub-groups
  - Axial Length, K's and Refraction

Surgically Induced Refractive Change SIRC

- From Keratometry
  - Cataract & Clear Lensectomy
  - Keratorefractive Sx.
- From Refraction
  - Keratorefractive Sx.

Outcome Analysis

- Prediction Error (50% < 0.50 D)
- Formula Comparisons
- Induced Astigmastism (SIRC)
- Visual Acuity
  - Best Corrected
  - Uncorrected

Back-Calculations

- Helpful in determining cause of refractive surprise
  - Back-calculated K, AL and IOL power compared to pre-op & to post-op remeasured values
  - Back-calculated ELP compared to preoperative prediction by formula