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 Keratorefractive 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
Advanced IOL Power Calculations

Jack T. Holladay, MD, MSEE, FACS
Clinical Professor of Ophthalmology
Baylor College of Medicine
Houston, Texas, USA

Vergence Formula

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

Financial Disclosure

- I have the following financial interests or relationships to disclose:
  - Acufocus® – Consultant
  - Alcon® – Consultant
  - AMO® – Consultant
  - Oculus® – Consultant
  - Visiometrics® – Consultant
  - Wavetec® – Consultant
  - Zeiss® – Consultant

For more information, visit www.docholladay.com
**Vergence Formula**

\[ IOL = \frac{1336}{AL - ELP} - \frac{1336}{1000} - \frac{1000}{V - DPostRx} + K \]

**Effective Lens Position (ELP)**

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

**Prediction of ELP**

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
5. 1996 Holladay 2 (7) AL, K, ACD, LT, HWTW, REF, AGE

**Investigation**

- International Study - 1993
- 34 investigators (15 U.S.)
- Additional measurements are taken
  - 35 eyes < 21 mm
  - 35 eyes > 26 mm
  - 35 eyes = normal
Measurements taken for Predictors of ELP
1. Axial Length
2. Average K
3. Horizontal WTW
4. ACD
5. LT
6. Pre-op Refraction
7. Age

HWTW Gauge
- Horizontal Corneal Diameter.

ASICO # AE 1576

Normal Eyes

<table>
<thead>
<tr>
<th>Anterior Segment Size</th>
<th># of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>2%</td>
</tr>
<tr>
<td>Normal</td>
<td>98%</td>
</tr>
<tr>
<td>Large</td>
<td>2%</td>
</tr>
<tr>
<td>N = 824</td>
<td></td>
</tr>
</tbody>
</table>

Short Eyes (< 21 mm)

<table>
<thead>
<tr>
<th>Anterior Segment Size</th>
<th># of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>20%</td>
</tr>
<tr>
<td>Normal</td>
<td>80%</td>
</tr>
<tr>
<td>Large</td>
<td>0%</td>
</tr>
<tr>
<td>N = 93</td>
<td></td>
</tr>
</tbody>
</table>
Anterior Segment Size

- Small Normal Large
- Long Eyes (> 27 mm) 90% 10%
- N = 162

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: 9 EYES

Eye Model must include

NINE types of eyes not only

THREE
Relative Importance of Predictors for ELP

1. Axial Length 100
2. Average K 76
3. Horizontal WTW 24
4. Refraction 18
5. ACD 8
6. LT 7
7. Age 1

THE HOLLADAY 2 FORMULA

More Measurements
More Accuracy

FORMULA PERFORMANCE

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. 5-1. Myopic cornea.
Linear Regression to compensate for AVERAGE Index of Refraction in Long Eyes

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

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

Cataract Surgery ...
IOL Power Calculations Following Refractive Surgery

Subtract from Ascan measured Axial Length ~ 0.8 mm

Zeiss - IOL Master - 2000

Zaldívar-Holladay JCRS May 2000

Zeiss-Humphrey IOL Master

Optimizing intraocular lens power calculations in eyes with axial lengths above 25.0 mm

Li Wang, MD, PhD, Martin Shimony, MD, Yingying Jack Ma, Thomas Keilhauer, MD, PhD, FERCO, Douglas D. Koch, MD


PURPOSE: To evaluate the accuracy of refractive predictions of 4 intraocular lens (IOL) power calculation formulas in eyes with axial length (AL) greater than 25.0 mm and to propose a method of optimizing AL to resolve the accuracy.

METHODS: A total of 12 eyes from the Keilhauer, Texas, USA, and Department of Ophthalmology, Cochin University, Frankfurt am Main, Germany.

DESIGN: Case series.

METHODS: Refractive prediction errors with the Holladay 1, Haigis, SRK-T, and Holladay 1 formulas were evaluated in correction cases. Eyes were randomized to groups used to develop the method of optimizing AL by back-calculation or a group used for validation. Further validation was performed in 2 additional data sets.
### 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 pachymetry.
4 mm OZ with 6 cuts  ~  4.00 D

3 mm pinhole

Rigid Contact Lens

Trial Frame
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

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
- Calc Mean K = 39.50 D

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
- Calc Mean K = 39.50 D

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
Post-operative

- Initial Hyperopic Shift
- Long Term Hyperopic Drift
- ATR Astigmatism Drift
Normal       LASIK         RK
41 to 44 D  36 to 41 D  32 to 45 D
3 D   Range  5 D Range  13 D Range

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

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)

Keratoconus Calculation #2

Dear Dr. Holladay,

> Will you please review this case and give me some insight. A KKC with Intacs patient underwent ECCE/IOL the doc targeted -4.00 so as to not make him anisometropic. I used the Pentacam 3.5mm zone EKR and the Holladay II formula. The patient came out Pt = 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 26.00, for a target of -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

3/28/2014 JTH 126
Keratoconus Calculation #2

- Used \( K_m = 39.60 \) 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 \( KKC \) => use steeper \( K \) to size eye)

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 \( K \)s from a paracentral region derived from the EKR Distribution scale on Holladay report. I used the \( K \)s from the smaller peak which I approximated to be about 44D. With those \( K \)s and Holladay consultant we obtained the above results. I think this case demonstrates the invaluable utility of the Holladay report when calculating IOL power in pts with KCN.

I attached the screenshots of Pentacam and IOL calcs. The technician who performed 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

Keratoconus Calculation

- \( K_{\text{mean}} = 48.8 \) 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 \( K \)
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

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

Primary Piggy-Back IOL’s

- Current Formulas are very inaccurate
  - ELP underestimated due to AL
  - Back lens displaced posteriorly
- Severe hyperopic errors (+5 D)

Primary PIGGY-BACK INTRAOCULAR LENSES

Polypseudophakia

Up to 4 IOL’s
Primary Piggy-Back Complications

Acrylic
- Interlenticular membrane
- 3 to 5 D hyperopic shift @ 3 yr

Silicone
- Interlenticular membrane
- Flat Spot

Minimizing Prediction Error

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

Toric IOL’s

- Current Formulas do not work because calculate different ELP for steep and flat meridian
- Predicted ELP must be the same for each meridian – only one IOL position

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
**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)

### Ratio and Power of IOL Cylinder to Corneal Cylinder

**TABLE 1**

<table>
<thead>
<tr>
<th>Surgeon Factor</th>
<th>A-constant</th>
<th>ELP</th>
<th>IOL POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.287</td>
<td>116.348</td>
<td>4.000</td>
<td>1.742, 2.227, 2.713</td>
</tr>
<tr>
<td>0.772</td>
<td>117.203</td>
<td>4.500</td>
<td>1.742, 2.227, 2.713</td>
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<tr>
<td>1.257</td>
<td>118.059</td>
<td>5.000</td>
<td>1.742, 2.227, 2.713</td>
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<td>1.742</td>
<td>118.916</td>
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<tr>
<td>2.713</td>
<td>120.630</td>
<td>6.500</td>
<td>1.742, 2.227, 2.713</td>
</tr>
</tbody>
</table>

**TABLE 2**

<table>
<thead>
<tr>
<th>Surgeon Factor</th>
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### Dioptric Error vs. Angular Error for a 1.00 D of astigmatism

<table>
<thead>
<tr>
<th>Angle Error (°)</th>
<th>Dioptric Error (D)</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0.00</td>
<td>0%</td>
</tr>
<tr>
<td>15°</td>
<td>0.52</td>
<td>52%</td>
</tr>
<tr>
<td>30°</td>
<td>1.00</td>
<td>100%</td>
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<tr>
<td>45°</td>
<td>1.41</td>
<td>141%</td>
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<tr>
<td>60°</td>
<td>1.73</td>
<td>173%</td>
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<tr>
<td>75°</td>
<td>1.93</td>
<td>193%</td>
</tr>
<tr>
<td>90°</td>
<td>2.00</td>
<td>200%</td>
</tr>
</tbody>
</table>

**Dioptric Error = 2 * Cyl * sin (angular error)**
Silicone in Vitreous Cavity

- Use Convexo-Plano IOL to minimize effect of Silicone (add 3 D to calculated IOL)
- If Biconvex IOL (add 6 D to calculated IOL)
- When Silicone removed -- 2 to 5 D of induced myopia

IOL Calculations using a Refractive Formula (ignore axial length)

IOL Calculation without AL

- Secondary AC or PC IOL for Aphakia
- Secondary Piggy-Back AC or PC IOL for Pseudophakia
- Primary AC IOL in Phakia

REFRACTION FORMULA

IOL = \frac{1336}{1000 + K} V + \frac{1336}{1000 + \frac{K}{V}} 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

IOL Power Calcs for Phakic IOLs
(2º Piggy-Back & IOL Exchange after Refractive Surprise)

Jack T. Holladay, MD, MSEE, FACS
Clinical Professor of Ophthalmology
Baylor College of Medicine
Houston, Tx

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 and Vertex

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

REFRACTION FORMULA

\[
IOL = \frac{1336}{1000 + K} \left( V - \frac{1000}{PreRx \cdot V} \right) + \frac{1336}{1000 + K} \left( V - \frac{1000}{DPostRx \cdot V} \right)
\]


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
  
  $$\text{AACD} + 0.40 \text{ mm} = \text{ELP}_x$$

---

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 Astigmatism (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

Thank you!