Advanced IOL Power Calculations

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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
  - Elsena: C, O
  - Oculus, Inc.: C
  - Visiometrics: C, O
  - Wavetec: C

Vergence Formula

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

\[ IOL = \frac{1336}{AL - ELP} - \frac{1336}{1000} - ELP \]
**Effective Lens Position (ELP)**

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

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

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**Investigation**

- International Study - 1993
  - 34 investigators (15 U.S.)
  - Additional measurements are taken
    - 35 eyes < 21 mm
    - 35 eyes > 26 mm
    - 35 eyes = normal

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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-op Refraction
7. Age
HWTW Gauge

Horizontal Corneal Diameter.

ASICO # AE 1576

Normal Eyes

Anterior Segment Size

# of Cases

N = 824

2% 
98% 
2%

Short Eyes (< 21 mm)

Long Eyes (> 27 mm)

Anterior Segment Size

# of Cases

20% 
80% 
0%

0% 
90% 
10%
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

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
RESULTS

New Holladay 2:
- Normal eye: 50% ± 0.40 D
- Unusual eye: 50% ± 0.80 D

Previous results:
- Normal eye: 50% ± 0.50 D
- Unusual eye: 50% ± 5.00 D

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
Figure 6-1. Myopic astigmatism.

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

Li Wang, MD; Thomas Kohner, MD, PhD, FBOA

Subtract from Ascan measured Axial Length ~ 0.8 mm

Zeiss - IOL Master - 2000
Zaldivar-Holladay JCRS May 2000

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

If > 0.70 mm then concern!


Horizontal Angle & Alpha & Kappa

<α < Κ

BEST CENTRATION
OF IOL

Data Screening
Monocular and Binocular

- Using Mean and St. Dev. an exact p-value for each measurement can be calculated
- Any measurement beyond two Std. Dev. from the mean should be double checked (p<0.05)

Monocular: AL = 19.75 mm
p = 0.001

Binocular: K<sub>right</sub> - K<sub>left</sub> = 1.5 D
p = 0.0005
Preoperative Assessment

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

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

Methods listed in order of reliability

- Methods 3, 4 and 5 almost always exceed true power & result in hyperopic error
- Use lowest reliable value
ToPography: Measures Total Power and Total Astigmatism of Lenticle

ToMography: Measures Front Surface Power of Lenticle and then uses back radius of 0.82 of front radius for Total Power and can ADD 0.22 D ATR for Total Astigmatism

Keratometry: Measures Front Surface Ring or annulus Power of Lenticle (nominal 2.0 to 3.2 mm for 44 D cornea) then uses back radius of 0.82 of front radius for Total Power and can ADD 0.22 D ATR for Total Astigmatism

Ring Diameter affects Keratometry

Manual Keratometer Measures 44.0 D
Causes Optical A-Constant to be ~0.3 D Higher than Manual Keratometry

4 mm OZ with 6 cuts ~ ~ 4.00 D
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
\[ 40.00 \text{ D} - 10\% (4.50) \] = 39.50 D
Mean \( K \) = 39.50 D

Post-operative

- Initial Hyperopic Shift
- Long Term Hyperopic Drift
- ATR Astigmatism Drift
Accuracy of EKR

<table>
<thead>
<tr>
<th></th>
<th>Prior</th>
<th>STD 4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sx</td>
<td></td>
<td>(D)</td>
</tr>
<tr>
<td>LASIK</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>RK</td>
<td>0.94</td>
<td></td>
</tr>
</tbody>
</table>


New algorithm for intraocular lens power calculations after myopic laser in situ keratomileusis based on rotating Scheimpflug camera data

J Cataract Refract Surg Feb 2015; 41:339–347

Holladay Report
Equivalent Keratometric Power
Normal       LASIK         RK

41 to 44 D   3 D   Range
36 to 41 D   5 D Range
32 to 45 D   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 undewent ECCE/IOL. The doc targeted -4.00 so as to not make him anisometropic. I used the Pentacam 3.0mm zone EKR and the Holladay II formula. The patient came out ≈ -4.75x 135° ≈ 20/30. UCVA = 20/40. Patient is 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 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

Keratoconus #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)

Keratoconus Case #3

Dear Dr. Holladay,
I am so pleased and excited to tell you about a very successful outcome involving IOL calculations on KCN patients 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
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 scales 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 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—this is the reason that field is blank.

Yvonne
Keratoconus Calculation

- $K_{\text{mean}} = 48.8 \text{ D}$
- Used 44 D $\Rightarrow$ SEQ = -2.12 D $\left(-0.50-3.25 \times 65 = 20/50\right)$
- 65% mean = 46.2 D $\Rightarrow$ +0.08 D
- Always $\checkmark$ KKC
- Use 65% mean K

Axial Length Measurements

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

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

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

PIGGY-BACK INTRAOCULAR LENSES

J.T. Holladay    James P. Gills
Jane Leidlein    Myra Cherchio

"Achieving Emmetropia In Extremely Short Eyes With Two Piggy-Back Posterior Chamber Intraocular Lenses,"

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

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)

### Table 1

<table>
<thead>
<tr>
<th>IOL Power</th>
<th>Surgeon Factor</th>
<th>A-constant(D)</th>
<th>ELP(mm)</th>
<th>Effective Lens Position (ELP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.287</td>
<td>116.346</td>
<td>4.000</td>
<td>1.277</td>
</tr>
<tr>
<td>22</td>
<td>0.772</td>
<td>117.203</td>
<td>4.500</td>
<td>1.330</td>
</tr>
<tr>
<td>34</td>
<td>1.257</td>
<td>118.059</td>
<td>5.000</td>
<td>1.387</td>
</tr>
<tr>
<td>46</td>
<td>1.742</td>
<td>118.916</td>
<td>5.500</td>
<td>1.442</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>IOL Power</th>
<th>Surgeon Factor</th>
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<td>5.500</td>
<td>1.442</td>
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**Note:** ELP values are highlighted in red to indicate the required IOL toricity for 2 D of corneal astigmatism.
### 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>
</tr>
<tr>
<td>45°</td>
<td>1.41</td>
<td>141%</td>
</tr>
<tr>
<td>60°</td>
<td>1.73</td>
<td>173%</td>
</tr>
<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

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

Secondary Piggy-Back IOL’s
Indications

Intolerable Pseudophakic Refractive Error

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

Refractive Surprises

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

\[
IOL = \frac{1336}{1000} \left( \frac{1}{V_{\text{PreRx}}} - ELP \right) + \frac{1336}{1000} \left( \frac{1}{V_{\text{DPostRx}}} - ELP \right)
\]


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

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

\[\text{AACD} + 0.67 \text{ mm} = \text{ELPx}\]

Visian ICL Avg ELP = 4.00 mm

\[\text{AACD} (20 \text{ y/o}) = 3.60 \text{ mm}\]

\[\text{AACD} + 0.40 \text{ mm} = \text{ELPx}\]

**Phakic IOL Calculations**

+ IOL’s to Specs ~ 1.5 to 1

- IOL’s to Specs ~ 1.0 to 1

Approximation only

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

<table>
<thead>
<tr>
<th>White to White (mm)</th>
<th>ACD (mm)</th>
<th>Recommended ICL Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10.0</td>
<td>&gt;3.5</td>
<td>Not Recommended</td>
</tr>
<tr>
<td>10.0-10.6</td>
<td>&gt;3.5</td>
<td>12.1</td>
</tr>
<tr>
<td>10.7-11.0</td>
<td>All</td>
<td>12.1</td>
</tr>
<tr>
<td>11.1</td>
<td>&gt;3.5</td>
<td>12.2</td>
</tr>
<tr>
<td>11.1-11.4</td>
<td>All</td>
<td>12.2</td>
</tr>
<tr>
<td>11.5-11.6</td>
<td>&gt;3.5</td>
<td>12.6</td>
</tr>
<tr>
<td>11.6-11.8</td>
<td>&gt;3.5</td>
<td>12.6</td>
</tr>
<tr>
<td>11.7-12.0</td>
<td>All</td>
<td>13.1</td>
</tr>
<tr>
<td>12.1</td>
<td>&lt;3.5</td>
<td>13.2</td>
</tr>
<tr>
<td>12.2</td>
<td>&gt;3.5</td>
<td>13.2</td>
</tr>
<tr>
<td>12.3-12.9</td>
<td>All</td>
<td>13.7</td>
</tr>
<tr>
<td>&gt;=13</td>
<td>All</td>
<td>Not Recommended</td>
</tr>
</tbody>
</table>
The International Society of Refractive Surgery

April 23, 2002

Sydney

Thank you!