Axial Length Biometry and IOL Calculations

Axial Length Measurement

Axial length measurement is one of the crucial measurements necessary for predicting the appropriate intraocular lens (IOL) power to replace the natural lens during cataract/clear lens extraction surgery. In addition, it is used for verification of eye length postoperatively and for IOL power calculations of secondary IOLs. There are now two methods of determining axial length: ultrasound biometry (A Scan) and optical biometry (partial coherence interferometer = Zeiss IOL Master/Haag-Streit Lenstar). Both are valid methods for obtaining accurate axial length measurements.

ULTRASOUND BIOMETRY

What is an A Scan?

An A scanner is an ultrasonic scanning device that emits high frequency waves (higher than hearing range) in short pulses generated by a reverberating crystal (a piezoelectric crystal). The scanner does this by sending out a high voltage current to the crystal that, in turn, vibrates and emits short pulses. These pulses are sent out as waves into the ocular tissue. Some waves are reflected by ocular tissue interfaces. Waves that are reflected back to the probe are converted back to electrical impulses that are digitally displayed on a screen.

Features of Ultrasound

1. Frequency: The frequency of a device determines its penetration and resolution
   Higher frequency = less penetration
   Higher frequency = higher resolution
2. Sound Velocity: The more dense the medium, the faster transmission
3. Sound Beam: The way the sound is emitted (focused, non-focused)
4. Acoustic Interface: Formed when sound travelling in one medium encounters a different medium
5. Measurement: Can measure the amount of time a wave travels in a media to measure distances
6. Gain: Degree of machine echo amplification
   The higher the gain, the more penetration and sensitivity and less resolution
   The lower the gain, the less penetration and less sensitivity and more resolution
7. Beam Incidence: The angle that the beam meets with the interface will create differing degrees of reflection back to the probe. The strongest signal will come if the beam is perpendicular to the interface or structure.
8. Reflectivity: It is dependent on the shape of the structure the beam encounters.

<table>
<thead>
<tr>
<th>Medium</th>
<th>Velocity (M/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cornea</td>
<td>1,641</td>
</tr>
<tr>
<td>Aqueous &amp; vitreous</td>
<td>1,532</td>
</tr>
<tr>
<td>Crystalline lens</td>
<td>1,641</td>
</tr>
<tr>
<td>Soft tissue</td>
<td>1,550</td>
</tr>
<tr>
<td>PMMA</td>
<td>2,718</td>
</tr>
<tr>
<td>Silicone</td>
<td>980</td>
</tr>
<tr>
<td>Acrylic</td>
<td>2,120</td>
</tr>
<tr>
<td>Glass</td>
<td>6,040</td>
</tr>
<tr>
<td>Silicone oil</td>
<td>980</td>
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</tbody>
</table>

What are Echo Spikes?

They are produced by different mediums or interfaces in the eye creating reflections. A good reflection is generated when the sound beam is perpendicular to the tissue. The spikes seen in a normal ultrasound are: cornea, lens, retina, sclera and orbital fat

Cornea
It is the first spike on the ultrasound screen. It is where axial measurement begins. When the probe touches the cornea, it creates a single broad spike. It is labeled A in our picture.

Lens
These are the two spikes generated from the anterior and posterior lens capsule (labeled C and D in our picture). A cataract can generate extra reflections between the two normal spikes of the capsule. Sometimes a small echo can be seen behind posterior lens spike. This is simply a reverberation of sound generated from the lens.
Retina
It is a tall ninety-degree angle from baseline after the lens spikes (labeled F in our picture). There should be no stair steps in this spike.

**If it isn’t tall and sharply rising?**
- The sound beam isn’t perpendicular to the retina.
- Pathology: vitreous membrane, hemorrhage, or staphyloma.

Sclera and Orbit Fat
After the retinal spike, you should see a strong spike followed by shorter spikes (labeled G in our picture). This strong spike after the retinal spike represents sclera. Shorter spikes after the sclera represent orbital fat.

**If there is only one echo from post. Pole?**
- The sound beam is not perpendicular to the retinal surface
- The sound beam is directed to the optic disc

Performing A Scan
The best way to exam a patient is with the patient seated in a reclined position. The examiner should be comfortable and may be seated as well. The machine should be in eyesight and close to the patient. Then, anesthetize the eye with a single drop. There are two techniques proposed in practice: contact versus immersion technique.

Contact
In the contact method, you should gently touch the cornea repeatedly with breaks allowing the patient to blink and rehydrate the cornea. The probe should be directed to the corneal apex. The patient should focus on fixation light.

Immersion
In the immersion method, a scleral shell is placed in the eye. The shell is then filled with saline or a mixture of methylcellulose and saline to create a bath. The probe is then placed in the bath and angled to generate two symmetric corneal spikes.

**Automated vs. Manual**
If you choose the automated mode, the machine will set-up parameters for recognizing a good scan. It does this by establishing gates. Gates are markers or cursors on the display that provide electronic measurement of the distance between 2 or more structures or interfaces.

In the manual mode, it isn’t recognizing a pattern on the screen. It simply sets up two gates and a threshold to measure the axial length. Modern machines will add more gates to compartmentalize the different velocities (anterior chamber, lens, vitreous).

**Choosing Eye Types**

**Phakic**
Both anterior and posterior lens spike with a retinal spike
No significant echoes between lens spikes

**Cataract**
Same as phakic but allows for echo return in lens area

**Dense Cataract**
Doesn’t require a post lens echo return. The reason for this is that there is high reflectivity in a dense lens that blocks signals from getting further in the eye. This is called sound attenuation. There are also lots of sound reverberations.

**Aphakic**
Doesn’t require any lens echo returns

**Pseudophakic**
Anterior lens spike and retina lens spike only
Sources of Error (Byrne 1995)

<table>
<thead>
<tr>
<th>Short Measure =&gt; post op myopic surprise</th>
<th>Long Measure =&gt; post op hyperopic surprise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corneal compression</td>
<td>Air bubble in bath</td>
</tr>
<tr>
<td>Sound velocity Slow</td>
<td>Fluid bridge</td>
</tr>
<tr>
<td>Corneal gate to right</td>
<td>Sound velocity too fast</td>
</tr>
<tr>
<td>Retinal gate too left</td>
<td>Retinal gate too right</td>
</tr>
<tr>
<td>Gain set too high</td>
<td>Gain too low</td>
</tr>
<tr>
<td>Misaligned sound beam</td>
<td>Lens measured too thick</td>
</tr>
<tr>
<td>Lens measured too thin</td>
<td>Misaligned sound beam</td>
</tr>
</tbody>
</table>

Patient related errors (Byrne 1995)

<table>
<thead>
<tr>
<th>Inadequate fixation</th>
<th>Irregular Posterior Ocular Wall</th>
<th>Fluid Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Blepharospasm</td>
<td>• Macular thickening/detachment</td>
<td>• Excess tear film, ointment, or drops</td>
</tr>
<tr>
<td>• Nystagmus</td>
<td>• Optic disc elevation</td>
<td>prior to exam</td>
</tr>
<tr>
<td>• Strabismus</td>
<td>• Staphyloma</td>
<td></td>
</tr>
</tbody>
</table>

OPTICAL BIOMETRY => Zeiss IOL MASTER/ Haag Streit LENSTAR

How is Optical Biometry different from Ultrasound?

It uses wavelets of ultraviolet light that are split and propagated into the eye. They are strongly reflected by the cornea and the retina and a photo detector captures those reflections. If two wavelets meet each other within a short length, they can interfere and the optical biometer will measure the increased intensity as a signal. The accuracy is due to the precise measure of a movable mirror used to create one of the wavelets of light propagated into the eye. Its reflection from the retina is strongest at the RPE and measures from the cornea to the RPE. It is calibrated to a high-resolution ultrasound biometry unit. It is a noncontact method that is virtually tester independent and doesn’t depend on the distance of observer to machine. Because the velocity of light isn’t as affected by tissue media, the optical biometer is superior for measuring pseudophakic and silicone filled eyes. The table below shows how optical velocities aren’t as affected as ultrasound (from Shammas, 2004).

The Lenstar differs from the IOL Master in that it captures corneal thickness, AC depth, lens thickness, and axial length all using laser interferometry vs. the IOL master captures axial length using laser interferometry and determines anterior chamber depth visually with no measure of corneal thickness or lens thickness.

Advantages of Optical Biometry

a) Increased precision with minimal training - ±25µm (Vogel JCRS 2001)
b) Consistency between tests - variability 21µm between 5 examiners
c) Superior for Staphylomas, Pseudophakic eyes, Silicone Oil eyes

Disadvantages of Optical Biometry

d) Limited by media opacity (Corneal scars, PSC, VH, Mature Cataract)
b) Requires patient fixation
c) So 10-20% of eyes are immeasurable by optical biometry (perhaps 5% with the new advanced modality software package - version 5 composite scans with Zeiss IOL Master)

<table>
<thead>
<tr>
<th>Material</th>
<th>PCI (mm)</th>
<th>Ultrasound (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicone</td>
<td>+0.12</td>
<td>-1.09</td>
</tr>
<tr>
<td>PMMA</td>
<td>+0.11</td>
<td>+0.35</td>
</tr>
<tr>
<td>Acrylic</td>
<td>+0.10</td>
<td>+0.16</td>
</tr>
<tr>
<td>Silicone Oil</td>
<td>-0.75</td>
<td>-8.79</td>
</tr>
<tr>
<td>Phakic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aphakic</td>
<td>+0.21</td>
<td>0</td>
</tr>
</tbody>
</table>

IOL CALCULATIONS

Sources of Refractive Surprises

1. Measurement error (Olsen JCRS 1992)
   a) Axial Length-54%
2. Formula Error (Olsen JCRS 1992)
   a) ELP (estimated lens position) error-38%
   b) Lack of Personalization
3. IOL insertion Error
   a) IOL mislabeling
   b) improper IOL power insertion at time of surgery

**Importance of A scan** (Holladay JCRS 1988)
- 43-67% of large refractive surprise due to inaccurate preoperative measurement (axial length or keratometry)
- 1mm AL error = 3D error (depending on the axial length of the eye)
- Best accuracy is +/- 0.1mm
- The most common error is corneal compression!!!!

**Ultrasound Accuracy Improvement**
- Immersion eliminates variable corneal compression
  - Immersion measures 0.2-0.3mm longer than applanation (Schelenz JCRS 1989)
- Ultrasound Velocities (Hoffer JCRS 1994, Hoffer Focal Points 1999)
  - The longer the eye, the higher percentage of liquid to solid percentage of axial length and therefore the lower average velocity.
  - avg phakic velocity for 20mm eye is 1560 m/sec
  - avg phakic velocity for 23.5mm eye is 1555 m/sec
  - avg phakic velocity for 30mm eye is 1550 m/sec
- If an eye is measured with wrong velocity, it can be corrected easily by using formula:
  \[ \text{AL}_{\text{correct}} = \frac{\text{AL}_{\text{measured}} \times \text{Velocity}_{\text{correct}}}{\text{Velocity}_{\text{measured}}} \]
- Pseudophakic Axial Length measure should be done with velocity of 1532m/sec and add CALF formula result to it.
  - \( \text{CALF}_{\text{PMMA}} = T_L \times (1-1532/2660) = +0.424 \times T_L \)
  - \( \text{CALF}_{\text{Silicone}} = T_L \times (1-1532/980) = -0.563 \times T_L \)
  - \( \text{CALF}_{\text{Acrylic}} = T_L \times (1-1532/2026) = +0.243 \times T_L \)
- CALF Method (Holladay JCRS 1997 but corrected for cornea by Hoffer Focal Points 1999)
  - Because the lens is a small part of the total length of the eye, Dr. Holladay determined that you should measure the whole eye with velocity of aqueous and vitreous (1532m/sec) and add a correction factor for the lens thickness.
  - The lens thickness varies by age but the maximum error caused by this variable would be from 0.07D to 0.14D and so he recommends using the lens thickness of a 70 year old (CALF value of 0.28).
  - His original description ignored the corneal thickness. If you correct for that you would get CALF value of 0.32
  - So measure the eye at velocity of 1532 m/sec and add to it +0.32 for axial length.

- \( \text{AL}_{\text{corrected}} = \text{AL}_{1532} + 0.32 \)

**Data screening criteria** (Holladay JCRS 1988)
- Repeat measurements with second observer if:
  1. Axial Length < 22.0 mm or > 25.0 mm
  2. Avg Corneal Power < 40 D or > 47 D
  3. Calculated emmetropic IOL power is more than 3D from avg. for a specific lens style (using AL=23.5mm, Avg. K=43.81, and A constant for lens style)
  4. Between eyes, the difference in
    - Average corneal power > 1D
    - Axial length > 0.3mm
    - Emmetropic IOL power >1D

**Optical Biometry Capture Improvement**
- Multiple measurements with the measurement reticule
  - Useful for cases corneal scars, anterior cortical spokes, PSC plaques
- Useful to take all 20 measurements for Zeiss IOL Master/ all 5 Measures of Haag Streit Lenstar
  - At least 4 of the measurements should be within 0.04mm of each other with good characteristics
  - Version 5 IOL master now utilizes digital signal processing to eliminate noise and identify the signal peak reported as a composite. By using all 20 measurements, the machine has a greater ability to distinguish signal from noise.
  - Lenstar averages 16 measures for each reported axial length capture and averages 4 measures for each reported
keratometry capture. The more captures, the better standard deviation reporting.

Lenstar allows you to selectively review and delete each measurement capture to improve your average and standard deviation.

c) Review the retinal signal peaks and confirm the device is capturing the RPE spike in cases of double humps

http://www.doctor-hill.com/zeiss_iolmaster/interpretation.htm

d) Improve outcomes in eyes with Axial Length > 25.00 mm (Wang JCRS 2011)

- In Axial Myopes we tend to get hyperopic outcomes with the same a constant we use for normal axial lengths.

Wang et al, developed a conversion method for each formula that will compensate for this drift.

- Holladay1 optimized AL =0.8814 x AL + 2.8701
- Haigis optimized AL =0.9621 x AL + 0.6763
- SRK/T optimized AL = 0.8981 x AL + 2.5637
- Hoffer Q optimized AL = 0.8776 x AL + 2.9269

e) Autokeratometry

- Avoid using automatic capture without reviewing values
- Use artificial tears (preferably early) to keep uniform surface and blink before capture
- Missing peripheral points or distorted points suggest poor tear film layer or scar or eyelid in the way.

f) Data screening criteria (Knox Cartwright Eye 2010)

Repeat measurements with second observer if:

1. Axial Length < 21.30 or > 26.60 mm
2. Avg Corneal Power < 41.00 or > 47.00 D and cylinder > 2.50 D
3. Between eyes: asymmetry of AL > 0.70 mm
4. Between eyes: mean K > 0.90 D

g) Recommend reading manual or visiting


Corneal Power

a) Importance of Keratometry

1. 1D K error = 1D IOL error
2. Remove Hard Contact Lens > 2 weeks before measuring corneal power

- Avg Corneal Power < 40 D or > 47 D
- Avg Corneal Power difference between eyes > 1 D
- Patient Can’t Fixate
- Astigmatism > 2.50 D
- Corneal Diameter < 10.75 mm or > 13.0 mm
- If using IOL master, each measure within 0.25 D for each meridian
4. Be consistent and use the same machine consistently for your IOL formula calculations


Some of the methods recommended to correct for refractive surgery (not complete):

A) Clinical History method

\[ K = K_{preop} + R_{preop} - R_{po} \]

K = predicted corneal power, \( K_{preop} = \) preoperative corneal power, \( R_{preop} = \) preoperative spherical equivalent refractive error at spectacle plane, \( R_{po} = \) postoperative spherical equiv refractive error at spectacle plane

b) Contact Lens method

\[ K = B + P + R_{CL} - R_{NoCL} \]

K = predicted corneal power, B = contact lens base curve, P = power of contact lens \( R_{CL} = \) contact lens over refraction at spectacle plane \( R_{NoCL} = \) bare refraction at spectacle plane
c) Corneal Topography (Wang 2004)
   \[ K = (C_{CP} \times 1.114) - 6.1 \]
   \( K = \) predicted corneal power
   \( C_{CP} = \) the corneal power with the cursor in the center of the refractive map of the topographer

   ****WARNING- NOT TESTED IN LARGE SERIES****

d) No History Method (Shammas 2004)
   \[ K = 1.14 \times K_{po} - 6.8 \]
   \( K = \) predicted corneal power
   \( K_{po} = \) avg corneal power with manual Keratometry after refractive surgery

   ****WARNING- NOT TESTED IN LARGE SERIES****

e) Double K method
   the formulas inaccurately predict estimated lens position because of an inaccurate estimate of corneal power
   Aramberri uses the preoperative \( K \) to predict IOL position and then uses postoperative \( K \) for IOL Power
   -PLEASE read Aramberri and Koch article JCRS 2003.

f) Corneal Bypass method (Walter 2005)
   Keith Walter et al proposed preop LASIK refraction spherical equivalent and preop LASIK Keratometry readings into the IOL calculation formulas.
   -He presented a small case series of patient with myopic LASIK and found it to be very accurate when you enter the preoperative LASIK refraction as your target refraction or postoperative target into your IOL calculation formulas.

   ****WARNING- NOT TESTED IN LARGE SERIES****

g) Holladay Equivalent K
   Jack Holladay in conjunction with the Oculus Pentacam developed an average Keratometry of the first 4mm of the cornea where the Pentacam directly measures the anterior and posterior curvature of the first 4 central mm of the cornea.

   ****WARNING- NOT TESTED IN LARGE SERIES****

3. Recommend you go to one of these sites for details on calculating accurate corneal power in refractive surgery patients
   - www.doctor-hill.com/iol-main/keratorefractive.htm
   - www.aao.org (specialty clinical update /cataract /module 2)
   - www.ascrs.org (provides a nice summary sheet of the various methods calculated for you).
      The Modified Masket, Shammas, Haigis L seem to be most accurate as well as average suggested by calculator(Wang JCRS 2010)

IOL Formulas

First Generation
1. Theoretical formula: \( P = n/L-\text{ACD}-nK/n-K\times\text{ACD} \)
   - ex. Fyodorov, Colenbrander, Hoffer, Binkhorst
2. Regression formula: \( P = A - 2.5L - 0.9K \)
   - ex. Lloyd/Gills, SRK
   - ACD was replaced by A-constant individual to each IOL style

Second Generation
1. Estimate postop IOL position based on axial length
2. Stepwise adjustments for long and short eyes
3. Example: SRK II formula, Hoffer, Binkhorst II
4. SRK II inaccurate in Myopic Eyes (Sanders JCRS 1990)

Third Generation
1. Modify according ACD according to corneal curvature and axial length
2. Examples: SRK/T, Hoffer Q, Holladay (all theoretic)
Fourth Generation

1. Holladay II Formula
   a) Modification of ACD by preoperative ACD, axial length, corneal diameter, lens thickness, age, refraction
   b) Particularly helpful for long and short eyes (Fenzl/Gills Ophthalmology 1998)

2. Haigis Formula
   a) Introduces additional constants for measured ACD and Measured axial length
   b) Three variable function that allows for adjustment of surgeon/IOL combination.

Which Formula to use? (Hoffer JCRS 1993, Hoffer JCRS 2000)

1. Short eyes (<22 mm) => Holladay II or Hoffer Q
2. Normal eyes (22 to 24.5) => Average of Formulas
3. Medium long eyes (24.5 to 26.0 mm) => Holladay I
4. Long eyes (> 26.0 mm) => SRK/T, Holladay II

Summary

1. Check patient history (refraction)
2. Check appropriate lens type
3. Obtain quality scan and rate
   -Consider immersion or IOL Master in all cases
4. Do the measurements meet Data Screen Criteria?
   -If inappropriate, check with another examiner or doctor
5. Involvement of everyone in outcomes and surprises
6. Seek consistency in measurements (Pierro, Norrby)
7. Pick appropriate Lens Formula for eye length
8. Personalization of constants
   • Should be for individual surgeon, technique and IOL
   • Need a minimum of 20 to 25 cases to start using personalization (Holladay JCRS 1988)
   • Incorporates variation in lens style, AL measurement, Keratometer, wound closure, technician measurements and refractions
   • Develop spreadsheet or database to monitor prediction error of formulas by axial length

References