Accurate Biometry and Intraocular Lens Power Calculations

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Introduction

Technology employed in small incision cataract surgery is constantly evolving and continues to improve upon outcomes that already exceed acceptable standards. The modern surgical cataract goal has become more refractive in nature, which is highlighted by the widespread use of presbyopic multifocal and accommodative intraocular lenses (IOLs). Patients are informed and have high expectations for their visual result following surgery. This demands a high level of precision in biometry measurements. The ability to accurately predict the postoperative refraction is required more critically now than ever.

There are several factors that contribute to the final refractive outcome. These include biometry measurements, IOL power formulas, and surgical technique. Surgical technique is not covered in this chapter as it is obviously an intrinsic property of each surgeon, but may still influence the final result. For example, when the capsulorrhexis is larger than the optic of the IOL, a postoperative myopic shift may occur as the capsular bag contracts and displaces the IOL anteriorly. A retrospective analysis of the results for each surgeon will allow customization of the IOL power formula to account for these differences in surgical technique.

Causes of Unexpected Outcomes

Of all the components required to determine IOL power, inaccurate measurement of the axial length (AL) of the eye is the most frequent factor causing unexpected outcomes.[1,2] An AL measurement that is erroneous by only 100 µm translates into a 0.28-D error in the postoperative refraction.[2] Though inaccurate corneal power measurements account for a much smaller percentage of unexpected outcomes,[1] careful attention should always be paid to keratometry. It is best to designate one keratometer that is regularly calibrated for all biometry measurements.

The remaining error may be attributed to inaccurate calculation of the final IOL position within the eye.[1] This is the predicted depth of the power plane of the IOL optic after surgery and is sometimes referred to as the postoperative anterior chamber depth (ACD). It is more

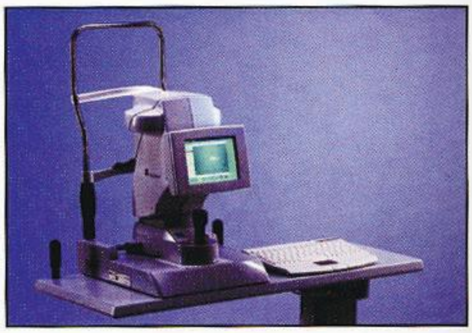


Figure 24-1. IOLMaster. (Reprinted with permission from Agarwal A. *Phaco Nightmares: Conquering Cataract Catastrophes*. Thorofare, NJ: SLACK Incorporated; 2006.)

accurately termed the effective thin-lens position (ELP). The final position of the IOL in the capsular bag can have an effect on the final refraction. A lens that sits more posteriorly than expected will lead to postoperative hyperopia and vice versa.[3] Considering the crystalline lens is approximately 5 mm thick and an IOL averages about 1 mm in thickness, there is a significant margin for potential error. The final ELP is naturally dependent to a certain extent on surgical technique but is also a predicted value within the IOL power formulas. Thus, while accurate determination of AL and corneal power are critical, the use of an appropriate IOL power formula is also of great importance.

Biometry Techniques for Measuring Axial Length

Regardless of the biometry technique employed, it is important to check the results of the scan for inconsistencies. Biometrists need to be trained in detecting unusual measurements that should raise an alarm. For instance, if there is a significant difference in AL or keratometry between eyes, the measurements should be examined more closely. If there is more than 1.00 D difference in IOL power between eyes, this also needs to be confirmed. The predicted IOL power and AL should correlate with the refraction; if the results indicate a 15.00-D IOL for a +6.00-D hyperope, then an error has occurred somewhere. Of course, both eyes should have biometry measurements prior to the first surgery as standard practice to allow a comparison between eyes.

Applanation ultrasound A-scan is the most common technique employed for the measurement of axial length,[2,4] though a trend to move toward the highly accurate partial coherence laser interferometry (PCLI), otherwise known as optical biometry, is emerging. Sixty-one percent of ophthalmology departments in the United Kingdom now employ this method.[5] Immersion ultrasound biometry is the least commonly used method.

Partial Coherence Laser Interferometry

This technique of optical biometry measures the axial length of the eye from the anterior cornea to the retinal pigment epithelium along the visual axis using a coaxial dual beam.[6] It is highly accurate as the resolution is greater than that with ultrasound (0.012 mm compared to 0.10 to 0.12 mm).[5] This results in an outstanding accuracy of 15 to 20 μm, significantly greater than that of applanation ultrasound technique.[2] The measured AL with PCLI is approximately 0.30 mm longer than immersion ultrasound, and up to 0.96 mm longer than in applanation ultrasound.[6]

PCLI technology is commercially available as the Zeiss IOLMaster (Dublin, Calif) (Figure 24-1). The retinal endpoint of the AL measurement is different with PCLI compared to ultrasound A-scans (retinal pigment epithelium compared to internal limiting membrane), and

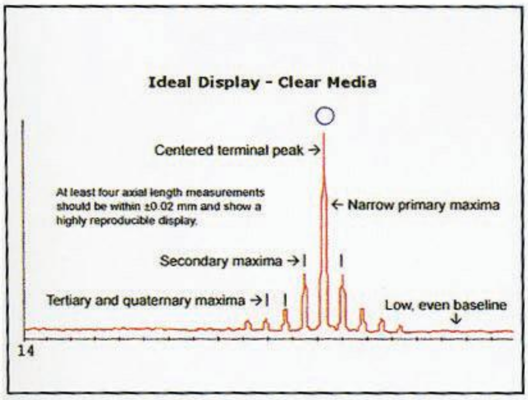


Figure 24-2. IOLMaster display for AL measurement in clear media.

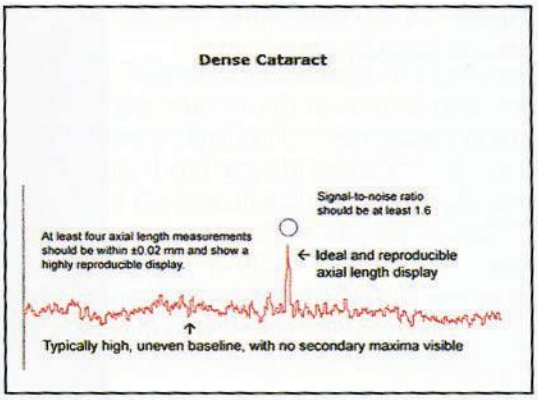


Figure 24-3. IOLMaster display for AL measurement in dense cataract.

as such, the PCLI software has built in correction factors to allow for this (Figures 24-2 and 24-3). Despite this, different constants for the same IOL must be used for the 2 different biometry techniques.[5]

The measurement of the preoperative ACD with the IOLMaster is done using a photographic technique rather than with PCLI. The corneal power is measured with automatic keratometry, which has been shown to correlate well with manual readings over an average power range.[7] However, automatic keratometry may be an unreliable technique for measuring the magnitude and meridian of astigmatism, particularly when the magnitude is small. It is therefore recommended that the measurements are cross-checked with manual readings for accuracy.

The test is fairly comfortable as it is noncontact and performed in a sitting position rather than supine. It is essentially operator independent with results reproducible to 0.02 mm, even when technicians have minimal experience.[2,5] There can be no confusion between measuring right and left eyes as the machine automatically detects and records this.

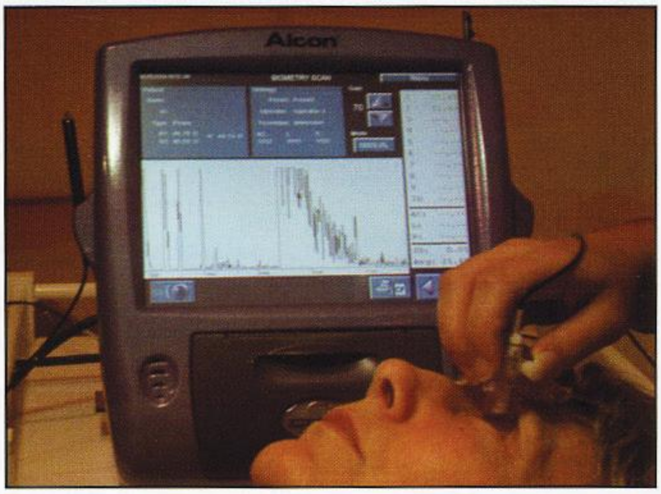
Another advantage over ultrasonography is the ability to accurately measure the AL in an eye filled with silicone oil following vitreoretinal surgery.[8] The software does this by changing the mean refractive index to account for the silicone oil. Ultrasonography may also be used to measure through the silicone oil, but it is more challenging because oil droplets may create artifacts, resulting in the absence of a retinal peak. This is particularly the case for immersion ultrasonography where the patient is lying down. The PCLI software also allows easy measurement through phakic IOLs, a problem that will become more widespread as implantation of these devices gains popularity.

PCLI does require adequate fixation, and this may be a source of difficulty in patients with poor cooperation or reduced visual acuity. It also will not take measurements through dense cataracts. Consequently, the test may be rendered ineffective in approximately 10% to 20% of cases.[2,4,7] Therefore, proficiency in the other methods of measuring AL is still required.

Immersion Ultrasound A-Scan

Though the resolution with ultrasonography is not as great as with PCLI, this is still a highly-accurate technique and is useful particularly in cases in which a measurement cannot be obtained with optical biometry. This might include patients with poor fixation from maculopathy, nystagmus, or dense cataracts. Although the results are comparable with PCLI,[7] the immersion technique is not widely utilized. This is likely due, in part, to the use of the

Figure 24-4. Immersion A-scan ultrasonography.



water and the scleral shell that renders this test more uncomfortable for the patient. Due to physical constraints, it is not always feasible for the patient to lay flat for the measurement either (Figure 24-4).

In contrast to optical biometry, the axial length is measured from the anterior cornea to the inner limiting membrane (ILM).[6] This may account for slight differences in results between ultrasonography and PCLI as the ILM is more variable in thickness compared to the retinal pigment epithelium. However, as previously mentioned, the PCLI software has been calibrated against results from immersion biometry to account for this to some extent.

One disadvantage with ultrasonography is that small misalignments may occur with the transducer probe, and the ultrasonic beam may not be perpendicular to the intraocular surfaces. This results in a jagged retinal peak or the absence of a posterior lens peak on the A-scan. However, 2 corneal peaks (anterior and posterior cornea) are seen with an immersion ultrasound scan compared to a single peak with the applanation method. These 2 peaks may be aligned to judge whether the measurement has been taken on the optical axis.[5]

In ultrasonography A-scans, the AL measurements are made along the optical axis rather than the visual axis, which can lead to erroneous results in long eyes. For instance, the AL measured along the optical axis in an eye with a posterior staphyloma may be overestimated by 3.0 mm, resulting in an unwanted refractive error of up to +8.00 D.[4] In cases of high myopia, a combination A/B-scan may be more accurate.

Combination Immersion A/B-Scan

A high proportion of highly myopic eyes with an AL of greater than 30.0 mm have a posterior staphyloma temporal to the fovea.[9] This often leads to erroneously long measurements of AL and subsequent postoperative hyperopia. In these cases, an immersion A/B-scan may be appropriate.[9,10] A horizontal immersion B-scan with simultaneous vector A-scan is taken. The B-scan allows visualization of the fovea so the retinal peak of the A-scan may be aligned more exactly with it to avoid measurement of a staphyloma. This technique also allows precise centration of the corneal peak. The main disadvantage of this technique is that it requires an experienced operator who is familiar with B-scan technology because the fovea is not always easy to identify.[9]

Applanation Ultrasound A-Scan

Despite being one of the most widely performed techniques, this method has the lowest accuracy.[2] The main disadvantage of this method is applanation of the cornea, resulting in corneal compression of between 0.14 to 0.47 mm, depending on the experience of the biometrist.[2,5,11] An A-scan that has indented the cornea will still appear acceptable to view on the screen, but it could result in an unwanted error of the calculated IOL power of more than 1.00 D.[12] This technique is highly operator dependent. If one technician performs all A-scans within a clinic, a retrospective analysis may be performed to allow for the applanation within the IOL power formula. However, as the amount of compression is likely to vary with the level of intraocular pressure, errors may still occur.[12]

Intraocular Lens Power Formulas

It has been shown that the modern third- and fourth-generation theoretical IOL power formulas are more accurate than the earlier empirical formulas such as the SRK I, SRK II, and Binkhorst.[13,14] There are 5 well-known theoretical IOL power formulas: Holladay 1 and 2, Hoffer-Q, SRK/T, and Haigis. All are based on thin lens optics and utilise the refractive vergence formula in the calculation of IOL power, which has 6 variables and 2 constants.[15] The formulas differ in how they estimate the final ELP.

The 3 third-generation formulas (Holladay 1, Hoffer-Q, and SRK/T) predict the ELP based on 2 variables: net corneal power and AL. This makes a number of broad assumptions about the eye, including that the anterior and posterior segments are roughly proportional. The 2 fourth-generation formulas (Holladay 2 and Haigis) utilize more variables when calculating the ELP. These formulas address the variable relationship between the ACD and length of the posterior segment, and as such have a higher rate of accuracy over a wider range of ALs. The Holladay 2 formula is widely considered to be very accurate, though it has the disadvantage of requiring the measurement of 7 variables. The Haigis formula has a similar level of accuracy if properly customized (see later) and has the advantage of requiring only 3 variables (AL, corneal power, and ACD).[14]

Customizing Intraocular Lens Formula Constants to Improve Accuracy

Each formula has a "constant" associated with predicting the ELP. The Holladay 1 formula uses a "surgeon factor" that is the distance between the iris plane and the power plane of the IOL, where the distance from the cornea to the iris plane is calculated as the dome height of the cornea.[16] The Hoffer-Q formula uses the "ACD-constant" which is the average distance between the power plane of the cornea and the IOL.[16] The SRK/T formula uses the "A-constant" supplied by the manufacturer of the IOL. The Holladay 2 formula also uses an "ACD-constant."[16] The Haigis formula uses 3 constants: a0, a1, and a2. The a0 constant works in a similar manner as the constants for the other formulas. The a1 constant relates to the measured ACD, and the a2 constant to the measured AL.[14]

It is recommended that these constants be customized through retrospective analysis for the individual surgeon and IOL type to further increase accuracy in IOL power calculations.[5,16,17] In the case of the Haigis formula, all 3 constants may be customized, though at present this regression analysis is only carried out by either Dr. Wolfgang Haigis himself or his colleague Dr. Warren Hill.[14] The IOLMaster also includes software to track outcomes and personalize the A-constant for the SRK/T formula. However, even with personalized constants, there are still errors with predicting IOL power in high ametropia.[16]

Table 24-1

Preferred Intraocular Lens Power Formulas for Differing Axial Length[5]

Short eyes <22.0 mm	Hoffer-Q, Holladay 2
Medium eyes 22.0 to 24.5 mm	Holladay 1 or 2, Hoffer-Q, SRK/T, Haigis
Medium long eyes 24.6 to 26.0	Holladay 1 or 2
Long eyes >26.0 mm	SRK/T, Haigis*, Holladay 2

*Customized to the surgeon and type of IOL

Intraocular Lens Power Formulas for Extreme Ametropia

Accuracy in IOL calculations for extreme ametropia has always been challenging, even with personalized modern IOL power formulas. It has been shown that the different formulas perform differently depending on the AL of the eye.[18] This is summarized in Table 24-1. For an eye of average length (22.0 to 26.0), any modern formula performs well.[18] For very short eyes (<22.0 mm) the Hoffer-Q or Holladay 2 formula is the most accurate.[5,18] For very long eyes (>26.0 mm), the SRK/T formula gives the best results,[5,9,18] though it still has a tendency to predict an IOL power that is too great.[9]

Accurate prediction of IOL power in patients with extreme axial hyperopia is relatively easy; accurately obtaining the AL is easier, and the Hoffer-Q or Holladay 2 formula predicts the IOL power with a high degree of accuracy. By contrast, accurately predicting the IOL power for extremely high axial myopia is more challenging even using the SRK/T and fourth-generation formulas.

In patients with extreme myopia, the required IOL is one of a low positive power, zero power, or a low negative power. Implantation of a zero power IOL is more beneficial than leaving the eye aphakic because it provides a barrier function to reduce the rate of posterior capsule opacification.[10,19] The IOL also stabilizes the vitreous base if a YAG capsulotomy is required, potentially reducing the incidence of retinal detachment. When an IOL of low positive power is predicted, the results are more accurate than if a negative-powered IOL is predicted.[9,19] If the calculated IOL power is between –1.00 to –4.00 D, postoperative hyperopia is more often seen.

This could be due in part to inaccurate estimation of AL in these highly myopic patients. As discussed earlier, PCLI with the IOLMaster and immersion A/B-scans are the 2 most accurate methods of biometry in long eyes. However, while these techniques of biometry have been shown to improve accuracy of the SRK/T formula, it is still not uncommon for a postoperative refraction of approximately +1.00 D to occur.[19] It has been suggested that transforming the AL scale to a population mean AL of 24.00 mm may help reduce the error in the Holladay 1, Hoffer-Q, and SRK/T IOL power formulas in cases of extreme ametropia.[16]

The answer to predicting IOL power in extreme myopia remains elusive. In patients whose predicted IOL is of a negative power, it is worthwhile considering the possibility of an overcorrection and factoring this into the final selection of IOL for implantation by choosing a lens of less negative power.

Summary

There are many factors that contribute to the final refractive outcome of small incision cataract surgery. These include the measurement of axial length, corneal power, and selection of the appropriate IOL power formula. Though some occur more commonly than others in unexpected outcomes, they all have equal importance in preventing a postoperative surprise. The method employed to measure axial length should be considered, and keratometry readings should be cross-checked for accuracy. A single IOL power formula should not be used across the board for all calculations, especially in cases of extreme ametropia. The appropriate formula must be considered for the individual case, and for greater accuracy it should be personalized for the surgeon and type of IOL.

Key Points

1. The modern surgical cataract goal has become more refractive in nature, which is highlighted by the widespread use of presbyopic multifocal and accommodative IOLs.
2. Of all the components required to determine IOL power, inaccurate measurement of the axial length (AL) of the eye is the most frequent factor causing unexpected outcomes.
3. The final position of the IOL in the capsular bag can have an effect on the final refraction.
4. The retinal endpoint of the axial length measurement is different with partial coherence laser interferometry (PCLI) compared to ultrasound A-scans (retinal pigment epithelium compared to ILM.
5. For an eye of average length (22.0 to 26.0) any modern formula performs well. For very short eyes (<22.0 mm), the Hoffer-Q or Holladay 2 formula is the most accurate. For very long eyes (>26.0 mm), the SRK/T formula gives the best result.

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Please see Cataract After Radial Keratotomy video on enclosed CD-ROM.