Optimizing Refractive Outcomes

H. John Shammas, MD, Eric Donnenfeld, MD, and Renée Solomon, MD

Part A:
Biometry and Intraocular Lens Power Calculation

H. John Shammas, MD

Formulas for Intraocular Lens Power Calculation

Modern cataract surgery replaces the natural lens of the eye with an intraocular lens (IOL). After surgery, the optical system of the eye will consist of two major refractive elements, the cornea and the newly inserted IOL. This two-lens system is at the basis of IOL power calculation. To facilitate calculations, both the cornea and the IOL are considered thin lenses. Although there are multiple IOL power formulas, most are similar in nature. They all require measurements of the axial length and of the corneal power. However, all these formulas require knowledge of the distance separating the two thin lenses, also known as the estimated lens position (ELP).

\[ P = \frac{n}{L - c} - \frac{n}{(n/K) - c} \]

In this vergence formula, \( P \) is the power of the IOL needed for emmetropia in diopters, \( L \) is the axial length in meters (all formulas adjust the equation to allow the axial length to be entered in millimeters), \( K \) is the corneal power in diopters, \( c \) is the ELP, and \( n \) is the index of refraction of the aqueous and vitreous, which is known to be 1.336.

All formulas will require measurement of the axial length and of the corneal curvature. ELP is the distance between the anterior corneal surface and the implant’s optical center. This value cannot be measured before surgery and thus has to be estimated. The difference between the different formulas lies in the estimation of ELP.

Original Theoretical Formulas

The original theoretical formulas, published between 1975 and 1980, considered ELP to be a constant value, referring to it as the postoperative anterior chamber depth (c). The accuracy of these original formulas was mediocre. It was immediately noticed that ELP was not a constant and varied mainly with the axial length. Three main formulas emerged in the 1980s to address this issue. These were the Hoffer formula, the Shammas’ formula, and Binkhorst’s adjusted formula.
Regression Formulas

During the same period, Sanders, Retzlaff, and Kraff reviewed their results and thought that they could get better results with a regression equation. Their equation became known as the SRK formula:

\[ P = A - 2.5L - 0.9K \]

where \( P \) is the power for emmetropia, \( L \) is the axial length in mm, \( K \) the corneal power in diopters, with \( A \) being a constant.

In 1988, the authors of the SRK formula realized that their regression equation did not perform well in very long and very short eyes. They modified it by fudging the calculations in these very long and very short eyes, and calling it the SRK II formula. The results improved but they were still not satisfactory.

Modern Theoretical Formulas

After 1988, three modern theoretical formulas were introduced. These are the Holladay formula (1988), the SRK/T formula (1990), and the Hoffer Q formula (1993). In all three formulas, ELP varies not only with axial length but also with the corneal curvature. However, each formula uses a different constant: \( SF \) (surgeon factor) for the Holladay formula, \( A \) for the SRK/T formula, and \( ACD \) (anterior chamber depth) for the Hoffer Q formula.

The last decade saw the introduction of some advanced theoretical formulas, mainly the Holladay II and the Haigis formulas. In the Holladay II formula, ELP varies with the axial length, corneal curvature, white-to-white measurement, anterior chamber depth, lens thickness, and age. This formula requires the purchase of a special software program to run it. The Haigis formula is widely available on the IOLMaster (Carl Zeiss Meditec, Dublin, CA).

Clinical Pearl

For your IOL power calculations, only use a modern or advanced theoretical formula. Avoid the SRK and SRK II formulas.

Clinical Pearl

The \( A \) constant has become a value characterizing each IOL, and every manufacturer prints an \( A \) constant on the box holding the IOL. Although this \( A \) constant has to be personalized for each surgeon and for each lens model, the value given by the manufacturer is often very close.

Please note that \( P \), the IOL power for emmetropia, varies on a one-to-one ratio with \( A \). This can be very helpful when switching between implants. For example, an IOL with an \( A \) constant of 118.9 will require a 0.50 D stronger power than an IOL with an \( A \) constant of only 118.4.

Please also note that the \( A \) constant, among other things, relates to the position of the IOL within the eye. This can be very helpful if the surgeon encounters complications during surgery. Let us suppose that the surgeon is planning to insert a one-piece IOL in the capsular bag and that implant has an \( A \) constant of 118.9. If the posterior capsule is compromised, a three-piece IOL has to be inserted in the sulcus; the \( A \) constant drops to 117.5 requiring a 1 to 1.5 diopters weaker IOL. If vitreous is lost, and an anterior chamber IOL is to be used, the \( A \) constant drops to 115.3 requiring a 3.5 diopters weaker IOL.

Measuring the Axial Length

A-Scan Biometry

The axial length is conventionally measured with ultrasonography, using a biometry unit. An immersion technique is recommended where the ultrasound probe remains 5 to 8 mm away from the cornea.

It is important to recognize the A-scan pattern of a normal phakic eye examined with an immersion technique. The following echospikes are displayed from left to right (Figure 16-1):

- The initial spike is produced at the tip of the probe. It has no clinical significance.
- The corneal spike is double peaked representing the anterior and posterior surfaces of the cornea.
- The anterior lens spike is generated from the anterior surface of the lens.
- The posterior lens spike is generated from the posterior surface of the lens.
- The retinal spike is generated from the anterior surface of the retina. It is straight, highly reflective, and tall whenever the ultrasound beam is perpendicular to the retina, as it should be during axial length measurement.
- The scleral spike is another highly reflective spike generated from the scleral surface, right behind the retinal spike, and should not be confused with it.
- The orbital spikes are low reflective behind the scleral spike.
Most modern biometers use separate sound velocities for the different eye components. The biometer provides an anterior chamber depth, the lens thickness, and the total axial length. The anterior chamber depth is measured between the anterior corneal surface and the anterior lens surface using a velocity of 1532 m/s. The lens thickness is measured between the anterior lens surface and the posterior lens surface using a velocity of 1641 m/s. The instrument also gives the total axial length measurement in mm.

Immersion A-scan biometry produces consistent and reproducible axial length measurements. In comparison, the contact method for axial length measurement does not yield the same results as high precision immersion A-scan biometry. When measuring the same eye, the contact technique yields a 0.20 to 0.24 mm shorter measurement than the immersion technique, most probably due to corneal compression during examination.

Optical Coherence Biometry

Optical coherence biometry (OCB) has gained popularity because of the ease of its use. The IOLMaster is extremely accurate and very easy to use. It also has the added advantage of measuring the central corneal power and the corneal white-to-white. Unfortunately, the use of OCB is limited in the presence of a dense cataract. Ophthalmologists who choose to use the OCB must also have a biometer for those patients with moderate to severe cataracts, because the OCB cannot measure them.

Recommendations to Avoid Errors in Axial Length Measurement

There is no foolproof method to avoid an error in axial length measurement, but I would like to share a protocol that has proven to be very effective.

- Bilateral axial length measurements are performed. Optical coherence or immersion A-scan biometry is strongly recommended for reproducible measurements.
- The measurements are correlated with the clinical data and an implant is chosen. In most cases, both eyes are within 0.5 mm of each other and the measurements correlate with the clinical data; hypermetropes usually measure less than 23 mm, emmetropes between 23 mm and 24 mm, and true myopes over 24 mm. However, discrepancies will be encountered in some cases. The surgeon should then use his or her clinical judgment in analyzing the data. If the surgeon is not satisfied with the calculations or suspects a possible error, he or she should have the measurements repeated, either under his or her supervision or by an outside consultant. When needed, a B-scan examination will rule out intraocular pathology.

Clinical Pearl

Review your measurements and compare to preoperative refraction if the axial length is less than 22 mm or over 25 mm, and if there is a difference between the two eyes of over 0.30 mm.

Clinical Pearl

More and more ophthalmologists are now using the IOLMaster. However, in the presence of a dense cataract, they have to use A-scan biometry. The IOLMaster is calibrated to yield similar results as the immersion A-scan biometry (Figure 16-2). However, if contact biometry is used, it might yield a shorter axial length measurement, calling for the use of a stronger power IOL. In these cases measured by contact biometry, the A constant should be decreased by at least 0.5 to avoid any postoperative myopia.

MEASURING THE CORNEAL POWER

The corneal power is expressed in diopters. However, current instruments only measure the radius of curvature (r) of the anterior corneal surface in Figure 16-1. Ultrasound display of the different echospikes during immersion biometry, identifying from left to right: the initial spike (IS), the anterior and posterior corneal (C) surfaces, the anterior (L1) and posterior (L2) lens surfaces, the retina (R), sclera (S), and orbital tissues.
meters and convert it to diopters using an average index of refraction of $1.3375$, and where:

$$K = \frac{(1.3375 - 1)}{r}$$

Keratometers, including the one within the IOLMaster, measure 4 to 6 points within the central 2 to 4 mm of the cornea. The average K readings are used for IOL power calculations. Corneal topography units produce a simulated K value (SimK) that averages the readings within the central 3-mm circumference.

Newer units such as the Pentacam (Oculus, Lynnwood, WA) measure the anterior and the posterior radius of curvature. The true power of the cornea equals the power at its anterior surface minus the power at its posterior surface.

**Clinical Pearl**

Review your measurements and reevaluate with corneal topography if there is a difference between the two eyes of over 1 diopter in the average corneal power, or if the average K is less than 40 D or over 47 D. The same holds true if the cornea is irregular, in the presence of keratoconus, or following refractive surgery.

**The Post-LASIK Cataractous Eye**

More and more patients who have undergone refractive surgery are developing cataracts. These patients are usually more demanding and they will be expecting clear distance vision post-cataract surgery just like they had after LASIK. Accurate calculations become more critical if the patient is having a premium IOL for clear distance and reading vision.

If no adjustment is made to the calculations, the patient will end up with an unexpected postoperative hyperopia.

After refractive surgery, two errors are introduced in the IOL power formulas.

First, the refractive surgery produces an error in the evaluation of the correct K value. After LASIK, the measurements taken by keratometry or by topography are not correct and should not be used. LASIK alters the anterior corneal surface and the relationship between the anterior and posterior corneal curvature is no longer the same, and this changes the index of refraction. The correct K is usually lower than the measured one. There are multiple methods that have been developed to perform these calculations. The Clinical History Method is recommended if the pre-LASIK K readings and the amount of LASIK correction are available. The corrected K readings are calculated by subtracting the amount of LASIK correction obtained at the corneal plane from the pre-LASIK K readings.

The Shammas No-History method is recommended if the pre-LASIK K readings and the amount of LASIK correction are not available. The corrected K ($K_c$) is calculated from the measured post-LASIK K ($K_{post}$), and where:

$$K_c = 1.14 K_{post} - 6.8$$

The second error is in the evaluation of the postoperative ELP by the commonly used IOL power formulas (SRK/T, Holladay 1, and Hoffer Q). These formulas use the K readings to estimate how far the implant used in surgery will be from the cornea. After myopic LASIK, the central cornea is flattened. In these formulas, ELP is mathematically linked to the corneal curvature; the steeper the cornea, the deeper the ELP, and vice versa. In other words, in the presence of the flattened cornea, the formula calculates a smaller ELP (shallow anterior chamber depth) that is used in the IOL power calculations. This anomaly can be corrected by using the Double-K method, where the corrected post-LASIK K is used for the corneal power and the pre-LASIK K for ELP measurement. The other way would be to use a formula where ELP does not vary with the corneal curvature, such as the Shammas or the Haigis formula. Multiple computer programs are now available to perform these complex calculations.
Clinical Pearl
Eyes that had refractive surgery require special calculations to avoid postoperative hyperopia. The easiest way to do so is to use one of these available computer programs:

- The ASC online IOL calculator, available at www.ascrs.org
- The Haigis L formula, available on the IOL-Master
- The Holladay II formula, available on the Holladay IOL consultant software
- The "No History" post-LASIK Shammas formula, available as a PDF file
- The Hoffer computer programs

**Intraocular Power Selection**
In the process of IOL power selection, some surgeons routinely aim toward emmetropia. In some cases, consideration should be made for the patient's expectations and needs.

**Patient Expectations**
It is important for the surgeon to understand the patient's expectations and select the IOL power accordingly, especially if a conventional IOL is being used.

- Most patients want good distance vision and accept wearing reading glasses.
- Some patients might want monovision with one eye focused for distance and one eye focused for near.
- Hyperopic patients are used to wearing glasses for distance and for reading. They will enjoy clear distance vision and will have no problems wearing reading glasses.
- Moderately myopic patients are used to reading with no glasses and have difficulties understanding why they have to wear reading glasses after the surgery, especially if they are promised clear distance vision.

**Patient Needs**
The surgeon should not recommend postoperative emmetropia for every patient. The decision on whether to aim for emmetropia or what the target postoperative refraction should be depends on the condition and the refraction of the fellow eye. In most cases, the patient has bilateral cataracts requiring surgery on both eyes.

The problem arises in very long and very short eyes and when surgery is not contemplated on the fellow eye because it has no cataract or because the patient refuses to have it. In these cases, the surgeon should avoid anisometropia and/or aniseikonia. Anisometropia is the difference in refraction between the two eyes and patients can tolerate a difference of 1.5 to 2.0 diopters with no risk of asthenopia and/or diplopia. Aniseikonia is the difference of retinal image size between the two eyes and patients can ignore aniseikonia of up to 5%, which reflects a refractive error variation of around 2.5-diopter difference between the two eyes.

**Clinical Pearl**
To optimize the refractive outcome, you should perform accurate biometry and accurate keratometry, use a modern or advanced theoretical IOL power formula, and personalize its constant (the A constant for the SRK/T formula, the SF for the Holladay formula, and the ACD for the Hoffer Q formula).

**BIBLIOGRAPHY**


Part B: Limbal Relaxing Incisions

Eric Donnenfeld, MD, and Renée Solomon, MD

While the absence of operative complications is the traditional benchmark by which most of us evaluate the success of our surgical efforts, our patients tend to measure the success of their cataract procedures by the quality of their uncorrected visual acuity. Meeting the needs and heightened expectations of our patients today is a challenge that we cannot ignore and, like it or not, each of us must now view cataract surgery as a refractive procedure. Achieving an optimal refractive outcome requires attention to detail and necessitates both precise biometry and careful management of astigmatic errors.

Regular corneal astigmatism decreases uncorrected visual acuity through meridional blur as one axis of the cornea, steeper than the other, causes image distortion (Figure 16-3). Astigmatism of as little as 0.50 diopters may result in glare, symptomatic blur, ghosting, and halos. Regular astigmatism in most instances is associated with a 90-degree angle between the steep and flat meridians. Regular astigmatism may be characterized as with-the-rule (Figure 16-4A), against-the-rule (Figure 16-4B), and oblique (Figure 16-4C). In general, irregular astigmatism (Figure 16-4D) should not be treated with limbal relaxing incisions (LRIs). There are several different corneal-based options for treating astigmatism including LRIs, excimer laser photoablation, and conductive keratoplasty. In general, the reduction of corneal astigmatism with LRIs at the time of surgery is the most cost-effective and convenient approach. IOL patients are often highly sensitive even to minor refractive errors, and in order to achieve the best possible refractive outcome, surgeons must be willing and able to treat small astigmatic errors.

LRIs are corneal incisions placed adjacent to the limbus that are used to relax the steep axis of regular corneal astigmatism while steepening the flat axis. The procedure allows the eye to heal into a more spherical shape (Figure 16-5). There are several advantages of LRIs over astigmatic keratotomy (AK), a similar incisional procedure that is performed more centrally toward the visual axis. The advantages of LRIs over AK includes a reduced tendency to cause axis shift, less irregular astigmatism, a 1:1 coupling ratio, and a reduced likelihood of perforation.

For regular astigmatic errors ranging from 0.5 to 1.5 diopters, LRIs work very well. Patients with more than 1.5 diopters of astigmatism may benefit from LRIs but there is an increased risk of inducing irregular astigmatism. For patients with higher levels of astigmatism, a LRI may be performed to “debulk” the astigmatic error and an excimer laser photoablation can be performed after IOL implantation for the reduction of the residual refractive error.

LRIs are usually performed during cataract surgery for the treatment of pre-existing astigmatism (Figure 16-6). In experienced hands, LRIs may also be performed postoperatively at the slit lamp (Figure 16-7), although the use of an operating microscope is advised for less experienced surgeons.

A number of LRI nomograms are available, and many studies evaluating LRIs have been performed. LRIs have been shown to result in an average reduction of cylinder by 60%, with 79% of patients corrected to less than 1 diopter of cylinder and 59% corrected to less than 0.5 diopter of cylinder. The 60% reduction in cylinder compares favorably with the results achieved using toric IOLs, which result in 58.4% mean reduction in cylinder.

Many LRI nomograms are adjusted for age and cylinder axis, making them detailed and complex, and giving the impression that the procedure is extremely precise and unforgiving. However, in our experience, this simply is not the case. LRIs are as much an art as a science. For this reason, we have developed a very simple nomogram that works extremely well (Tables 16-1 and 16-2) and is ideal for the novice LRI surgeon. The Donnenfeld nomogram (DONO) is available on the Internet at www.lricalculator.com (Figure 16-8). The online LRI calculator uses vector analysis to calculate where to make LRI incisions based on preoperative patient keratometry and the surgeon’s induced astigmatism. The LRI calculator employs the Donnenfeld nomogram.
Figure 16-4. In with-the-rule astigmatism, the steep axis is vertical (A). In against-the-rule astigmatism, the steep axis is horizontal (B). Oblique astigmatism occurs when the steep axis is neither vertical nor horizontal (C). Irregular astigmatism occurs when the steep and flat axis are not at a 90-degree angle (D).

Figure 16-5. LRIs relax the steep axis of the astigmatism and allow the eye to heal into a more spherical shape.
nomogram and provides a visual map of the axis and length of incisions that should be performed. A printout of the LRI calculator can be brought to the operating room and used as a guide when marking the cornea and performing LRIs.

The operating room is the best place to start doing LRIs and they can be done with routine cataract surgery. LRIs should be done at the beginning of the cataract surgery while the eye is firm and when the cornea has not been thinned by dehydration under the operating microscope. A preset diamond knife is employed, and the arc is made in clear cornea 0.5 mm central to the limbus and centered on the axis as determined by vector analysis of residual cylinder. There are several companies that make preset diamond knives. I prefer to use a preset depth of 0.6 mm. While in the operating room, the LRI calculator printout or the preoperative corneal topography can be used to locate the axis of the intended LRI incisions. The topography may be turned upside down and held near the patient's eye. When the topography is held upside down, the top of the topography correlates with 12 o'clock on the patient's eye. The episclera is grasped at the limbus with a 0.12 calibri forceps, 180 degrees away from the incision's intended site. An incision is made into clear cornea 0.5 mm from the limbus with the diamond knife held perpendicular to the cornea. Once the diamond knife has been placed into the cornea, it is held in position for a full second before advancing to make sure that the full depth of the blade is achieved. The incision is then extended to its desired length. We prefer to draw the diamond knife toward the surgeon to increase control. For most patients, a preset diamond knife with a depth of 0.6 mm is used for the LRIs. For 0.75 diopters of cylinder or less I do not mark the cornea. For larger cylindrical errors, an astigmatism marker can be placed on the cornea and the cornea can be marked (Figure 16-9). One of the most common mistakes novice LRI surgeons make is to not press the LRI blade firmly against the cornea, which results in a shallow ineffective incision.

An LRI is performed on all patients who, judging from their topography and surgical incision, are likely to end up with 0.50 diopter or more of residual cylin-

Figure 16-6. LRIs can easily be performed in the operating room for preexisting astigmatism.

Figure 16-7. Performing a LRI at the slit lamp in the office.

Figure 16-8. The Donnenfeld nomogram is available at www.lricalculator.com.
der. For example, surgeons who make their incisions superiorly need to be aware that additional against-the-rule cylinder will be induced. For a patient who has against-the-rule cylinder of 0.5 diopter, it would be appropriate to perform a LRI at 180 degrees preoperatively. On the other hand, for a patient who has pre-existing 0.5 diopter of cylinder with-the-rule, this astigmatism will be corrected by the surgical technique of a superior incision. For oblique astigmatism, a vector analysis of the preoperative astigmatism and incision will yield the correct axis and magnitude of cylinder to be corrected.

As with any surgical procedure, there are potential complications associated with LRIs, but most are either temporary or correctable. The procedure is generally not associated with glare or starburst as may be seen with radial keratotomy or AK. The possible problems with LRIs include overcorrection, undercorrection, infection, perforation of the cornea, decreased corneal sensation, induced irregular astigmatism, and discomfort. For patients with significant remaining astigmatism, it may be necessary to retreat by redeepening or extending the LRI. For overcorrections, we recommend waiting and then later cleaning out the wound with a Sinskey hook and then suturing the wound with 10-0 nylon if necessary. For smaller overcorrections, an excimer laser photoablation may be employed. We never recommend placing LRIs perpendicular to the original LRIs for consecutive cylinder as this may induce irregular astigmatism. If the cornea is perforated, it may be self-sealing or a suture may be needed.

Figure 16-9. An astigmatism marker can be used and the cornea can be marked.

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<tr>
<th>Incidence of Astigmatism in Cataract Patients</th>
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<td><strong>Diopter Range</strong></td>
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<th>Table 16-2 Nomogram for Limbal Relaxing Incisions</th>
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<td><strong>Astigmatism (in Diopters)</strong></td>
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- Use 5 degrees more for against-the-rule astigmatism.
- Use 5 degrees more for younger patients.
- Use 5 degrees less for older patients.
Improving refractive outcomes is an important goal for cataract surgeons today and learning to perform LRIs is a useful step in achieving this end. The good news is that LRIs are not difficult to learn and, when performed properly, they are both predictable and uniformly successful.

REFERENCES