

Cataract & Refractive Surgery

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**Master Your Toric Planning
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With the LENSTAR LS 900**

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Master Your Toric Planning and Improve Refractive Outcomes With the LENSTAR LS 900



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Lenstar and the T-Cone Toric Platform

Offering sophisticated planning for toric IOL implantation and improved refractive outcomes.

BY WARREN E. HILL, MD

Until recently, a logical, validating approach to planning for toric IOL implantation was lacking, and surgeons typically relied on a series of keratometry (K) readings taken preoperatively to provide an acceptable postoperative outcome for both the sphere and cylinder values of a toric IOL. What was missing, however, was an additional and crucial step to measuring the cornea—validating the necessary information to be used with a toric IOL calculator.

A SOUND APPROACH

Generally speaking, nailing the refractive target with toric IOLs requires three basic elements. First, one must determine how the anterior corneal power is distributed in order to establish that the astigmatism is both symmetrical and regular. Second, one must properly identify the orientation of the steep meridian, which is a major determinant of calculation accuracy. And third, one must measure the power difference between principal meridians. Although a set of K readings could potentially determine the second and third elements, for improved outcomes and physician confidence there should be a way to confirm that the information to be used is correct.

Other than just getting a set of K readings, a more sound approach to establishing the orientation of the steep meridian in the presence of symmetrical and regular astigmatism is to use a topographic axial power map. The T-Cone Toric Platform, integrated into the Lenstar LS 900 (both by Haag-Streit; Figure 1), not only produces a 6-mm axial power map of the anterior corneal surface, but it also allows the user to manually conform the orientation of the steep meridian. In eyes with regular, symmetrical astigmatism, this can be achieved by simply drawing a line through the corneal vertex and then the center of the two steep lobes that straddle it (Figure 2). This line is continued and, where it intersects, the peripheral axis scale is noted. With few exceptions, such an orientation can only be the steep meridian. It is advisable to pay closest attention to the astigmatic lobes in the central 3.5 mm, as changes in this more central



Figure 1. The Lenstar LS 900.

region typically have a greater impact than those in the intermediate and marginal areas of the cornea.

If the manually achieved steep meridian does not line up with the same information from a keratometer, the K reading may be incorrect, or, possibly, the patient may not be a toric IOL candidate due to significant irregular astigmatism, asymmetric astigmatism, or both. If these values line up, then the K readings are validated for the power difference, and the patient is likely a good toric IOL candidate.

I believe that, for the most predictable and reproducible outcomes, the Lenstar LS 900 T-Cone Toric

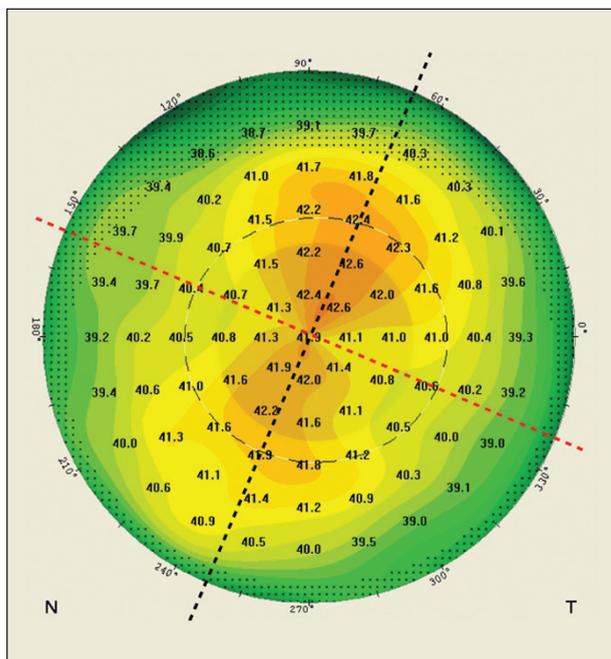


Figure 2. Example of how an anterior corneal axial power map with the Lenstar LS 900 can be used to determine the steep (black dotted line) and flat (red dotted line) meridians within the central 3.5-mm zone (shaded area). The steep meridian is calculated by drawing a line through the corneal vertex and the center of each of the two astigmatic lobes; this is read from the peripheral axis scale.

Platform should first be used to confirm that the anterior corneal astigmatism is both regular and symmetrical. The steep meridian is then manually determined, paying close attention to the central 3.5-mm zone, and the power difference between the principal meridians is validated by confirming that the steep meridians—determined by K readings and manually by topography—both agree.

When a series of K readings correctly identifies the steep meridian, it is safe to assume that the power measurements were taken in the correct location and that the power difference between meridians is also correct. If any uncertainty exists, I use a Javal-Schiötz instrument, beginning at the manually determined steep meridian from the Lenstar LS 900 T-Cone axial power map, to double check the power difference.

AN ALL-IN-ONE DEVICE

For planning toric IOL implantations, the Lenstar LS 900 is an all-in-one device. Its main function has always been keratometry, but it now gives users a deeper insight for toric IOLs. Because a measurement is only as good as our ability to know what it means, this technology is a crucial component to the success of refractive outcomes with toric IOLs.

What makes the Lenstar different from other instru-

Because a measurement is only as good as one's ability to know what it means, the Lenstar technology is a crucial component to the success of refractive outcomes with toric IOLs.

ments is that it gives the user access to more than just the numbers. When looking at the axial measurements, for instance, the user will see a clearly defined display represented in the style of an immersion A-scan and can place the measurement calipers in exactly the right places, if needed, to ensure that the measurements are correct. This form of measurement validation prior to acceptance by the user is also possible for keratometry. For example, less-than-optimal measurements due to a less-than-optimal ocular surface can be deleted and repeated. For white-to-white measurements, a caliper that overlies an image of the eye can easily be adjusted.

MORE ACCURATE OUTCOMES

Incorporating a well-reasoned and logical plan for the measurement of corneal astigmatism can help one to strengthen postoperative outcomes with toric IOLs. Before the T-Cone Toric Platform became available, I had to use a separate topography device to make sure that the patient's astigmatism was regular and symmetrical, manually determine orientation of the steep meridian, and then perform keratometry with the Lenstar. The addition of the T-Cone platform has allowed me to omit that additional step of separate topography, and I can now do everything needed for the preoperative measurements on this one device.

Not only does the Lenstar LS 900 give the user measurements with a higher level of technology than other biometers, it also allows the user to inspect and validate the measurements for keratometry, anterior chamber depth, lens and corneal thicknesses, axial length, and white-to-white.

After LASIK, more than 90% of patients are within ± 0.50 D of intended correction. Although there are still several challenges in lens-based surgery that keep us from consistently achieving that same level of accuracy, the Lenstar LS 900 with T-Cone Toric Platform brings us one step closer to this goal. ■

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A Formula for All Seasons

The Barrett Universal II and True K formulas and the Barrett Toric Calculator provide the best results for toric, postrefractive, and standard cataract patients.

BY GRAHAM D. BARRETT, MD, FRACO

Achieving predictable outcomes after cataract surgery has become increasingly important. Many formulas, both regression and theoretical, perform reasonably well in average eyes but are less predictable in eyes with short or long axial lengths (ALs). In the late 1980s, I conceived the Universal formula, based on the intersection of two globes, which divides the anterior chamber depth (ACD) into anatomically and IOL-related components. The radius of the globe is unknown but can be expressed in terms of a third-order polynomial including AL, keratometry (K), and optical ACD obtained from clinical data. The effective lens position (ELP) is expressed in terms of an anatomic chamber depth and a lens factor (LF).

Unlike most formulas, the Universal formula is a thick lens formula that takes into account the change in principal planes encountered with IOLs of different powers. A crucial difference in the Universal formula compared with other formulas is that it recognizes, in the presence of a negative-powered IOL, that the LF has a negative vergence that must be accounted for in calculating the ELP. Therefore, the formula does not require AL modification or unusual A-constants in highly myopic patients requiring low- or negative-powered IOLs.

AN UPDATED FORMULA

The LF is similar to the A-constant, surgeon factor, or C-constant of other formulas. More recently, however, I recognized that this component of the ELP is also influenced by anatomic factors such as AL, K, optical ACD, lens thickness (LT), and horizontal white-to-white (HWTW). This relationship is included in the latest update of the formula, known as the *Barrett Universal II*. AL, K, and optical ACD are the most important variables, but LT and HWTW, both available on the Lenstar LS 900 (Haag-Streit), provide additional accuracy to the formula.

In a series of 106 highly myopic patients (ALs greater than 26 mm) from Ein-Tal Eye Center in Tel-Aviv, Israel, the Barrett Universal II formula with the above-mentioned modifications performed better than other formulas (Figure 1).¹

I have compared the performance of formulas in many thousands of eyes with different IOL models in datasets provided by Warren E. Hill, MD, and found that

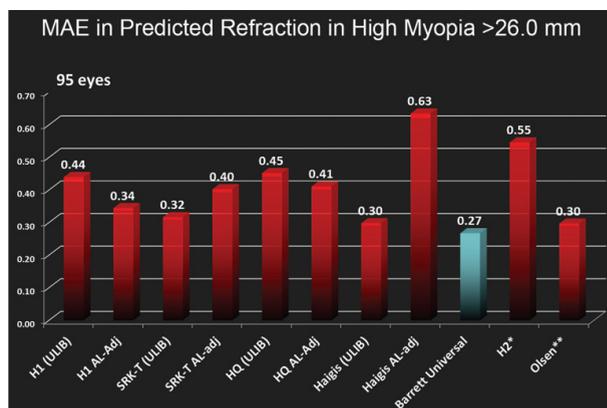


Figure 1. Mean absolute error in predicted refraction using multiple formulas in a series of highly myopic patients.

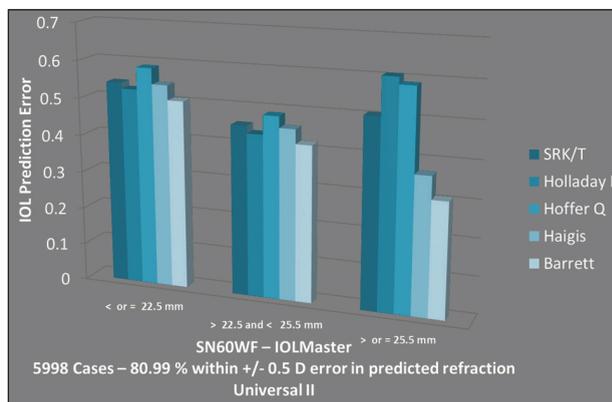


Figure 2. Pooled data from 5,998 eyes: IOL prediction error with the SRK/T, Holladay I, Hoffer Q, Haigis, and Barrett Universal II formulas.

the Universal II formula provides consistent outcomes regardless of AL. In a series of 5,998 eyes comprising pooled data, 80.99% were within ± 0.50 D of intended correction (Figure 2). The mean absolute error in predicted refraction was lower for short, medium, and long eyes with the Barrett Universal II formula compared with the SRK/T, Holladay I, Hoffer Q, and Haigis formulas.

A MORE ATTRACTIVE STRATEGY

Although it has been customary for surgeons to select their formula of choice depending on AL, using a single formula is a more attractive strategy. Choosing

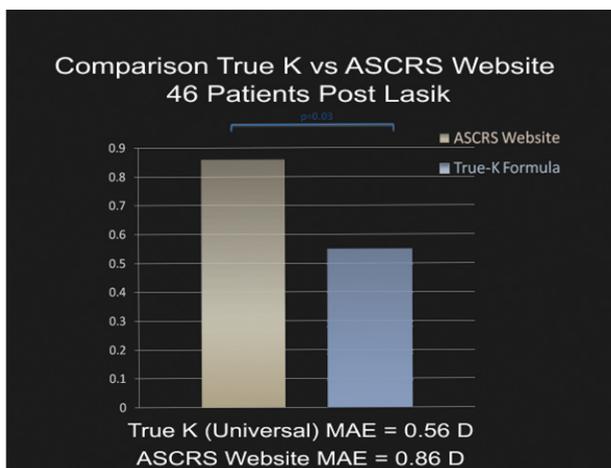


Figure 3. Comparison of the True K formula and the formulas used with the ASCRS toric IOL calculator.

the correct IOL for patients who have previously undergone LASIK or radial keratotomy (RK) is challenging, as traditional keratometry may no longer represent the effective corneal power; rather, it has the tendency to overestimate the true K value. Instruments such as a keratometer or topographer actually measure the anterior radius of curvature and use an assumed refractive index to correct for the power of the posterior cornea; however, this method assumes a normal ratio of posterior-to-anterior radius, which is no longer valid after corneal refractive procedures.

Many solutions have been suggested to address the biometry problems in patients who have had previous refractive surgery and now require cataract surgery. I have developed the True K formula, which is based on the Barrett Universal II formula but calculates a modified K value for postrefractive patients. This requires the input of the measured K from the Lenstar and the pre- and post-LASIK refractions. The formula also provides a double-K solution to address the problem that arises when the central K used for the vergence calculation does not match the peripheral K for the height calculation.

The True K formula is suitable for patients who have undergone myopic or hyperopic LASIK or RK. Although results are more accurate if reliable pre- and post-LASIK refractions are available, the formula is able to predict the required implant when no refractive history is available.

In a study comparing the mean absolute error for the True K formula versus the formulas used with the ASCRS toric IOL calculator, the True K was more predictable and the differences between the True K and other commonly used formulas were statistically significant (personal data; Figure 3). Therefore, the Barrett Universal II and True K were found to be reliable formulas for predicting IOL power in eyes with different ALs and for post-LASIK patients. One must keep in mind, however, that choosing the correct toric IOL is more challenging, as

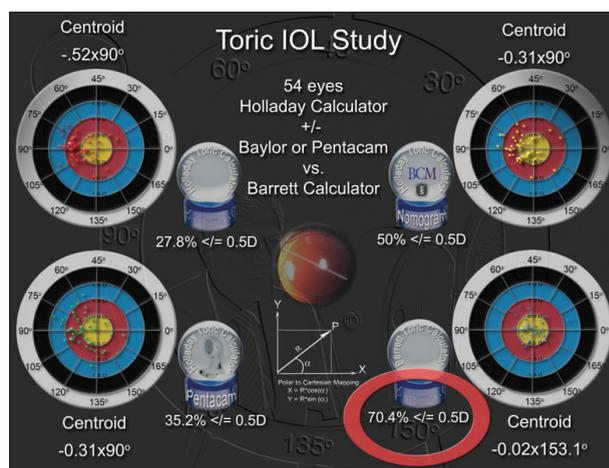


Figure 4. The Barrett Toric Calculator versus the Alcon toric IOL calculator alone and combined with the Baylor nomogram or Pentacam values for the posterior cornea.

one must always consider the magnitude and axis of the toric cylinder required.

CORNEAL CURVATURE AND ASTIGMATISM

Our understanding of the true nature of corneal curvature and its contribution to astigmatism began with the development of the keratometer by Louis Emile Javal in 1881.

Javal noted that he could not account for total ocular astigmatism by measuring the power of the anterior cornea with his newly invented Javal-Schiotz keratometer. This phenomenon is known as *Javal's Rule* and is thought to be due to the posterior cornea contributing an average of 0.50 D of against-the-rule astigmatism.

In his Innovators Lecture in 2012, Douglas D. Koch, MD, further noted that posterior corneal astigmatism increases as the amount of with-the-rule astigmatism increases; however, he found no relationship with against-the-rule astigmatism measured from the anterior corneal surface.² He proposed the Baylor nomogram to address this issue, and I have constructed a theoretical model to explain the observed behavior.

The cornea has a unique architecture. The horizontal diameter is almost always greater than the vertical, and, therefore, the radius of the posterior cornea is steeper in the vertical than the horizontal meridian. A key feature of my Universal II formula is that it predicts a ciliary diameter. This enables me to construct a horizontal and vertical corneal diameter and derive the posterior corneal curvature for each eye. The calculator uses vector mathematics and the Universal II formula to calculate the ELP, the corneal vector of the intended toric IOL, and a value for the posterior cornea.

I conducted a study with my fellow, Adi Abulafia, MD, in patients who had a toric lens implanted. Patients were refracted, and, their keratometry was measured using the

The Barrett Universal II and True K formulas and the Barrett Toric Calculator are solutions for predicting IOL power in eyes with different ALs, those that have previously undergone refractive surgery, and those with astigmatism requiring toric IOLs.

Lenstar, IOLMaster (Carl Zeiss Meditec), or Pentacam (Oculus) to measure the posterior cornea.³ After the pupil was dilated, the axis of alignment was determined at the slit lamp. We compared the percentage of cases within ± 0.50 D of intended correction and the centroid value with the Alcon toric IOL calculator alone and combined with the Baylor nomogram or Pentacam values for the posterior cornea. The centroid for the Barrett Toric Calculator was essentially 0, with 76% of patients within ± 0.50 D of predicted astigmatism. (For more information on this study, see Dr. Abulafia's article on page 9.)

The new calculator proved to be more accurate, even when the posterior cornea was taken into account with the Baylor nomogram and when it was measured with the Pentacam (Figure 4). I also analyzed the data to determine the relative contribution of the estimation of surgically induced astigmatism (SIA), the alignment of the toric IOL, and the method of calculating the required toric IOL power to the error in predicted residual astigmatism in these patients. The use of the Barrett Toric

Calculator had a much greater impact in improving the prediction of residual astigmatism than errors in the estimation of SIA or alignment of the toric IOL.

The analysis also demonstrated that the use of the centroid value for SIA, rather than the mean or median, is appropriate. I recommend that a typical centroid SIA value of 0.10 D be used for a 2.2- to 2.4-mm temporal incision with the Barrett Toric Calculator rather than 0.35 D, which is the typical mean or median SIA value recommended for this purpose.

CONCLUSION

The Barrett Universal II and True K formulas and the Barrett Toric Calculator are solutions for predicting IOL power in eyes with different ALs, those that have previously undergone refractive surgery, and those with astigmatism requiring toric IOLs. These tools can therefore be considered formulas for all seasons. ■

Graham D. Barrett, MD, FRACO, is an Associate Professor of Ophthalmology at The Lions Eye Institute, and is Head of the Department of Ophthalmology at Sir Charles Gairdner Hospital, both located in Nedlands, Western Australia. Dr. Barrett states that he has licensed the Barrett Universal II formula to Haag-Streit for use in the Lenstar. He may be reached at tel: +61 8 9381 0872; e-mail: barrett@cyllene.uwa.edu.au.



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Hitting Your Target With Toric IOLs

The Barrett Toric Calculator can be used to calculate the cylinder power and axis of a toric IOL.

BY ADI ABULAFIA, MD

The correction of corneal astigmatism with toric IOLs has become a standard of care and a means to improve refractive outcomes after cataract surgery. However, the results are not always predictable. During my work as the medical director of the IOL calculation unit at Ein-Tal Eye Center in Tel-Aviv, Israel, I learned that even correcting for rotational misalignment of the IOL and unexpected surgically induced astigmatism (SIA) did not always explain an unexpected postoperative astigmatic outcome.

TWO IMPORTANT COMPONENTS IN ASTIGMATISM CORRECTION

Optimal correction of astigmatism requires accurate measurement of the cornea and a reliable method to calculate toric IOL power.

Accurate measurement of the cornea. For many years, manual keratometry (K) has been advocated as

Optimal correction of astigmatism requires two important components: (1) accurate measurement of the cornea and (2) a reliable method to calculate toric IOL power.

the preferred method to measure corneal astigmatism and determine the correct axis and cylinder power needed for a toric IOL. A number of recent papers have suggested that several devices produce results that are equivalent to manual K.¹⁻³

In a study conducted on 35 volunteers from Ein-Tal medical staff,⁴ we compared the repeatability of two

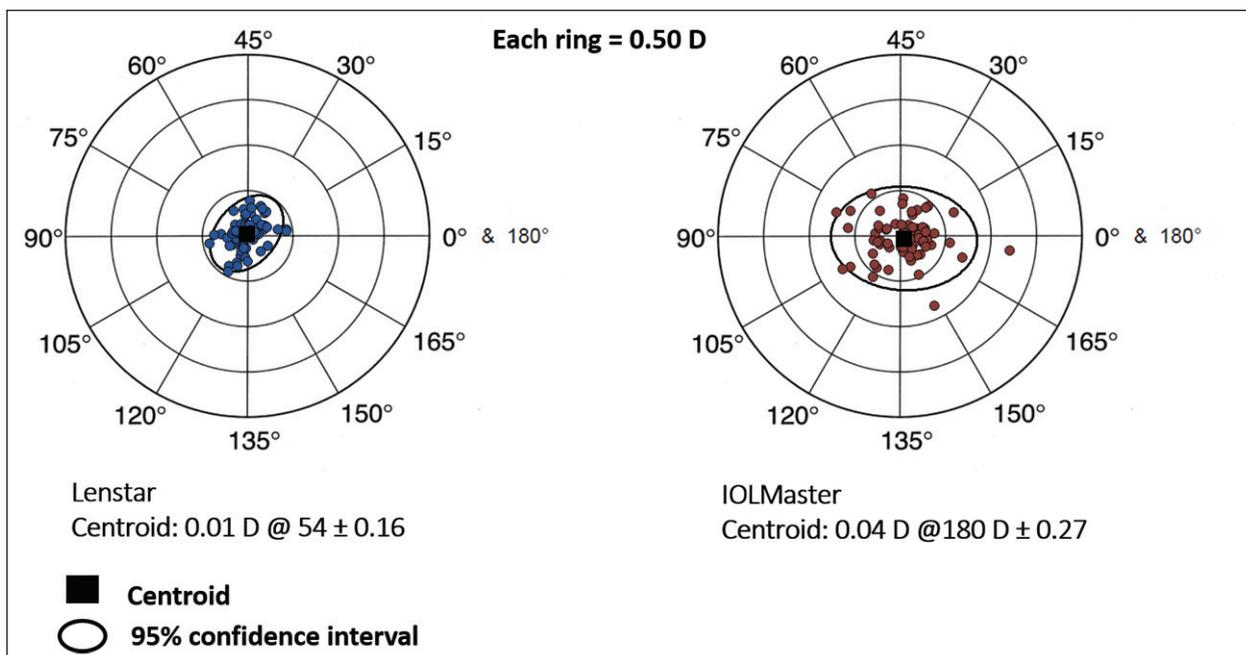


Figure 1. Double-angle plots of the differences in the measured corneal astigmatism of the same eyes, 1 week apart, using the Lenstar (left) and IOLMaster (right).

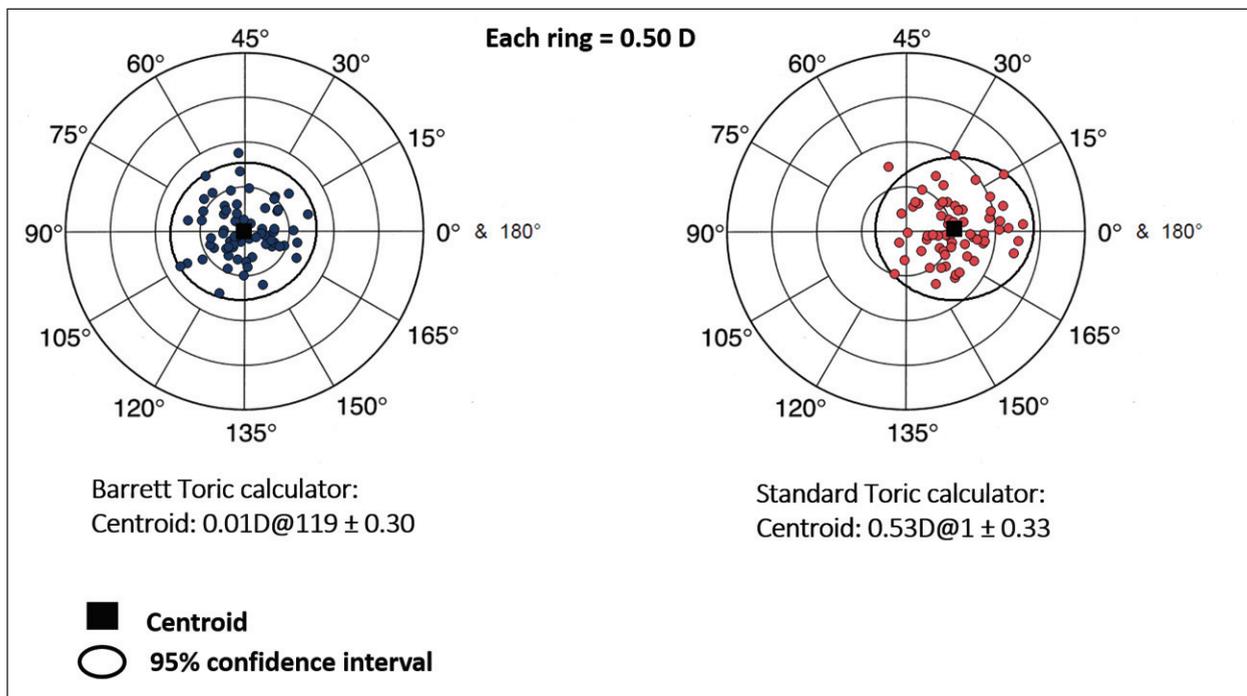


Figure 2. Double-angle plots of errors in predicted residual astigmatism using the Lenstar with the Barrett Toric Calculator (left) and a standard toric IOL calculator (right).

corneal astigmatism measurements taken 1 week apart with the Lenstar (Haag-Streit) and the IOLMaster (Carl Zeiss Meditec). The Lenstar showed better reproducibility compared with the IOLMaster; the absolute cylinder power difference was 0.50 D or less in 100% and 82.9% of eyes with the Lenstar and IOLMaster, respectively (Figure 1). These results can be attributed to the 32 measuring points, arranged in two concentric rings, of the Lenstar as opposed to the six measuring points of the IOLMaster. Another potential advantage of the Lenstar is the strict validation criteria that can be applied for each measurement, such as standard deviation (SD) values for flat and steep Ks and axes.

A reliable method to calculate toric IOL power. In addition to proper and reproducible measurements, the method for calculating toric IOL power plays a key role in achieving accurate prediction results. Many toric IOL calculators use a fixed ratio to determine the toric IOL power at the corneal plane. However, even with a commercial toric IOL calculator that uses an anticipated effective lens position (ELP) to predict the toric IOL power at the corneal plane, our results were not always optimal.

Douglas D. Koch, MD, has highlighted the role of the posterior cornea in assessing net corneal astigmatism,⁵ questioning the validity of the way in which ophthalmologists have traditionally measured the amount of the total corneal astigmatism. The Baylor toric nomogram, subsequently described by Koch et al,⁶ is based on a regression analysis derived from direct posterior corneal

Another potential advantage of the Lenstar is the strict validation criteria that can be applied for each measurement, such as standard deviation values for flat and steep Ks and axes.

astigmatism measurements⁷ and addresses this issue by taking into account the effect of the posterior cornea in the presence of with-the-rule (WTR) or against-the-rule (ATR) corneal astigmatism. The nomogram can be used in conjunction with standard toric IOL calculators.

The Barrett Toric Calculator (available at www.ascrs.org/barrett-toric-calculator and www.apacrs.org/), developed by Graham D. Barrett, MD, will be available on the Lenstar soon. This calculation method uses the ELP of the Barrett Universal II formula in conjunction with a mathematical model for the posterior cornea to calculate the required cylinder power and axis for toric IOLs.

THE CAUSES OF UNEXPECTED OUTCOMES

In a study conducted at Ein-Tal Eye Center, under the supervision of Ehud I. Assia, MD, and with the collaboration of Drs. Barrett and Koch and Li Wang, MD,⁸

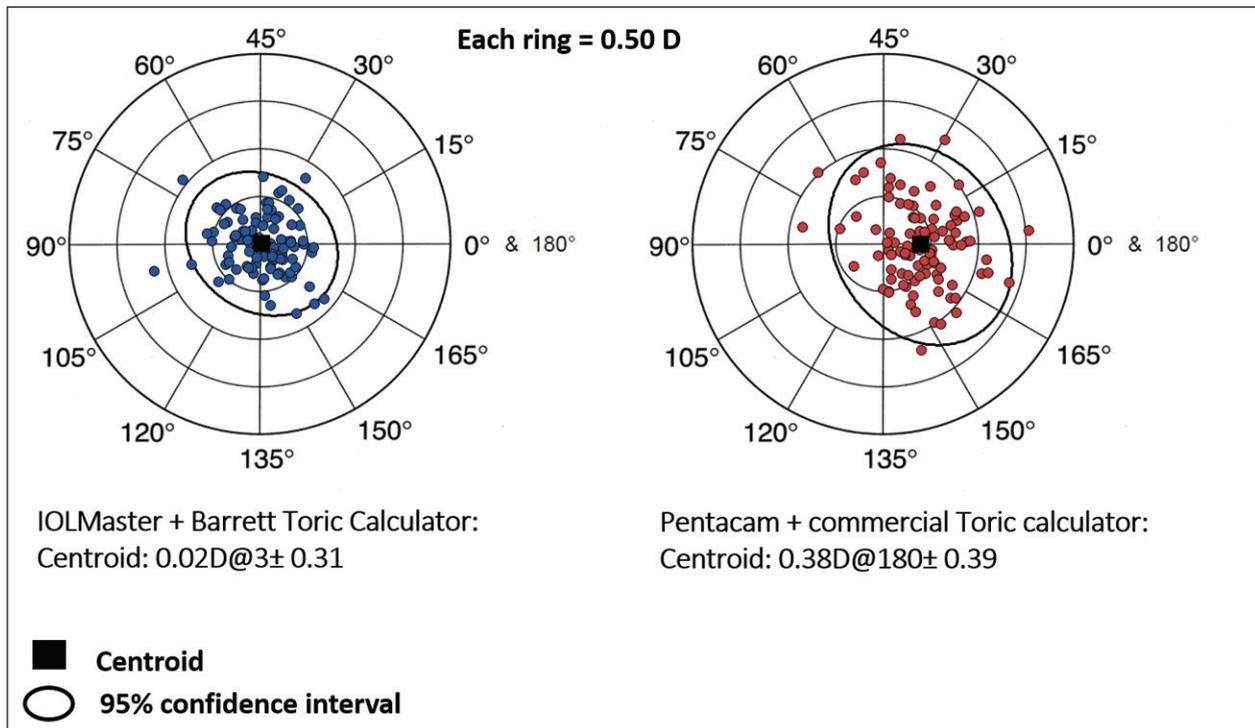


Figure 3. Double-angle plots of errors in predicted residual astigmatism using the IOLMaster with the Barrett Toric Calculator (left) and the Pentacam with a commercial toric IOL calculator (right).

we evaluated a cohort of 68 eyes and examined the two factors that we thought could contribute to unexpected outcomes with toric IOLs: (1) the method of measuring corneal astigmatism and (2) the method of predicting the required power and axis of a toric IOL.

The purpose of this study was to compare the error in predicted residual astigmatism for different corneal measurement devices and using several methods of toric IOL calculation. We found that the Lenstar and IOLMaster were superior to the Atlas Corneal Topographer (Carl Zeiss Meditec) and that the online and commercial toric IOL calculators adjusted with the Baylor nomogram and the Barrett Toric Calculator were superior to the online and commercial toric calculators on their own. The most accurate prediction of residual astigmatism was achieved with the Barrett Toric Calculator in combination with the Lenstar (Figure 2).

A subsequent study compared the accuracy of direct measurements of the corneal astigmatism in 100 eyes using the Pentacam (Oculus) and a commercial toric calculator to the IOLMaster with the Barrett Toric Calculator.⁹ Results showed that the Barrett Toric Calculator had a lower median absolute and centroid prediction error as compared with direct measurements of the net corneal astigmatic power (Figure 3).

CONCLUSION

Today, my preferred method for toric IOL calculation is to use the Barrett Toric Calculator with the

guidelines recommended by Warren E. Hill, MD. These guidelines include using the Lenstar as the primary measuring device for corneal astigmatic power and axis (with strict validation criteria) along with a corneal topographer or Scheimpflug-based device and a manual keratometer as supporting devices for validation. ■

Adi Abulafia, MD, is an anterior segment fellow at Sir Charles Gairdner Hospital, Nedlands, Australia, and a former consultant surgeon, founder, and Medical Director of the IOL calculation unit at Ein-Tal Eye Center, Tel-Aviv, Israel. Dr. Abulafia states that he has no financial interest in the products or companies mentioned. He may be reached at e-mail: adi.abulafia@gmail.com.

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Patient-Specific Factors in IOL Power Calculations

The additional data included in the Holladay 2 and Olsen formulas can positively affect clinical outcomes.

BY RICK POTVIN, OD; WARREN E. HILL, MD; AND EDWARD MEIER, MD

There is no question that advances in both cataract surgery technique and IOL power calculation formulas have significantly improved outcomes in patients undergoing cataract surgery.¹ One of the largest and most current databases collected to date regarding the overall outcomes of cataract surgery is the European Registry of Quality Outcomes for Cataract and Refractive Surgery (EUREQUO), with records for more than 1.5 million cases treated between January 2009 and August 2014.² Of the more than 500,000 cases treated between January 2009 and August 2011 and in the eyes for which postoperative refractive data were available, 91.5% of the mean spherical equivalent results were within ± 1.00 D of the target refraction.³ Behndig et al reported similar results in a Swedish outcomes registry containing more than 15,000 eyes, as 71% of these were within ± 0.50 D of target refraction and 93% within ± 1.00 D.⁴ Likewise, Gale et al analyzed a UK outcomes database over three audit periods and found results within ± 0.50 D in 49% to 60% of eyes and results within ± 1.00 D in 80% to 87%.¹

IOL POWER AND ELP

The major factors that affect the calculation of an appropriate IOL power are the power of the anterior cornea, the axial length (AL) of the eye, and the position at which the IOL is situated in the eye after surgery. Determining the latter—effective lens position (ELP)—is slightly more complex because it depends on two factors, one that is lens-related and another that is patient-related. As ELP increases, IOL power must also increase to keep the focal point of the lens at the fovea.

Lens-related factors. The profile of an IOL is the main consideration among the lens-related factors affecting ELP. Because IOLs are thick lenses, formulas that rely on a thin-lens approximation of IOL power are affected by this lens profile. The top and bottom edges of the two IOLs shown in Figure 1 are similar, suggesting that they will be in a similar position in the lens capsule. The power of the top lens is on the anterior surface, but the

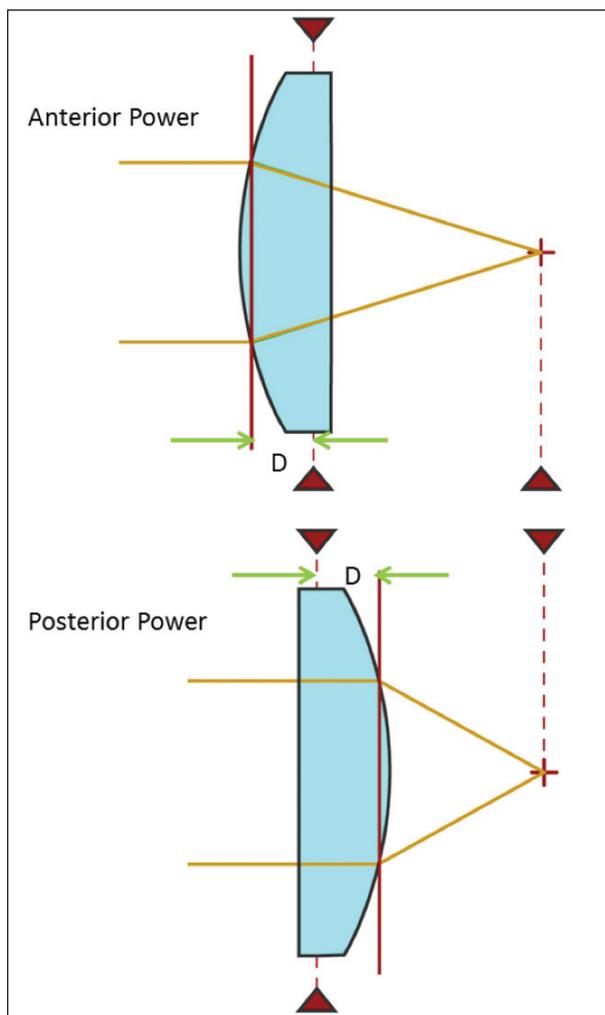


Figure 1. IOL-related factors affecting ELP. (*D* = the difference between the lenses)

power of the bottom lens is on the posterior surface. The difference between the two lenses represents the lens-related component of ELP. Manufacturers provide surgeons with an A-constant for each lens, which is a factor that accounts for this. The lens with the power at the posterior surface will require more power than the

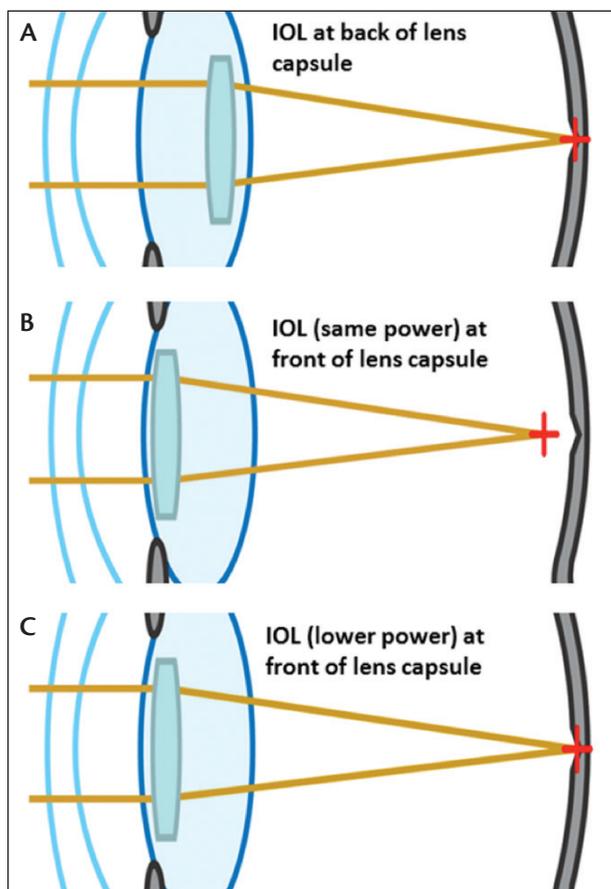


Figure 2. Patient-related factors affecting ELP.

lens with the power at the anterior surface, as it has a higher relative ELP.

Patient-related factors. The patient-related component of ELP is a function of eye and lens geometries (Figure 2). An IOL in one patient's eye may sit further back in the capsule after surgery than it will in another eye (Figure 2A). For instance, if the same lens is implanted in a patient with identical anterior chamber depth (ACD), AL, and keratometry (K) but different crystalline lens geometry and lens thickness, it would stabilize more anteriorly—essentially creating a higher power than required and resulting in residual myopia (Figure 2B). Adjusting the lens power down would be necessary to achieve an accurate refractive result (Figure 2C). This consideration of lens position is for illustrative purposes only. The final lens position in the eye is generally determined by where the equator of the capsule is; lens geometry and overall lens thickness will determine exactly where that equator is.

BIOMETRIC FORMULAS

Early biometric formulas were based on two factors only: AL measurements and the average K of the anterior cornea. Regression equations were then used to optimize

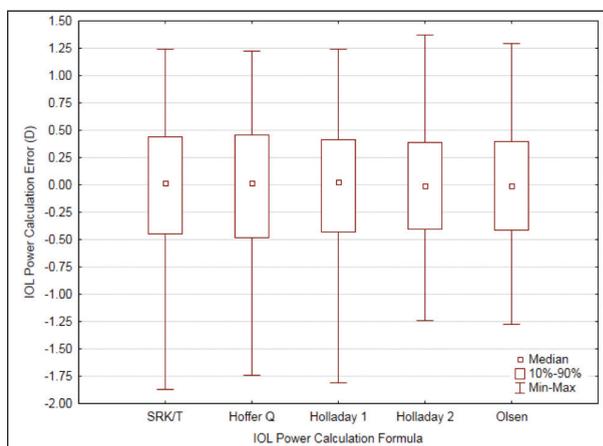


Figure 3. Box plot of IOL power calculation errors.

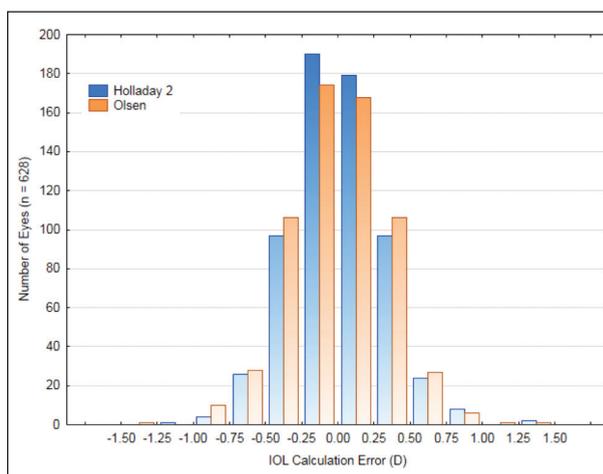


Figure 4. IOL power calculation error by formula (using optimized constants).

the predicted IOL power for a given AL and anterior corneal curvature, and ELP was calculated based on the manufacturer's A-constants and a presumed fixed relationship between AL and ACD. In other words, for a given lens model (same A-constant) and AL, the ACD and subsequent calculation of ELP were based on population averages.

More recent formulas such as the Haigis, Holladay 2, Barrett Universal II, and Olsen formulas include consideration of the measured ACD in the eye. The Olsen, Holladay 2, and Universal II formulas also consider lens thickness (LT) data in customizing the IOL power calculation. The data below show how this additional information can improve IOL power calculation.

A series of 628 IOL power calculations were performed for 424 patients at two sites using the Holladay IOL Consultant software (Holladay Consulting). Patient data included AL, K, horizontal white-to-white (HWTW), ACD, LT, age, and sex. Postoperative refractive data allowed the determination of the optimal IOL power to be back-calculated using an appropriate vergence formula. The known refractive outcomes were then

TABLE 1. PERCENTAGE OF EYES WITHIN (X) D OF TARGET REFRACTION

| Formula | % of Eyes within (x) D of Target | | | >1.00 D Error |
|------------|----------------------------------|--------|--------|---------------|
| | 0.50 D | 0.75 D | 1.00 D | |
| SRK/T | 84.1% | 96% | 98.9% | 1.1% |
| Hoffer Q | 83.6% | 95.7% | 99% | 1% |
| Holladay 1 | 85.7% | 97.1% | 99.5% | 0.5% |
| Holladay 2 | 89.6% | 97.6% | 99.5% | 0.5% |
| Olsen | 88.2% | 97% | 99.5% | 0.5% |

used to optimize each formula, and the calculations were repeated with the optimized constants in order to ensure that the mean result for all calculations was near zero and to remove calculation bias from the results.

The Holladay 1, Holladay 2, Hoffer Q, and SRK/T formulas were evaluated. Separately, the data set was used to calculate IOL powers using the Olsen formula. Again, the results were used to optimize the calculation constants so that the mean for the data set was zero, and the calculations were repeated with the optimized formula.

Figure 3 shows a box-whisker plot of the results by formula. The median value, indicated by the small box, is near zero for all formulas. The larger box includes the central 80% of calculated errors, and the whiskers show the minimum and maximum. Although results from the optimized calculations are good, the Holladay 2 and Olsen formulas show a slightly lower error range for the central 80% of calculations. To consider these results another way, Table 1 shows the percentage of eyes within ± 0.50 , ± 0.75 , and ± 1.00 D of the intended corrections. The Holladay 2 and Olsen formulas, which include ACD and LT data, provide slightly better results for eyes within ± 0.50 D. A series of log-likelihood tests of the odds ratios between the formulas shows that the Holladay 2 and Olsen formulas resulted in a statistically significantly higher percentage of eyes within ± 0.50 D than the other formulas. There were no statistically significant differences between Holladay 2 and Olsen, or between SRK/T, Hoffer Q, and Holladay 1.

As noted above, with the exception of the Holladay 2 and Olsen, the formulas we evaluated do not include patient-specific measurements of ACD or LT but rather presume the effect of these values based on assumptions from population averages. A correlation analysis showed that ACD and LT have a weakly significant correlation to AL, suggesting that individual measurements may be more useful than population averages; the results here support that premise.

The two formulas (Holladay 2 and Olsen) that include patient-specific measures of LT and ACD showed comparable performance. An analysis of variance of the calculation errors showed no statistically significant difference between

the two ($P=.66$). In the histogram of the power calculation error for both formulas in Figure 3, the distributions are similar. The IOL power calculation errors by formula using optimized constants are shown in Figure 4.

CONCLUSION

It is evident from the data presented above that more detailed patient-specific biometry, such as measured ACD and LT, is important in making further improvements in IOL power calculation. The additional patient-specific data included in the Holladay 2 and Olsen formulas have a modest but positive effect on clinical outcomes; current clinical outcomes for uncomplicated cataract surgery are sufficiently good that only such incremental improvements are likely to be possible. As the precision of patient-specific biometry increases, further improvements in clinical outcomes are likely. ■

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