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New Frontiers in IOL Prediction

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New Frontiers in IOL Prediction for Improved Refractive Outcomes

Contents

IOL Power Selection by Pattern Recognition

The Hill-RBF method is a new data-driven and self-validating method for IOL power selection.

BY WARREN E. HILL, MD

In the modern era of cataract surgery, where patient expectations are increasingly high, accurate and reliable IOL power selection is crucial. For many years now, surgeons have relied on incremental improvements to theoretical formulas. And while preoperative planning continues to significantly improve, outcomes have not always been consistent.

A fundamental problem with any theoretical formula is that the effective lens position—representing a significant portion of the calculation—is something that can only be estimated and not directly calculated. Recent improvements, like the Barrett Universal II and the Olsen formulas, do an outstanding job in this area, but, at the end of the day, the effective lens position remains a sophisticated estimation.

It is also an unfortunate reality that many surgeons and their staffs are still using older third-generation, two-variable formulas. I am quite certain that these same physicians no longer drive a car from 1988, have a TV from 1991, or use a cell phone from 1993, yet they continue to use IOL power selection methods from these years. Given the fact that we, as surgeons, are now being judged by our patients, and by our peers, by our refractive outcomes, the time has arrived to move to calculation methods from this century.

For the past 6 years, I have been working with the engineers and mathematicians at MathWorks (a world leader in mathematical modeling), Haag-Streit, and a large group of dedicated surgeon-investigators to develop a new method of IOL power selection using pattern recognition. Based in artificial intelligence, the Hill Radial Basis Function (Hill-RBF) method (Figure 1) is entirely data driven and seemingly free of calculation bias. It also does not depend on the effective lens position.

HOW DOES THIS WORK?

A radial basis function (RBF) neural network is a form of sophisticated mathematical modeling.[1] Although it may sound unfamiliar, or even exotic, its use in the modern world is all around us. EKG interpretation, fingerprint identification, facial recognition, sophisticated financial forecasting, and engine calibration and operation are just a few commonly applied applications that many of us may already have used without being aware.

The fundamental advantage of pattern recognition for selecting IOL power is achieved through the process of adaptive learning—the ability to learn tasks based solely on data and independent of what is previously known. Theoretical formulas limit possibilities to situations that are already understood. This method is also self-organizing, meaning that it has the ability to create an independent representation of data. Such an approach is well suited to the complex, nonlinear relationships that make up many aspects of the human eye.

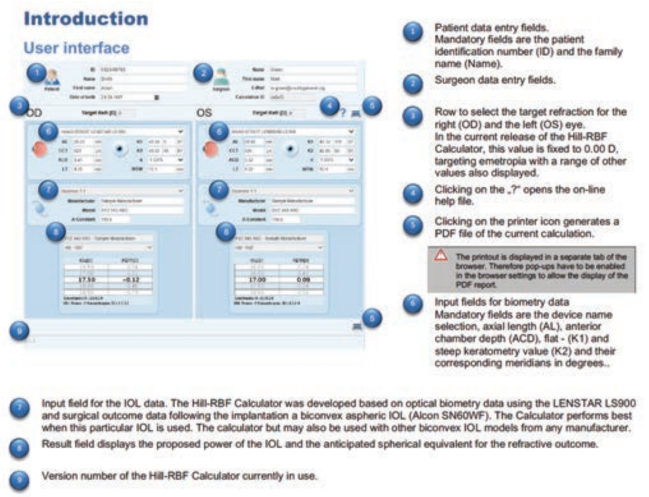

Figure 1. A screen shot of the Hill-RBF calculator and explanation of its functions.

For example, for an axial length of 23.5 mm, consider how many associated combinations of keratometry (K), anterior chamber depth (ACD), lens thickness, and white-to-white are possible; it is therefore easy to imagine why theoretical, regression-based formulas may perform below expectations in certain situations. Most surgeons have a preferred method for short or long eye, steep or flat Ks, and unusual combinations. For the RBF method, combinations of preoperative measurements are instead viewed as a pattern. And when this is combined with a sophisticated form of data interpolation, it becomes free of calculation bias.

The use of RBFs for IOL power selection fundamentally is a big data exercise. The greater the number of individual cases that are fit to the RBF model, the better it will perform. When creating the Hill-RBF method, we started out with data from about 680 Lenstar (Haag-Streit) measurements. In its present form, it is now based on 3,445 eyes measured by the Lenstar. By the end of 2016, an additional 1,400 short eyes, along with 9,000 normal and long eyes, will be used to update the existing Hill-RBF model.

With increasing data, the breath and depth of the RBF model

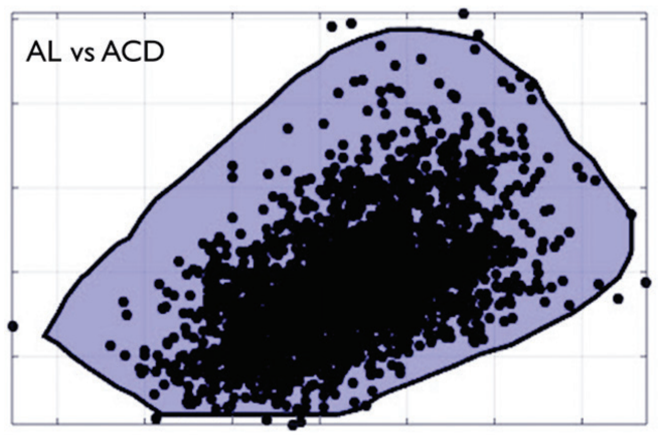

Figure 2. Axial length versus anterior chamber depth, one of six pair-wise boundary models for the RBF method. If a preoperative measurement falls outside the blue area, the calculation will be flagged with an out-of-bounds indication.

is expanded, improving both the accuracy of pattern recognition and data interpolation. Stated differently, the more cases we have, the smarter the RBF method becomes. This is enormously powerful technology limited only by the amount and the quality of the data used to augment it.

SELF-VALIDATION

Another component of the RBF method is the concept of self-validation. This is achieved through the use of multiple, pair-wise boundary models, such as ACD versus axial length (Figure 2).

A boundary model is a commonly used engineering tool to aid in accuracy prediction for individual calculations. For IOL power selection, when all preoperative measurements reside within each of six pair-wise boundary models, the IOL power recommendation is deemed as being an in-bounds calculation (Figure 3), and the likelihood that the intended outcome will be achieved is high. When any preoperative measurement resides outside one of the pair-wise boundary models, the IOL power recommended is flagged as being an out-of-bounds calculation (Figure 4). An out-of-bounds indication tells the user that the intended outcome may not necessarily be achieved.

While there will always be exceptions, with the RBF method, an in-bounds indication when the eye has been measured by the Lenstar typically has an accuracy of ±0.50 D of approximately 90%. Lenstar users typically cross reference this with the Barrett Universal II and Olsen formulas.

PROSPECTIVE TESTING

In order to evaluate the usefulness of the Hill-RBF method in clinical practice, Michael E. Snyder, MD; Stephen Scoper, MD; and I conducted a prospective study of 459 consecutive surgeries with a beta version of the Hill-RBF calculator. Using the typical benchmark for intended correction of ±0.50 D, we found that, with the Hill-RBF calculator, 91% of all eyes with an in-bounds indication were within this range. Furthermore, 92% of normal eyes, 98% of eyes with high axial myopia, and 84% of eyes with high axial hyperopia—eyes that are more prone to end up with a refractive surprise—were within ±0.50 D of the target spherical equivalent postoperatively. This result is certainly as good as and, quite possibly, even better than any other methodology currently available.

Wang and others conducted a study of 86 eyes and concluded that the Hill-RBF method had the best overall accuracy for eyes with high axial hyperopia (axial length < 22 mm) than any other IOL power formula they used.[2] Furthermore, both our prospective study and the study presented at ARVO[2] used an RBF model that had only been fit to 3,445 eyes. As more cases are added to the RBF model-fitting dataset, it is likely that the accuracy for these unusual eyes will continue to improve.

I have been using the Hill-RBF Calculator in my practice since September 2015. Although I continue to crosscheck the results from the Hill-RBF method with the Barrett Universal II and the Olsen formulas, the recommendations are remarkably similar. At the present time, the Hill-RBF method, at the very least, is on par with the best theoretical formulas. It is the goal of all who are involved in this project that in the near future we are going to be even better.

GROWING THE DATABASE

There are currently 25 beta test sites in 14 countries from which we continue to collect Lenstar biometry data and surgical outcomes. In a further attempt to grow the database, a website was launched the first week in May 2016, www.rbfcalculator.com. This open-access site allows surgeons to use this method to select an IOL power for their patients. If a user email address is entered, 3 months later, they will receive

WE CAN ALL DO BETTER

For more than a decade, I have offered my services, free of charge, to optimize physicians' databases. So far, I have about 260,000 cases in which to draw from.

Using that data, it appears that less than 1% of physicians achieve postoperative refractive outcomes that are within ±0.50 D of intended correction in at least 92% of cases. About 6% of physicians are within this range in about 84% of cases, and the other 93% are within this range about 78% of the time. (It is important to note that these statistics were calculated after the removal of outliers and after the optimization of lens constants.)

As we all know, patient expectations today are high, especially in those selecting premium IOLs such as multifocal and toric lenses. The bottom line is that we can all be doing better, and I believe that the Hill-RBF method can be one way to achieve consistently better refractive outcomes.

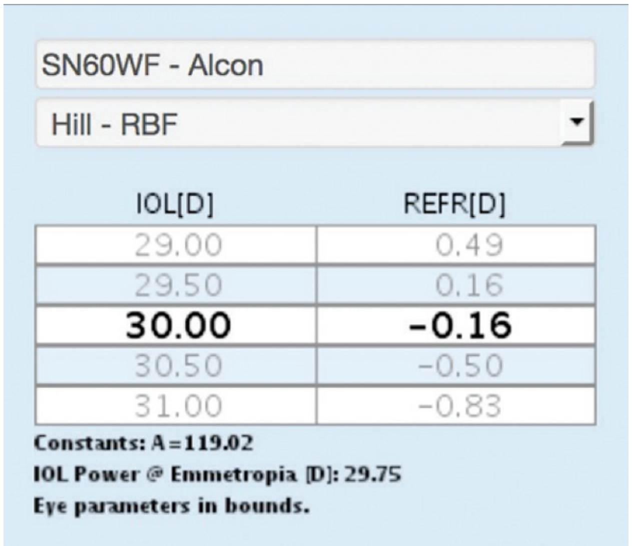

Figure 3. Close-up screen shot of an IOL power calculation with an in-bounds calculation.

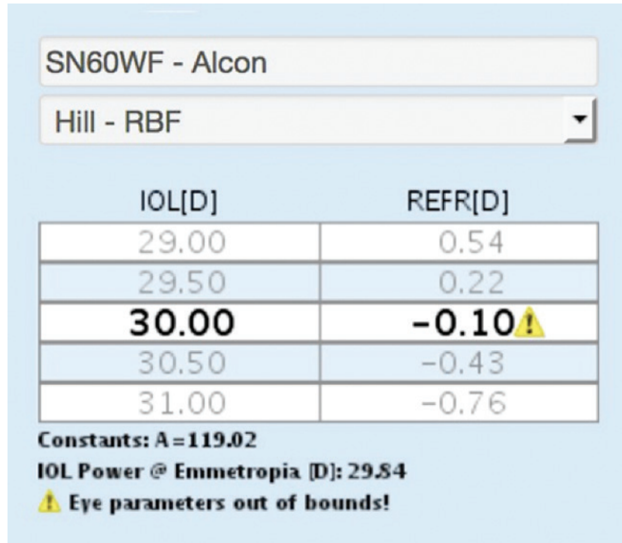

Figure 4. Close-up screen shot of an IOL power calculation with an out-of-bounds calculation.

an email asking for the make, model, and power of the IOL implanted and also the patient's final refractive outcome. And while the Hill-RBF method was optimized for the Lenstar, it can still be used with other biometers. Ideally, biometers other than the Lenstar should employ high-density keratometry and all axial measurements should be by optical biometry.

In the past 5 months, our beta testers have provided more than 10,000 Lenstar cases. Imagine where this project will be 5 years from now, with the potential for 100,000 or even 200,000 cases. This is exciting to consider.

HOW TO USE

Instructions for use of the Hill-RBF Calculator can be found at http://rbfcalculator.com/docs/Hill-RBF-Calculator-Instructions.pdf.

Although The Hill-RBF method will only available on the Lenstar for the foreseeable future, anyone can use the calculator on the website by simply selecting the appropriate biometry method from the drop-down menu.

What makes this project unique is that it has taken the form of a worldwide collaborative effort. All users of the online calculator will have the option to participate in future revisions. In this way, everybody has a stake in its success. In the last 17 weeks there have been over 35,700 calculations. It is wonderful to see the ophthalmic community so readily accepting of this new technology.

1. Bors AG. Introduction of the Radial Basis Function (RBF) Networks. Accessed October 19, 2016.
2. Wang L, Gokce S, Zeiter, Weikert MP, Hll WE, Koch DD. Comparison of seven IOL power calculation formulas in eyes with axial length ≤ 22 mm. Poster presented at ARVO; May 1-5, 2016; Seattle.

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Hill-RBF Calculator in Clinical Practice

The potential to further enhance refractive outcomes after cataract surgery.

BY MICHAEL E. SNYDER, MD

Over the past decade, the term *refractive cataract surgery* has become more commonly used to describe cataract surgery. This terminology, in large part, is due to the accuracy of refractive outcomes that we can now provide our patients after surgery.

Although many elements are involved in the practice of refractive cataract surgery, one of the most crucial is the ability to calculate IOL power effectively and efficiently.

BATTLING REFRACTIVE SURPRISES

Historically, surgeons have relied on formulas such as the Hoffer, Holladay, and SRK-T, and, more recently, on the Olsen and Barrett Universal II, to calculate IOL power. Each has added incrementally to our overall accuracy, yet we still have refractive surprises that fall short of our patients' and of our expectations.

Even as the formulas parse the variables involved in vergence calculations of the expected lens position into smaller subsets of patient cohorts, within each subset a regression still exists with data to either side of a regression line.

Another new alternative, the Hill-RBF Calculator, selects IOL power using artificial intelligence–driven pattern recognition. Available on the Lenstar (Haag-Streit), this new data-driven method to determine IOL power does not depend on effective lens position and does not have any calculation bias. The basis of the Hill-RBF Calculator is described in the previous article by Warren E. Hill, MD, and below I provide a general history of IOL power calculation and further focus on the clinical outcomes with this new method of IOL power calculation.

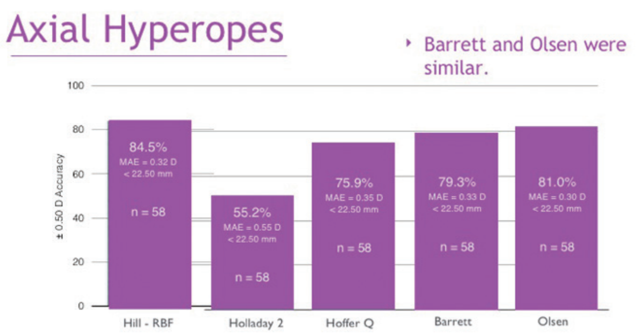

Figure 1. The Hill-RBF Calculator compared with other IOL power calculation formulas in long eyes.

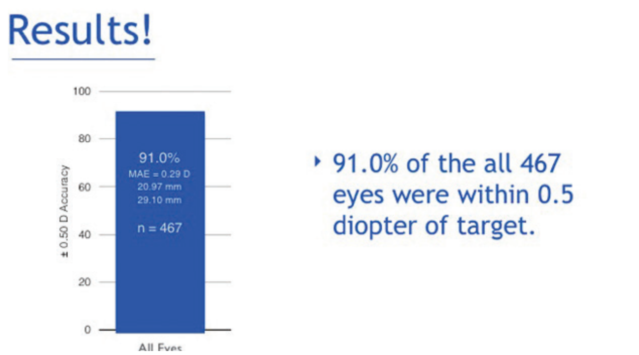

Figure 2. The percentage of eyes within ±0.50 D target spherical equivalent with the Hill-RBF Calculator.

OLD VERSUS NEW

In the very early days of IOLs, before the emergence of accurate biometry, lens power was selected solely based on type of refractive error: rules of thumb assigned average eyes to a 21.00 D lens, myopic eyes a 15.00 D lens, and hyperopic eyes a 25.00 D lens, with gross interpolations based on refractions.

Then, in the 1980s, regression formulas surfaced, helping to incrementally increase the predictability of refractive outcomes after cataract surgery. These empiric formulas were generated by retrospectively analyzing and averaging data from a large number of patients who had undergone cataract surgery. Although the use of regression formulas provided better means of refractive prediction than simply correlating IOL power to the type of refractive error, lens power errors were commonplace.

The development of better diagnostic technologies to measure parameters such as anterior chamber depth, keratometry, and axial length then allowed cataract surgeons to use more precise mathematical formulas to calculate IOL power. Today, theoretical formulas such as SRK-T, Holladay 1 and 2, Hoffer-Q, Haigis, Olsen, and Barrett Universal II are rooted in geometrical optics. However, because they require an estimation of the lens position (ie, effective lens position), refractive errors can still occur postoperatively. Additionally, whereas increasingly sophisticated IOL power calculation formulas can get closer to its goal

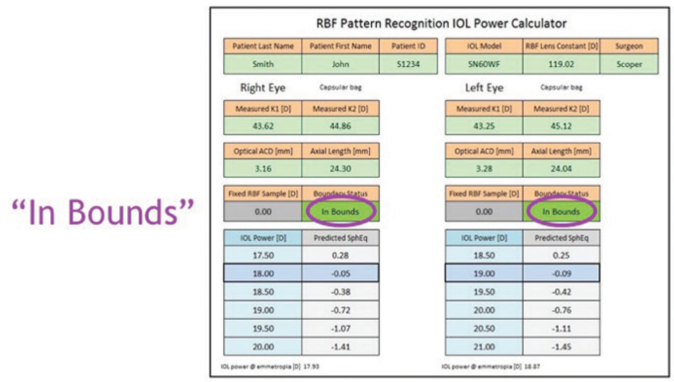

Figure 3. An in-bounds calculation with the Hill-RBF calculator.

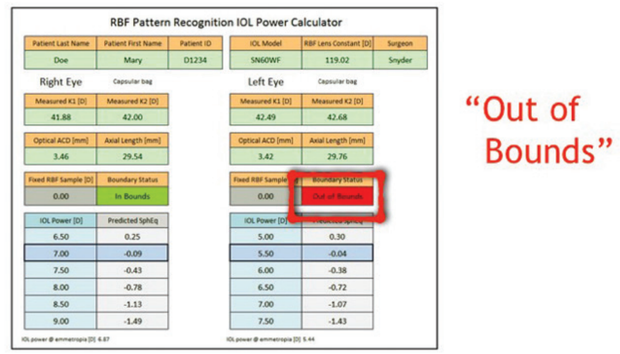

Figure 4. An out-of-bounds calculation with the Hill-RBF calculator.

by adding more data (eyes), there still will be points that are above and below the line.

A LEAGUE OF ITS OWN

The above is not true for the Hill-RBF calculator, which looks at each data point (eye) independently, as it exists relative to outcomes from its fellow data points (eyes). The reason that the Hill-RBF Calculator is so fundamentally different from theoretical IOL power calculation formulas is this: The more eyes that are added to the database, the higher the likelihood that similar eyes are available and the more accurate the calculator becomes.

Additionally, the Hill-RBF Calculator can determine if it does not have enough data to make a good estimation of IOL power. In simpler terms, it tells you when it is likely to be right and when it is not sure. From a clinical perspective, that is great, as there is nothing I like more than knowing what my level of confidence in a piece of information should be.

EARLY EXPERIENCE

I have been using the Hill-RBF Calculator since January 2016. I was privileged to be part of the initial multicenter prospective study, conducted across three sites, to test the beta version of the calculator. In 459 eyes scheduled for cataract surgery, IOL power was calculated based on the legacy formulas and on the Hill-RBF beta calculator, which included data points from the initial 3,400 eyes used to train the artificial intelligence program. We then looked at patients' 1-month final refractions in order to determine how well the Hill-RBF Calculator compared with the IOL power calculation formulas.

What we found was that the Hill-RBF Calculator outperformed all of the selected formulas in long eyes (Figure 1), in average eyes, and in short eyes. Using the benchmark of ±0.50 D target spherical equivalent, 91% of all eyes that were considered in-bounds by the calculator—that is, all preoperative measurements resided within the six pair-wise boundary models—were within this range (Figure 2). An out-of-bounds calculation, on the other hand, was defined as any preoperative measurement that resided outside just one of the pair-wise boundary models (Figures 3 and 4). This occurred in a very low percentage of eyes.

Considering that more than 3 million cataract surgeries are performed yearly in the United States alone, 3,400 eyes is a small data set. We can postulate that, as data from more eyes are imported into the calculator, its preciseness will continue to increase.

GOOD NEWS FOR PATIENTS

A lot of the IOL power calculation formulas in use today harken to the pre-millenium change era in which they had been held to a standard of ±1.00 D target spherical equivalent; however, with patient expectations after cataract surgery being so high, we really need to be within ±0.50 D to meet the refractive outcomes required of spectacle independence, especially with premium IOLs. The Hill-RBF Calculator could very well be the best tool to get us within this range.

Personally, ever since the data from the prospective study was analyzed, I have been using the Hill-RBF Calculator exclusively for eyes in which it provided an in-bound result. In these approximate 1,000 cases, the postoperative refractive results have been phenomenal. I have not crunched the exact numbers since the prospective study closed, but, if I had to guess, only a low single-digit percentage of eyes returned an out-of-bounds result.

Given that the prospective study was conducted using the highest standard of target spherical equivalent (±0.50 D) and that the Hill-RBF Calculator outperformed several sophisticated IOL power calculation formulas in every category, it is safe to say that the Hill-RBF Calculator has the potential to further enhance refractive outcomes beyond even high levels of success that we and our patients enjoy today. ■

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Hitting Your Target With Toric IOLs

High-quality corneal astigmatism measurements are crucial.

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: Surgically induced astigmatism, toric IOL misalignment, corneal astigmatism measurements, and the method of calculation have all been described as factors that might contribute to unexpected residual astigmatism. This article focuses on the latter two.

TWO KEY COMPONENTS OF OPTIMAL CORRECTION

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

Accurate measurement of the cornea. Most devices that measure corneal astigmatism are based on anterior corneal measurement; however, some measure the posterior cornea as well. Also, not all biometry devices measure at the same location, and some have better repeatability and accuracy than others (see *The Power of Repeatability*).

Being familiar with the measuring devices available at your practice, including their features, strengths, and weaknesses, is therefore invaluable. It is also important to be critical when evaluating your measurements and to try not to cruise on automatic pilot mode. One helpful tip is to rely on validation criteria checklists such as the one available on http://doctor-hill.com/lenstar_haag_streit/lenstar_main.htm. When determining the power and meridian of the corneal astigmatism, the first step is to verify if it is symmetrical regular astigmatism. If so, it is advisable to follow the methodology of Warren E. Hill, MD,[1] and to use primary and secondary supporting instruments to verify the steep meridian. The same process also should be repeated for the power difference between the meridians (Figure 1).

A reliable method to calculate toric IOL power. In addition to proper and reproducible measurements, the method for calculating the toric IOL power plays a key role in achieving accurate prediction results. Some of the standard toric IOL calculators still 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 optimal.[2-4]

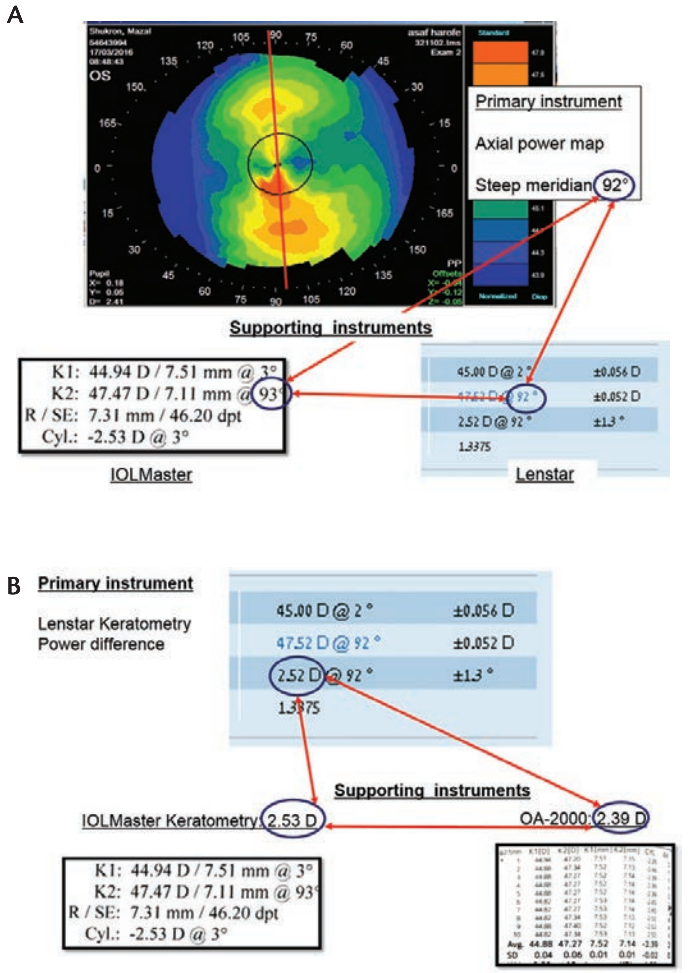

Figure 1. The use of primary and secondary supporting instruments is recommended to verify the steep meridian (A). The same process should be repeated for the power difference between the meridians (B).

A REFINED UNDERSTANDING

Douglas D. Koch, MD, highlighted the role of the posterior cornea in assessing the net corneal astigmatism in 2012,[5] questioning the validity of the traditional method to determine the corneal astigmatism. In short, with the traditional method, devices measure only the anterior corneal curvature and assume that the ratio of the front and the back curvature of the cornea is

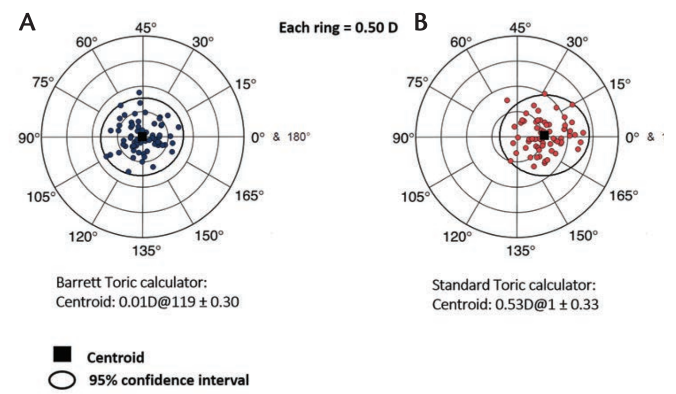

Figure 2. Double-angle plots of errors in predicted residual astigmatism with the Barrett Toric IOL calculator (A) and a standard toric calculator (B) using the Lenstar LS 900 measurements.

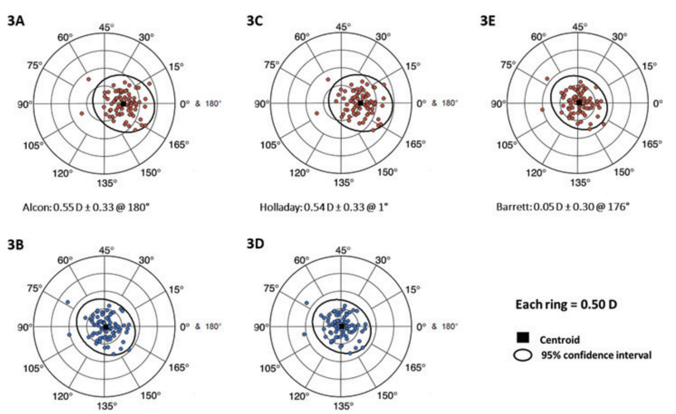

Figure 3. Double-angle plots of errors in predicted residual astigmatism using the IOLMaster 500. The Alcon toric calculator with no adjustments (A) and adjusted by the Abulafia-Koch formula (B); the Holladay toric calculator with no adjustments (C) and adjusted by the Abulafia-Koch formula (D); the Barrett toric calculator with no adjustments (E).

THE POWER OF REPEATABILITY

Good repeatability of corneal astigmatism measurements is essential for high accuracy. In a study conducted on 27 right eyes of healthy volunteers from Ein-Tal Eye Center medical staff,[1] we compared the repeatability of two corneal astigmatism measurements taken 1 week apart with two different biometry devices: the Lenstar LS-900 (Haag-Streit) and the IOLMaster 500 (Carl Zeiss Meditec).

The Lenstar LS-900 showed better repeatability compared with the IOLMaster 500. The absolute astigmatism power difference was 0.50 D or less in 96.3% and 77.8% of eyes with the Lenstar LS-900 and IOLMaster 500, respectively (Figure 1). These results can be attributed to the 32 measuring points, arranged in two concentric rings, of the Lenstar LS-900 as opposed to the six measuring points of the IOLMaster 500. Another potential advantage of the Lenstar LS 900 is the strict validation criteria that can be applied for each measurement, such as standard deviation values for flat and steep keratometry values and meridians.

1. Belkin A. Repeatability of corneal astigmatism measurements. Paper presented at: the ESCRS Annual Meeting; September 5-9, 2015; Barcelona, Spain.

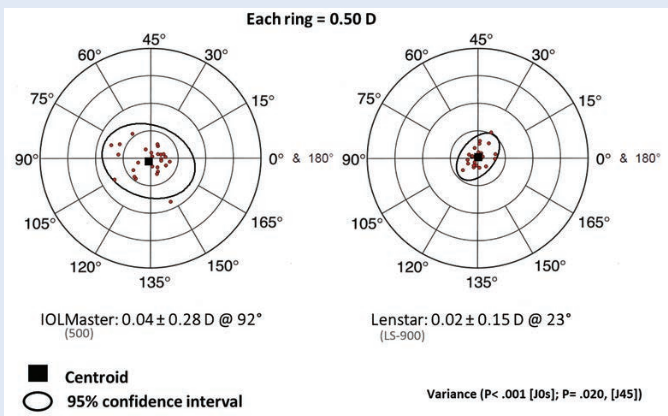

Figure 1. The absolute astigmatism power difference with the IOLMaster 500 and the Lenstar LS-900.

constant. Alternatively, the Baylor toric nomogram, subsequently described by Koch at el,[6] is based on a regression analysis derived from direct posterior corneal astigmatism measurements[7] and addresses this issue by taking into account the effect of the posterior cornea in the presence of with-the-rule (WTR) and against-the-rule (ATR) corneal astigmatism. The nomogram can be used in conjunction with standard toric IOL calculators.

Since then, a great deal of work has been done to refine our understanding of posterior corneal astigmatism and to improve our precision when incorporating this into toric IOL planning. This includes:

- The use of intraoperative aberrometry;
- The use of standard toric calculators with a nomogram like the Baylor,[5] or direct measurements of the posterior cornea;[3]
- The use of the Barrett toric calculator, which, based on the Universal II formula, takes into account the ELP and includes a mathematical model that calculates the estimated net corneal astigmatism by using anterior corneal–based measurements (the full version of the Barrett toric calculator is currently available on the Lenstar LS 900 [Haag-Streit] and at http://www.ascrs.org/barrett-toric-calculator and http://www.apacrs.org/); and
- The use of standard toric calculators with a correction formula like the Abulafia-Koch.[2] This formula was developed based on a vector regression model, in order to convert anterior corneal–based measurements to an estimated net corneal astigmatism, hence it can easily be used as an add-on to any standard toric calculator.

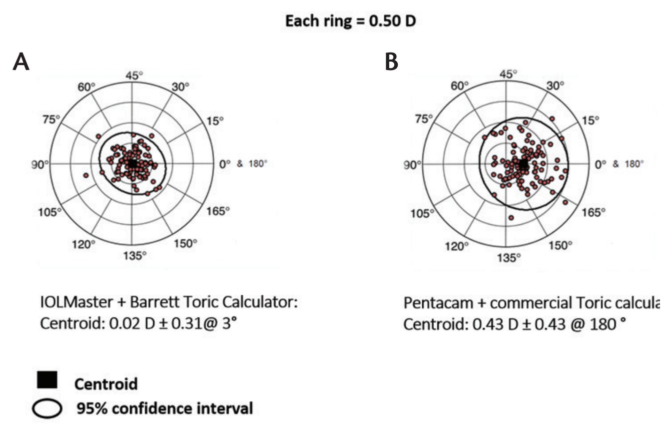

Figure 4. Comparison of the Barrett Toric calculator to direct corneal astigmatism measurements: IOLMaster 500 and Barrett toric calculator (A) vs Pentacam and commercial toric calculator (B).

THE CAUSES OF UNEXPECTED OUTCOMES

In a study conducted at Ein-Tal Eye Center, and in collaboration with Drs. Barrett and Koch and Li Wang, MD,[7] 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 several methods of toric IOL calculation. We found that the Lenstar LS 900 and IOLMaster 500 (Carl Zeiss Meditec) 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 IOL calculator in combination with the Lenstar LS 900 (Figure 2).

In an additional study, we found that standard toric IOL calculators with anterior corneal-based keratometry adjusted by the Abulafia-Koch formula had significantly reduced errors in the prediction of residual astigmatism in toric IOL calculations to a level similar to that of the Barrett toric calculator without adjustments (Figure 3).[8]

A subsequent study compared the accuracy of direct corneal astigmatism measurements with the Pentacam (Oculus) and a commercial toric calculator to the IOLMaster 500 with the Barrett toric calculator.[3] Results in the 99 enrolled eyes showed that the Barrett toric calculator had a lower median absolute and centroid prediction error than direct measurements of the net corneal astigmatic power (Figure 4). These results suggest that using direct measurements of the posterior cornea with this device may not be accurate enough at this stage and should be addressed with caution.

CONCLUSION

Today, my preferred method for preforming routine toric IOL calculation is to use high-quality corneal astigmatism measurements with several measuring devices combined with either the Barrett Toric calculator or a standard toric IOL calculator that takes into account the ELP with the Abulafia-Koch formula adjustments. ■

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The Role of Iris Fingerprinting in Toric IOL Alignment

Making alignment a precise science.

BY ROBERT H. OSHER, MD

I have probably been working with astigmatism correction at the time of cataract surgery longer than any other surgeon in the world. In the early 1980s, when most were concerned with surgically induced astigmatism, I was researching ways to reduce preexisting astigmatism. I eventually performed the first astigmatic keratotomy at the time of cataract surgery, which I think was the first true refractive cataract surgery procedure, and reported the promising results of my series at the Welsh Cataract Congress in Houston in 1984.

Astigmatic keratotomy was certainly an effective method for reducing preexisting astigmatism during cataract surgery; however, it lacked accuracy because we could not guarantee precise incision depth nor control healing. When the toric IOL was introduced, I was hopeful that the *Art* of incisional surgery would be transformed into a precise *Science*. But this was not the case.

Once Douglas D. Koch, MD, discovered the contribution made by posterior corneal astigmatism, I believed that the missing link had been found. Still, the penetration for toric IOLs remained dismally low at about 7% to 8% in the United States and about 10% globally (data on file with Alcon). One deterrent to toric IOLs had been the inaccuracy of preoperative marking, identifying the target meridian, and then aligning the lens in surgery.

AN IDEA IS BORN

After implanting a series of toric lenses, I reached several conclusions. First, marking the major meridia before surgery and the target meridia with ink in the operating room was problematic. Not only could the marks be off axis by 10° or 15°, but the ink could diffuse or completely disappear. Second, I became aware that every patient has unique iris landmarks such as crypts, nevi, pigment, holes, Brushfield spots, stromal patterns, and ridges.

Initially I tried using limbal vessels as landmarks, but these would often blanch when the neosynephrine was instilled to dilate the pupil. Then I started to record the major landmarks on the iris by taking a photograph at the time of the initial examination, when the pupil was dilated. Micron Imaging developed the original software that would allow me to touch a cursor over a landmark and the degree at which it was located would be printed on the photograph. Additionally, a target line could be added to represent the exact alignment for the toric IOL. This photograph was taken to the operating room and placed on the microscope, so I always had confidence in my orientation and lens alignment.

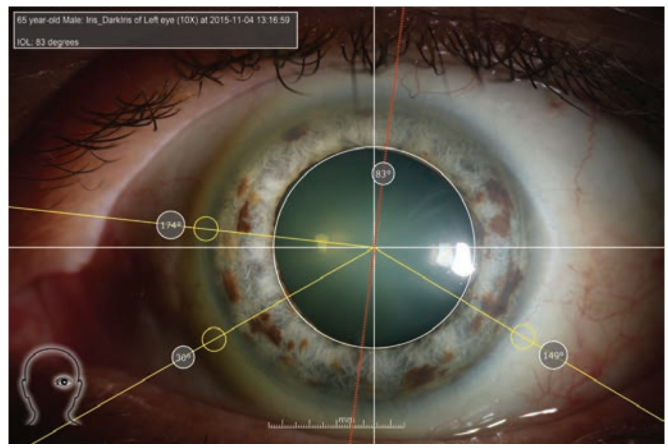

Figure 1. Iris fingerprinting: The white lines indicate the major meridia, the yellow lines show the locations and degrees of the edges of iris nevi, and the red line shows the target meridian at which the toric IOL will be aligned.

I later approached the president of Haag-Streit, Dominik Beck, PhD, and he improved upon the initial technology to develop the Osher Toric Alignment System (OTAS). Sophisticated technologies such as Callisto Eye (Carl Zeiss Meditec) and Verion (Alcon) using similar principles to my original idea for landmark identification were introduced. Other less expensive options of iris fingerprinting were developed by Eye Photo Systems. A similar system with registered information of the planned axis of implantation, incision location, and size as well as measurement data on high-resolution images of the patient's eye is available on the Lenstar biometer (Haag-Streit).

ADVANTAGES

The advantages of iris fingerprinting include cost, simplicity, and efficiency of time. Compared to more expensive technologies, I have found that fingerprinting is extremely accurate for several reasons. With fingerprinting, it is unneccesary to guesstimate the major meridia and mark with ink. (However I still ask the nursing staff to place an ink mark at the 6-o'clock position as a "belt-and-suspenders"

THREE HELPFUL HINTS FOR IRIS FINGERPRINTING

HINT NO. 1

A high-resolution photograph of the iris should be taken at the slit lamp, during the patient's original examination. The patient's pupil must be dilated so that the landmarks appear similar in surgery, the patient's head must be oriented properly, and the patient must be looking far away and straight ahead.

With this technique, the eye will be oriented properly when the image is captured. The Lenstar (Haag-Streit) and the IOLMaster 700 (Carl Zeiss Meditec) provide this information as an integral part of the biometry measurement accurately and efficiently.

HINT NO. 2

Bring a printed image into the operating room, either on paper or on a computer.

HINT NO. 3

Never depend on one technology alone to orient a toric IOL—regardless of the technology you use, whether it is iris fingerprinting, Callisto Eye, or Verion. With iris fingerprinting, I still ask my nurses to make an ink mark at the 6-o'clock position in the preoperative area; with a more sophisticated technology, like Verion or Callisto Eye, I always have iris fingerprinting in case something happens to interfere with registration.

approach.) I have considerable experience with limbal registration, having introduced Verion and more recently becoming a fan of Callisto. One drawback of these technologies, however, is that they depend upon accurate vessel registration. This can be lost if the limbal anatomy becomes altered by conjunctival ballooning from balanced saline solution during phacoemulsification or irrigation/aspiration, chemosis from a subconjunctival anesthetic, or a subconjunctival hemorrhage. We have published a technique for restoring the limbal anatomy should one of these complications occur.[1]

Alternatively, once you are oriented using iris landmarks, fingerprinting is foolproof. Nothing changes during surgery because the dilated pupil is the same in the operating room as it was during the initial examination. For tips in the use of iris fingerprinting, see *Three Helpful Hints for Iris Fingerprinting*.

CONCLUSION

Regardless of which technology is preferred, I strongly recommend a "safety net," as having at least two options available can help to ensure precise toric IOL placement in every circumstance. In my case, I use ThermoDot, which I developed with Beaver-Visitec, to place two tiny cautery marks on the target meridian at the limbus. The ink marks do not diffuse or disappear like ink. I also have an ink mark at the 6-o'clock position, a fingerprinting photograph hanging from my microscope (Figure 1), and the luxury of Callisto and Holos Intraop (Clarity Medical). While this is overkill, I believe that many more surgeons would use toric IOLs if they had the confidence that they were achieving accurate alignment in every case.

For more than a decade, I have been predicting that toric IOLs would become the standard of care. I am confident that, eventually, every refractive cataract surgeon will feel comfortable with this lens technology.

1. Avakian A, Osher RH. Rescue technique for salvaging toric intraocular lens alignment. *J Cataract Refract Surg*. 2012;38(10):1716-1781.

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