The Creator's Forum:
IOL Power Calculations for Postrefractive Surgery Eyes

Olsen Formula

By Thomas Olsen, MD, PhD

The calculation of IOL power in an eye that has undergone corneal refractive surgery is not a straightforward task. However, if you understand why the calculation may go wrong, you will have a fair chance of getting a good result using modern technology.

It is important to understand that the calculation errors of post-LASIK eyes are the sum of the traditional errors plus the errors associated with the abnormal corneal shape. The post-LASIK eye exposes some of the weaknesses of the traditional IOL power calculation formulas.

ERRORS OF TRADITIONAL FORMULAS

Many of the old thin-lens IOL power calculation formulas, such as the Binkhorst, Hoffer Q, Holladay 1, and SRK/T use only the K reading and the AL as input.[1] When these formulas are used in post-LASIK cases, two problems occur.

Problem No. 1. The flatness of the K reading makes the formula believe the ELP is more anterior than it really is. With a shallow ELP, the formula will predict a low IOL power, causing a hyperopic surprise. Figure 1 explains Fyodorov's concept of the corneal height, which is the ELP principle of the SRK/T and the Holladay 1 formulas.

Problem No. 2. A simple K reading measures only the curvature of the anterior surface of the cornea. However, most keratometers calculate the power according to the formula $K = (1.3375-1)/r$, where r is the anterior radius in meters and 1.3375 is the fictitious refractive index of the

cornea, as if the cornea were a thin lens. Therefore, in order for the anterior curvature measurement to be translated into the true power of the cornea, the following must be calculated: the curvature of the posterior surface, the corneal thickness, and the true refractive index of the cornea (1.376). In normal corneas, it is reasonable to assume that there is a constant ratio (called the Gullstrand ratio from the Gullstrand exact schematic eye) between the anterior and posterior curvatures. For the post-LASIK cornea, however, the Gullstrand ratio is reduced, and the keratometer-reported K reading will overestimate the true corneal power. Again, the formula will think the IOL power should be reduced, and the patient ends up with a hyperopic error.

Modern Scheimpflug imaging and other tomography techniques provide more insight into the variation of the Gullstrand ratio in normal and post-LASIK eyes. Figure 2 shows the results of Pentacam (Oculus Optikgeräte GmbH) measurement of the anterior and posterior corneal curvatures, giving the distribution of the Gullstrand ratio in a normal population and in a post-LASIK population (average ablation, -7.00 D). The reduction of the Gullstrand ratio is dependent on the amount of laser ablation (Figures 3 and 4). For example, if the Gullstrand ratio is 0.7 (ie, as a result of a 7.00 D ablation; Figure 3), the difference between the true corneal power and the K reading is approximately 2.00 D. However, for the normal cornea (Gullstrand ratio, 0.83), the difference is not nil. This is because the conventional K reading carries an inborn overestimation of the corneal power of approximately 1.00 D.

The effect of the two sources of error on IOL power prediction with the SRK/T formula is shown in Figure 5. The K reading error and the ELP error are the same magnitude, and both tend to give a hyperopic error. The total
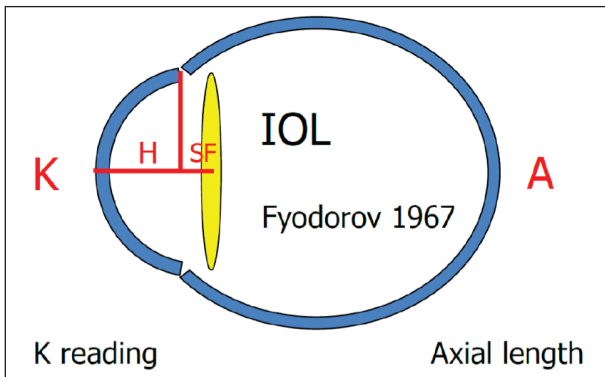
Figure 1. The Fyodorov concept predicts the IOL position as a function of the corneal height (H), which is calculated from the corneal curvature and diameter. This model is used by the SRK/T formula and the Holladay formula (surgeon's factor [SF] is calculated as an addition to H).
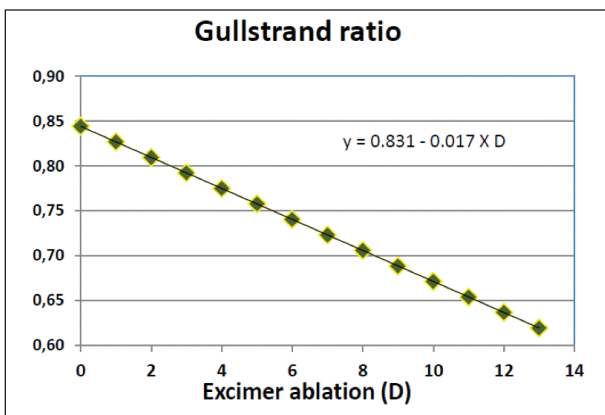

Figure 3. Calculated change of the Gullstrand ratio as a function of the amount of excimer laser myopic ablation on a standard cornea. This figure also includes a regression equation stating the average change per diopter ablation.
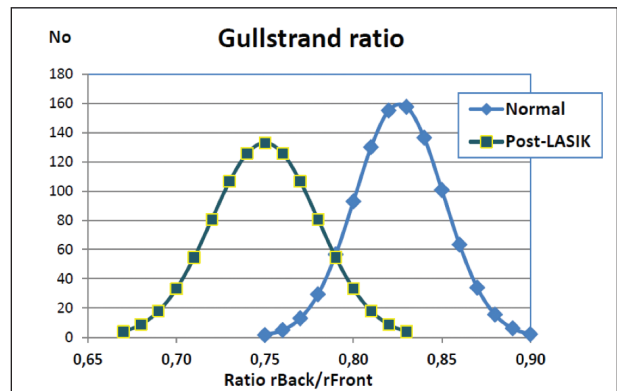

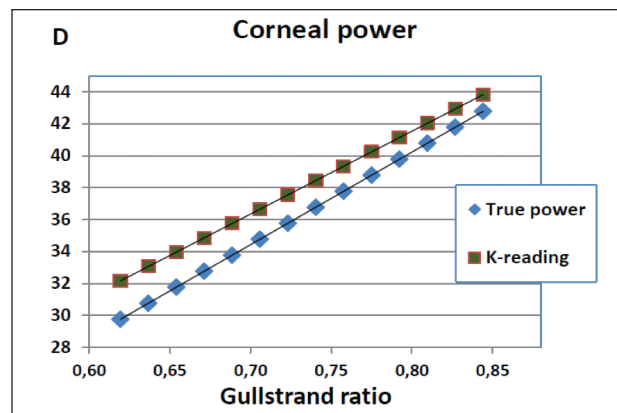Figure 2. Distribution of the Gullstrand ratio in normal and post-LASIK populations, as measured by Pentacam.

Figure 4. The difference between conventional K reading of the anterior surface and the true corneal power as a function of the Gullstrand ratio.

prediction error is about one-third the amount of the excimer laser ablation if not corrected for.

MY PREFERRED METHOD

If available, pre-LASIK K readings and amount of laser correction should be recorded. The historic method is not regarded as reliable, and therefore we use these data only to check whether our measurements are consistent. As with any other case, the patient should have optical biometry; I prefer the Lenstar LS900 biometer because this instrument measures all intraocular distances (corneal thickness, ACD, lens thickness, and AL) with the accuracy of laser biometry. Additionally, the pupil diameter is also measured.

Next, the patient is examined with the Pentacam to determine the anterior and posterior curvatures of the

cornea. I like to inspect the readings of the central cornea to check what the effective central reading might be. Useful tools of the Pentacam are its power distribution (Figure 6) and Fourier transformation (Figure 7) functions. These tools allow the surgeon to extract the effective radius in the pupillary area of the cornea.

COMMENT

Difficulties with reading the effective central part of the cornea add error to any formula. Keratometers usually measure the cornea in a noncentral ring of about 3 mm (about 2.5 mm with the IOLMaster). This is not adequate for a cornea with central flattening, and, in fact, all keratometers and topographers are blind to the central, most significant area of the cornea. Again, the potential error on the IOL power calculation is hyperopic.

When information on the effective central anterior curvature of the cornea and the posterior curvature
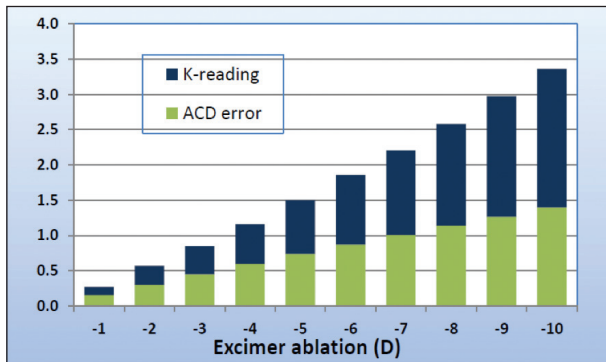
Figure 5. The prediction error with the SRK/T formula divided into two sources of error: K reading error and ELP error (postoperative ACD) as a function of the amount of laser ablation.
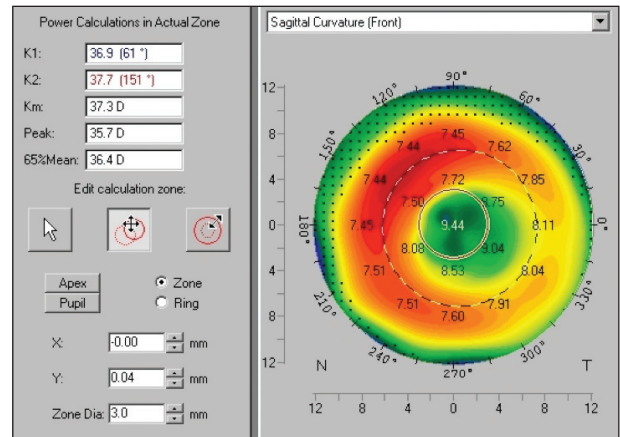

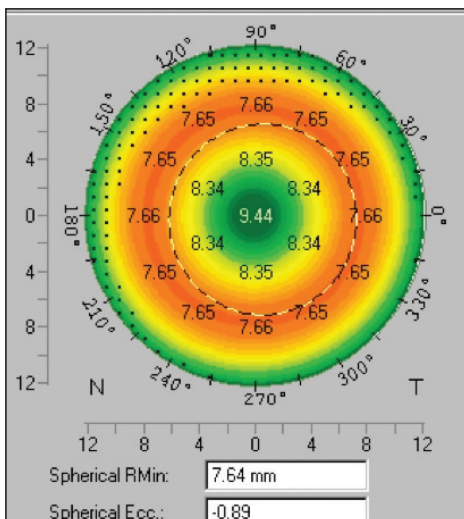Figure 6. Power distribution tool of the Pentacam.

Figure 7. Fourier transformation of the central area, showing the spherical component.
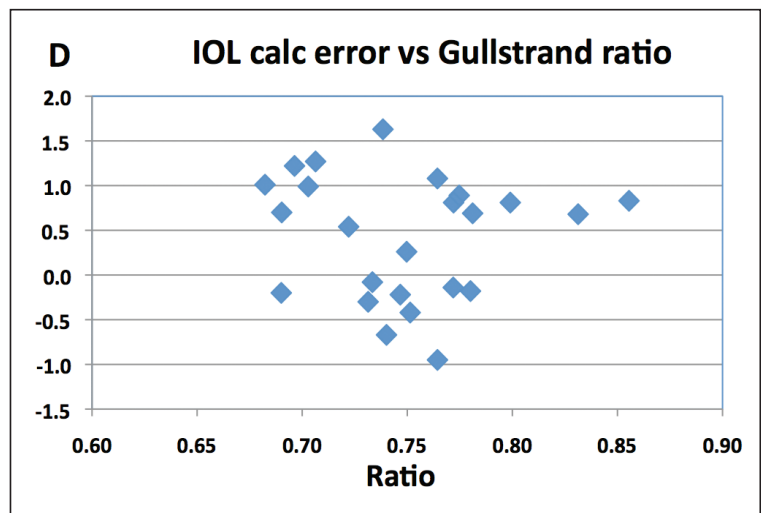

Figure 8. IOL power prediction error in 24 post-LASIK cases plotted against the Gullstrand ratio.

are available, we enter these values directly in the PhacoOptics software (PhacoOptics.com) using the Olsen formula for IOL power calculation.[2]

The advantage of the Olsen formula is that equivalent K readings are not needed, as the program accepts direct input of front and back corneal curvature. Moreover, the Olsen formula uses an improved algorithm for the prediction of the IOL position, making it possible to base the ELP on the anterior segment anatomy only (ie, preoperative ACD and lens thickness) and avoiding troublesome K reading dependence (eyetube.net/?v=fuhal).

In 24 eyes of 19 post-LASIK patients for which the Olsen formula was used to calculate IOL power, we found a mean refractive prediction error of 0.41 ±0.68 D (range, -0.92 to 1.63 D; Figure 8). There was no correla-

tion with the Gullstrand ratio. The one patient with the highest error (1.63 D) was later reexamined and found to have a central cornea that was flatter than was measured at the preoperative visit, possibly caused by wearing a contact lens a few days before. The overall prediction accuracy is not as accurate as in normal eyes (and will never be), but we think the results are encouraging for our approach to be a feasible one.

NEW DEVELOPMENTS: RAY TRACING

As described above, much of the inaccuracy of IOL power calculations in post-LASIK eyes is due to the problem of getting reliable information on the effective refractive power of the cornea. To this end, various models are often used to fit the corneal measurement to certain well-defined shapes, such as ellipsoids,
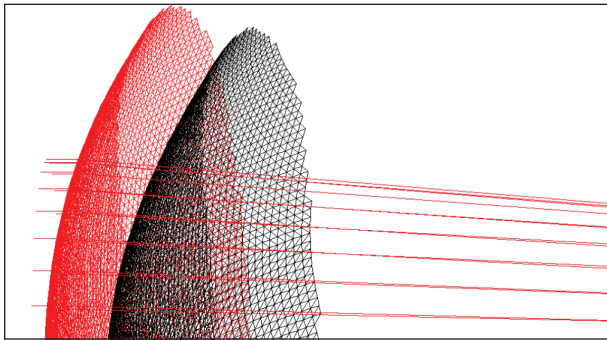
Figure 9. Pentacam data of front and back surface of the cornea transformed into a polygonal shape and imported by the Zemax software. The individual measurements can be found as points in a meshwork of miniature triangles, suitable for exact ray tracing. Ray tracing is performed directly on the raw physical shape without further model fitting.
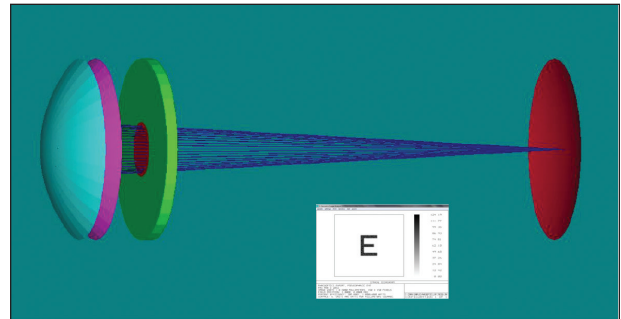

Figure 10. The optical system of a pseudophakic eye imported into Zemax software, in this case to solve for the optimal optical properties of the IOL giving the best image at the retinal plane. Insert shows the simulated quality of a Snellen letter projected on the retina.

Zernike polynomials, and Fourier transformations. In physical optics, ray tracing is widely used and recognized as the most effective tool in optical design. The eye is an optical device, so why isn't ray tracing the method of choice in our hands? The answer, perhaps, is because this technology is still evolving.

We have recently begun a study to import the Pentacam raw height data into the Zemax software (Radiant Zemax, LLC) for optical engineering.[3] To import the data, we had to transform the matrix array of individual measurement points into a polygonal

shape that could then be imported by Zemax. When the data are successfully transformed, it is possible to construct the cornea as a meshwork of miniature triangles, suitable for exact ray tracing (Figure 9). The fascinating thing about Zemax and other ray tracing software programs is that it is possible to compose and analyze the entire optical system and ask for optimal performance of any element. For example, how should the IOL be designed to fit the optical properties of the cornea (Figure 10)? For the post-LASIK cornea, it might be possible to solve for the higher-order aberrations of the selected IOL needed to correct for the HOA of the cornea. We expect this technology to be further elaborated in the future. ■

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THE BESSᴛ AND BMR-BHR FORMULAS

These formulas are useful for eyes that have previously undergone myopic or hyperopic laser treatments.

By Edmondo Borasio, MD, MedCBQ Ophth, FEBO

Using standard keratometry and raw data taken from corneal topography to calculate refractive corneal power in postrefractive surgery eyes can result in an inaccurate representation of the true corneal power. In these cases, instead of using a pseudophakic IOL power calculation that incorporates preoperative data, which can result in refractive surprises, I prefer to use direct corneal measurements.

I use two approaches to calculate IOL power following laser refractive surgery, the first of which, the Borasio Edmondo Smith and Stevens formulas (BESSt and BESSt 2), is based on direct anterior and posterior corneal surface measurements and requires the Pentacam (Oculus Optikgeräte GmbH).[1] The second approach, the more recently developed Borasio Myopic Regression and Borasio Hyperopic Regression (BMR-BHR) formula, requires direct measurements from the IOLMaster (Carl Zeiss Meditec). These formulas can be used for eyes that have previously undergone myopic or hyperopic excimer laser treatments, even if there is a lack of prerefractive surgery information.

BESSᴛ AND BESSt 2

Based on direct anterior and posterior corneal curvature and corneal thickness measurements using the Pentacam and a modified Gaussian optics formula, the BESSt algorithm estimates corneal power in eyes after laser refractive surgery for myopia or hyperopia. It is not possible to use values obtained from the Gaussian optics formula in most current IOL power formulas because they are calibrated using a standard keratometric index of 1.3375, which does not take true posterior corneal curvature into account. This can therefore yield inaccurate results, especially in postrefractive surgery eyes where the relationship between the anterior and posterior corneal radii is no longer constant. BESSt starts from the true net corneal power as calculated with the Gaussian optics formula, but then it makes crucial adjustments based on the actual measured postoperative corneal radii and the altered anterior/posterior radius relationship.

We have found that the BESSt 2, a second iteration of the formula, results in greater prediction accuracy and less risk of refractive surprise after hyperopic treatments (unpublished data). BESSt 2 incorporates the following improvements compared with its predecessor: (1) automatic prediction of the preoperative anterior corneal radius from postoperative posterior corneal radius measurement, thus allowing automatic application of Aramberri's double-K adjustment for a more accurate prediction of the estimated IOL position, (2) two separate algorithms based on the results of regression analyses, one for myopic and one for hyperopic treatments, (3) automatic application of the BESSt 2-derived corneal power to a modified third-generation formula for the purpose of IOL power calculation, and (4) an error-limitation algorithm to prevent serious errors in eyes with extreme axial lengths.

BMR-BHR

The latest formulas I have developed for postrefractive surgery eyes, the BMR and BHR, require the use of the IOLMaster to measure K values and axial length.[2-4] From the measured postrefractive surgery K value, a new corneal power value is obtained by using one of these regression formulas. The resulting corneal power values are then automatically entered into the SRK/T formula, yielding a suggested IOL power.

The BMR-BHR formulas are based on linear, logarithmic, and polynomial regression analyses and give similar results in most cases, with no greater than 0.25 D difference between the analyses with the exception of eyes with very steep or very flat corneas, where differences can be more substantial. Further studies are needed to determine which formula is the most accurate, but I tend to use linear regression. Polynomial regression has a smaller error in the majority of cases, but it can also have more serious outliers than linear regression; logarithmic regression lies in between the other two. It is best to use polynomial regression only when the suggested IOL power value is neither too low nor too high.

BMR-BHR is currently available only as part of Eye Pro 2012 for the iPhone/iPad. A desktop version will soon be available as an upgrade to the BESSt 2 IOL Power Calculator.

CONSIDERATIONS AND RESULTS

The same considerations apply to the BESSt, BESSt 2, and BMR-BHR formulas; they should not be used in the presence of significant corneal haze or scarring or after incisional refractive surgery such as radial keratotomy. Additionally, these formulas should be used with caution in eyes that have undergone astigmatic keratotomy; in eyes that have previously undergone myopic or hyperopic treatments for severe refractive errors; or in eyes that were operated on a long time ago using small optical zones. Other considerations include the following:

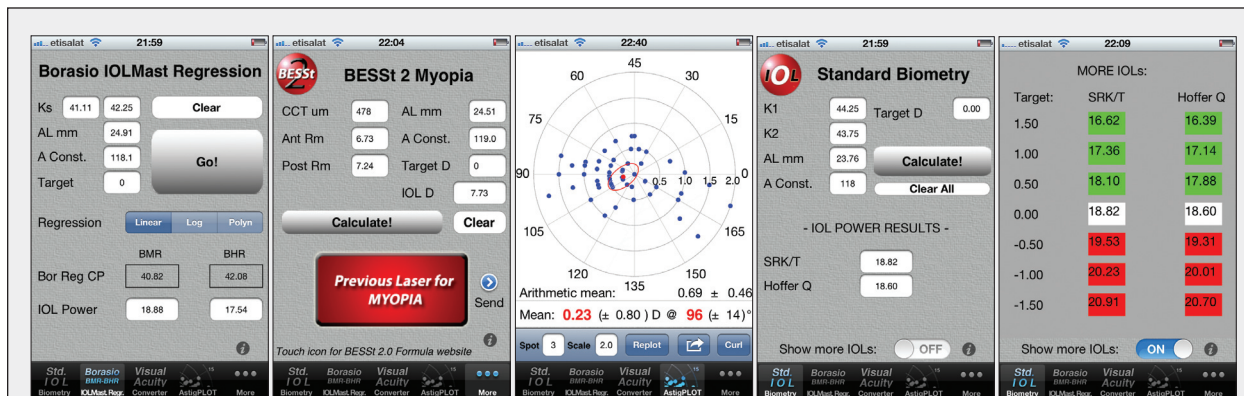- The BMR-BHR requires K values specifically mea-

Figure 1. Screenshots taken from Eye Pro 2012: (From left to right) BMR-BHR for IOLMaster, mobile version of BESSt 2 myopia, double-angle polar plot showing the average surgically induced astigmatism in a group of eyes, standard biometry on the go, and IOL power matrix.

sured by the IOLMaster;

• I recommended comparing BESSt 2 with BMR-BHR. If the BESSt 2 formula suggests a very low (or very high) IOL power, I either use the BMR-BHR formula instead or the average of the two. It is always advisable to compare with other methods before proceeding with surgery. Whenever in the doubt, opt for a stronger IOL to target myopia;

• Be suspicious of very low or very high IOL powers resulting from BMR-BHR or BESSt in eyes with very steep or very flat corneas. These cases are at the extreme edges of any regression analysis, and the risk of a refractive surprise is high; and

• The BESSt 2 and the Eye Pro have not been approved by the US Food and Drug Administration (FDA) or received the Conformiteé Europeénne (CE) Mark.

I recently conducted a study in 62 eyes, of which 38 received a myopic treatment and 24 a hyperopic, to compare the accuracy of the BESSt, BESSt 2, and BMR-BHR formulas. In the myopic group, BESSt and BESSt 2 performed similarly (mean error, -0.21 ±0.78 D and -0.02 ±0.81 D, respectively; P>.05), but in the hyperopic group BESSt 2 performed statistically significantly better (-1.10 ±0.90 D and 0.02 ±1.00 D, respectively; P<.05). The proportion of eyes within ±0.50 D of the intended target changed negligibly (from 37% to 38%) in the myopic group but improved significantly (from 13% to 38%) in the hyperopic group. The proportion of eyes within ±1.00 D of the target changed from 73% to 76% in the myopic group and from 38% to 75% in the hyperopic group.

Comparing the results with BESSt 2 to those with BMR and BHR, in the myopic group, the mean error was -0.02 ±0.81 D with BESSt 2 and 0.00 ±0.75 D with BMR (P>.05).

In the hyperopic group, the mean error was 0.02 ±1.00 D for BESSt 2 and 0.01 ±0.75 D for BHR (P>.05). Although these differences were not statistically significant, 31% more eyes were ±0.50 D or less from the target refraction with BMR compared with BESSt 1 and 30% more compared with BESSt 2. Similarly, with BHR 50% more eyes were ±0.50 D or less from the target compared with BESSt 1 and 13% more compared with BESSt 2. We believe this represents an improvement.

PC VERSION FOR THE PENTACAM

The BESSt 2 IOL Power Calculator (EB Eye Ltd, UK; besstformula.com) is available as an optional software add-on for the Pentacam. The main advantage of this calculator is that it can be installed on the same computer as the Pentacam. Therefore, calculations can be done directly from the Pentacam program by clicking on the BESSt 2 button, which will export all the required data (anterior and posterior corneal curvature and central pachymetry) to the program for the calculations. The program also keeps a database of calculations for future reference and for recalculation. A standalone version for research purposes is also available and can be used on a laptop not physically connected to the Pentacam hardware.

Another feature of the BESSt 2 IOL Power Calculator for PC is real-time IOL power plotting to show the behavior of different biometry formulas when parameters are modified for any given axial length. This allows immediate identification of potential biometry artifacts that affect any given formula. Examples include the SRK/T negative square root and cusp phenomena that occur for certain combinations of axial length and K values (most frequently for steep corneas). When not identified, these artifacts can lead to inaccurate IOL power calculations.

The BESSt IOL Power Calculator also allows the practitioner to compare the results with the historical method—with or without the double-K adjustment, and using refractions at the spectacle or at the corneal plane—for eyes for which prerefractive surgery information is available.

A video presentation on BESSt and BMR-BHR is available at eyetube.net/?v=fireb.

MOBILE VERSION AND APP

A mobile version of the program, Eye Pro 2012 (Figure 1), is more suited for quick calculations. It includes not only BESSt 2 and BMR-BHR algorithms but also many other functions such as standard biometry and surgically induced astigmatism calculations. Our smartphone application (app) is a suite of ophthalmic calculators that includes the following advanced functions:

- Standard biometry (SRK/T, Hoffer Q formulas);
- BESSt 1 combined with third-generation formulas with double-K adjustment for biometry after refractive surgery;
- Toric IOL calculator that also accounts for surgically induced astigmatism (SIA);
- SIA calculator for K values or refractions;
- SIA plotter for group analysis showing both the vector and the arithmetic means;
- Visual acuity converter between Snellen/decimal/logMAR notation;
- Refraction converter between corneal/spectacle plane;
- Astigmatism converter between cartesian/polar notation; and
- Optical formulas including thin lens equation, Gaussian optics formula, and calculations using customized keratometric refractive indexes.

Eye Pro 2012 is available for the iPhone and iOS-compatible devices and can be downloaded directly from the Apple store. A free trial version, Eye Pro Lite, is available at the Apple store and shows all the functions available in the 2012 version. ∎

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