Method for IOL Power Calculation in the Second Eye of Patients With Previous Keratorefractive Surgery

Shawn R. Lin, MD, MBA; Max Nutkiewicz, BS; Haroon Rasheed, BS; Mitra Nejad, MD; D. Rex Hamilton, MD, MS

ABSTRACT

PURPOSE: To describe and evaluate a method for calculating intraocular lens (IOL) power in the second operative eye of patients with a history of keratorefractive surgery.

METHODS: All eyes had undergone cataract surgery by a single surgeon from 2015 to 2018. Postoperative outcomes on the first eye (eg, IOL power implanted and postoperative refractive error) were used to back calculate a "Real K" for the first eye. The difference (delta) between the second and first eye topographic simulated keratometry values was then added to the first eye Real K to calculate the second eye Real K. This Real K value was inputted into the Holladay IOL Consultant software as an "alternate K" to derive an accurate IOL power for the second eye. Mean absolute error, mean error, and percentage of eyes on target using the Delta K method were compared with results obtained with intraoperative aberrometry and the Haigis-L and Barrett True-K No History formulas.

RESULTS: The mean error for the Delta K method was significantly better than the Haigis-L (P = .00001) and Barrett True-K No History (P = .027) formulas, and on par with intraoperative aberrometry (P = .25). The mean absolute error of the Delta K method was significantly better than the Haigis-L formula (P = .03). The Delta K mean absolute error was on par with intraoperative aberrometry (P = .81) and the Barrett True-K No History formula (P = .56).

CONCLUSIONS: The Delta K mean absolute error is comparable to the Barrett True-K No History formula. The mean error is lower than that calculated with the Barrett True-K No History formula and comparable to intraoperative aberrometry.

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Patients who have refractive surgery report an improved quality of life and a 95% satisfaction rate following the procedure.[1] Once these patients develop cataracts, many have similarly high expectations for the outcome of their cataract surgery. However, accurate lens calculations are notoriously challenging in this group due to several factors. First, the alteration of the central corneal surface leads many topography machines to inaccurately estimate true corneal power.[1-5] Second, the ratio of corneal powers of the anterior surface relative to the posterior surface is altered.[2] Finally, third generation formulas that use corneal power to predict effective lens position do not account for prior refractive surgery.[3] All of these factors can lead to inaccuracies in intraocular lens (IOL) power that can ultimately result in a refractive surprise, typically leading to postoperative hyperopia in eyes that have undergone previous myopic refractive surgery.[6-8] It is estimated that only 55% of eyes that have had keratorefractive surgery will have an outcome within ±0.50 diopters (D) of the surgeon's target refraction.[9]

Different methods have been developed to improve the accuracy of lens selection after refractive surgery. In this article, we describe a novel method that uses data from the first eye to fine tune the accuracy of the

From Stein Eye Institute (SRL, MNejad), David Geffen School of Medicine, University of California–Los Angeles, Los Angeles, California (SRL, HR, MNejad); University of Cincinnati College of Medicine, Cincinnati, Ohio (MNutkiewicz); and Hamilton Eye Institute, Los Angeles, California (DRH).

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Correspondence: D. Rex Hamilton, MD, MS, 10884 Santa Monica Blvd., Suite 201, Los Angeles, CA 90025. Email: rexeyemd66@gmail.com

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second eye. We also describe our approach to IOL power calculations in patients who have had refractive surgery and compare the Delta K method to intraoperative aberrometry and the Haigis-L and Barrett True-K No History formulas.

PATIENTS AND METHODS

Institutional review board/ethics committee approval was obtained (University of California–Los Angeles IRB #17-001514) prior to the initiation of this study. All consecutive cases of post-refractive cataract surgery in the second eye of patients between July 2015 and May 2018 were included in this study. All cases, both first and second eyes, were performed at the UCLA Stein Eye Institute by a single surgeon (DRH).

Biometry

Biometric parameters were captured using either the IOLMaster 500 (Carl Zeiss Meditec) or the LenStar LS 900 without T-Cone (Haag-Streit). Calculations for IOL power were based only on values from the biometry devices. Topographic parameters used for all Delta K calculations were measured using the Galilei G4 topographer (Ziemer Group).

Delta K Calculation

Selected lens power and 1-month postoperative refraction for the first operated eye of patients were entered into the Holladay IOL Consultant software (Holladay Consulting). The back-calculation feature with the "Previous LASIK" box checked was used to calculate an outcome-adjusted keratometric value for the first eye. We label this the "Real K."

The difference in the topographic mean simulated keratometry (Sim K) between the first and second eye was calculated from the preoperative Galilei keratometric data and added to the first eye Real K to derive a best estimated Real K for the second eye. All topographic maps for first and second eyes were created with the Galilei topographer.

Real K First Eye + (Sim K Second Eye – Sim K First Eye) = Real K Second Eye

This Real K second eye was then inputted as an alternate keratometric value in the Holladay IOL Consultant software to be used for the second eye IOL power calculation. The Holladay 1 formula with the "previous LASIK" box checked was used. An overview of this process is shown in **Figure A** (available in the online version of this article).

The 1-month postoperative refraction of the second eye was compared to the predicted refraction using the Delta K method, intraoperative aberrometry, and the Haigis-L[10] and Barrett True-K No History[11] formulas.

Surgical Procedure

All surgeries were performed under topical anesthesia using a 2.4-mm clear corneal incision and either a traditional phaco-chop or femtosecond laser–assisted phacoemulsification technique. Lens selection was performed by one author (DRH) using a combination of data from traditional lens calculation formulas, the Delta K method, and intraoperative aberrometry.

Intraoperative Aberrometry

The Optiwave Refractive Analysis (ORA) device (Alcon Laboratories, Inc) was installed in December 2016 and was used to assist with IOL power selection in most of the subsequent cases. All preoperative data were inputted with the "post-refractive" box selected.

Haigis-L and Barrett True-K No History Calculation

Haigis-L and Barrett True-K No History calculation was performed using the calculator on the American Society of Cataract and Refractive Surgery (ASCRS) website (http://iolcalc.ascrs.org). Results were used for IOL power selection for the first eye and for comparison to the other methods for the second eye.

Statistical Analysis

Statistical analysis and *P* values were calculated using Microsoft Excel software version 2017 (Microsoft Corporation). Given the relatively small sample size, the Kruskal-Wallis test was used to compare differences in values of continuous variables.

Surgical Planning

Figure B (available in the online version of this article) illustrates our surgical planning strategy for patients who have had refractive surgery. When monovision is employed, it is preferred to begin with the near eye if possible because there is a larger margin for error in the near eye. For example, an eye targeted at plano with a large unanticipated error of 1.00 D will result in an unacceptable distance refraction of -1.00 or +1.00 D. Conversely, an eye with the same unanticipated error of 1.00 D targeted at a near refraction of -1.75 D will result in a more tolerable near refraction of -2.75 or -0.75 D. Unanticipated refractive error uncovered by surgery in the first eye can then be used to adjust the surgical plan for the second eye. This is especially useful when employing the Delta K method to improve accuracy in the distance (second) eye.

For the first eye, which may be targeted for plano or near (eg, -1.75 D), a Modified Maloney alternate K

TABLE 1

Refractive Targets for the First and Second Eyes Undergoing Surgery

Eye/Target	Plano	-0.05 D	-1.00 D	-1.50 D	-1.75 D	-2.00 D
First eye	17 (45%)	0 (0%)	0 (0%)	3 (8%)	16 (42%)	2 (5%)
Second eye	36 (95%)	0 (0%)	0 (0%)	0 (0%)	2 (5%)	0 (0%)

D = diopters

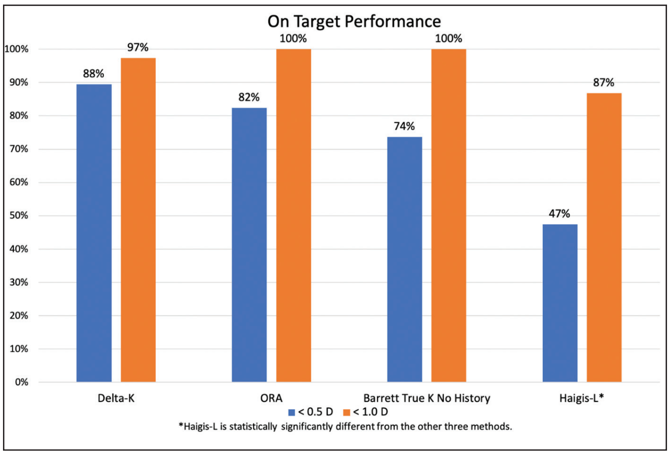

Figure 1. Cumulative percentage of postoperative refractions that were within ±0.50 or ±1.00 diopters (D) of target. D = diopters; ORA = Optiwave Refractive Analysis device (Alcon Laboratories, Inc)

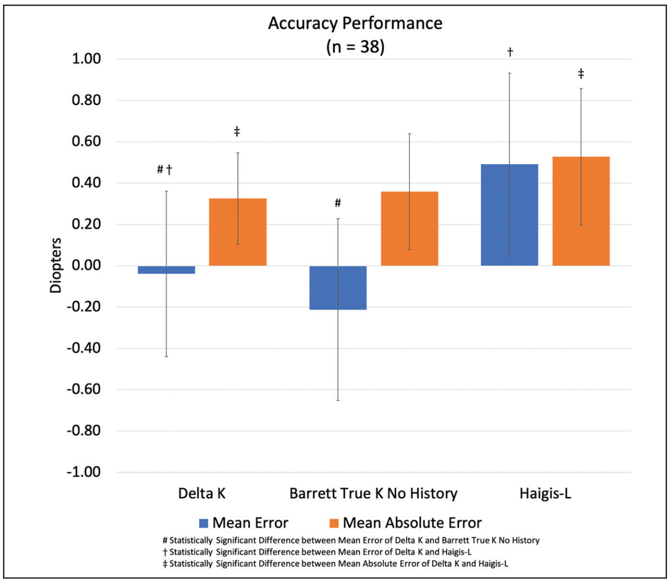

Figure 2. Mean error and mean absolute error data for the Delta K method, Barrett True-K No History formula, and Haigis-L formula (n = 38). D = diopters

is calculated, and this keratometric value is used to calculate IOL power using the Holladay IOL Consultant with the Holladay 1 formula and the "previous LASIK" button checked.[12] In addition, the Haigis-L and Barrett True-K No History formulas are used to calculate IOL power using the ASCRS calculator. These IOL power calculations, together with the IOL power obtained from intraoperative aberrometry (when available), were used for IOL power selection. For the second eye, we most often targeted a result near plano. In this case, we used the Delta K method for IOL power selection. Postoperative manifest refraction was measured at a minimum of 4 weeks, with a mean of 74.4 ± 58.7 days.

RESULTS

A total of 38 eyes of 38 patients undergoing second eye cataract surgery following prior laser in situ keratomileusis (LASIK) and photorefractive keratometry (PRK) surgery between July 2015 and May 2018 were included. Twenty-seven patients had previously undergone myopic LASIK, 10 patients had undergone hyperopic LASIK, and 1 patient had undergone myopic PRK.

PATIENT DEMOGRAPHICS

Patient ages ranged between 51 and 79 years, with a mean of 65.2 ± 7.1 years. Fourteen of these patients were men and 24 were women. Of the 38 patients included in the study, 21 patients were operated on prior to availability of intraoperative aberrometry. The 17 patients operated on after this point had intraoperative aberrometry data.

LENS SELECTION

In the first eye, a ZCB00 IOL (Johnson & Johnson Vision, formerly Abbott Medical Optics) was implanted in 25 eyes, an SA60AT IOL (Alcon Laboratories, Inc) in 7 eyes, and a Toric ZCTxx IOL (Johnson & Johnson Vision, formerly Abbott Medical Optics) in 6 eyes. In the second eye, a ZCB00 IOL was implanted in 30 eyes, an SA60AT IOL in 6 eyes, and a Toric ZCTxx IOL in 2 eyes.

REFRACTIVE TARGETS AND POSTOPERATIVE MANIFEST REFRACTIONS

Table 1 presents the refractive targets for the first and second eye groups for each refractive target group. The performance of the various formulas based on postoperative refraction is shown in **Figures 1-3**.

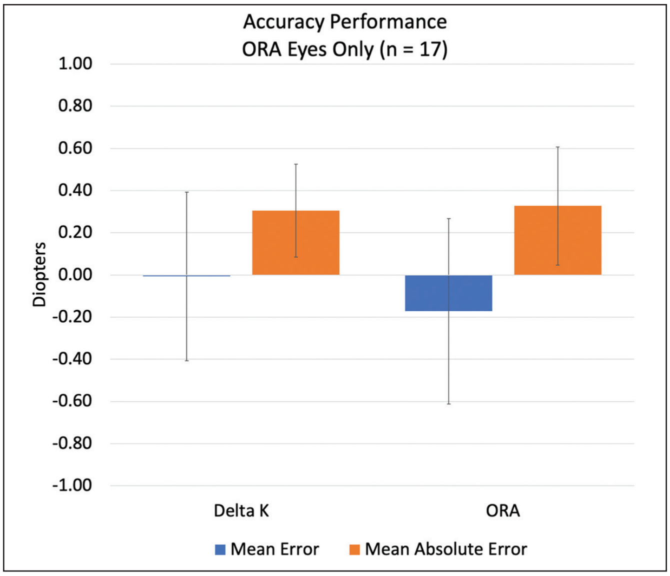

Figure 3. Mean error and mean absolute error data for the Delta K method and the Optiwave Refractive Analysis device (ORA) (Alcon Laboratories, Inc) for eyes in which ORA was used (n = 17). D = diopters

Refractive Results

The mean error was -0.04 ± 0.40 for the Delta K method, -0.21 ± 0.44 for the Barrett True-K No History formula, and 0.49 ± 0.49 for the Haigis-L formula. The mean absolute error was 0.33 ± 0.22 for the Delta K method, 0.42 ± 0.24 for the Barrett True-K No History formula, and 0.53 ± 0.39 for the Haigis-L formula. For eyes in which the ORA was used (n = 17), the mean error was -0.01 ± 0.36 for the Delta K method and -0.17 ± 0.38 for the ORA, and the mean absolute error was 0.33 ± 0.17 for the Delta K method and 0.33 ± 0.26 for the ORA method. For the myopic and hyperopic subgroups, the Delta K mean absolute error was 0.33 ± 0.24 for post-myopic LASIK/PRK and 0.33 ± 0.20 for post-hyperopic LASIK.

The mean error of the Delta K method was significantly lower than that of the Haigis-L (P = .00001) and Barrett True-K No History (P = .027) formulas. The mean absolute error of the Delta K method was significantly lower than the Haigis-L formula (P = .03). The mean absolute error for the Delta K method was not significantly different from that of intraoperative aberrometry (P = .81) or the Barrett True-K No History formula (P = .56) (**Figure 2**). We further noted that the difference in Sim K values between the first and second eyes (the Delta K) did not have a statistically significant impact on the mean absolute error (**Figure 4**). This is an important result, because it predicts that differences in the preoperative Sim K value of eyes do not make a significant impact on the accuracy of the Delta K method. For example, a difference in ablation pattern if a patient had -4.00 D of myopia in 1 eye and -2.00 D of myopia in the other eye does not result in measurably decreased accuracy for the Delta K method.

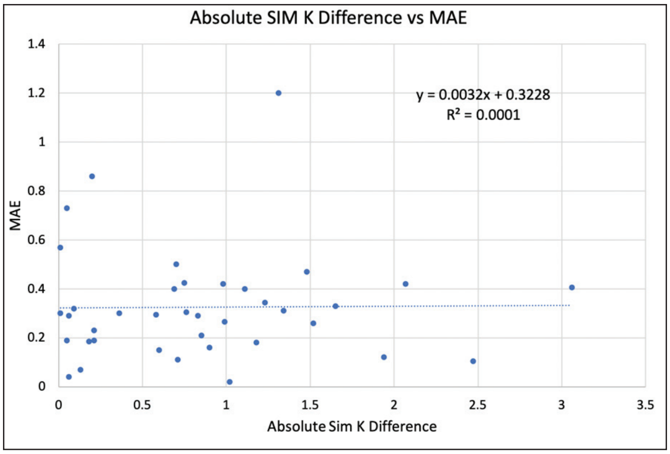

Figure 4. Comparison of relationship between absolute simulated keratometry (Sim K) difference between the first and second eyes and mean absolute error (MAE) of the Delta K method. D = diopters

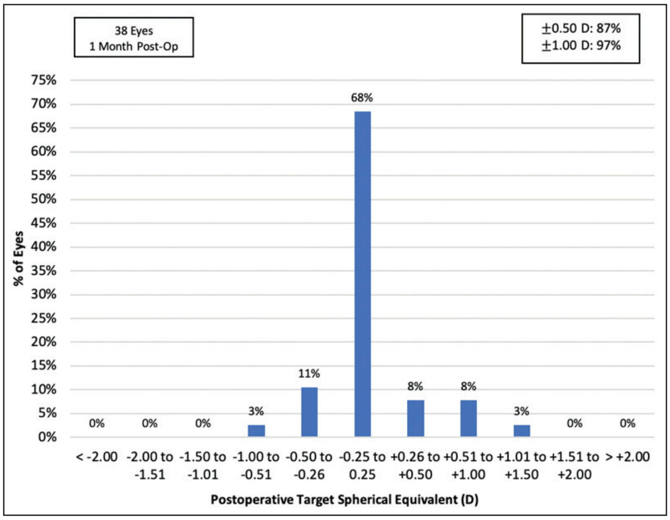

Figure 5. Standard graph for postoperative refractive spherical equivalent. D = diopters

Postoperative target spherical equivalent was within ±0.50 and ±1.00 D in 87% and 97% of eyes, respectively (**Figure 5**). The P values were not significant for the Delta K method versus the Barrett True-K No History formula or the Delta K method versus the ORA. More than 72% of eyes achieved 20/25 and more than 83% achieved 20/32 uncorrected distance visual acuity (**Figure 6**). The Delta K method was more often within ±0.50 D of target compared to the Haigis-L formula (P = .0001).

DISCUSSION

Although refractive surgery is highly effective, it presents a unique challenge to the cataract surgeon. Many formulas have been developed to address the

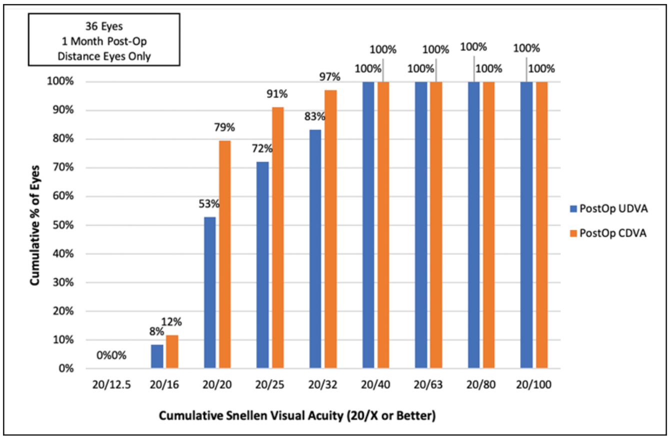

Figure 6. Standard graph for uncorrected distance visual acuity (UDVA). A portion of eyes were targeted for near vision. CDVA = corrrected distance visual acuity; D = diopters

calculation errors that occur using standard techniques for these altered eyes. Some of the more commonly used techniques include the Modified Maloney, Haigis-L, and, most recently, Barrett True-K No History formulas and intraoperative aberrometry. Previous studies have reported that less than 50% of post-refractive eyes calculated with the Modified Maloney and Haigis-L formulas are within ±0.50 D of target.[13-15] The Barrett True-K No History formula is among the more effective methods, with less than 0.50 D on-target accuracy reported between 55% and 67%.[13-15] Other studies have demonstrated the benefits of intraoperative aberrometry using devices such as the ORA in patients who have had refractive surgery, with less than 0.50 D on-target accuracy ranging from 67% to 74%.[14,16,17] However, many surgeons worldwide do not have access to intraoperative aberrometry. By using the Delta K method, we were able to reach 88% on-target accuracy less than 0.50 D and 97% on-target accuracy less than 1.00 D, achieving accuracy similar to that of the ORA on second eyes.

The percentage of eyes within ±0.50 D of target using the Delta K method was significantly higher when compared to the Haigis-L formula. On-target performance for the Delta K method was higher than the Barrett True-K No History formula, but the difference was not significant ($P = .14$). This comparison did not reach statistical significance, likely due to the small sample size in our study of 38 eyes.

As far as we are aware, there are no published techniques that systematically use postoperative results from the first eye to improve the accuracy of the calculations for the second eye. We describe a logical approach to post-refractive lens calculations to minimize the postoperative refractive error in the second eye and maximize the useful range of uncorrected vision for patients who place a premium on reducing spectacle dependence. By using the refractive result from the first operated eye, the targeting of the second eye can be more precise. By using a subtraction technique, the influence of parameters that have traditionally been difficult to measure or estimate, such as effective lens position and posterior corneal astigmatism, no longer contribute to the inaccuracy of the second eye calculation. This technique is reproducible, accurate, and relatively cost-effective, requiring only the ability to perform a back calculation.

Using the Delta K method, we achieved a statistically significant lower mean error compared to the Haigis-L and Barrett True-K No History formulas and a mean absolute error comparable to intraoperative aberrometry and the Barrett True-K No History formula. The fact that the mean error using the Delta K method is close to zero (-0.04) and statistically lower than the Haigis-L (0.49 mean error) and Barrett True-K No History (-0.21 mean error) formulas indicates the absence of myopic bias (as seen with the Barrett True-K No History formula) or hyperopic bias (as seen with the Haigis-L formula). In addition, we show an on-target accuracy that is on par with the ORA and Barrett True-K No History formula, and better than the Haigis-L formula. This is particularly useful in situations where monovision is employed and surgery for the near eye is performed first. Although the first eye targeting is more challenging, the near refractive endpoint is fortunately more forgiving. The Delta K method can then be employed, using the refractive results from the first eye, to improve accuracy for the distance-targeted second eye.

There were several weaknesses in this study. First, this technique assumes that both eyes had a history of the same type of refractive surgery in each eye. Moreover, even if the same refractive surgery was done on both eyes, many of our patients had refractive surgery to induce monovision and thus had different ablation profiles between eyes. We evaluated whether different ablation profiles would lead to decreased accuracy of the Delta K method (**Figure 6**) by plotting the difference in Sim K between eyes versus the final mean absolute error. We did not detect a correlation here, suggesting that differences in ablation profile in this dataset did not significantly impact the Delta K method in this particular dataset. However, because it is known that ablation profile impacts the accuracy of lens calculations, a larger study would be necessary to clearly delineate the effect of ablation profile on the accuracy of the Delta K method.

Nevertheless, the Delta K method is not recommended for situations where only one eye received a refractive treatment or where a myopic refractive technique was used in one eye and a hyperopic refractive technique was used in the other eye. It is always prudent for the surgeon to obtain corneal topography prior to cataract surgery. Topography should be used not only to assess the regularity of the astigmatism and to compare the topographic astigmatism with biometrically obtained values, but also to assess the type of previous refractive surgery employed. In addition, this study would benefit from inclusion of more second eyes.

In future studies, we plan to sub-segment different refractive surgery techniques to determine whether there are differences in the efficacy of the Delta K method when used on corneas altered by these various techniques. In addition, an expanded study that includes surgeons from multiple centers who use different topographic and biometric instruments could investigate which devices provide the best Delta K data for calculating the difference in curvature between fellow eye corneas after refractive surgery.

AUTHOR CONTRIBUTIONS

Study concept and design (SRL, DRH); data collection (SRL, MNutkiewicz, HR); analysis and interpretation of data (SRL, MNutkiewicz, MNejad, DRH); writing the manuscript (SRL, MNutkiewicz, DRH); critical revision of the manuscript (SRL, MNutkiewicz, HR, MNejad, DRH); statistical expertise (MNutkiewicz, DRH); supervision (DRH)

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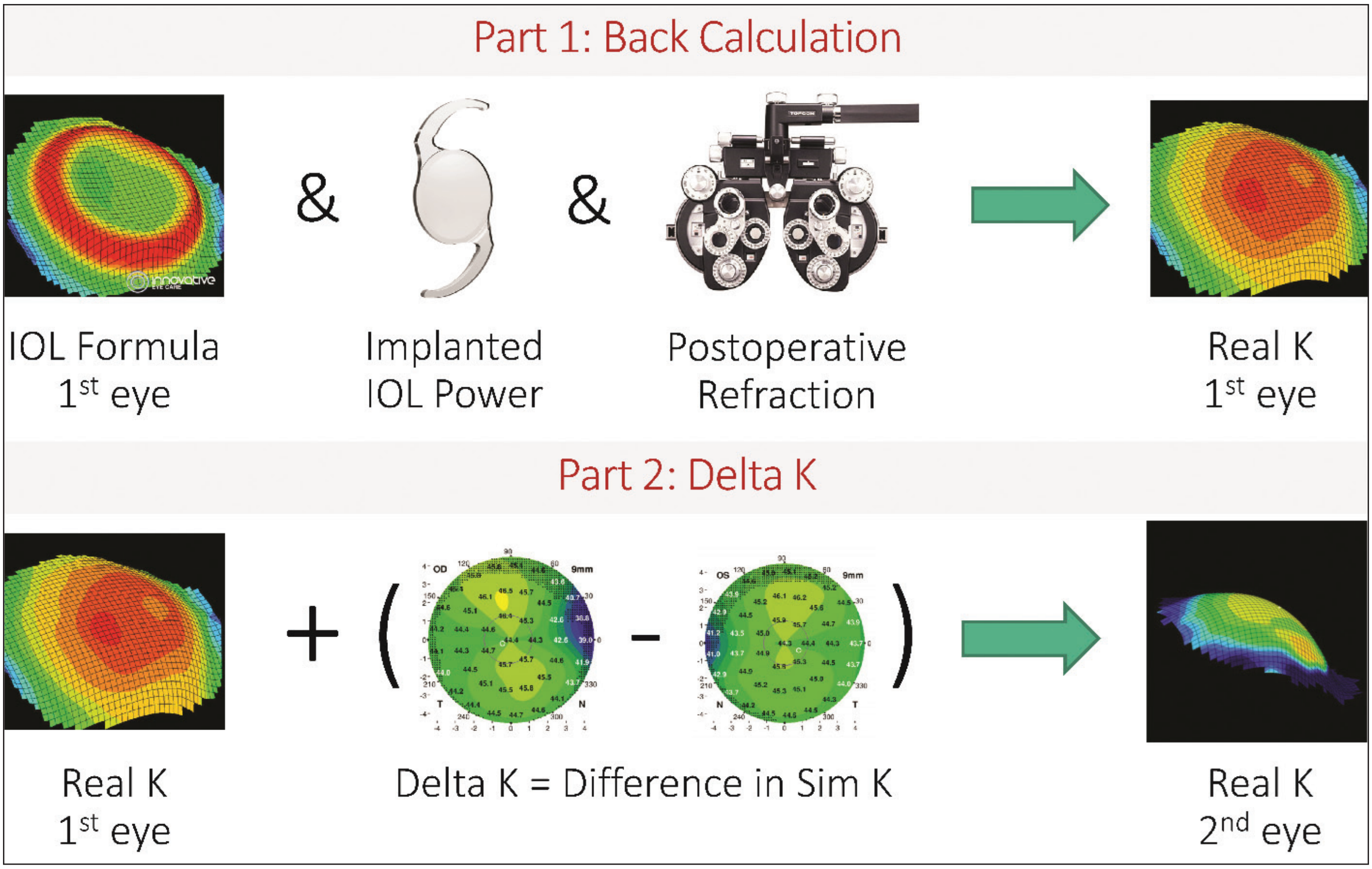

Figure A. Back calculation–Delta K methodology. First, the "Real K" is determined by back calculation using postoperative refraction. Second, the difference in simulated keratometric values (Sim Ks) between the two eyes is added to the Real K for the first eye to yield the predicted Real K for the second eye. IOL = intraocular lens

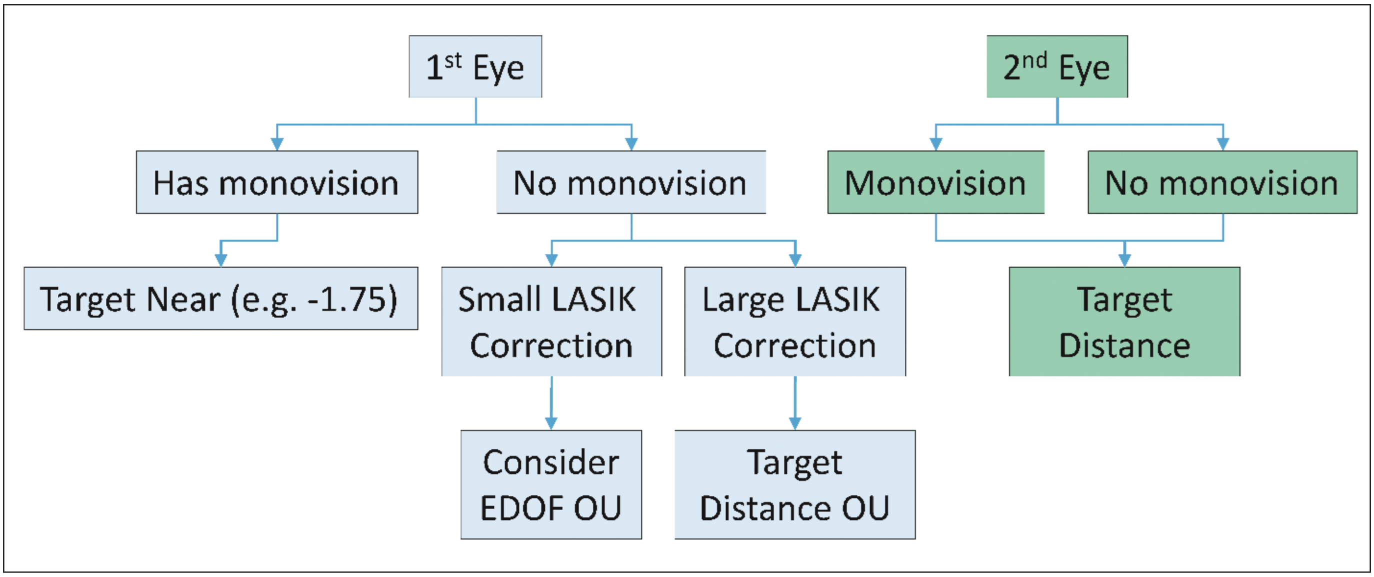

Figure B. Surgical planning algorithm for post-refractive eyes. EDOF = extended depth of focus; LASIK = laser in situ keratomlieusis; OU = both eyes