Open

ARTICLE

Predicted vs measured posterior corneal astigmatism for toric intraocular lens calculations

H. John Shammas, MD, Fei Yu, PhD, Maya C Shammas, MD, Renu Jivrajka, MD, Christine Hakimeh, MD

Purpose: To evaluate the astigmatic correction obtained with a toric intraocular lens using the keratometric readings (Ks) from a swept-source optical coherence tomography (SS-OCT) biometer and the Barrett toric formula with its predicted posterior corneal astigmatism (PCA) value and to compare the results with those expected by using the OCT Ks and a measured PCA from a scheimpflug topographer and by using the SimKs and the measured PCA from the Scheimpflug topographer.

Setting: Private practice, Lynwood, California.

Design: Retrospective observational study.

Methods: All measurements were performed by the SS-OCT biometer and the Scheimpflug topographer and using the Barrett toric formula.

Results: We evaluated 122 eyes of 122 patients. The mean absolute errors in predicted residual astigmatism for the entire series were 0.41 ± 0.19 diopters (D) (0.00 to 0.85 D) using the OCT Ks and predicted PCA, 0.45 ± 0.25 D (0.00 to 1.01 D) using the OCT Ks and measured PCA, and 0.49 ± 0.25 D (0.00 to 1.30 D) using the SimKs and measured PCA. The statistically significant differences between the errors had a *P* value of .062 for the entire series (n = 122), .26 for the subgroup with against-the-rule astigmatism (n = 68), .47 for the subgroup with oblique astigmatism (n = 11), and .05 for the subgroup with with-the-rule astigmatism (n = 43). The percentage of eyes within ±0.50 D were 74% (n = 90), 71% (n = 87) and 64% (n = 78) (*P* = .13) and within ±0.75 D were 99% (n = 121), 95% (n = 116) and 84% (n = 102) (*P* < .001), respectively.

Conclusions: The Barrett toric formula and its predicted PCA performed better with the OCT K readings than with the topographer SimKs and a measured PCA.

J Cataract Refract Surg 2022; 48:690–696 Copyright © 2021 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of ASCRS and ESCRS

Toric intraocular lenses (IOLs) provide a reliable option to correct preoperative corneal astigmatism at the time of cataract surgery[1–3] and require precise measurements of the keratometric readings (Ks). The Ks displayed on all biometers are not because of a direct measurement of that power; instead, the integrated keratometer measures the anterior corneal radius in millimeters and converts to power values (K in diopters [D]) according to the laws of Gaussian optics using the following formula:

$$K = 1000\,(n - 1)/r$$

where n is the standard refractive index of 1.3375; thus, the displayed corneal astigmatism only reflects the anterior corneal toricity.[4,5] Early formulas based their calculations solely on that anterior corneal astigmatic (ACA) measurement, and the results showed an overcorrection in some eyes that had with-the-rule (WTR) corneal astigmatism and an undercorrection in some eyes that had against-the-rule (ATR) astigmatism. This has led to multiple studies evaluating the contribution of the posterior corneal astigmatism (PCA) to the total corneal astigmatism.[6–9]

The Barrett toric calculator gathers the amount of anterior corneal astigmatism from the Ks in the flattest and the steepest meridians taken by the biometer. The formula requires a PCA value. The PCA can be measured (measured PCA) from a Scheimpflug or optical coherence tomography (OCT) device, or if such a measurement is not available, a predicted PCA value is automatically used. This predicted PCA uses a theoretical model to predict the PCA for an individual eye based on measured parameters. In addition, the formula, whether used with a predicted or a measured PCA value, contains an additional algorithm to take into account additional factors that contribute to postoperative pseudophakic residual astigmatism such as

Submitted: July 19, 2021 | Final revision submitted: September 8, 2021 | Accepted: September 15, 2021

From the University of Southern California, Keck School of Medicine, Los Angeles, California.

Supported by an investigator-initiated study grant from Alcon (ITT#632844090), Fort Worth, Texas.

Corresponding author: H. John Shammas, MD, Shammas Eye Medical Center, 3510 Martin Luther King Jr. Boulevard, Lynwood, CA 90262. Email: HShammas@aol.com.

0886-3350/$ - see frontmatter
https://doi.org/10.1097/j.jcrs.0000000000000819

lens tilt (G. Barrett, Personal communication, February 28, 2021). Since most biometers do not measure PCA, the predicted PCA value is often used in the Barrett toric calculations.

The objective of the study was to evaluate the astigmatic correction obtained from cataract surgery with a toric IOL (Alcon AcrySof IQ Toric IOL), calculated using the K readings from the Argos swept-source OCT (SS-OCT) and the built-in Barrett toric formula with the predicted PCA, and to compare the clinical results with the following: (1) those expected by using the OCT Ks and substituting the predicted PCA by a measured PCA from the Pentacam Scheimpflug topographer and (2) those expected by substituting the OCT Ks by the SimK readings and the measured PCA from the topographer, whereas keeping all other biometric data as measured by the OCT biometer.

METHODS

This was a comparative noninterventional study comprising a retrospective chart review of patients with a history of cataract surgery with insertion of a toric IOL at 1 center between January 1, 2019, and December 31, 2020. If both eyes of a patient were eligible to be included in the study, only the first operated eye was included.

The study was approved by the Milkie-Shammas Surgery Center Institutional Review Board. Informed consent was waived to allow the use of deidentified patient data. Data were collected in compliance with the tenets of the Declaration of Helsinki.

Sample size calculations suggested a minimum of 23 eyes to achieve the statistical significance for a minimum detectable mean difference of 0.50 D between the 2 instruments with the assumption of a common SD of 0.25 D for the postoperative residual refractive astigmatism in both instruments, using a 2-sided paired t test at an alpha level of 0.05 and a power of 90%. This study included 122 cases. Under the same assumption in the abovementioned sample size calculations, the 122 cases can achieve a statistical significance for a minimum detectable mean difference between the two instruments of 0.10 D.

Eligible charts were those from patients who have had previous uneventful cataract surgery with insertion of a toric IOL. The decision for a toric IOL was not based on the preoperative refractive astigmatism but solely on a corneal astigmatism of 0.70 D and more in the cataractous eye. One week prior to surgery, all eyes were measured on the same day by the OCT biometer and the Scheimpflug topographer.

Demographic data included the age, sex, and the eye to be operated on. The biometric data retrieved from the OCT biometer included the displayed axial length, the anterior chamber depth, the lens thickness, the corneal diameter, and the Ks along its steepest (K1) and its flattest (K2) meridians. The amount of astigmatism was calculated by subtracting K1 from K2. The astigmatic steepest meridian was also noted.

IOL power calculations were performed with the Barrett Universal II formula, and the toric calculations were performed with the Barrett toric formula using the predicted PCA. We also measured the actual PCA with the Scheimpflug topographer. The choice of the IOL spherical and toric powers were based on the OCT measurements and calculations.

The surgical treatment data, IOL power calculations, and power of the IOL implanted were also recorded. To reduce variability related to the IOL implanted, only eyes receiving the AcrySof IQ Toric IOL (Alcon Laboratories, Inc.) were included. On the first postoperative day, the IOL position is checked confirming that the axis is within 5 degrees from the intended position. Six to 8 weeks postoperatively, the final subjective refraction was recorded, including the amount of astigmatism and its axis.

The postoperative corrected distance visual acuity in the eye had to be 20/30 or better to reduce the likelihood of variability in the postoperative refraction. Eyes with clinically significant ocular pathology other than residual refractive error (eg, macular degeneration and advanced glaucoma) and eyes where the postoperative toric IOL axis orientation differed by more than 5 degrees from the planned axis insertion were excluded.

Both manual and electronic data records were used to identify a consecutive series of eyes that fit the abovementioned inclusion and exclusion criteria. Personal identity data were removed to preserve the privacy of the participants. Deidentified data were used for the study.

The primary end point is a comparison between the postoperative refractive astigmatism prediction error obtained by the Barrett toric formula with the OCT K readings and the predicted PCA and the postoperative refractive astigmatism prediction error using the Barrett toric formula with the following: (1) the OCT K readings and a measured PCA value by the topographer and (2) the SimK readings and the measured PCA from the topography device. The ASCRS website (ascrs.org/tools/barrett-toric-calculator) was used to complete the latter 2 calculations. Results from the 3 sets of data are compared. The Astigmatism Double-Angle Plot Tool V130-Excel, available on the ASCRS website (ascrs.org/tools/barrett-toric-calculator), was used to analyze and compare the results. The double-angle plot transforms the astigmatic data into 360-degree Cartesian coordinates. Such methodology allows the display of the magnitude and axis or meridian of the mean (centroid) and the confidence ellipse, which is the 2-variable analog of the CI for single variable analyses.[10] The mean absolute error (MAE) and its SD are calculated and compared between the 3 groups.

Secondary end points included the percentage of eyes that achieve a refractive astigmatism error ≤0.50 D and ≤0.75D. These comparisons are evaluated in the entire cohort and in 3 subgroups based on the astigmatic steep axis orientation: WTR (60 to 120 degrees), ATR (0 to 30 degrees and 150 to 180 degrees), and oblique (OBL; 30 to 60 degrees or 120 to 150 degrees) astigmatism.

Statistical Analysis

All statistical analyses were performed using SAS 9.4 (SAS Institute, Inc.). Bland-Altman plots were used to examine the agreement in astigmatism between the OCT keratometer and the Scheimpflug topographer, and the paired difference in astigmatism between the two devices was assessed using signed-rank test. The difference in PCA between eyes with ATR and WTR astigmatism was compared using Wilcoxon rank-sum test. To account for multiple MAE calculations with the same patients, the difference in MAE across the 3 calculations within the same patients was examined using Friedman test, a nonparametric rank test for repeated measurements alternative to the 1-way analysis of variance with repeated measurements. The percentage of errors within ±0.5 D and ±0.75 D across three calculations within the same patient was compared using the repeated-measures logistic regression model with generalized estimating equation, and Fisher exact test was performed when the logistic regression model could not be used because of zero cell count in at least 1 MAE calculation. A P value less than 0.05 was considered statistically significant.

RESULTS

Charts from a total of 122 consecutive eligible eyes were identified for inclusion in the dataset. The patients ranged

Table 1. Preop Basic Measurements.

SS-OCT, mean ± SD (range)	
AL, mm	23.70 ± 1.34 (20.75, 28.18)
ACD, mm	3.24 ± 0.39 (2.05, 4.40)
LT, mm	4.61 ± 0.48 (3.13, 5.93)
White-to-white distance, in mm	12.29 ± 0.51 (10.68, 13.53)
Flat K, D	43.17 ± 1.76 (39.56, 48.52)
Steep K, D	44.67 ± 1.69 (40.66, 49.28)
Mean K, D	43.92 ± 1.67 (40.25, 48.90)
Calculated astigmatism, D	1.49 ± 0.86 (0.71, 4.38)
Topographer, mean ± SD (range)	
Flat SimKs, D	43.19 ± 1.82 (39.20, 49.00)
Steep SimKs, D	44.46 ± 1.69 (40.80, 49.40)
Mean SimKs, D	43.83 ± 1.70 (40.15, 49.20)
Calculated astigmatism, D	1.27 ± 0.91 (0.10, 4.00)
Posterior corneal radius, mm	6.33 ± 0.29 (5.41, 6.90)
PCA, D	0.34 ± 0.22 (0, 0.90)

ACD = anterior chamber depth; AL = axial length; Ks = keratometric readings; LT = lens thickness; PCA = posterior corneal astigmatism; preop = preoperative; Sim Ks = simulated keratometric readings

in age from 26 to 88 years with a mean age of 70 ± 11 years and included 61 women (50%) and 65 operated right eyes (53%). Table 1 summarizes the preoperative basic measurements of the cohort taken by the OCT biometer and by the topography device. Table 2 summarizes the data on the type and frequency of the implanted toric IOLs.

The decision to insert a toric IOL was based on the ACA values retrieved from the OCT biometer. The amount of preoperative measured corneal astigmatism ranged from 0.71 to 4.38 D; 68 eyes (56%) had ATR astigmatism, 11 eyes (9%) had OBL astigmatism, and 43 eyes (35%) had WTR astigmatism. Bland-Altman plot (Supplemental Figure a, http://links.lww.com/JRS/A480) shows the difference in astigmatism between the OCT keratometer and the topographer device.

Table 1 summarizes the flat K, steep K, and astigmatism values taken by both instruments. The calculated amount of astigmatism by the SS-OCT biometer ranged from 0.71 to 4.38 D with a mean value of 1.49 ± 0.86 D, whereas the calculated amount of astigmatism measured by the Scheimpflug topographer ranged from 0.10 to 4.00 D with a mean value of 1.27 D. The mean amount of calculated astigmatism differed by 0.22 ± 0.38 D (1.49 ± 0.86 vs 1.27 ± 0.91 D) between the 2 instruments (Table 1). The difference between the 2 values was statistically significant (signed-rank test, $P < .0001$).

The radius of the posterior cornea as measured by the topographer ranged from 5.41 to 6.90 mm with a mean of 6.33 ± 0.29 mm, and the measured PCA ranged from 0 to 0.9 D with a mean of 0.34 ± 0.22 D. In most cases, PCA was ATR astigmatism with its steepest meridian between 60 degrees and 120 degrees (Supplemental Figure b, http://links.lww.com/JRS/A481). PCA ranged from 0 to 0.6 D with a mean of 0.22 ± 0.13 D in eyes with ATR astigmatism, from 0.2 to 0.6 D with a mean of 0.37 ± 0.17 D in eyes with OBL astigmatism, and from 0.1 to 0.9 D with a mean of 0.52 ± 0.23 D in eyes with WTR astigmatism. The

Table 2. Type of IOL and Frequency of Implantation.

IOL model	IOL cylinder corrected	Eyes (n)	ATR/WTR/ OBL (n)
SN6AT3	1.50 D	63	34/20/9
SN6AT4	2.25 D	29	18/9/2
SN6AT5	3.00 D	17	12/5/0
SN6AT6	3.75 D	10	4/6/0
SN6AT7	4.50 D	1	0/1/0
SN6AT8	5.25 D	2	0/2/0

ATR = against-the-rule astigmatism; OBL = oblique astigmatism; WTR = with-the-rule astigmatism

difference between the amount of PCA in eyes with ATR and WTR astigmatism was statistically significant (Wilcoxon rank-sum test, $P < .0001$) (Supplemental Figure c, http://links.lww.com/JRS/A482).

Figure 1 shows the double-angle plots of the preoperative and postoperative astigmatism in the entire series. Figure 2 shows the postoperative refractive astigmatism prediction error measured at the corneal plane using the Barrett toric formula with the OCT Ks measurements and a predicted PCA value, showing a centroid of 0.06 D @ 134 degrees ± 0.45 D and a MAE of 0.41 D ± 0.19 D ranging from 0.00 to 0.85 D. Double-angle plots were then performed on the 43 eyes with WTR astigmatism, the 68 eyes with ATR astigmatism, and the 11 eyes with an OBL astigmatism. The same calculations were also performed using the OCT Ks and the measured PCA and using the SimK and measured PCA.

Table 3 summarizes the centroid value, and the MAE and its standard deviation for the entire series and for the three subgroups. Statistical analyses (Friedman test) for the differences in MAE across the 3 MAE calculations within the same patient showed a P value of .062 for the entire series, .26 for the ATR cases, .47 for the OBL cases, and .05 for the WTR cases.

Table 4 summarizes the difference in percentage of errors within ±0.50 D and within ±0.75 D. These percentages were statistically evaluated using the repeated-measures logistic regression model with a generalized estimation equation for the difference in percentage of MAE within ±0.50 D and within ±0.75 D. The differences were not statistically significant ($P > .05$) for all percentages within ±0.50 D. The differences were statistically significant for the differences within ±0.75 D with a P value of <.001 for the entire series, <.001 the ATR cases, and .03 for the WTR cases.

DISCUSSION

Astigmatism is a refractive error due to rotational asymmetry in the eye's refractive power; this results in a distorted or blurry vision at any distance. In regular astigmatism, the principal meridians (steepest and flattest) are perpendicular; the astigmatism is WTR when the steepest meridian is vertical (between 60 degrees and 120 degrees), ATR when the steepest meridian is horizontal (between 0 to 30 degrees and 150 to 180 degrees), and OBL when the steepest

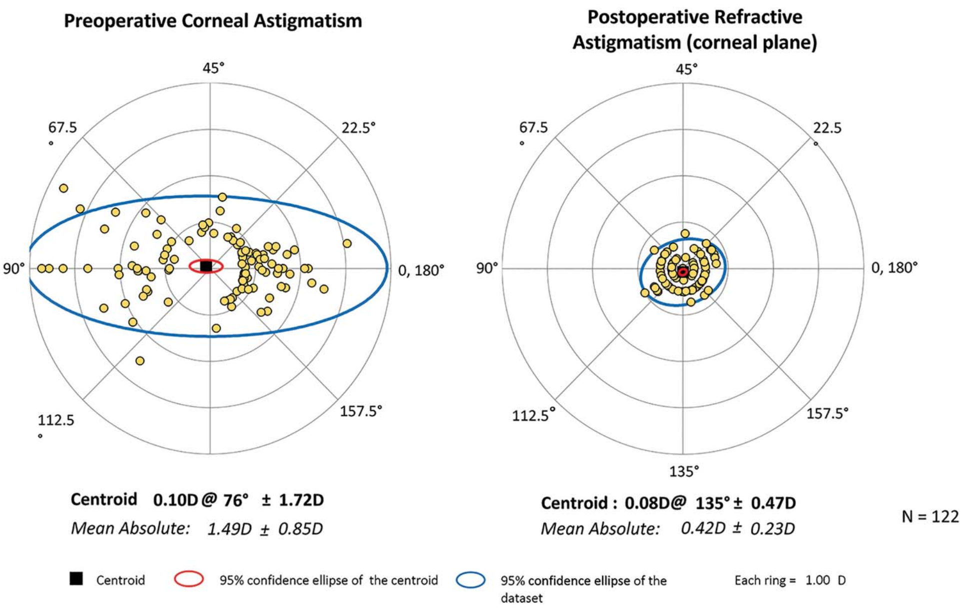

Figure 1. Double-angle plots of preoperative and postoperative corneal astigmatism. Each ring = 1.0 D.

meridian is OBL (between 30 and 60 degrees or 120 and 150 degrees). In these definitions, the axis is always recorded as an angle in degrees, between 0 and 180 degrees in a counterclockwise direction. Both 0 and 180 degrees lie in a horizontal line at the level of the center of the pupil, and as seen by an observer, 0 lies on the right of both the eyes. Refractive astigmatism is usually caused by a combination of optical distortions, mainly in the cornea and in the lens. The lenticular portion is sometimes significant, especially with cataract formation, but this portion is always eliminated with cataract removal; thus, the toric IOL will have to mainly correct the corneal astigmatism. Corneal astigmatism arises from the anterior and the posterior surfaces of the cornea. Although the ACA is easily measured by keratometry, the posterior component can be measured only with Scheimpflug or OCT technology. The decision to use a toric IOL was strictly based on the presence of a corneal astigmatism ranging between 0.71 D and 4.38 D.

Fluctuations in the measured corneal curvature in magnitude and axis of the cylinder have been previously documented. According to Norrby et al., the cornea is not a static optical component of the eye but rather a dynamic one.[4] The differences in the corneal power measurements at different timepoints reflect natural fluctuations and are not necessarily due to measurement errors. The measured corneal power could be different by up to 0.50 D from one occasion to another in approximately 5% of the cases.

The Argos SS-OCT biometer is based on SS-OCT to measure the axial length.[11] The Ks are measured through videokeratometry using 16 LED lights positioned in a circle at 2.3 mm in diameter. The camera provides a panoramic view of the eye and allows alignment of the patient's eye regarding the pupil's center for a more accurate acquisition process; the unit generates the Ks in the flattest and steepest meridians, the amount of astigmatism, and its axis. In a previous study evaluating the Argos SS-OCT biometer, the average anterior corneal radius of curvature showed excellent repeatability with a mean variation of 0.01 mm, which translates to approximately 0.05 D for repeated measurements performed in the same session, and excellent reproducibility with a mean variation of 0.02 mm, which translates to approximately 0.10 D when 3 acquisitions were performed, and the patient was realigned every time.[11]

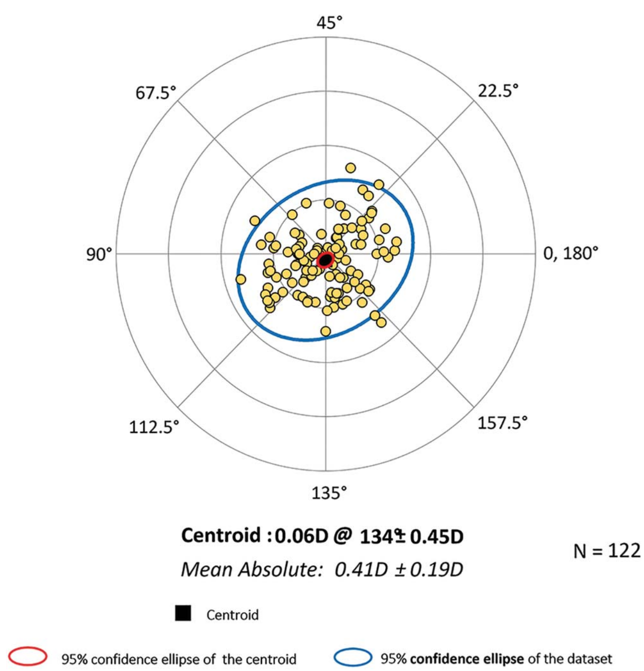

Figure 2. Postoperative refractive astigmatism prediction error measured at the corneal plane using the Barrett toric formula with the OCT measurements and a predicted PCA value. Each ring = 0.50 D. PCA = posterior corneal astigmatism

TABLE 3. Postop Refractive Astigmatism Prediction Error Using the Astigmatism Double-Angle Plot.

	Centroid	MAE ± SD	Range
Entire series (n = 122), D			
OCT Ks + pred PCA	0.06 @ 134° ± 0.45	0.41 ± 0.19	0.00, 0.85
OCT Ks + meas PCA	0.12 @ 107° ± 0.51	0.45 ± 0.25	0.00, 1.01
Topographer SimKs + PCA	0.09 @ 121° ± 0.55	0.49 ± 0.25	0.00, 1.30
WTR astigmatism (n = 43), D			
OCT Ks + pred PCA	0.11 @ 168° ± 0.42	0.39 ± 0.19	0.02, 0.85
OCT Ks + meas PCA	0.08 @ 98° ± 0.53	0.44 ± 0.30	0.00, 1.01
Topographer SimKs + PCA	0.15 @ 96° ± 0.53	0.50 ± 0.24	0.01, 1.30
ATR astigmatism (n = 68), D			
OCT Ks + pred PCA	0.07 @ 114° ± 0.45	0.41 ± 0.19	0.00, 0.74
OCT Ks + meas PCA	0.11 @ 106° ± 0.46	0.43 ± 0.19	0.02, 0.84
Topographer SimKs + PCA	0.10 @ 145° ± 0.56	0.50 ± 0.26	0.00, 1.19
OBL astigmatism (n = 11), D			
OCT Ks + pred PCA	0.18 @ 111° ± 0.52	0.46 ± 0.27	0.05, 0.71
OCT Ks + meas PCA	0.19 @ 117° ± 0.66	0.45 ± 0.27	0.01, 0.99
Topographer SimKs + PCA	0.19 @ 121° ± 0.44	0.44 ± 0.23	0.03, 0.70

AE = astigmatic error; MAE = mean absolute error; Ks = keratometric readings; Meas PCA = measured posterior corneal astigmatism; Sim Ks = simulated keratometric readings; OBL = oblique; Pred PCA = predicted posterior corneal astigmatism; posteop = postoperative

Simulated keratometry, on the other hand, is an output from computerized corneal topography systems, including the Pentacam Scheimpflug topographer.[5] It is obtained by averaging power along the corneal 3.0 mm central ring. A refractive index of 1.3375 is used in both instruments; according to Haigis, the Javal index of 1.3375 can be deduced by calculating the corneal back vertex power of the Gullstrand eye.[12]

On average, the topographer measured a lower astigmatic value than the OCT biometer. A 0.26 D lesser amount of astigmatism was also noted by Savini and Naeser when comparing a rotating Scheimpflug camera to a Placido-disc corneal topographer.[1] In another study, Wang et al.[13] also noted a lower total astigmatic value with a dual Scheimpflug analyzer compared with an OCT-based biometer. By contrast, a mean statistically significant difference of only 0.03 D was found by Visser et al. comparing the standard Ks with the IOLMaster 500 with the SimKs and by Shajari et al. comparing the Ks from the IOLMaster 700 to the SimKs.[14,15] In 2013, we reported on 50 eyes of 50 patients measured by the IOLMaster 500 and the Pentacam Scheimpflug topographer; in that study, the use of the 2.0 mm keratometric measurements from the sagittal corneal front map yielded the best results for the IOL power calculation.[5] Reviewing the data to evaluate the measured astigmatism by both units (unpublished data), the IOLMaster 500 measured an astigmatism of 1.04 ± 0.84 D ranging from 0.00 to 5.08 D. In comparison, the average SimK was lower by 0.13 D ranging from 0.00 to 4.80 D with a mean of 0.91 ± 0.83 D, the 2.0 mm ring and zone from the sagittal corneal front map were higher by 0.08 D (1.12 ± 0.83 D, ranging from 0.00 to 4.70 D) and by 0.11 D (1.15 ± 0.82 D, ranging from 0.10 to 4.50 D), respectively, and the 3.0 mm ring and zone readings were lower by 0.1 D (0.94 ± 0.82 D, ranging from 0.10 to 4.80 D) and 0.03 D (1.01 ± 0.81 D, ranging from 0.10 to 5.00 D), respectively. These differences in the astigmatic readings make the surgeon question which ring or zone diameter will yield the most accurate astigmatic value that needs to be corrected.

PCA is routinely measured by the Scheimpflug topographer. In most cases, PCA is ATR with its steepest meridian between 60 degrees and 120 degrees. The magnitude of the PCA seems to be larger in eyes with WTR astigmatism (mean of 0.52 ± 0.23 D, ranging from 0.1 to 0.9 D) than in eyes with ATR astigmatism (average of 0.22 ± 0.13

TABLE 4. Prediction Error Within ±0.50 and ±0.75 D.

	Error ≤ ±0.50 D	Error ≤ ±0.75 D
Entire series (n = 122), n (%)		
OCT Ks + pred PCA	90 (74)	121 (99)
OCT Ks + meas PCA	87 (71)	116 (95)
Topographer SimKs + PCA	78 (64)	102 (84)
P value	.13	<.001
WTR astigmatism (n = 43), n (%)		
OCT Ks + pred PCA	32 (74)	42 (98)
OCT Ks + meas PCA	31 (72)	39 (91)
Topographer SimKs + PCA	28 (65)	35 (81)
P value	.53	.03
ATR astigmatism (n = 68), n (%)		
OCT Ks + pred PCA	50 (74)	68 (100)
OCT Ks + meas PCA	46 (68)	67 (99)
Topographer SimKs + PCA	43 (63)	56 (82)
P value	.30	<.001
OBL astigmatism (n = 11), n (%)		
OCT Ks + pred PCA	8 (73)	11 (100)
OCT Ks + meas PCA	10 (91)	10 (91)
Topographer SimKs + PCA	7 (64)	11 (100)
P value	.22	NA

ATR = against-the-rule; GEE = generalized estimating equation; Ks = keratometric readings; Meas PCA = measured posterior corneal astigmatism; OBL = oblique; Pred PCA = predicted posterior corneal astigmatism; Sim Ks = simulated keratometric readings; WTR = with-the-rule
The *P* value was calculated using the repeated-measures logistic regression model with GEE

D, ranging from 0.00 to 0.60 D). These results are in line with previous studies showing that the PCA is predominantly ATR with a steep vertical meridian.[6] In this study, the PCA value is obtained solely from the Scheimpflug topographer; one of the limitations of such a measurement is the lack of any test object or other calibration method that can validate it.[6] In another comparative study by Wang et al., OCT produced a lower magnitude of posterior corneal astigmatism than those obtained by a dual Scheimpflug analyzer, along with a lower percentage of eyes with vertical alignment of steep meridian on the posterior corneal surface.[13] The postoperative refractive astigmatism prediction MAE was lower when the calculations with the Barrett toric calculator used the OCT Ks and the predicted PCA (0.41 ± 0.19 D, ranging from 0.00 to 0.85D) than with the OCT Ks and the measured PCA (0.45 ± 0.25 D, ranging from 0.00 to 1.01 D) or the topographer SimKs and the measured PCA (0.49 ± 0.25 D, ranging from 0.00 to 1.30 D). Our results compare favorably with those of Abulafia et al. who reported a MAE of 0.46 ± 0.29 D with the optical low-coherence reflectometry (OLCR) Ks, 0.63 ± 0.40 D with the topographer SimKs and 0.55 ± 0.38 D with the topographer mean Ks.[16] Furthermore, the number of eyes within ±0.50 D and ±0.75 D was higher with the OCT Ks and predicted PCA (74% and 99%, respectively) than with the OCT Ks and the measured PCA (71% and 95%, respectively) and with the topographer SimKs and measured PCA (64% and 84%, respectively). Similar findings were also noted by Abulafia et al. with errors within ±0.50 and ±0.75 D of 88% and 96% with the PCI device, 75% and 97% with the optical low-coherence reflectometry device, 44% and 69% with the topographer (SimKs), and 54% and 77% with the topographer (mean Ks), respectively.[16]

When the subgroups were evaluated, similar results were noted in eyes with ATR astigmatism and eyes with WTR showing a MAE of 0.41 ± 0.19 D (ranging from 0.00 to 0.74 D) and 0.39 ± 0.19 D (ranging from 0.02 to 0.85 D), respectively. The MAE in eyes with OBL astigmatism was slightly higher but the number of cases in this category was relatively small.

Limitations of the study include the following: (1) the two instruments measured different zones on the anterior corneal surface to derive the K value; the OCT biometer uses 16 LED lights positioned in a circle at 2.3 mm in diameter, whereas the Scheimpflug topographer averages power along the 3.0 mm central ring; (2) our mean surgically induced astigmatism was 0.1 D; however, interpatient variability of surgically induced astigmatism has been found to be one of the main reasons for such range of errors; (3) the eyes were checked for correct alignment at postoperative day 1 without checking for any subsequent IOL rotation; however, in a large study, the 1-year clinical results of toric IOLs were highly stable and satisfactory; (4) all eyes were refracted at 4 to 6 weeks postoperatively; Holladay and Pettit recommend a final refraction 6 months postoperatively; the additional change with time is a progressive increase in ATR astigmatism.[1,2,17]

In summary, the use of the predicted PCA integrated in the Barrett toric formula was superior to using a measured PCA value from a Scheimpflug topographer, with a lower MAE and a higher percentage of eyes within ±0.50 D and ±0.75 D.

WHAT WAS KNOWN

- Early toric formulas based their calculations solely on the anterior corneal astigmatic measurement resulting in an overcorrection in some eyes that had with-the-rule corneal astigmatism and an undercorrection in some eyes that had against-the-rule astigmatism.
- Multiple studies evaluated the contribution of the posterior corneal astigmatism (PCA) to the total corneal astigmatism.
- The Barrett toric formula incorporates a predicted posterior corneal astigmatic value that can be used instead of a measured value.

WHAT THIS PAPER ADDS

- The SimK readings from the Scheimpflug topographer measured a lower astigmatic value than the K readings from the OCT biometer.
- The use of the predicted PCA integrated into the Barrett toric formula was superior to using a measured PCA value from a Scheimpflug topographer.
- Using the keratometric values from the OCT biometer with the Barrett formula yielded better postoperative astigmatic correction than using the SimK values from the Scheimpflug topographer.

REFERENCES

1. Savini G, Næser K. An analysis of the factors influencing the residual refractive astigmatism after cataract surgery with toric intraocular lenses. Invest Ophthalmol Vis Sci 2015;56:827–835
2. Ninomiya Y, Minami K, Miyata K, Shuichiro E, Sato R, Okamoto F, Oshika T. Toric intraocular lenses in eyes with-the rule, against-thr-rule, and oblique astigmatism: one-year results. J Cataract Refract Surg 2016;42:1431–1440
3. Ferreira TB, Riebero P, Ribeiro F, O'Neill JG. Comparison of astigmatism prediction errors associated with new calculation methods for toric intraocular lenses. J Cataract Refract Surg 2017;43:340–347
4. Norrby S, Hirnschall N, Nishi Y, Findl O. Fluctuations in corneal curvature limit predictability of intraocular lens power calculations. J Cataract Refract Surg 2013;39:174–179
5. Saad E, Shammas MC, Shammas HJ. Scheimpflug corneal power measurements for intraocular lens power calculation in cataract surgery. Am J Ophthalmol 2013;156:460–467
6. Koch DD, Ali SF, Weikert MP, Shirayama M, Jenkins R, Wang L. Contribution of posterior corneal astigmatism to total corneal astigmatism. J Cataract Refract Surg 2012;38:2080–2087
7. Goggin M, van Zyl L, Caputo S, Esterman A. Outcome of adjustment for posterior corneal curvature in toric intraocular lens calculation and selection. J Cataract Refract Surg 2016;42:1441–1448
8. Savini G, Næser K, Schiano-Lomoriello D, Ducoli P. Optimized keratometry and total corneal astigmatism for toric intraocular lens calculation. J Cataract Refract Surg 2017;43:1140–1148
9. Ferreira T, Ribeiro F. How can we improve toric intraocular lens calculation methods? Current insights. Clin Ophthalmol 2020;14:1899–1908
10. Abulafia A, Koch DD, Holladay JT, Wang L, Hill WE. Editorial. Pursuing Perfection in IOL Calculations IV: astigmatism analysis, SIA and double angle plots. J Cat Refract Surg 2018;44:1169–1174
11. Shammas HJ, Ortiz S, Shammas MC, Kim SH, Chong C. Biometry measurements using a new large-coherence-length swept-source optical coherence tomographer. J Cataract Refract Surg 2016;42:50–61

12. Haigis W. Corneal power after refractive surgery for myopia: contact lens method. J Cataract Refract Surg 2003;29:1397–1411. erratum, 1854
13. Wang L, Cao D, Vilar C, Koch DD. Posterior and total corneal astigmatism measured with optical coherence tomography-based biometer and dual scheimpflug analyzer. J Cataract Refract Surg 2020;46:1652–1658
14. Vissr N, Berendschot TT, Verbakel F, de Brabander J, Nujits RMMA. Comparability and repeatability of corneal astigmatism measurements using different measurement technologies—ScienceDirect. J Cataract Refract Surg 2016;42:569–576
15. Shajari M, Sonntag R, Ramsauer M, Kreutzer T, Vounotrypides E, Kohnen T, Priglinger S, Mayer WJ. Evaluation of total corneal power measurements with a new optical biometer. J Cataract Refract Surg 2020;46:675–681
16. Abulafia A, Barrett GD, Kleinmann G, Ofir S, Levy A, Marcovich AL, Michaeli A, Koch DD, Wang L, Assia EI. Prediction of refractive outcomes with toric intraocular lens implantation. J Cataract Refract Surg 2015;41:936–944
17. Holladay JT, Pettit G. Improving toric intraocular lens calculations using total surgically induced astigmatism for a 2.5 mm temporal incision. J Cataract Refract Surg 2019;45:272–283

Disclosures: *H. J. Shammas is a consultant for Alcon Laboratories, Inc. and receives licensing fees from various biometry companies for the Shammas post-LASIK formulas license. No other disclosures were reported.*

First author:
H. John Shammas, MD

University of Southern California, Keck School of Medicine, Lynwood, California