ARTICLE

Effect of posterior corneal astigmatism on refractive outcomes after toric intraocular lens implantation

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PURPOSE: To compare the prediction error after toric intraocular lens (IOL) (Acrysof IQ) implantation using corneal astigmatism measurements obtained with an IOLMaster automated keratometer and a Galilei dual rotating camera Scheimpflug–Placido tomographer.

SETTING: Jules Stein Eye Institute, University of California Los Angeles, Los Angeles, California, USA.

DESIGN: Retrospective case series.

METHODS: The predicted residual astigmatism after toric IOL implantation was calculated using preoperative astigmatism values from an automated keratometer and the total corneal power (TCP) determined by ray tracing through the measured anterior and posterior corneal surfaces using dual Scheimpflug–Placido tomography. The prediction error was calculated as the difference between the predicted astigmatism and the manifest astigmatism at least 1 month postoperatively. The calculations included vector analysis.

RESULTS: The study evaluated 35 eyes (35 patients). The preoperative corneal posterior astigmatism mean magnitude was 0.33 diopter (D) $\pm$ 0.16 (SD) (vector mean 0.23 $\times$ 176). Twenty-six eyes (74.3%) had with-the-rule (WTR) posterior astigmatism. The postoperative manifest refractive astigmatism mean magnitude was 0.38 $\pm$ 0.18 D (vector mean 0.26 $\times$ 171). There was no statistically significant difference in the mean magnitude prediction error between the automated keratometer and TCP techniques. However, the automated keratometer method tended to overcorrect WTR astigmatism and undercorrect against-the-rule (ATR) astigmatism. The TCP technique lacked these biases.

CONCLUSIONS: The automated keratometer and TCP methods for estimating the magnitude of corneal astigmatism gave similar results. However, the automated keratometer method tended to overcorrect WTR astigmatism and undercorrect ATR astigmatism.

Financial Disclosure: Dr. Hamilton has received honoraria for educational lectures from Ziemer Ophthalmic Systems. No other author has a financial or proprietary interest in any material or method mentioned.

J Cataract Refract Surg 2015; 41:84–89 © 2015 ASCRS and ESCRS

The development of new intraocular lenses (IOLs) for cataract surgery has decreased the amount of postoperative refractive error. Toric IOLs minimize significant astigmatism and have been shown to produce good visual outcomes.[1–3] Corneal astigmatism is the primary source of astigmatic refractive error that has to be corrected by the toric IOL. The anterior and posterior corneal surfaces contribute to the total corneal astigmatism. Manual keratometry methods account for only the anterior astigmatism when calculating the astigmatic correction required with toric IOL implantation. Results in several studies[4–8] indicate that posterior corneal astigmatism contributes significantly to the total corneal astigmatism; these studies report posterior astigmatism values of −0.26 to −0.78 diopter (D). Incorporating posterior astigmatism into the toric IOL calculation might improve refractive outcomes.

Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.jcrs.2014.04.033
0886-3350

Accurate corneal power measurement is important when calculating astigmatism correction by toric IOLs. Current methods of astigmatism measurement for toric IOL calculations include manual keratometry, automated keratometry, and simulated keratometry from corneal topography. The IOLMaster (Carl Zeiss Meditec AG) is a biometer with an automated keratometer that measures anterior corneal power. Keratometric corneal power is estimated using the anterior corneal curvature measurement and the keratometric index (1.3375). The Galilei system (Ziemer Ophthalmic Systems AG) is a combined dual Scheimpflug camera–Placido system that images the anterior curvature and the anterior and posterior corneal surface elevations. Total corneal power and astigmatism can be calculated using ray tracing through the anterior and posterior corneal surfaces. Corneal power measurements obtained using the 2 devices have been shown to be highly reproducible and comparable.[9] Shirayama et al.[10] also found the accuracy of IOL power calculation to be comparable between the 2 devices.

The purpose of this study was to determine the prediction error of astigmatism measurements after toric IOL implantation using the automated keratometer and dual Scheimpflug–Placido tomographer. Simulated outcomes calculated using the dual Scheimpflug–Placido tomographer and anterior and posterior astigmatism were compared with actual postoperative outcomes assessed using the automated keratometer.

PATIENTS AND METHODS

This retrospective case series was performed at the Jules Stein Eye Institute, University of California, Los Angeles, USA, after institutional review board approval was obtained. It comprised eyes in which phacoemulsification with toric IOL implantation was performed between December 2009 and August 2012.

Submitted: October 9, 2013.
Final revision submitted: March 29, 2014.
Accepted: April 7, 2014.

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Patients who had preoperative automated keratometry and dual rotating Scheimpflug–Placido keratometry readings and postoperative manifest refraction at least 1 month after surgery were included. Exclusion criteria were corneal pathology such as keratoconus and corneal scars, previous corneal surgery, and a postoperative corrected distance visual acuity of 20/25 or better.

Preoperative dual rotating Scheimpflug–Placido simulated keratometry, posterior keratometry, and total corneal power (TCP) readings were collected. The biometer was used to obtain automated keratometry measurements. The biometry measurements were used with the Holladay 1 formula to calculate the spherical power of the toric IOL to be implanted.[11] The manifest refraction measured at least 1 month postoperatively was recorded. The same surgeon (D.R.H.) performed all surgeries using a 2.4 mm temporal clear corneal incision (CCI) and a standard stop-and-chop phacoemulsification technique.

The Acrysof IQ Toric IOL (Alcon Laboratories, Inc.) was used in all cases. This hydrophobic acrylic foldable IOL has a 6.0 mm optic diameter. It is available in cylinder powers at the IOL plane ranging from 1.5 to 6.0 D (SN60T3 to SN60T9). The astigmatism correction is 1.03 D, 1.55 D, 2.06 D, 2.57 D, 3.08 D, 3.60 D, and 4.11 D at the corneal plane for the T3, T4, T5, T6, T7, T8, and T9, respectively. The automated keratometry values obtained by the biometer were used with an online calculator[A] to calculate the IOL cylinder power and alignment axis. A surgically induced corneal astigmatism of 0.2 D for a 2.4 mm temporal CCI was used for toric IOL calculation based on the surgeon's personal data. The mean surgically induced astigmatism (SIA) value was determined using preoperative and postoperative topographies from 50 previous cases (data not shown). The spherical and astigmatic powers of the IOL and the axis of implantation were recorded. Postoperative dilated slitlamp photographs were taken to determine whether the IOL had rotated and if so, the degree of rotation.

The following corneal astigmatism values were obtained: automated keratometry within a 2.3 mm radius measured with the biometer and dual Scheimpflug–Placido keratometry measurements, including posterior astigmatism, simulated keratometry, anterior astigmatism, and TCP using ray tracing through the anterior and posterior corneal surfaces. All dual Scheimpflug–Placido keratometry measurements were made across the 1.0 to 4.0 mm central zone of the cornea. Because of the difference in the index of refraction between the cornea and the aqueous, the posterior astigmatic power is the opposite of the anterior astigmatic power, which is determined by the index of refraction difference between the air and the cornea. The with-the-rule (WTR) posterior astigmatic shape subtracts from the WTR anterior astigmatic shape, while the WTR posterior astigmatic shape adds to the against-the-rule (ATR) anterior astigmatic shape (Figure 1).

Actual corneal astigmatism was calculated as the sum of the postoperative manifest astigmatism and the IOL cylinder. Before analysis, the manifest refraction was converted to the corneal plane, adjusting for the vertex distance (12.5 mm). The prediction error was calculated as the actual corneal astigmatism minus the preoperative corneal astigmatism estimate. The actual corneal astigmatism and the prediction error were calculated using vector analysis.[12]

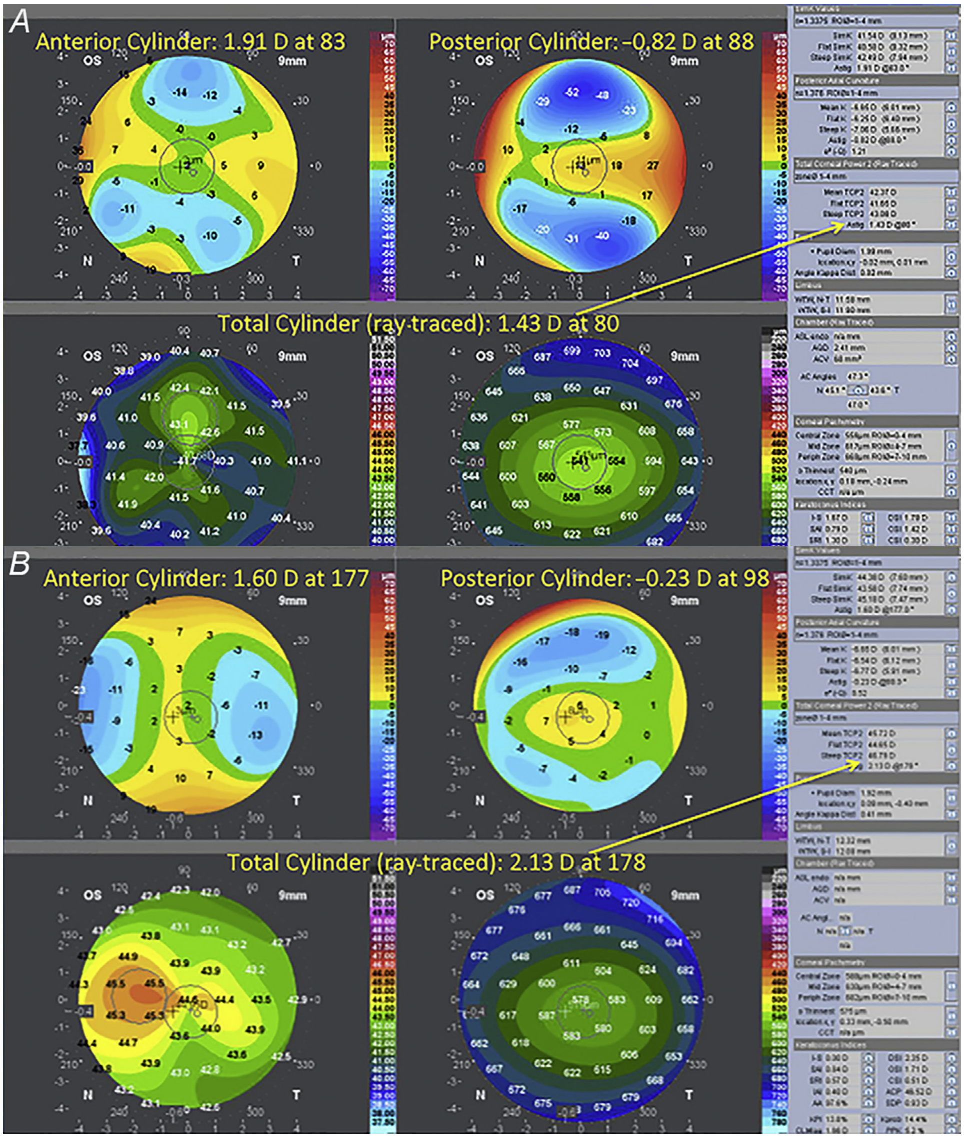

Figure 1. *A*: Symmetric anterior and posterior astigmatism measurements. A WTR posterior astigmatic shape subtracts from the WTR anterior astigmatic shape, reducing the overall WTR astigmatism power. *B*: Asymmetric anterior and posterior astigmatism measurements. A WTR posterior astigmatic shape adds to the ATR anterior astigmatic shape, increasing the overall ATR astigmatic power.

The simulated toric IOL astigmatic powers were calculated using the preoperative TCP astigmatism. The simulated outcomes were compared with the postoperative astigmatism results obtained using the automated keratometer method. All values were stratified as WTR (within $\pm$30 degrees of 90 degrees) or ATR (within $\pm$30 degrees of 0 or 180 degrees) astigmatism. Postoperative manifest astigmatism was classified as corrected ($<$0.45 D), overcorrected ($>$0.45 D and axis $>$45 degrees different from preoperative cylinder axis), or undercorrected ($>$0.45 D and axis $<$45 degrees different from preoperative cylinder axis).

Statistical Analysis

Statistical analysis was performed using SAS software (version 9.3, SAS Institute, Inc.). The difference in the magnitude of astigmatism between the automated keratometer and TCP methods was analyzed using analysis of variance (ANOVA), and the difference in the vector of astigmatism between the 2 methods was analyzed using multivariate ANOVA. The percentage of eyes that were corrected, overcorrected, and undercorrected was compared between the WTR group and the ATR group using the Fisher exact test. A P value less than 0.05 was considered statistically significant.

RESULTS

The study evaluated 35 eyes (21 right, 14 left) of 35 patients. The mean age of the 17 men (49%) and 18 women (51%) was 68 years $\pm$ 11 (SD) (range 48 to 97 years). There were no intraoperative complications. No IOL was rotated more than 5 degrees from the intended position. Table 1 shows the mean preoperative astigmatic magnitudes in the 2 study groups.

Table 1. Preoperative corneal astigmatism and prediction error.

	Preoperative Astigmatism		Prediction Error	
Method	Mean Magnitude (D) ± SD	Vector Mean (D @ °)	Mean Magnitude (D) ± SD*	Vector Mean (D @ °)†
Automated keratometry	1.61 ± 0.48	0.31 @ 69	0.44 ± 0.36	0.25 @ 70
Total corneal power (ray traced)	1.71 ± 0.63	0.20 @ 45	0.63 ± 0.38	0.16 @ 38

*P = .068 (analysis of variance [ANOVA])
†P = .19 (multivariate ANOVA)

The ranges were 0.73 to 2.83 D and 0.46 to 3.26 D for the automated keratometer group and TCP group, respectively.

The mean magnitude of the preoperative posterior corneal astigmatism measured by the dual Scheimpflug–Placido tomographer was 0.33 ± 0.16 D (vector mean 0.23 × 176) (Figure 2, *A*). The magnitude was 0.25 D or less in 12 eyes (34%) and greater than 0.50 D in 3 eyes (8.6%). Twenty eyes (57%) had a WTR anterior astigmatic shape, and 26 eyes (74%) had a WTR posterior astigmatic shape.

The mean magnitude of the postoperative manifest refractive astigmatism was 0.38 ± 0.18 D (vector mean 0.26 × 171) (Figure 2, *B*). Eighteen eyes (39%) had no postoperative manifest astigmatism. In the automated keratometer group, 18 eyes (51%) were corrected, 8 eyes (23%) were overcorrected, and 9 eyes (26%) were undercorrected. In the TCP group, 13 eyes (37%) were corrected, 12 eyes (34%) were overcorrected, and 10 eyes (29%) were undercorrected.

Table 1 also shows the prediction errors calculated from the automated keratometer and dual Scheimpflug–Placido tomographer measurements. There was no statistically significant difference in the postoperative prediction error mean magnitude (P = .068) or the vector mean (P = .19) between the 2 study groups. Overall, the automated keratometer group had a lower mean magnitude prediction error and a larger vector mean prediction error than the TCP group.

Table 2 shows the actual (automated keratometer) and simulated (TCP) toric IOL powers stratified by WTR and ATR astigmatism. Postoperatively, more eyes were corrected to less than 0.45 D of refractive astigmatism using the automated keratometer method than using the simulated TCP values, regardless of whether the preoperative astigmatism was WTR or ATR. However, there was a statistically significant bias toward overcorrection of WTR astigmatism and undercorrection of ATR astigmatism using the automated keratometer method. This bias was not seen in the simulated results using the TCP method (Figures 3 and 4).

DISCUSSION

Posterior astigmatism can be measured by several techniques, including Purkinje imaging, scanning-slit topography, and Scheimpflug topography.[4–8] The mean posterior astigmatism of 0.33 ± 0.16 D in our study is similar to the values reported by Ho et al.[7] (−0.33 D) and Koch et al.[8] (−0.30 ± 0.15 D). In previous studies, posterior corneal astigmatism resulted in average reductions in anterior astigmatism from

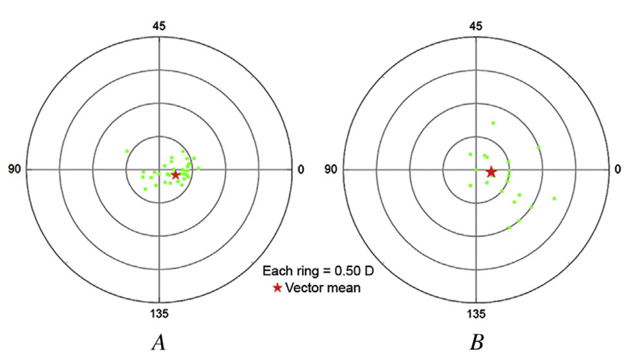

Figure 2. *A*: Preoperative posterior astigmatism measured by the dual Scheimpflug–Placido tomographer. *B*: Postoperative manifest astigmatism. Note the almost identical vector means for preoperative posterior astigmatism and postoperative manifest astigmatism.

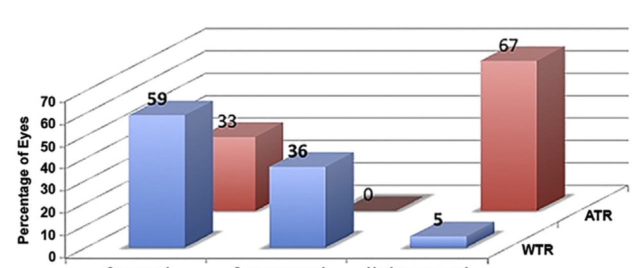

Figure 3. Actual astigmatic outcomes using automated keratometry to determine toric IOL cylinder power (ATR = against-the-rule; WTR = with-the-rule).

Table 2. Actual and simulated toric IOL powers stratified by preoperative WTR and ATR astigmatism.

Method/Result	WTR (%)	ATR (%)	*P* Value*
Actual toric IOL power (automated keratometry)			.0001
Corrected	59	33	
Overcorrected	36	0	
Undercorrected	5	67	
Simulated toric IOL power (TCP)			.43
Corrected	40	33	
Overcorrected	40	25	
Undercorrected	20	42	

ATR = against the rule; IOL = intraocular lens; TCP = total corneal power; WTR = with the rule
*Fisher exact test

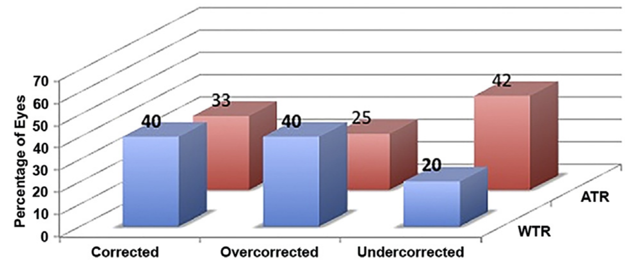

Figure 4. Simulated astigmatic outcomes using dual rotating Scheimpflug tomographer–derived TCP to determine toric IOL cylinder power (ATR = against-the-rule; WTR = with-the-rule).

12.9% to 31%.[4–7] Most eyes (26 [74%]) in our study had WTR posterior astigmatic shape, which subtracts from overall WTR anterior astigmatic power and adds to overall ATR astigmatic power.

Dual rotating Scheimpflug tomography can measure the anterior and the posterior corneal surface elevations. This enables calculation of the TCP using ray tracing through the anterior and posterior corneal surfaces, taking into account the effect of corneal thickness on the corneal power.

Current toric IOL calculations are based on keratometric astigmatism values derived from anterior astigmatism measurements only.[7,13] Cheng et al.[14] found that the SIA of the posterior cornea contributes significantly to the total corneal SIA; twenty-four percent of eyes in that study had a difference of 0.50 D between the keratometric corneal SIA and total corneal SIA. The outcomes of toric IOL implantation depend on accurate estimation of corneal astigmatism, which includes the contribution from the posterior corneal surface.

The rate of prediction error is an important parameter of success of cataract surgery with toric IOL implantation and can be significantly decreased by improving the accuracy of the IOL cylinder power calculation. In our study, the prediction error of the postoperative mean astigmatic magnitude was 0.44 $\pm$ 0.36 D for the automated keratometer group and 0.63 $\pm$ 0.38 D for the TCP group; the difference between the 2 groups was not statistically significant. The prediction error of the vector mean postoperative astigmatism was slightly smaller in the TCP group than in the automated keratometer group, although the difference was not statistically significant (P=.19). Most important, there was a statistically significant bias toward overcorrection of WTR astigmatism and undercorrection of ATR astigmatism in the actual outcomes using the automated keratometer for toric IOL cylinder power calculation (P=.0001, Fisher exact test). This bias was not seen in the simulated outcomes using the TCP method (P=.43, Fisher exact test). This result is similar to a result in the study by Koch et al.[15] The automated keratometer calculations have this bias because they do not account for posterior astigmatism. Most eyes (26 [74%]) had a WTR posterior astigmatic shape that was not accounted for in the automated keratometer calculations. The vector mean of the preoperative posterior corneal astigmatism measured by the automated keratometer method (0.23 $\times$ 176) is almost identical to the vector mean of the postoperative residual manifest astigmatism (0.26 $\times$ 171). This suggests that the occult posterior astigmatism remains untreated when the automated keratometer method is used. That the vector mean of the prediction error for the TCP method was smaller than that of the automated keratometer method suggests that the dual Scheimpflug–Placido tomographer accounts for the posterior astigmatism more successfully.

Limitations of this study include the retrospective design, the use of a first-generation toric IOL calculator, and a relatively small sample. The first-generation toric IOL calculator used does not account for the effects of anterior chamber depth and axial length on the astigmatic power of the toric IOL. Newer calculators such as the Tecnis Toric IOL calculator[B] and the Alpins Assort calculator[C] factor in these additional parameters to improve the accuracy of the toric IOL power calculation. Future calculators could benefit from including the contribution of the posterior cornea to the total corneal astigmatism.

Because current IOL calculation techniques use only automated keratometry or manual keratometry values, neither of which accounts for posterior corneal astigmatism, the surgeon should consider imaging the posterior surface of the cornea in eyes scheduled for toric IOL implantation. The surgeon should then consider selecting the next lower toric IOL astigmatic power (eg, 0.5 D lower astigmatic power) for preoperative corneal shapes in which the back-surface astigmatic shape matches that of the front surface and is of significant magnitude. Conversely, the surgeon should consider selecting the next higher toric IOL astigmatic power for preoperative corneal shapes in which the back-surface astigmatic shape is the opposite of the front surface and is of significant magnitude. Future studies should focus on the development of new IOL power calculation formulas that are based on TCP, with the goal of improving the spherical and astigmatic refractive outcomes for cataract patients.

WHAT WAS KNOWN

- Anterior corneal power measurements obtained using the automated keratometer do not account for the effects of posterior corneal astigmatism. Dual Scheimpflug–Placido tomography can reproducibly and accurately measure anterior power, posterior power, and TCP.

WHAT THIS PAPER ADDS

- In the prediction of error of corneal astigmatism measurements after toric IOL implantation, the automated keratometer method was biased toward overcorrection of WTR astigmatism and undercorrection of ATR astigmatism because it does not take into account the posterior corneal astigmatism, which had a WTR shape and contributed ATR astigmatic power in the majority of eyes.
- The dual Scheimpflug–Placido tomographer method showed no biases because it accounts for posterior astigmatism.

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