Assessing the Likely Effect of Posterior Corneal Curvature on Toric IOL Calculation for IOLs of 2.50 D or Greater Cylinder Power

Benjamin R. LaHood, MBChB, PGDipOphth, FRANZCO; Michael Goggin, FRCSI(Ophth), FRANZCO, MS; Adrian Esterman, PhD, AStat

ABSTRACT

PURPOSE: To establish whether average refractive overcorrection or undercorrection of corneal astigmatism based on the orientation (rule) of the astigmatism occurs if toric intraocular lenses (IOLs) are calculated on the basis of anterior corneal measurements in eyes requiring toric IOL cylinder power of 2.50 diopters (D) or greater.

METHODS: One hundred thirteen consecutive eyes with anterior corneal keratometric astigmatism requiring IOL cylinder power of 2.50 D or greater underwent phacoemulsification with IOL powers calculated using anterior corneal curvature data alone. Eyes were grouped as either “with-the-rule” (WTR) or “against-the-rule” (ATR) on the basis of the steep anterior corneal meridian. Targeted and achieved astigmatic outcomes were compared. The main outcome measure was the postoperative refractive astigmatic prediction error.

RESULTS: A mean overcorrection occurred in anterior WTR eyes of 0.16 ± 0.57 D and a mean undercorrection of ATR eyes of -0.14 ± 0.53 D. These were significantly different from the ideal value of zero (WTR: P = .04, ATR: P = .05). Although statistically significant, the effect sizes of these prediction errors were 0.40 for WTR and 0.36 for ATR and the error values fell below a clinically significant value of 0.25 D.

CONCLUSIONS: In eyes requiring toric IOLs of cylinder power 2.50 D or greater, an overcorrection occurs in anterior WTR eyes and an undercorrection in ATR eyes. This probable posterior corneal astigmatism effect is not clinically significant. IOL cylinder powers are sufficiently accurately calculated using unadjusted anterior keratometry values in these eyes.

al astigmatism with toric IOL choices based purely on anterior corneal curvature has been reported. Statistically significant overcorrection and undercorrection was seen in subgroup analysis of eyes requiring IOL cylinder power of 2.00 diopters (D) or less. Subsequent application of a coefficient of adjustment to anteriorly measured keratometric cylinder values based on the “rule” of the eye led to improved astigmatic outcomes. Eyes requiring IOL cylinder of 2.50 D or greater trended toward similar overcorrection and undercorrection, but this trend did not reach statistical significance.

The purpose of this study was to establish whether there was an average overcorrection or undercorrection of corneal astigmatism based on the “rule” of anterior corneal astigmatism in patients with toric IOLs of cylindrical power of 2.50 D or greater calculated on the basis of anterior corneal measurements alone, and, if appropriate, to calculate a coefficient of adjustment to avoid systematic error for toric IOLs in this cylinder power range subsequently implanted.

**PATIENTS AND METHODS**

Approval for this study was obtained from the Central Adelaide Local Health Network Human Research Ethics Committee.

Retrospective data were collected for 113 consecutive eyes of 101 patients with anterior corneal surface astigmatism requiring implantation of a toric IOL with cylinder power of 2.50 D or greater. They all underwent cataract surgery between November 2009 and November 2016, receiving AT TORBI 709M or 709MP toric IOLs (Carl Zeiss Meditec, Jena, Germany). Eyes with oblique keratometric astigmatism were excluded because the number of patients was too small for analysis. Demographic data for patients with with-the-rule (WTR) and against-the-rule (ATR) astigmatism were similar (Table 1), except the average age of patients with ATR astigmatism was 16 years older than those with WTR astigmatism. This is consistent with population data showing a shift from WTR to ATR anterior keratometry with age.

Preoperative IOL calculations were performed using the IOLMaster 500 (Carl Zeiss Meditec) prior to November 2016 and the IOLMaster 700 from December 2016 onward for keratometry and biometry. IOL powers (sphere and cylinder) were calculated using the Carl Zeiss Meditec online calculator (https://zcalc.meditec.zeiss.com/zcalc/), which provides predicted postoperative refraction values. This calculator incorporates anterior chamber depth and axial length to minimize prediction error but does not make any adjustment for posterior corneal curvature.

All eyes underwent micro-incision phacoemulsification using a 1.9-mm temporal clear corneal incision on the horizontal meridian performed by four surgeons using identical techniques. This incision technique is astigmatically neutral, allowing the use of preoperatively measured keratometric values in the IOL calculations and obviating the necessity to predict postoperative keratometric astigmatism using previously established surgically induced corneal astigmatism. For all eyes studied, the surgically induced astigmatism summed vector mean (or centroid) of the corneal incisions was 0.16 D. The mean surgically induced corneal astigmatism axis was 96° ± 44° (range: 7° to 179°).

To exclude further the possibility of corneal shape change due to our cataract incision, we compared astigmatic prediction error on the same eyes using preoperative keratometric astigmatism versus postoperative keratometric astigmatism as the targeted error for correction with the toric implant. Using preoperative astigmatism as the error to be corrected, the mean signed astigmatism prediction error was -0.003 D (95% confidence interval: -0.11 to 0.10 D). Using the postoperative astigmatism as the error to be corrected (avoiding the effect of any inadvertent corneal astigmatic change), the mean signed astigmatism prediction error was -0.037 D (95% confidence interval: -0.15 to 0.08 D). The 95% confidence interval of the difference between these means (-0.013 to 0.082 D) falls within a range of ±0.25 D and can consequently be considered not only not significantly different but statistically equivalent. This equivalence of values strongly supports our assertion that overall corneal astigmatism was unchanged by the incision (ie, that our technique is astigmatically neutral). As a consequence, keratometric surgically induced corneal astigmatism was not included in our calculation of prediction error.

The inferior end of the vertical corneal meridian was marked preoperatively using a previously described technique. The incision and IOL toric meridians were planned from this mark using a Mendez ring. Postoperative review was performed at 6 weeks by one of four surgeons and included subjective refraction, keratometry, and anterior chamber depth on the

<table>
<thead>
<tr>
<th>TABLE 1</th>
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<tbody>
<tr>
<td><strong>Demographic Data</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
<tr>
<td>Patients</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Mean age (y)</td>
</tr>
<tr>
<td>Left eye</td>
</tr>
<tr>
<td>Right eye</td>
</tr>
<tr>
<td><strong>WTR</strong> = with-the-rule astigmatism; ATR = against-the-rule astigmatism</td>
</tr>
</tbody>
</table>
IOLMaster (Carl Zeiss Meditec) and observation of the toric axis of the IOL. Eyes were grouped according to the “rule” of anterior corneal astigmatism (WTR: anterior keratometric astigmatism with steep meridian between 60° and 120°; ATR: anterior keratometric astigmatism with steep meridian between either 0° and 30° or 150° and 180°). Eyes with steep meridians outside of these classifications were considered “oblique” and excluded. The small number of oblique eyes would not allow adequate analysis. Vector analysis was used to compare preoperative anterior keratometric astigmatism with postoperative targeted refractive astigmatism provided by the online toric IOL calculator and the achieved postoperative refractive astigmatism, the latter two values being corrected to the corneal plane. Target induced astigmatism and surgically induced astigmatism vector values for IOL insertion were thus derived for each eye. The arithmetic difference of vector powers (magnitude of error), subtracting the target induced astigmatism power from the surgically induced astigmatism power, established whether overcorrection (positive value) or undercorrection (negative value) had occurred for each eye.

The ratio of surgically induced astigmatism power to target induced astigmatism power expresses the proportion of astigmatism corrected. The inverse of this ratio can be used as a coefficient of adjustment for subsequent calculations. A coefficient of adjustment was derived for each eye and geometric means of these coefficients were calculated. WTR eyes were compared with ATR eyes. To establish whether the magnitude of error for WTR and ATR eyes represented real prediction error, one-sample t tests were used to examine whether the values differed significantly from zero. Two-sample t tests with equal variances were used to compare means between the groups. A probability of less than 5% or a P value of less than .05 was considered statistically significant. Analysis of statistical equivalence conforms to the extension of the Consort 2010 statement.

RESULTS

One hundred thirteen eyes with anterior keratometric astigmatism indicating the use of a toric IOL with cylinder power of 2.50 D or greater were analyzed (Table A, available in the online version of this article). Postoperative refractive astigmatism and targeted refractive astigmatism were both corrected to the corneal plane for analysis (Table B, available in the online version of this article).

Table 2 shows the comparison of the magnitude of error between WTR and ATR eyes to assess whether there is a difference in refractive outcome between these two groups. As expected, there was a significant difference between the two groups and the effect size was medium. Table 3 shows the magnitude of error in WTR and ATR eyes analyzed using a one-sample t test to examine whether the values differed significantly from zero (i.e., if there were significant errors in outcome prediction). Both comparisons reach statistical significance but have small to medium effect sizes.

Estimations of astigmatism correction index and coefficient of adjustment for WTR and ATR eyes are presented in Table 4 as geometric means. Figure 1 illustrates the low trend to overcorrection in WTR eyes and undercorrection in ATR eyes suggested by the mean values we report. Limited data in eyes with high anterior corneal astigmatism make comment on trends in such eyes problematic.

DISCUSSION

Clinically and statistically significant refractive overcorrection and undercorrection of corneal astigmatism

### Table 2: Magnitude of Error: Two Sample t Tests With Equal Variances

<table>
<thead>
<tr>
<th>Rule</th>
<th>N</th>
<th>Mean ± SD (Range)</th>
<th>P</th>
<th>Effect Size</th>
<th>95% CI Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATR</td>
<td>60</td>
<td>-0.14 ± 0.53 D (-1.72 to 0.96 D)</td>
<td>.005</td>
<td>0.54</td>
<td>0.16 to 0.92</td>
</tr>
<tr>
<td>WTR</td>
<td>53</td>
<td>0.16 ± 0.57 D (-2.94 to 1.26 D)</td>
<td>.01</td>
<td>0.40</td>
<td>0.16 to 0.92</td>
</tr>
</tbody>
</table>

**Rule** = designated using anterior keratometric astigmatism; SD = standard deviation; CI = confidence interval; ATR = against-the-rule; D = diopters; WTR = with-the-rule

### Table 3: Magnitude of Error: One-Sample t Test Comparing Means to Zero

<table>
<thead>
<tr>
<th>Rule</th>
<th>N</th>
<th>Mean ± SD (D)</th>
<th>95% CI Mean</th>
<th>P</th>
<th>Effect Size</th>
<th>95% CI Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATR</td>
<td>60</td>
<td>-0.14 ± 0.53</td>
<td>-0.27 to 0.00</td>
<td>.05</td>
<td>0.36</td>
<td>0.00 to 0.72</td>
</tr>
<tr>
<td>WTR</td>
<td>53</td>
<td>0.16 ± 0.57</td>
<td>0.01 to 0.32</td>
<td>.04</td>
<td>0.40</td>
<td>0.01 to 0.78</td>
</tr>
</tbody>
</table>

**Rule** = designated using anterior keratometric astigmatism; SD = standard deviation; D = diopters; CI = confidence interval; ATR = against-the-rule; WTR = with-the-rule
based on the orientation or rule of the astigmatism has previously been shown to occur if toric IOLs are calculated on the basis of anterior corneal measurements alone in eyes requiring an IOL cylinder power of 2.00 D or less.  

Subsequent adjustment of the toric IOL cylinder power by the application of a coefficient of adjustment (0.75 for WTR and 1.41 for ATR anterior keratometric astigmatism) to anteriorly measured keratometric cylinder values led to a significant improvement in refractive astigmatic outcome in eyes requiring a toric IOL cylinder power of 2.00 D or less. Whereas eyes requiring an IOL cylinder power of 2.50 D or greater trended toward similar overcorrection and undercorrection, previous analysis in this IOL power range did not reach statistical significance.

By comparison, the current study analyzed a larger number of eyes requiring an IOL cylinder power of 2.50 D or greater. The data presented show that average refractive astigmatism overcorrection and undercorrection also occurs, although on a smaller scale, in eyes requiring an IOL cylinder power of 2.50 D or greater when the IOL cylinder power is calculated on the basis of anterior corneal astigmatism alone.

This overcorrection and undercorrection of astigmatism by IOLs related to “rule” is likely to be due to the finding that the steep meridian of the posterior cornea is vertically oriented in most eyes. Because the steepest meridian of the posterior cornea is not vertically oriented in all eyes, the universal use of a coefficient of adjustment may not lead to an optimal outcome. A more appropriate solution would be to measure the posterior cornea reliably in every eye with the assistance of a corneal tomographer. We have shown that one of these devices (Pentacam; Oculus Optikgeräte, Wetzlar, Germany) at least has demonstrable test-to-test variability that may make it unreliable for this purpose, meaning an adjustment of the keratometry on the basis of observed refractive results in a population of eyes is currently legitimate and likely to improve toric IOL refractive outcome in most eyes.  

In eyes requiring an IOL cylinder power of 2.50 D or greater, we report a mean ± standard deviation prediction error analyzed by “rule” of -0.14 ± 0.53 (an under-correction) for ATR eyes and +0.16 ± 0.57 (an over-correction) for WTR eyes. These values are small in clinical terms and any adjustment based on these values to attempt to decrease the overcorrection and undercorrection would be small (coefficients of adjustment of 1.06 for ATR and 0.93 for WTR). Given the small magnitude of adjustment to anterior corneal data indicated by these coefficients of adjustment for this level of astigmatism (IOLs of 2.50 D cylinder power or greater), as well as the small effect size, our recommendation is that, despite being statistically significant, the clinical significance is too small to warrant use in practice. Current standard available steps in toric IOL cylinder power mean that the effect of application of such small adjustments would more likely manifest as small adjustments in the astigmatic refractive target rather than a change in recommended IOL cylinder power for a given eye.

Also, this study confirms that eyes requiring a toric IOL cylinder power of 2.50 D or greater require different coefficients of adjustment. It would seem anatomically unlikely that there is a precise cut-off value above which posterior corneal astigmatism ceases to affect total corneal astigmatism. It would be more plausible that, in common with most biological variables, there would be a gradation of effect that might be demonstrable with more data. The published Baylor nomogram suggests slightly less than 1.00 D of reduction in the implanted IOL cylinder powers versus the power calculated using anterior corneal power data alone in the cylinder power range of 1.00 to 4.00 D for WTR eyes and an augmentation of slightly more than 0.45 D for ATR eyes of the same range. In principle, this will lead to greater proportional adjustment of lower powered cylinders. However, it adjusts IOL cylinder power for eyes in which we would suggest the IOL cylinder power based on unadjusted keratometric data is currently adequate to achieve close to full astigmatism correction (with IOL cylinder powers of 2.50 D or greater).

Vector analysis allowed calculation of the effect of the toric IOL cylinder power (regardless of orientation) at the corneal plane accurately in each eye using...
the known postoperative anterior chamber depth. The larger remaining prediction errors could conceivably be accounted for by the posterior cornea or the inherent failure of prediction with any IOL power calculation up to values of 1.50 or 1.75 D.

Ongoing refinement in precision and repeatability of measurement of the posterior cornea will undoubtedly eventually mean that anatomical analysis will replace mathematical adjustments. Early studies of new methods for measuring total corneal power, taking into account the posterior corneal surface, are showing promise but are not yet ideal.²⁰ To optimize outcome prediction in cataract surgery requiring toric IOLs, we recommend that eyes be divided into two groups: those requiring a toric IOL with cylinder power of 2.00 D or less (lower power toricity) and those eyes requiring an IOL cylinder power of 2.50 D or greater (higher power toricity). For lower power toric IOLs, a coefficient of adjustment can be applied to the anterior keratometry values via an online calculator (www.goggintoric.com) and the new, adjusted keratometry values can be used in any IOL calculator that does not already make an allowance for the posterior cornea. For higher power toric IOLs, we recommend not adjusting anterior keratometry values in the knowledge that the anticipated adjustment for these eyes would not be clinically significant.

Our study indicates that the effect of posterior corneal astigmatism on total corneal astigmatism is proportionally lower as anterior corneal astigmatism increases. It is not possible from our analysis to deduce whether posterior corneal astigmatism stays at a consistent low value or whether it increases in magnitude as anterior corneal astigmatism increases but to a lesser extent. It would seem implausible that there exists a defined astigmatic cut-off value below which posterior corneal astigmatism is significant and above which it is not. It is far more likely that there is a gradual decrease in relevance from low to high anterior corneal astigmatism. Further studies with a greater number of eyes requiring higher power toric IOLs will allow for a more precise breakdown of what coefficient of adjustment would be most suitable for each step of IOL cylinder power.

**AUTHOR CONTRIBUTIONS**

**Study concept and design (BRL, MG, AE); data collection (BRL, MG); analysis and interpretation of data (BRL, MG, AE); writing the manuscript (BRL); critical revision of the manuscript (BRL, MG, AE); statistical expertise (MG, AE); administrative, technical, or material support (MG, AE); supervision (MG)**

**REFERENCES**


## TABLE A

**Preoperative Keratometric Astigmatism and Implanted IOL Powers**

<table>
<thead>
<tr>
<th>Rule</th>
<th>N</th>
<th>Preoperative Keratometric Astigmatism (Mean ± SD [Range])</th>
<th>Implanted IOL Sphere Power (Mean ± SD [Range])</th>
<th>Implanted IOL Cylinder Power (Mean ± SD [Range])</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTR</td>
<td>53</td>
<td>3.18 ± 1.33 D (1.70 to 9.00 D)</td>
<td>19.60 ± 8.32 D (-6.00 to 34.00 D)</td>
<td>4.00 ± 1.71 D (2.50 to 10.50 D)</td>
</tr>
<tr>
<td>ATR</td>
<td>60</td>
<td>2.95 ± 1.32 D (1.91 to 7.41 D)</td>
<td>19.18 ± 4.41 D (5.50 to 29.50 D)</td>
<td>3.64 ± 1.76 D (2.50 to 9.50 D)</td>
</tr>
<tr>
<td>Both</td>
<td>113</td>
<td>3.06 ± 1.32 D (1.70 to 9.00 D)</td>
<td>19.38 ± 6.51 D (-6.00 to 34.00 D)</td>
<td>3.81 ± 1.71 D (2.50 to 10.50 D)</td>
</tr>
</tbody>
</table>

*rule = measured anterior keratometric astigmatism; SD = standard deviation; IOL = intraocular lens; WTR = with-the-rule; D = diopters; ATR = against-the-rule; both = includes WTR and ATR but excludes oblique

## TABLE B

**Postoperative and Targeted Refractive Astigmatism**

<table>
<thead>
<tr>
<th>Rule</th>
<th>N</th>
<th>Postoperative Refractive Astigmatism (Mean ± SD [Range])</th>
<th>Targeted Refractive Astigmatism (Mean ± SD [Range])</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTR</td>
<td>53</td>
<td>+0.65 ± 0.63 D (0.00 to 3.59 D)</td>
<td>+0.15 ± 0.10 D (0.01 to 0.34 D)</td>
</tr>
<tr>
<td>ATR</td>
<td>60</td>
<td>+0.90 ± 0.64 D (0.00 to 3.59 D)</td>
<td>+0.17 ± 0.12 D (0.01 to 0.55 D)</td>
</tr>
<tr>
<td>Both</td>
<td>113</td>
<td>+0.78 ± 0.64 D (0.00 to 3.59 D)</td>
<td>+0.16 ± 0.11 D (0.01 to 0.55 D)</td>
</tr>
</tbody>
</table>

*rule = designated using anterior keratometric astigmatism; SD = standard deviation; WTR = with-the-rule; D = diopters; ATR = against-the-rule; both = includes WTR and ATR but excludes oblique

*Data include an eye with previous penetrating keratoplasty.