Outcome of Toric Intraocular Lens Implantation After Adjusting for Anterior Chamber Depth and Intraocular Lens Sphere Equivalent Power Effects

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Objective: To describe the refractive outcome of toric intraocular lens (IOL) implantation by taking into account the effect on astigmatic outcome of the anterior chamber depth and the sphere power of the IOL, and to examine whether the predictability of the toric effect can be improved.

Method: In a university department in a publicly funded hospital, 38 eyes of 29 patients underwent routine cataract surgery with insertion of a toric implant (SN60TT AcrySof Toric). The corneal plane effective cylinder power of the IOL was calculated, including the effect on this value on the anterior chamber depth and pachymetry and of the sphere power of the IOL.

Results: The mean (SD) corneal plane equivalent cylinder power of the IOL predicted preoperatively by the manufacturer as 1.58 (0.47) diopters (D) vs 2.02 (0.64) D by us (calculated using predicted postoperative anterior chamber depth and IOL sphere values). The mean (SD) measured postoperative value was 1.78 (0.89) D, which was better predicted by us.

Conclusions: The manufacturer currently appears to underestimate the corneal plane effective cylinder power of its toric IOLs. Improved outcome could be achieved by estimating the effective corneal plane cylinder power of the IOL, as altered by the anterior chamber depth and pachymetry and by the IOL sphere power, but this is currently not addressed by the manufacturer.

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With toric intraocular lenses (IOLs), the source of the refractive error (the anterior corneal surface) and its correcting lens are separated by the thickness of the cornea and the depth of the anterior chamber as it is after the IOL is inserted. The anteroposterior position of the IOL influences not only the IOL sphere power needed to correct the sphere equivalent requirement of any particular eye but also the cylinder power to correct the refractive effect of its corneal astigmatism. Furthermore, variation of the sphere power of a toric IOL for any constant cylinder power in the IOL plane will alter the effective cylinder power of that lens at the corneal plane. Currently, Alcon (Hünenberg, Switzerland), the manufacturer of a range of toric IOLs, advertises a corneal plane equivalent cylinder power, via its online Alcon AcrySof Toric Calculator (http://www.acrysoftoriccalculator.com), IOL package labeling, and other promotional material, that is not individualized for IOL sphere power and is based on 1 standard IOL plane to corneal plane equivalent cylinder power conversion factor of approximately 0.69 for all IOL sphere and cylinder power combinations and all anterior chamber depths (ACDs) (Table 1).

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Taken from the online Alcon AcrySof Toric Calculator on September 11, 2010 (http://www.acrysoftoriccalculator.com/calculator.aspx ), our Figure demonstrates that both a 17.0-diopter (D) sphere equivalent SN60T3 IOL and a 28.0-D sphere equivalent SN60T3 IOL are designated as having a 1.03-D cylinder at the corneal plane. Both the Web site and the SN60T3 product package label state that this IOL has a 1.50-D cylinder at the IOL plane. If the IOL plane cylinder is constant over the whole range of sphere equivalent powers, the anterior corneal plane equivalent power cannot be a con-
stant 1.03-D cylinder even if the ACD plus pachymetric (ACD+P) value is kept constant. Similarly, a SN60T9 IOL (labeled as having a 6.00-D cylinder at the IOL plane for all sphere powers) is designated as a constant 4.11-D cylinder corneal plane power for both 17.0-D and 28.0-D spherical equivalents. Furthermore, no feature exists in the calculator for alterations of ACD or pachymetric value. This estimated and averaged power is given “based on an average pseudophakic human eye” (http://www.acrysoftoriccalculator.com/Tutorial.aspx) as just described. Using the manufacturer’s effective lens position of 5.2 mm, we found that a 17.0-D SN60T3 would actually have an equivalent corneal plane power of 1.32 D and that a 28.0-D SN60T3 would have an equivalent corneal plane power of 1.22 D (not 1.03 D). A 17.0-D SN60T9 would have a corneal plane equivalent cylinder power of 5.28 D, and a 28.0-D SN60T9 would have a corneal plane equivalent cylinder power of 4.88 D (not 4.11 D). The potential for unplanned outcome is obvious; for example, for a 17-D SN60T9, an underestimate of IOL cylinder power of over 1 D can be made.

Our study, in contrast to the “standard eye and IOL combination” employed by the manufacturer, addresses the predictability of the postoperative ACD after implantation of the SN60TT AcrySof Toric IOL (Alcon) and compares the manufacturer’s prediction of corneal plane equivalent cylinder power with our prediction and with the postoperatively measured value of this parameter. These comparisons address the influence of ACD and IOL sphere power in combination. Other than the meridian of IOL placement, to our knowledge, we believe that ours is the first study to examine the effectiveness of these predictions, which are essential for toric IOL use.

### METHOD

A total of 38 eyes of 29 patients (18 women and 11 men with a mean [SD] age of 70 [14] years) underwent routine cataract surgery with insertion of a toric implant (SN60TT AcrySof Toric; Alcon). The hospital’s ethics committee decided that approval was not required for this observational case series, and the research adhered to the tenets of the Declaration of Helsinki. The method of selection of suitable eyes is described elsewhere.1 The mean (SD) predicted postoperative keratometric astigmatism was 2.26 (1.03) D. The sphere equivalent power was chosen in the conventional manner described elsewhere.1 The cylinder power was chosen using the online Alcon AcrySof Toric Calculator (http://www.acrysoftoriccalculator.com/).

At 6 weeks after surgery, data on the sites of the incisions were recorded, the manifest refraction of the patient established, the pupil dilated, and the IOL position noted using slit orientation referenced to the degree scale on the slitlamp. At this visit, the postoperative keratometric, ACD, and pachymetric measurements were made using the same devices that were used before surgery.

Although the manufacturer’s recommended IOL cylinder power was used during surgery, separate calculations were made using both predicted and measured postoperative ACD+P and sphere equivalent IOL power to derive effective corneal plane cylinder power, using the following estimation, and the calculated values were compared with the Web site values in each case. The IOL plane power of the flattest IOL meridian was calculated by subtracting half the cylinder power as printed on the IOL packaging from the sphere equivalent power, also as it appears on the packaging. The steepest IOL meridian power was calculated by adding these 2 values. These 2 powers (flattest and steepest) were converted to equivalent corneal plane values using a standard empirical thick lens “vertex power” formula: $E = F/(1 + (d/1.336)F)$, where $E$ is the equivalent corneal plane power, $F$ is the IOL plane power, and $d$ is the combined ACD and pachymetric measurement in meters; 1.336 is a standard refractive index for aqueous and corneal tissue.2 The 2 corneal plane meridian powers were then subtracted one from the other to yield a corneal plane equivalent cylinder power.

Analysis of outcome included an analysis of the refractive astigmatism outcome vs the predicted postoperative keratometric astigmatism. The accuracy and stability of the postoperative IOL meridian of placement vs the planned meridian of placement was examined elsewhere.1 Postoperative ACD+P predictions were assessed as a measured postoperative value. Predictions were made following the placement of the initial 9 toric IOLs and analysis of the mean increase in depth in those cases. The mean increase was found to be 0.36 mm, which was added to the preoperative ACD+P measurements to predict the ACD+P values in the subsequent 29 cases. A predicted equivalent corneal plane cylinder power was calculated for each eye and IOL combination (ie, the IOL actually used in each eye), as already outlined, and compared with the corneal plane value presented by the manufacturer for that eye. The calculated corneal plane equivalent cylinder power, calculated on the postoperative ACD+P measurement, was also compared with our prediction of this value. Furthermore, a comparison was made to determine which predicted corneal plane equivalent cylinder power of the lenses (ours or the manufacturer’s) more accurately matched the postoperatively observed estimate of this value derived from the patient’s 6-week refractive state.

### RESULTS

#### REFRACTIVE ASTIGMATISM

The visual acuity and sphere equivalent outcome at 6 weeks after surgery is described elsewhere.1 The mean (SD) targeted corneal plane refractive astigmatism after surgery, as calculated by the manufacturer’s online calculator (www.acrysoftoriccalculator.com), was 0.61 (0.72) D. Making our own calculations by taking into account the labeled sphere equivalent and cylinder IOL power and the predicted postoperative ACD+P value, we derived a

<table>
<thead>
<tr>
<th>Cylinder Power, D</th>
<th>Alcon Model</th>
<th>IOL Plane</th>
<th>Corneal Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>SN60T3</td>
<td>1.50</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>SN60T4</td>
<td>2.25</td>
<td>1.55</td>
<td></td>
</tr>
<tr>
<td>SN60T5</td>
<td>3.00</td>
<td>2.06</td>
<td></td>
</tr>
<tr>
<td>SN60T6</td>
<td>3.75</td>
<td>2.57</td>
<td></td>
</tr>
<tr>
<td>SN60T7</td>
<td>4.50</td>
<td>3.08</td>
<td></td>
</tr>
<tr>
<td>SN60T8</td>
<td>5.25</td>
<td>3.60</td>
<td></td>
</tr>
<tr>
<td>SN60T9</td>
<td>6.00</td>
<td>4.11</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: D, diopters; IOL, intraocular lens.

*Based on an “average pseudophakic human eye.”*
mean (SD) corneal plane target refractive astigmatism of 0.06 (0.61) D, and the mean (SD) predicted postoperative keratometric astigmatism (the error being treated) was 2.26 (1.03) D. The mean (SD) achieved postopera-

Figure. Examples of calculations produced by the online Alcon AcrySof Toric Calculator (http://www.acrysoftoriccalculator.com/calculator.aspx). D indicates diopeters; IOL, intraocular lens; OD, oculus dexter.
tive corneal plane refractive astigmatism power was 0.97 (0.72) D. Because the targeted induced astigmatism (TIA) vector is equivalent to the corneal plane equivalent cylinder power of the IOL and because the prediction of this value varies between the manufacturer and us, Table 2 presents the effect on vector analysis parameters of this difference.

### IOL MERIDIAN PLACEMENT

The IOL meridian placement is described in the study by Goggin et al.1 The mean (SD) absolute deviation from the intended axis was 1° (2.28°), and after assigning a negative sign to a clockwise deviation and a positive sign to counterclockwise deviation, Goggin et al1 found that the mean (SD) arithmetic deviation from the intended axis was −0.26° (2.48°).

### KERATOMETRIC OUTCOME

The mean (SD) postoperative keratometric astigmatism was 2.26 (1.23) D. This is compared with a preoperative mean (SD) keratometric astigmatism of 2.55 (1.16) D and a predicted mean (SD) postoperative keratometric astigmatism of 2.26 (1.03) D using a mean (SD) keratometric surgically induced astigmatism (SIA) of 0.62 (0.07) D. This is described in full in the study by Goggin et al.1

### ACD AND PACHYMETRY

The plane of the therapeutic target is the anterior corneal surface, which is separated from the IOL plane by the ACD and the thickness of the cornea. Ultrasonic and laser interferometric devices tend to label this combined measurement (ie, the ACD+P measurement) simply as ACD. In this series, the measurement used in calculations of effective lens power at the corneal plane vs the IOL plane is the combined ACD+P measurement.

Before surgery, the mean (SD) ACD+P measurement was 2.32 (0.38) mm. After surgery, the mean (SD) ACD+P measurement was 3.92 (0.86) mm, yielding a mean (SD) preoperative-to-postoperative deepening of 0.67 (0.83) mm. Preoperative ACD+P measurements were available for all eyes, and postoperative ACD+P measurements were available for 28 eyes. The initial 9 eyes of the study were used to establish a working model of deepening of the anterior chamber for predictions of an increase in ACD for the subsequent cases. This initial mean ACD+P deepening of 0.56 mm, derived from the initial 9 eyes, was used to predict the IOL cylinder corneal plane equivalent power and underestimated the cohort mean by 0.11 mm.

### PREDICTABILITY OF POSTOPERATIVE VALUES OF ACD+P AND CORNEAL PLANE EQUIVALENT CYLINDER POWER OF THE IOL

How well these parameters were predicted was examined using 1-sample t tests of the “residual value” (the difference between the preoperative predicted value and the postoperative measured value). The results are presented in Table 3. A significance of $P < .05$ suggests a less accurate prediction for such a parameter, since it implies that the mean of the residual value, which is the difference between that value predicted and value achieved (ideally 0), is significantly different from 0.

In Table 3, it can be seen that the preoperative mean (SD) corneal plane equivalent cylinder power of the IOLs was predicted to be 1.56 (0.47) D by the manufacturer and 2.02 (0.64) D by us (using predicted post-operative ACD+P values and IOL sphere values). A mean of 2.01 (0.63) D for this parameter was calculated after surgery using measured postoperative ACD+P and IOL sphere values. This would indicate a mean underestimate of the corneal plane power of the IOL of 0.45 D on the part of the manufacturer. There was a significant difference between the manufacturer’s and our preoperative predictions ($P < .001$).

### COMPLICATIONS

A sphere equivalent refractive surprise of between 0.5 and 1.0 D was present in 4 eyes. In only 1 of these eyes was the postoperative refractive cylinder error greater than that predicted by the manufacturer by more than 0.5 D. In this eye, a residual corneal plane refractive cylinder of 0.56 D yielded a magnitude of error (SIA-TIA) of 1.06 D, using the manufacturer’s TIA value. By comparison, the magnitude of error was 0.48 D using our calculated TIA, which implies that, had our value been used, a bet-

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**Table 2. Vector Analysis of Refractive Outcome vs Predicted Postoperative Keratometric Astigmatism**

<table>
<thead>
<tr>
<th>Value</th>
<th>Manufacturer’s Values$^a$</th>
<th>Our Values$^b$</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIA, mean (SD) D</td>
<td>1.58 (0.47)</td>
<td>2.04 (0.64)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Postoperatively measured</td>
<td>1.78 (0.89)</td>
<td>1.78 (0.89)</td>
<td>NA</td>
</tr>
<tr>
<td>SIA, mean (SD), D</td>
<td>0.21 (0.70)</td>
<td>−0.26 (0.71)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Magnitude of error, mean (SD), D</td>
<td>0.64 (0.35)</td>
<td>0.63 (0.41)</td>
<td>.99</td>
</tr>
<tr>
<td>Astigmatism correction index$^d$</td>
<td>1.01</td>
<td>0.78</td>
<td>NA</td>
</tr>
<tr>
<td>Angle of error, degrees</td>
<td>2.54 (11.87)</td>
<td>2.54 (11.87)</td>
<td>NA</td>
</tr>
<tr>
<td>DV, mean (SD), D</td>
<td>0.79 (0.39)</td>
<td>0.80 (0.48)</td>
<td>.82</td>
</tr>
<tr>
<td>Index of success$^e$</td>
<td>0.46</td>
<td>0.32</td>
<td>NA</td>
</tr>
<tr>
<td>DV summated vector mean</td>
<td>0.61 D</td>
<td>0.50 D</td>
<td>NA</td>
</tr>
<tr>
<td>at 91°</td>
<td></td>
<td>at 87°</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: D, diopters; DV, difference vector; NA, not applicable; SIA, surgically induced astigmatism vector; TIA, targeted induced astigmatism vector.

$^a$Based on the corneal plane cylinder power of the intracocular lens (IOL) provided by Alcon using its online AcrySof Toric Calculator (http://www.acrystortoriccalculator.com/calculator.aspx).

$^b$Based on IOL sphere power and predicted anterior chamber depth plus pachymetric (ACD+P) value.

$^c$Values of these means are identical regardless of whether calculated from data predicted by us or by Alcon because these values are not influenced by the ACD+P value or the IOL sphere power.

$^d$SIA/TIA ratio (geometric mean), ideally a value of 1. Geometric means are used for these vector power ratios and will differ from the ratio of arithmetic means.

$^e$DV/TIA ratio (geometric mean), ideally a value of 0. Geometric means are used for these vector power ratios and will differ from the ratio of arithmetic means.
ter prediction of outcome would have been possible. Persistent cystoid macular edema was present in 1 eye. These eyes were not excluded.

### Table 3. Relative Success of Predictions of Postoperative ACD + P and Corneal Plane Equivalent Cylinder Power Values

| Measure                                      | Preoperative Predicted Value | Postoperative Measured Value | Residual Value | P Value
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>ACD + P value, mm</td>
<td>3.81 (0.36)</td>
<td>3.92 (0.86)</td>
<td>-0.11 (0.84)</td>
<td>0.06</td>
</tr>
<tr>
<td>Our prediction of corneal plane cylinder power, D</td>
<td>2.02 (0.64)</td>
<td>1.78 (0.89)</td>
<td>0.17 (0.80)</td>
<td>0.28</td>
</tr>
<tr>
<td>Alcon’s prediction of corneal plane cylinder power, D</td>
<td>1.56 (0.47)</td>
<td>1.78 (0.89)</td>
<td>-0.28 (0.76)</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Abbreviations: ACD + P, anterior chamber depth plus pachymetric; CI, confidence interval; D, diopters.

The mean (SD) preoperative predicted keratometric astigmatism (putatively the major source of postoperative refractive astigmatism in the aphakic eye) of 2.26 (1.03) D was reduced to a mean (SD) postoperative corneal plane refractive astigmatism of 0.97 (0.72) D. Using the manufacturer’s method of calculation, we found that the mean (SD) targeted corneal plane refractive astigmatism after surgery was 0.61 (0.72) D. Using our empirical method, allowing for the ACD + P and IOL sphere-power effects, we found that the equivalent target value was a mean (SD) of 0.06 (0.61) D. These figures were based on the preoperative mean (SD) corneal plane equivalent cylinder power of the IOL predicted to be 1.58 (0.47) D by the manufacturer and 2.02 (0.64) D by us (calculated using predicted postoperative ACD + P values and IOL sphere values). A mean (SD) corneal plane equivalent cylinder power of 2.01 (0.63) was calculated after surgery using measured postoperative ACD + P and IOL sphere values. This implies a mean underestimate of the power of the IOL cylinder correction at the corneal plane on the part of the manufacturer of about 0.5 D, and one would expect a resultant net overcorrection of astigmatism.

Vector analysis of the refractive outcome vs the predicted postoperative keratometric astigmatism (Table 2) yielded a mean (SD) TIA of 1.58 (0.47) D derived by the IOL manufacturer and 2.02 (0.64) D derived by us. Of course, TIA values are the same as the corneal plane equivalent cylinder power values of the IOL already mentioned. The mean (SD) SIA was 1.78 (0.89) D. Calculation of this latter value, of course, is not influenced by varying estimates of the ACD + P and IOL sphere power because it is derived from the predicted keratometric values and the postoperative refraction. It is the observed refractive effect of the surgery. There is an apparent small loss of effect by comparison with our prediction (mean [SD] magnitude of the error, -0.26 [0.71] D). This loss of effect may be the result of errors in postoperative refraction, errors in the preoperative keratometry prediction of postoperative keratometry, and/or the presence of other sources of astigmatism in the aphakic eye. The apparent anomaly of a near “ideal” correction index (ie, SIA/TIA ratio) of 1.01 using the TIA predicted by the manufacturer vs the apparent undercorrection demonstrated by the correction index derived from our different TIA of 0.78 needs explanation. The manufacturer’s TIA value underestimates the effect of the IOL cylinder because of the failure to include the effect of IOL sphere power and the ACD + P measurement on the corneal plane equivalent cylinder power. Because the manufacturer ignores these simple optical principals, their value is not believable. The ratio of this underestimated TIA to the SIA will therefore appear favorable to the manufacturer given the small loss of effect already mentioned. With closely equivalent difference vectors (the vector difference between the SIA and the targeted remaining astigmatism), the index of success (ie, difference vector–to–TIA ratio) will be larger with the smaller TIA value of the manufacturer (0.46 for the manufacturer vs 0.32 for us [ideally 0]). Our method would appear to have done better by this measure, lending credence to the assertion that the manufacturer underestimates the corneal plane cylinder power of its IOLs.

The mean ACD + P measurement was 3.23 mm before surgery and 3.92 mm after surgery, yielding a mean preoperative-to-postoperative deepening of 0.67 mm vs a predicted deepening of 0.56 mm. One-sample t testing of the residual value on this prediction demonstrated P = .51, indicating reasonable accuracy. Further evidence of the accuracy of this prediction is to be found in the predicted corneal plane equivalent cylinder power of the IOLs based on the predicted ACD + P measurement and the postoperatively measured ACD + P value (2.02 [0.64] D vs 2.01 [0.63] D). Comparing our prediction and the manufacturer’s prediction of the postoperative corneal plane equivalent cylinder power, we found that our model is a better fit because the 95% confidence interval of the mean residual for the manufacturer is almost entirely negative, whereas our 95% confidence interval of the mean residual straddles 0. It is worth noting that some inconsistencies in usage of the terms axis and meridian appear in the Alcon AcrySof Toric Calculator Web site. In conclusion, no allowance has been made by Alcon in their product information for the alteration in corneal plane equivalent cylinder power of their toric IOLs as a result of varying sphere power of the IOLs. Consideration of the likely increase in ACD and the sphere power of the IOL increases the accuracy of the prediction of this value.
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REFERENCES


The wide variation in the ophthalmoscopic pictures in the reported cases, and the time at which vision was reduced, would seem to indicate that it depended upon the location of the hemorrhage in the optic nerve. The sudden blindness, followed immediately by optic atrophy, with retinal hemorrhages, would indicate a large hematoma in the optic nerve, between the papilla and the entrance of the ophthalmic artery and exit of the vein.

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