Accuracy of two devices and three different calculation methods for predicting residual astigmatism after intraocular lens implantation

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ABSTRACT

This study examined how different methods of biometric measurement, types of intraocular lens calculation, and levels of surgeon experience affected predicted postoperative astigmatism with toric intraocular lens implantation. The error in predicted residual astigmatism was determined using the IOL Master 500 and Lenstar LS 900 devices and was calculated by the Alcon toric calculator, Alcon toric calculator with Baylor nomogram, and Barrett toric calculator. Results were reviewed from 147 eyes of 125 patients. Of the three calculations, the Barrett toric calculator had the lowest mean absolute error in predicted residual astigmatism ($P < 0.0001$). The mean absolute errors of the IOL Master 500 and the Lenstar LS 900 were not significantly different when compared using three different calculation methods ($P = 0.54$). The mean absolute error was significantly lower ($P = 0.049$) for ophthalmology staff than for ophthalmology residents when calculation methods were considered. In conclusion, the calculation method used for IOL selection in cataract surgery significantly affects the accuracy of both staff and residents.

KEYWORDS astigmatism; toric intraocular lens

Optimizing refractive outcomes of toric intraocular lenses (IOL) is dependent on several variables: preoperative corneal measurement,^{1,2} IOL alignment,^{3,4} calculation methods⁵ (to determine IOL power and alignment), and surgically induced astigmatism (SIA)⁴ (incision placement and effect). While IOL alignment and SIA are both directly controlled by the surgeon in the operating room, many options for corneal measurement and toric calculators are available to the surgeon. Determining the most accurate method is necessary to improve toric outcomes.

METHODS

This study retrospectively reviewed the case records of consecutive patients who had cataract extraction with implantation of a toric Acrysof IOL through a 2.75-mm

clear corneal incision by multiple surgeons at Central Texas Veterans Health Care System from November 2013 to October 2015. Preoperative corneal marking was performed manually with the patient upright at 0° and 180°. A special device (such as a bubble marker or gravity marker) was not used to assist with preoperative corneal marking. Intraoperatively, a degree gauge was used to mark the recommended steep axis for toric IOL alignment. The study was approved by the institutional review board of Central Texas Veterans Health Care System in Temple, Texas, and informed consent was waived. All research was conducted with special attention to patient data confidentiality and in compliance with the Declaration of Helsinki and Veterans Affairs regulations.

To be included in the study, patients had to have (1) postoperative manifest refraction 4 to 6 weeks after surgery with a corrected distance visual acuity of 20/30 or better,

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and (2) preoperative measurements with two devices (partial coherence interferometry-based IOL Master; optical low-coherence reflectometry-based Lenstar LS 900). Exclusion criteria included (1) previous ocular trauma or surgery, (2) intraoperative or postoperative complications, (3) contact lens wear, and (4) corneal disease (such as irregular corneal astigmatism, corneal dystrophy/degeneration, and severe corneal surface disease).

The IOL Master (Carl Zeiss Meditec AG, Jena, Germany) uses automated keratometry to measure the anterior corneal curvature. Six spots of light are projected onto the cornea in a hexagonal pattern within a 2.3-mm diameter. The Lenstar (Haag-Streit AG, Köniz, Switzerland) measures the anterior corneal curvature using dual-zone automated keratometry. Thirty-two light spots, divided into two rings with a diameter of 1.65 mm and 2.30 mm, are projected onto the cornea. For both devices, a refractive index of 1.3375 was used to convert the anterior radius of curvature (mm) into a corneal power in diopters.

The Alcon online toric calculator⁶ was used alone and with the Baylor toric nomogram adjustment.⁷ The Barrett toric calculator was used without adjustment.⁸ The difference between the steep K values and flat K values from the IOL Master 500 and Lenstar were used to calculate our astigmatism values.

The Alcon toric calculator used in this study from 2015 has since been updated to incorporate the Barrett toric algorithm to account for the posterior cornea. The data presented in this study reflect a previous version of the Alcon toric calculator. The toric IOL cylinder power at the corneal plane for the Alcon toric calculator was obtained using the fixed ratio listed on the Alcon website.⁶ According to a technique described by Hill et al,⁹ the actual IOL implanted at the intended axis was mathematically “removed” from the postoperative manifest refraction (vertexed to the corneal plane), and the IOL recommended by the Alcon toric calculator was mathematically “implanted.” The recommended IOL adjusted postoperative refraction was then subtracted from the predicted residual astigmatism at the corneal plane to give the predicted error vector.

For the Alcon toric calculator with the Baylor nomogram, the above steps were performed, except the preoperative corneal astigmatism was adjusted according to published regression equations—subtracting [$0.1005 \times \text{measured corneal astigmatism} + 0.221$] or adding [$-0.011 \times \text{measured corneal astigmatism} + 0.225$] to the corneal astigmatism as measured by keratometry for with-the-rule and against-the-rule astigmatism, respectively—prior to calculation.⁷

The Barrett toric calculator used in this study from 2015 has also since been updated. The biometric measurements from the IOL Master 500 and Lenstar LS 900 were entered into the online calculator with the estimated SIA. The assumed toric IOL cylinder power at the corneal plane for the Barrett toric calculator was taken directly from the print-out.⁹ The actual IOL implanted at the intended axis was

mathematically “removed” from the postoperative refraction (vertexed to the corneal plane), and the IOL recommended by the Barrett toric calculator was mathematically “implanted.” The recommended IOL adjusted postoperative refraction was then subtracted from the predicted residual astigmatism at the corneal plane to give the predicted error vector.

We used the intended toric IOL alignment from the operative note, since postoperative toric IOL alignment was not directly measured. Subset analysis was performed by dividing the eyes into two groups based on surgeon experience (residents and staff). The mean absolute error and median absolute error in predicted residual astigmatism were calculated for each device and method.

All measurements were summarized using descriptive statistics. Means and standard deviations, as well as medians and ranges, were reported for continuous variables. The Wilcoxon signed rank test and the Kruskal-Wallis test were used to make comparisons between groups. Statistical significance is indicated by $P < 0.05$. Mixed effects models were used to compare the means of the device by calculation method magnitudes and take into account the repeated measurements by group and the correlation of observations within the patients. A variance components covariance structure was assumed and the residual diagnostics and the model selection confirmed this assumption.

RESULTS

The study evaluated 147 eyes of 125 patients (119 men and 6 women; age of 71.18 ± 9.10 years). The mean axial length was 24.26 ± 1.40 mm (range 21.18–29.18 mm), and the mean IOL power was 19.7 ± 4.16 D (range 7.5–28.0 D). The majority of the eyes (65%) had against-the-rule astigmatism; 29% had with-the-rule astigmatism, and 5% had oblique astigmatism. The mean corneal astigmatism using Lenstar LS 900 was 1.82 ± 0.85 D (range 0.63–7.58 D). The implanted toric IOLs were from Alcon Laboratories (Geneva, Switzerland), with the SN6AT3 model used most frequently (70 eyes, 47.6%). Other lens models used were SN6AT4, 37 eyes (25.2%); SN6AT5, 23 eyes (15.6%); SN6AT6, 11 eyes (7.5%); SN6AT9, 3 eyes (2.0%); SN6AT7, 2 eyes (1.4%); and SN6AT8, 1 eye (0.7%).

Table 1 shows the absolute error in predicted residual astigmatism for each device and method of calculation—for the group as a whole and for staff and residents considered separately. For the group as a whole, application of the Baylor nomogram reduced the mean absolute error for the Alcon toric calculator from 0.69 and 0.70 to 0.58 and 0.60 D with both keratometers. The Barrett toric calculator further reduced the mean absolute error to 0.56 and 0.56 D. The Barrett toric calculator had the lowest mean absolute error in predicted residual astigmatism of the three methods ($P < 0.0001$). Even though there was no significant difference between the keratometry devices with each calculation

Table 1. Absolute errors in predicted residual astigmatism by measuring device, method of calculation, and surgeon group

Measuring device	Methods of calculation								
	Alcon toric calculator			Alcon toric calculator (Baylor nomogram)			Barrett toric calculator		
	Total	Staff	Resident	Total	Staff	Resident	Total	Staff	Resident
IOL Master 500 (partial coherence interferometry)									
Mean $\pm$ SD (D)	0.69 $\pm$ 0.18	0.71 $\pm$ 0.21	0.68 $\pm$ 0.17	0.58 $\pm$ 0.22	0.59 $\pm$ 0.18	0.58 $\pm$ 0.14	0.56 $\pm$ 0.18	0.52 $\pm$ 0.20	0.59 $\pm$ 0.16
Range (D)	0.06, 2.63	0.08, 2.23	0.06, 2.63	0.06, 2.26	0.08, 2.26	0.06, 2.26	0.01, 2.28	0.06, 2.28	0.01, 1.98
Median (D)	0.63	0.63	0.63	0.47	0.51	0.47	0.48	0.41	0.58
Lenstar LS 900 (optical low-coherence reflectometry)									
Mean $\pm$ SD (D)	0.70 $\pm$ 0.21	0.71 $\pm$ 0.20	0.70 $\pm$ 0.21	0.60 $\pm$ 0.20	0.60 $\pm$ 0.18	0.60 $\pm$ 0.20	0.56 $\pm$ 0.21	0.53 $\pm$ 0.20	0.59 $\pm$ 0.21
Range (D)	0.05, 3.32	0.08, 2.45	0.05, 3.32	0.30, 2.86	0.06, 2.59	0.08, 2.86	0.07, 2.57	0.07, 2.57	0.08, 2.56
Median (D)	0.59	0.61	0.59	0.48	0.51	0.48	0.45	0.43	0.52

method, the combination of the Barrett and OLCR device had the lowest median absolute error (0.45 D).

In the ophthalmology resident subgroup, the mean absolute error was similar between the Alcon toric calculator with the Baylor nomogram (0.58 and 0.60 D) and the Barrett toric calculator (0.59 and 0.59 D) and highest with the Alcon toric calculator alone (0.68 and 0.70 D). The median absolute error was lowest for the Alcon toric calculator with the Baylor nomogram (0.47 and 0.48 D) in the resident subgroup.

For the staff ophthalmologists, the mean absolute error was lowest for the Barrett toric calculator (0.52 and 0.53 D), higher for the Alcon toric calculator with the Baylor nomogram (0.59 to 0.60 D), and highest with the Alcon toric calculator alone (0.71 to 0.71 D). There was no significant difference between the optical low-coherence reflectometry device and the partial coherence interferometry device. The staff had lower median (0.41 and 0.43) and mean (0.52 and 0.53) absolute error compared with the resident median (0.58 and 0.52) and mean (0.59 and 0.59) absolute error using the Barrett toric calculator with both devices. The mean absolute error was significantly lower ($P=0.0493$) for attendings vs residents when calculation methods were considered.

DISCUSSION

Several variables affect the predicted error of toric IOLs, including preoperative corneal measurement,^{1,2} IOL alignment,^{3,4} calculation methods,⁵ and SIA.⁴ In an experimental setting, where they could control for postoperative IOL rotation and the exact SIA induced, Abulafia et al⁵ showed that the Lenstar LS 900 was more accurate than the IOL Master 500 when the Barrett toric calculator was used. We compared the IOL Master 500 and Lenstar LS 900 in a real-world setting where these parameters cannot be controlled, since they are estimated preoperatively.

Several previous studies demonstrated the excellent agreement between different keratometry devices;^{9–12} however, these studies were not performed with calculation methods, such as the Alcon toric calculator and the Barrett toric calculator. Our research found the predicted error from the IOL Master 500 and Lenstar LS 900 measurements to be similar even when using three different toric calculators. Our study does not refute what Abulafia et al⁵ showed, since we may have noted a difference if we controlled for IOL alignment (with postoperative toric measurement) and SIA (with postoperative keratometry). But results suggest that the difference between keratometers is small enough to become negligible once the error from estimated IOL alignment and SIA is introduced.

A limitation of our study was the inability to eliminate axis misalignment or incisional SIA as confounding factors in the analysis. However, several studies have shown minimal postoperative toric misalignment,^{13–16} and due to the large sample size this error may be small. The surgically induced corneal astigmatism was assumed for each individual surgeon since postoperative keratometry was not performed. This assumption may be a cause of more significant error in our results, but some studies have shown these variables to have only a minor effect on prediction error.¹⁷

Despite the obvious weaknesses in our study, the results were remarkably similar to those of Abulafia et al.⁵ We also found the Barrett toric calculator to be more accurate than the Alcon toric calculator with or without the Baylor nomogram in the hands of attending surgeons, despite the extra “noise” or error introduced from the estimated SIA and IOL alignment. This is likely due to the calculator accounting for the effect of the posterior cornea. Koch et al¹⁸ first described the importance of considering the posterior cornea’s effect on the total corneal astigmatism, and later both Abulafia et al⁵ and Koch et al⁶ demonstrated that toric calculators (Barrett toric calculator) or methods (Baylor nomogram) that

account for the posterior cornea significantly reduced the predicted residual astigmatism error.

Our study showed that residents were significantly less accurate (higher mean and median absolute error) than their staff counterparts. Our hypothesis prior to the study was that residents would have higher predicted error since their IOL alignment and SIA may not be as consistent compared with the staff. However, we were surprised to find that this difference was much smaller than expected and only barely statistically significant with a *P* value of 0.0493. The difference between groups was not apparent when using the Alcon toric calculator with or without the Baylor nomogram, but only with use of the Barrett toric calculator. We believe this further emphasizes the importance of using the correct calculation method. It must be stressed that this is not a true outcome study, since we are comparing predicted error from our target refractive outcome. This is another incentive for residents to implant toric IOLs during their training to improve their outcomes by reducing their predicted error.

It is also important to point out that the online Alcon toric calculator used in this study from 2015 has since been updated to incorporate the Barrett toric algorithm to account for the posterior cornea. The Barrett toric calculator has also been updated since 2015.

The other paper published on this topic by Abulafia et al⁵ was based in Tel-Aviv, Israel. We believe the demographic of the veteran population could be a factor in refractive outcomes. The Veterans Health Administration is the largest provider of health professions training in the United States.¹⁹ Therefore, more research should be performed in this setting to improve resident outcomes across the country.

In conclusion, this study further confirms the importance of using accurate calculation methods for determining toric IOL power and alignment. We found no difference between the IOL Master 500 and the Lenstar LS 900. Surgeon experience correlated with significant prediction error when using accurate calculation methods.

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