Refractive Outcomes for Cataract Surgery With Toric Intraocular Lenses at a Veterans Affairs Medical Center

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Background: Refractive outcomes for cataract surgery with toric intraocular lenses (IOLs) are not well described in a teaching hospital setting. This study investigated the refractive outcomes of cataract surgery with toric IOLs at an academic-affiliated Veterans Affairs Medical Center (VAMC) and compared the accuracy of 2 biometric formulae for toric IOL power calculation.

Methods: A retrospective chart review of patients who received cataract surgery with toric IOLs from November 2013 to May 2018 was conducted. The Holladay 2 and Barrett toric IOL formulae were used to predict the postoperative refraction for each cataract surgery. The main outcome measures were best-corrected visual acuity (BCVA) and the difference in cylinder between the preoperative and postoperative manifest refractions. The accuracy of each biometric formula was also assessed using 2-tailed *t* tests of the mean absolute error, and subgroup analyses were conducted for short, medium, and long eyes.

Results: Of 325 charts reviewed, 283 patients met the inclusion criteria; 87% (248/283) of these surgeries were performed by resident surgeons. The median postoperative BCVA was 20/20, and 92% of patients had a postoperative BCVA of 20/25 or better. There was no statistically significant difference in mean absolute error between the 2 formulae for the entire axial length range ($P = .21$), as well as the short ($P = .94$), medium ($P = .49$), and long axial length ($P = .08$) groups.

Conclusions: To our knowledge, this is the largest study that compared the performance of the Barrett toric and Holladay 2 formulae and the first that made the comparison in a teaching hospital setting. This study suggests that the 2 formulae have similar refractive outcomes across all axial lengths.

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Cataract surgery is one of the most common ambulatory procedures performed in the US.[1-3] With the aging of the US population, the number of Americans with cataracts is projected to increase from 24.4 million in 2010 to 38.7 million in 2030.[4]

Approximately 20% of all cataract patients have preoperative astigmatism of > 1.5 diopters (D), underscoring the importance of training residents in the placement of toric intraocular lenses (IOLs).[5] However, the implantation of toric IOLs is more challenging than monofocal IOLs, requiring precise surgical alignment of the IOL.[6] Successful toric IOL implantation also requires accurate calculation of the IOL cylinder power and target axis of alignment. It is unclear which toric IOL calculation formula offers the most accurate refractive predictions, and practitioners have designed strategies to apply different formulae depending on the biometric dimensions of the target eye.[7-9]

Previous studies of resident-performed cataract surgery using toric IOLs[6,10-13] and studies that compare the performance of the Barrett and Holladay toric formulae have been limited by their small sample sizes (< 107 eyes).[7,14-16] Moreover, none of the studies that evaluate the comparative effectiveness of these biometric formulae were conducted at a teaching hospital.[7,14-16]

Given the added complexity of toric IOL placement and variable surgical experience of residents as ophthalmologists-in-training, it is important to assess outcomes in teaching hospitals.[13] The primary aims of this study were to assess the visual and refractive outcomes of cataract surgery using toric IOLs in a US Department of Veterans Affairs (VA) teaching hospital and to compare the relative accuracy of the Holladay 2 or Barrett toric biometric formulae in predicting postoperative refraction outcomes.

METHODS

The Providence VA Medical Center (PVAMC) Institutional Review Board approved this study. This retrospective chart review included patients with cataract and corneal astigmatism who underwent cataract surgery using Acrysof toric IOLs, model SN6AT (Alcon) at the PVAMC teaching hospital between November 2013 and May 2018.

Only 1 eye was included from each study subject to avoid compounding of data with the use of bilateral eyes.[17] In addition, bilateral cataract surgery was only performed on some patients at the PVAMC, so including both eyes from eligible patients would disproportionately weigh those patients' outcomes. If both eyes had cataract surgery and their postoperative visual acuities were unequal, we chose the eye with the better postoperative visual acuity since refraction accuracy decreases with worsening best-corrected visual acuity (BCVA). If both eyes had cataract surgery and the postoperative visual acuity was the same, the first operated eye was chosen.[17,18]

Exclusion criteria included worse than 20/40 BCVA, posterior capsular rupture, sulcus IOL, history of corneal disease, history of refractive surgery (laser-assisted in situ keratomileusis [LASIK]/photorefractive keratectomy [PRK]), axial length not measurable by the Lenstar optical biometer (Haag-Streit USA), or no postoperative refraction within 3 weeks to 4 months.[19,20]

Patient age, race/ethnicity, gender, preoperative refraction, preoperative BCVA, postoperative refraction, postoperative BCVA, and IOL power were recorded from patient charts (Table 1). Preoperative and postoperative refractive values were converted to spherical equivalents. The preoperative biometry and most of the postoperative refractions were performed by experienced technicians certified by the Joint Commission on Allied Health Personnel in Ophthalmology. The main outcomes for the assessment of surgeries included the postoperative BCVA, postoperative spherical equivalent refraction, and postoperative residual refractive astigmatism.

Axial length (AL), preoperative anterior chamber depth (ACD), preoperative flat corneal front power (K1), preoperative steep corneal front power (K2), lens thickness, horizontal white-to-white (WTW) corneal diameter, and central corneal thickness (CCT) were recorded from the Lenstar biometric device. Predicted postoperative refractions for the Holladay 2 formula were calculated using Holladay IOL Consultant software (Holladay Consulting). Predicted postoperative refractions for the Barrett toric IOL formula were calculated using the online Barrett toric formula calculator.[21] Since previous studies have shown that both the Holladay and Barrett formulae account for posterior corneal astigmatism, a comparison of refractive outcomes in eyes with against-the-rule astigmatism vs with-the-rule astigmatism was not performed.[14] An estimated standardized value for surgically-induced astigmatism was entered into both formulae; 0.3 diopter (D) was chosen based on previously published averages.[22-24]

A formula's prediction error is defined as the predicted postoperative refraction minus the actual postoperative refraction. The mean absolute prediction error (MAE),

TABLE 1 Patient Demographics and Clinical Data (N = 283)

Demographics	No. (%)
Left eye	118 (42.0)
Female	5 (1.8)
Race	
Black	7 (2.5)
White	265 (94.0)
Other	11 (3.5)
Ethnicity	
Hispanic or Latino	2 (0.7)
Not Hispanic or Latino	277 (97.9)
Unknown	4 (1.4)
Axial length subgroups	
Short (< 22.0 mm)	8 (2.8)
Medium (22.0-25.0 mm)	232 (85.0)
Long (> 25.0 mm)	43 (15.0)
Preoperative BCVA	278
20/25 or better	9 (24)
20/30 to 20/400	91 (254)
Postoperative BCVA	283
20/25 or better	92 (259)
20/30 to 20/40	8 (24)
	Mean (SD)
Age, y	76.0 (0.6)
Preoperative refraction	
25th percentile	-1.8125
median	-0.125
75th percentile	1.50
Postoperative refraction	
25th percentile	-0.5,
median	-0.125
75th percentile	0.0
IOL power, diopter	20.9 (3.2)
Anterior chamber depth, mm	3.2 (0.4)
Lens thickness, mm	4.7 (0.5)
Horizontal white-to-white corneal diameter, mm	12.1 (0.5)
Central corneal thickness, µm	551 (35)

Abbreviations: BCVA, best corrected visual acuity; IOL, intraocular lens.

TABLE 2 Barrett and Holladay 2 Toric Formula Prediction Outcomes

Mean Values					Eyes Within Diopter Range Indicated, %		
Formula	**MAE, D**	**MedAE, D**	**ME, D**	**SD**	**± 0.25 D**	**± 0.5 D**	**± 1.0 D**
Entire axial length range (n = 283, *t* = 1.23, *P* = .21)							
Holladay 2	0.372	0.280	0.036	0.487	44.6	74.5	95.7
Barrett toric	0.338	0.225	-0.075	0.474	53.2	77.3	96.1
Short eyes (n = 8, *t* = 0.071, *P* = .94)							
Holladay 2	0.613	0.597	-0.578	0.456	25.0	50.0	75.0
Barrett toric	0.598	0.617	-0.443	0.614	37.5	37.5	75.0
Medium eyes (n = 228, *t* = 0.67, *P* = .49)							
Holladay 2	0.372	0.282	0.028	0.485	45.6	74.6	96.5
Barrett toric	0.351	0.250	-0.051	0.488	50.7	76.2	96.5
Long eyes (n = 43, *t* = 1.76, *P* = .08)							
Holladay 2	0.329	0.265	0.197	0.397	42.8	78.5	95.2
Barrett toric	0.221	0.160	-0.136	0.327	69.8	90.7	97.7

Abbreviations: MAE, mean absolute prediction error; ME, mean error; MedAE; median absolute prediction error.

defined as the *mean of the absolute values of the prediction errors*, and the median absolute prediction error (MedAE), defined as the *median of the absolute values of the prediction errors*, were used to assess the overall accuracy of each formula. Also, the percentages of eyes with postoperative refraction within ≥ 0.25 D, ≥ 0.50 D, and ≥ 1.0 D were calculated for both formulae. Two-tailed *t* tests were performed to compare the MAE between the formulae. Subgroup analyses were performed for short eyes (AL < 22 mm), medium length eyes (AL = 22-25 mm), and long eyes (AL > 25 mm). Statistical analysis was performed using STATA 11 (STATA Corp). The preoperative corneal astigmatism and postoperative refractive astigmatism of all the cases were compared in double-angle plots to assess how well the toric IOL neutralized the corneal astigmatism.

RESULTS

Of 325 charts reviewed during the study period, 34 patients were excluded due to lack of postoperative refraction within the designated follow-up period, 5 for worse than 20/40 postoperative BCVA (4 had preexisting ocular disease), 2 for complications, and 1 for missing data. We included 283 eyes from 283 patients in the final study. Resident ophthalmologists were the primary surgeons in 87.6% (248/283) of the cases.

The median postoperative BCVA was 20/20, and 92% of patients had a postoperative BCVA of 20/25 or better. The prediction outcomes of the toric SN6AT IOLs are shown in Table 2. The Barrett toric formula had a lower MAE than the Holladay 2 formula, but this difference was not statistically significant. The Barrett toric formula also predicted a higher percentage of eyes with postoperative refraction within ≥ 0.25 D (53.2%), ≥ 0.5 D (77.3%), and ≥ 1.0 D (96.1%). For both formulae, > 95% of eyes had prediction errors that fell within 1.0 D.

While the Barrett formula demonstrated a lower MAE in all 3 AL groups, no statistically significant differences were found between the Barrett and Holladay formulae (*P* = .94, *P* = .49, and *P* = .08 for short, medium, and long eyes, respectively). Both formulae produced the lowest MAE in the long AL group: Barrett had a MAE of 0.221 D and Holladay 2 had one of 0.329 D. The Barrett formula produced its highest percentage of eyes with prediction errors falling within 0.25 D and 0.5 D in the long AL group. In comparison, both formulae had the highest MAEs in the short AL group (Barrett toric, 0.598 D; Holladay 2, 0.613 D) and produced the lowest percentage of eyes with prediction errors falling within ≥ 0.25 D and ≥ 0.5 D in the short AL group.

A cumulative histogram of the preoperative corneal and postoperative refractive astigmatism magnitude is shown in Figure 1. The same data are presented as double-angle plots in the Appendix, which shows that the centroid values for preoperative corneal astigmatism were greatly reduced when compared with the postoperative refractive astigmatism (mean absolute value of 1.77 D ≥ 0.73 D to 0.5 D ≥ 0.50 D).

Preoperative corneal astigmatism and

postoperative refractive astigmatism were compared since preoperative refractive astigmatism has noncorneal contributions, including lenticular astigmatism, and there is minimal expected change between preoperative and postoperative corneal astigmatism.[14] For comparison, double-angle plots of postoperative refractive astigmatism prediction errors for the Holladay and Barrett formulae are shown in Figure 2.

DISCUSSION

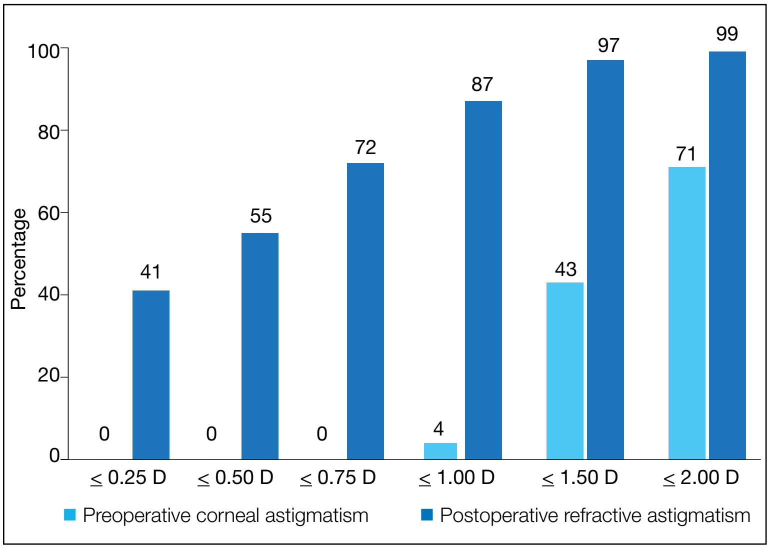
To our knowledge, this is the largest study of resident-performed cataract surgery using toric IOLs, the largest study that compared the performance of the Barrett toric and Holladay 2 formulae, and the first that compared these formulae in a teaching hospital setting. This study found no significant difference in the predictive accuracy of the Barrett and Holladay 2 biometric formulae for cataract surgery using toric IOLs. In addition, our refractive outcomes were consistent with the results of previous toric IOL outcome studies conducted in teaching and nonteaching hospital settings.[6,10-13]

In 4 previous studies that compared the MAE of the Barrett and Holladay formulae for toric IOLs, the Barrett formula produced a lower MAE than the Holladay 2 formula.[7,14-16] However, this difference was significant in only 2 of the studies, which had sample sizes of only 68 and 107 eyes.[14,16] Furthermore, the Barrett toric formula produced the lower MAE for the entire AL range, though this was not statistically significant at our sample size. In addition, both formulae produced the lowest MAE in the long AL group and the highest MAE in the short AL group. The unique anatomy and high IOL power needed in short eyes may explain the challenges in attaining accurate IOL power predictions in this AL group.[19,25]

Limitations

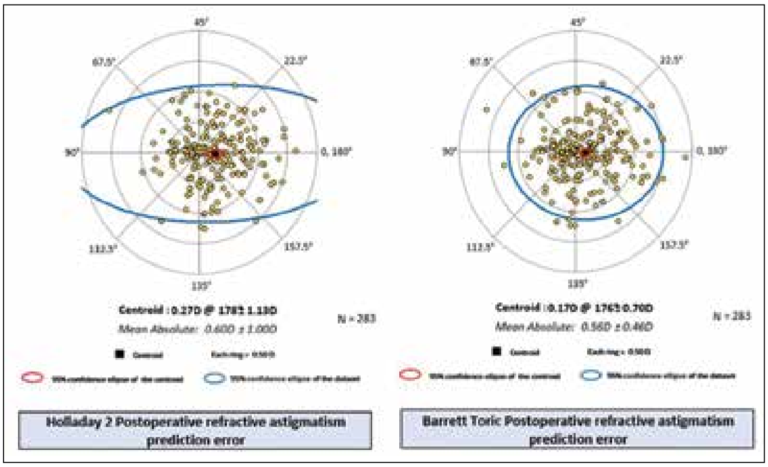
The sample size of this study may have prevented us from detecting statistically significant differences in the performance of the Barrett and Holladay formulae. However, our findings are consistent with studies that compare the accuracy of these formulae in teaching and nonteaching hospital settings. Second, the study was conducted at a VA hospital, and a high proportion of patients were male; thus, our findings may not be generalizable to patients who receive cataract surgery with toric IOLs in other settings.

FIGURE 1 Preoperative Corneal Astigmatism and Postoperative Refractive Astigmatism



Abbreviation: D, diopter.

FIGURE 2 Postoperative Refractive Astigmatism Prediction Errors Using the Holladay 2 and Barrett Toric Formulae

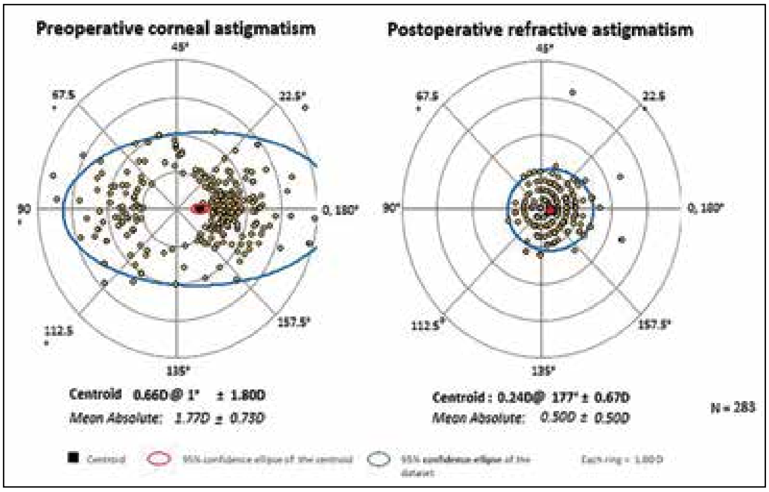


Abbreviation: D, diopter.
Double-angle plot of postoperative refractive astigmatism prediction errors, centroid values and standard deviations, and 95% confidence ellipses of the dataset and of the centroid values.

CONCLUSIONS

In a single VA teaching hospital, the Barrett and Holladay 2 biometric formulae provide similar refractive predictions for cataract surgery using toric IOLs. Larger studies would be necessary to detect smaller differences in the relative performance of the biometric formulae.

APPENDIX Double-Angle Plots of the Preoperative Corneal Astigmatism and Postoperative Refractive Astigmatism



Abbreviation: D, diopter.

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Author disclosures

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Disclaimer

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