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Total corneal astigmatism values for toric intraocular lens power calculation: Devices comparison

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ABSTRACT

Purpose: To compared the prediction error of three toric intraocular lens calculators including total cornea astigmatism mode of the Bausch and Lomb enVista toric calculator, Barrett toric calculator, and Panacea toric intraocular lens calculator. *Methods*: Thirty-six patients were included in this study who underwent cataract surgery on their 48 individual eyes by implantation of a toric Intraocular Lens (IOL). The actual residual astigmatism was compared to the predicted errors of the enVista toric calculator, the Panacea toric intraocular lens calculator, the Barrett toric calculator, using total cornea astigmatism mode. Prediction error was calculated using vector subtraction of predicted post-op astigmatism in each calculator from an actual refractive outcome. *Results*: The mean ± standard deviation (SD) of patients' ages was 69.97±10.65 (ranging from 28 to 85 years). This study was completed on 26 patient right eyes (54.2%), and 22 left eyes (45.8%). The mean actual residual astigmatic error was 0.98+/-0.84 diopters (D). The correlation between actual postoperative astigmatism and the Panacea, Barrett and enVista toric astigmatism predictions were -0.065 ($p = 0.659$), 0.088 ($p = 0.550$), and -0.170 ($p = 0.247$). *Conclusion*: The Bausch and Lomb enVista toric calculator, Barrett toric calculator, and the Panacea toric intraocular lens calculator using total cornea astigmatism mode, are not significantly different in predicting the residual astigmatic outcome after implanting toric IOLs in cataract surgery; however, the Barrett toric calculator formula seems to predict postoperative astigmatism better than the other two formulas.

Keywords: Toric intraocular lens; Total cornea astigmatism; Toric calculator

1. INTRODUCTION

Toric Intraocular Lens (IOL) implantation is one of the procedures for correcting vision refractive errors, but this procedure also has its own challenges. One of the important challenges in this method includes the possibility of rotation of toric IOLs, which may result in corneal astigmatism, especially observed in with-the-rule (WTR) astigmatism and axial length > 25 mm (Millimeters). Refractive outcome is greatly important to overcome is the limitation to guess the actual power of the cornea by the calculator, that calculates the corneal astigmatic power (Zhu et al., 2016; Shah et al., 2012; Osher et al., 2010; Refai, 2019). For minimizing the refractive errors after surgery, several toric calculators have been designed for this purpose, including nomograms, coefficients, formulas, and software, in order to calculate the toric IOL power (Koch et al., 2012; Goggin et al., 2015; Joharjy et al. 2020). Toric calculators like the Barrett toric calculator and the Abulafia–Koch formula for measuring and estimating the anterior and posterior corneal surfaces, have been indicated as effective methods for having the lowest astigmatic prediction errors (Ferreira et al., 2017; Panacea Iol and power calculator, 2019).

Researchers have confirmed the safety and effectiveness of the Bausch and Lomb enVista toric calculator (Packer et al., 2013), that was commonly used for implantation of IOLs, by only considering the anterior corneal surface (Envista toric calculator, 2019) not the posterior. Other conventional devices, such as the IOLMaster, Lenstar, Atlas, manual keratometer, and the Galilei also have a significant prediction error (Koch et al., 2013). However, we could not find a study evaluating the enVista IOLs prediction error in comparison with other methodologies. The Barrett toric calculator also estimates the posterior corneal surface but cannot directly measure and calculate it. Accordingly, we hypothesized that other methods, like the Panacea toric intraocular lens calculator, which directly calculates the anterior and posterior corneal surfaces, may lead to more accurate results.

With respect to the significance of calculating the corneal surfaces on the postsurgical outcome, the calculation power of these three methods; namely Bausch and Lomb enVista, Barret, and Panacea IOLs toric calculators, have not been compared for lowest prediction error, therefore, this study investigated two different prediction error methodologies; the Barrett toric calculator, and the Panacea toric intraocular lens calculator which estimate and calculate the posterior corneal surface of the eye, have been compared to the enVista IOL calculation in order to examine whether or not they can decrease the residual astigmatism prediction error.

2. METHODS

In this study, we retrospectively evaluated patients who underwent cataract surgery at two medical centers (Feiz and Parsian Hospital) in Isfahan province, Iran. The Ethics Committee of Iran (code: IR.MUI.MED.REC.1398.015) approved this study protocol. Patients who were selected for monofocal IOL implantation due to their having cataracts, with respect to the criteria presented by the American Academy of Ophthalmology, underwent IOL implantation over a 5-year study period having at least 3 months pass from the time of their procedure. The duration of the study was 9 months from June 2018 to March 2019. Any patient with systemic and ophthalmic diseases affecting their visual acuity was excluded from this study before recruitment. The design and objectives of the study were explained to all participants with written informed consent obtained from those who participated in the study. All principles of the Helsinki Declaration on human studies were met in this study.

Patients underwent cataract extraction with IOL implantation surgery by one surgeon, using the phacoemulsification technique, in temporal position of the patient with 2.8 mm corneal incison in the axis of 30 degrees. Before, and after surgery, patients underwent funduscopy and their visual acuity was examined using the Snellen visual acuity charts and the refraction using the auto refractometer (Topcon RM-8800, Topcon Corporation, Tokyo, Japan). Against the rule, astigmatism (ATR) was considered to be present if the steep meridian was oriented between zero and 30 or 150 and 180 degrees, with-the-rule astigmatism (WTR) was identified if the steep meridian was oriented between 60 and 120 degrees, and oblique astigmatism was recognized if the steep meridian was oriented between 31 and 59 or 121 and 149 degrees. Corneal astigmatism and curvature were measured using the Pentacam Scheimp flug imaging system (Oculus, Wetzlar, Germany) and the toric IOL power were calculated using the Bausch and Lomb enVista toric calculator. Patients were requested to refer to our optometry center as a follow up after surgery and those with complete medical records, without IOL rotation, or other ocular pathology (e.g. glaucoma, trauma, pseudoexfoliation) that could affect the vision or capsular bag stability, were included in this study. The toric IOL alignments were determined by using of slit lamp (Takachi, Japan). Preoperative calculations were repeated for each eye after the surgery using the Barrett toric calculator and the Panacea toric intraocular lens. For each calculation method, prediction error was considered as the difference between postoperative manifest refraction corrected for the corneal plane, and predicted remaining astigmatism. Prediction error in residual astigmatism was calculated using vector analysis. The error in predicted residual astigmatism was calculated by the subtraction of predicted residual astigmatism (corneal plane) and the postoperative manifest refraction (corneal plane).

Each astigmatism assessment was converted to rectangular vectors, J0 and J45, via the following equations: $J0 = -(C/2) \times \text{Cos}\ (2\alpha)$, $J45 = -(C/2) \times \text{Sin}\ (2\alpha)$, where J0 is the Jackson cross-cylinder power at 90° and 180° axes, J45 is the Jackson cross-cylinder power at 45° and 135° axes, C is the negative cylinder, and α is the axis of the flat meridian. Power J45 represents oblique astigmatism.

Predicted error = postoperative manifest refraction (corneal plane) - predicted residual astigmatism (corneal plane). Out of 56 patients included in this study, 8 were excluded because of having lens rotation of more than 5 degrees.

Statistical analysis

Results of the prediction error were indicated by mean ± standard deviation (SD), minimum, maximum, and a 95% confidence interval (95%CI). The generalized estimating equation (GEE) approach is an extension lead of linear reversion and is beneficial in ophthalmic studies to associate measurements made in the two eyes of the same person. The GEE approach was used for data analysis. The Pearson correlation coefficient was used to evaluate the relationship between predicted astigmatic error and actual residual astigmatism. Statistical software (IBM SPSS Statistics for Windows version 23.0, IBM Corp. 2014, Armonk, NY) was used for the statistical exploration. P values equivalent to 0.05 or less were reflected statistically significant.

3. RESULTS

Of the individual 36 patients participating in this study, a total of 48 right or left eyes underwent cataract surgery with implantation of toric intraocular lenses (IOL). The patients' mean age was 69.97±10.65 (ranging from 28 to 85 years). Male patients, individually, had 24 eye surgeries (50%). The mean follow-up time was ranged 6.2±3.4 months. From the patients' total 48 eyes receiving surgery, 26 were right eyes (54.2%) and 22 were left eyes (45.8%). The mean ± standard deviation (SD) of axial length (AL) was 23.64±1.32 mm (range: 20.90-28.17); mean ± SD of preoperative and postoperative spherical equivalent (SE) were -2.19±3.03 diopter (range: -12.00 to 5.00), and 0.06±.42 diopter (range: -1.00 to .88). The mean ± SD of IOL SE was 18.04±3.20 diopter (range: 11.88-26.88); and mean ± SD of IOL cylindrical power was -3.27±1.28 diopter (range: -5.75 to -1.25) as shown in Table 1. By considering the preoperative corneal astigmatism axis, 9 eyes were ATR (18.8%), 33 eyes were WTR (68.8%), and others were oblique (12.5%). The mean absolute and vectoral errors in predicted residual astigmatism for eyes with corneal astigmatism were summarized in Table 2 and Graph 1.

Table 1 The studied patients' demographic characteristics

Parameter	Value
Eyes (N)	48
Age, years (mean ±SD)	69.97±10.65
Male sex, N (%)	24 (50%)
Right eye, N (%)	26 (54.2%)
Rotation, degree (mean ±SD)	3.04±1.27 (range: 0-5)
Axial length, mm (mean ±SD)	23.64±1.32 (range: 20.90-28.17)
Preoperative SE, diopter (mean ±SD)	-2.19±3.03 (range: -12.00 to 5.00)
Postoperative SE, diopter (mean ±SD)	0.06±.42 (range: -1.00 to .88)
SimK, diopter (mean ±SD)	44.66±1.78 (range: 39.38-47.60)
ACD, mm (mean ±SD)	3.18±0.40 (range: 2.38-3.99)
IOL SE, diopter (mean ±SD)	18.04±3.20 (range: 11.88-26.88)
IOL cylindrical power, diopter (mean ±SD)	3.27±1.28 (range: 1.25 to 5.75)

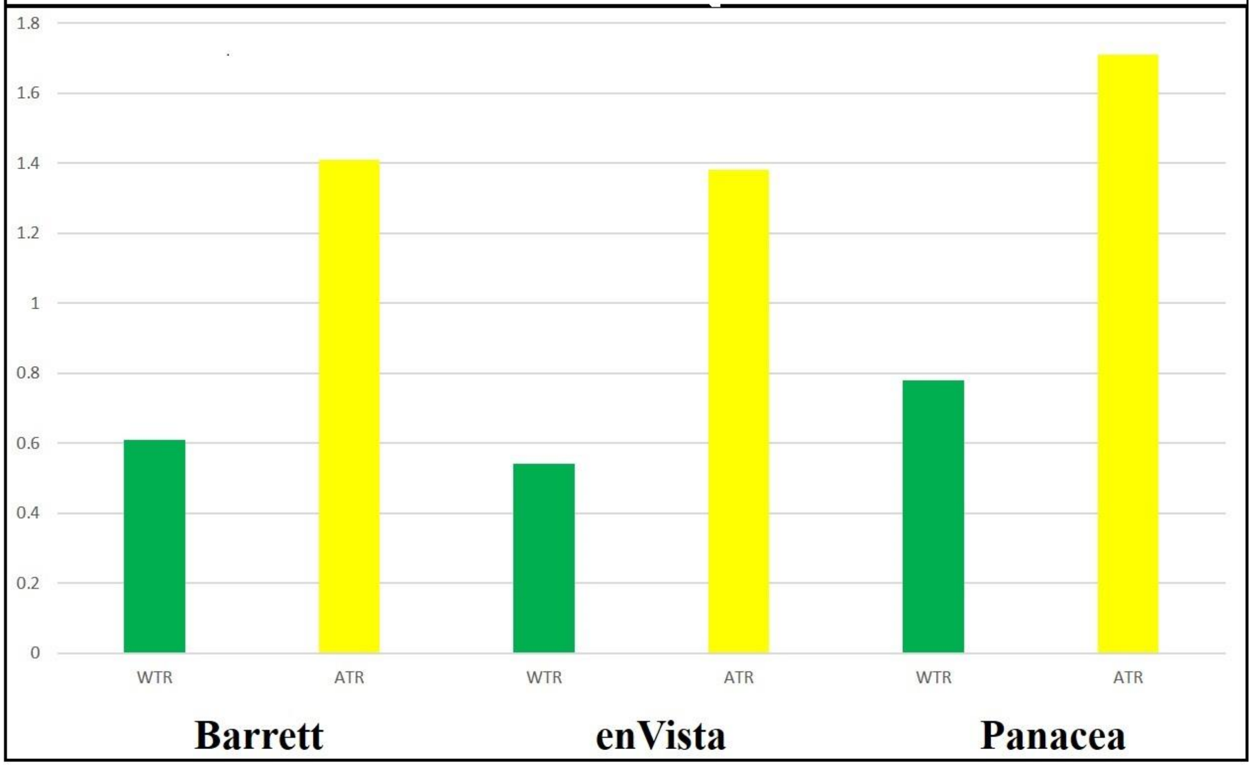
Abbreviations: SimK: Simulated keratometry; ACD: Anterior chamber depth; IOL: intraocular lens; SE: spherical equivalent; mm: Millimeter.

Table 2 Mean absolute and vectoral errors in predicted residual astigmatism for eyes with corneal astigmatism

Calculator	Absolute			Vectoral		
	Eyes with WTR corneal astigmatism (n = 33)	Eyes with ATR corneal astigmatism (n = 9)	p*	Eyes with WTR corneal astigmatism (n = 33)	Eyes with ATR corneal astigmatism (n = 9)	p*
Barrett toric calculator	0.61±0.7 (0 to 3.22)	1.41±1.21 (0.16 to 4.03)	0.013	0.18±0.42 (-2.09 to 0.97)	0.41±0.86 (-0.85 to 1.89)	0.464
enVista toric calculator	0.54±0.64 (0.01 to 2.96)	1.38±1.25 (0.15 to 4.25)	0.082	-0.39±0.46 (-1.75 to 0.77)	0.66±0.79 (-0.54 to 2.00)	0.031

Panacea	0.78±0.91 (0 to 4.00)	1.71±1.20 (0.39 to 4.16)	0.016	0.05±0.56 (-2.09 to 0.97)	0.75±1.08 (-0.74 to 2.61)	0.092
*p - value compared between WTR and ATR corneal astigmatism. WTR: With the rule; ATR: Against the rule						

Graph1.Mean absolute astigmatic prediction error with each calculation method



The correlation between actual postoperative astigmatism and Panacea, Barrett and enVista toric astigmatism predictions were -0.065 (p = 0.659), 0.088 (p = 0.550), and -0.170 (p = 0.247) (Table 3). The Barret formula seems to predict postoperative astigmatism better than the other two formulas.

Table 3 Pearson correlation of three formula and actual postoperative astigmatism

Formula name	Pearson correlation	P – value
Barrett	0.088	0.550
enVista	-0.170	0.247
Panacea	-0.065	0.659

4. DISCUSSION

This study results demonstrated that the three toric IOL power calculator methods; namely Bausch and Lomb enVista toric calculator, Barrett toric calculator and Panacea toric intraocular lens calculator, had no significant difference in error magnitude for predicting residual astigmatism, and the mean prediction error of all was about 1D (Diopter), although the Barrett toric calculator seems to predict postoperative astigmatism better than the other two formulas. According to other evidences, most cataract surgery candidates have astigmatism more than 1.25D (Ferrer-Blasco et al., 2009). The residual astigmatism issue is an important one for patients undergoing cataract surgery, not only because they require correction by spectacles, but they may also require an operation for vision correction (Ladi et al., 2017). The posterior corneal surface has astigmatism about 0.3D in most eyes and contributes to the total corneal astigmatism (Koch et al., 2013). Recent research has recommended that for choosing the best IOL, estimating the simulated keratometry (SimK) should not only be due to the anterior corneal surface, but on the posterior corneal surface as well (Jin et al., 2018). By not considering the posterior astigmatism, we may underestimate against–the–rule (ATR) astigmatism and overestimate WTR astigmatism (Savini et al., 2014). The refractive outcome is of great importance, so the role is important of calculators that calculate the corneal astigmatic power to guess the actual power of the cornea (Zhu et al., 2016; Bachernegg et al., 2013; Shah et al., 2012).

For IOL implantation, we initially utilized the Bausch and Lomb enVista toric calculator, which considers only the anterior corneal surface (Envista toric calculator, 2019). Although enVista IOLs have been confirmed effective (Packer et al., 2013), we found no study evaluating its prediction error in comparison with other methodologies (Koch et al., 2013). Therefore, the present study investigated two different methodologies; the Barrett toric calculator and the Panacea toric intraocular lens calculator which calculate the posterior corneal surface of the eye, in order to examine whether or not they can decrease the residual astigmatism prediction error.

In one study completed on 98 eyes of 54 individual patients, it was reported that the Barrett toric calculator with biometry data from the Lenstar LS900 biometer for toric IOLs caused postoperative residual astigmatism at about 0.2 D, which appears lower than what was expected from standard calculators (Gundersen et al., 2016). Although they have included no other calculator in their study for comparison, the prediction error that was reported by them is lower than what was reported in this study by utilizing the Barrett toric calculator as well as other methods. In the study by Ferreira et al., (2017), who investigated toric IOL implantation in 107 eyes of 107 individual patients having undergone cataract surgery. They reported that applying indirect estimation methods on the posterior surface of the eye resulted in a significantly lower prediction error in comparison with those calculating it directly. The mean error was 0.34D for the Barrett toric calculator and 0.59D for the Panacea toric intraocular lens calculator with a statistically significant difference. In our study, the Barrett toric calculator is better at predicting postoperative astigmatism.

Ferreira et al., (2017) reported that the Barrett toric calculator showed the lowest error for residual astigmatism prediction in two studies. In one study, they compared Barrett, Alcon, Holladay toric calculators (by the application of the Baylor nomogram, Abulafia-Koch formula, and the Goggin coefficient of adjustment) and reported the lowest centroid prediction errors in the Barrett and Alcon calculators (0.17 and 0.19D), respectively. In another study, they reported that Barrett shows a significantly lower error for residual astigmatism prediction, in comparison to Panacea and Phaco Optics, but did not have a significant difference from the Holladay calculator + Abulafia–Koch formula (Ferreira et al., 2017). Table 4 summarizes the information related to these studies. In our study, the best correlation with postoperative astigmatism was with the Barrett toric calculator; however, it could not achieve a significant error prediction.

In addition, Abulafia and other studies have reported the prediction errors with respect to postoperative keratometry (Abulafia et al., 2015), which is in agreement with this present study, while Ferreira et al. reported Barrett's prediction error in terms of preoperative keratometry (Ferreira et al., 2017). Other researchers have also declared that indirect estimation of the posterior corneal surface of the eye would lead to a smaller prediction error, compared to direct measurement methods (Ferreira et al., 2017). These results are in contrast with the initial hypothesis of this study, as we expected that direct estimation of the posterior corneal surface could end in more accurate results.

The present study contained several strengths, including the long-term follow-up and favorable sample size; however, it also has some limitations. One main limitation of this study was that we calculated the Barrett toric calculator and Panacea toric intraocular lens calculator methods with respect to postoperative keratometry, but the retrospective assessment could bring different outcomes due to the changes that occurred during and after cataract surgery. This study included 48 patients who underwent cataract surgery with toric IOL implantation, and also evaluated the error for astigmatism prediction calculated using the Bausch and Lomb enVista toric calculator, Barrett toric calculator and Panacea toric intraocular lens calculator. Although the calculation mechanism is different in these calculators, the overall results of comparing the mean prediction errors demonstrated that all methodologies had a prediction error of nearly 1D without significant difference. We measured two of these calculators postoperatively and compared them to the preoperative measurement; therefore, we propose that future studies could compare preoperative accuracy methods in order to indicate the previous method for corneal astigmatism calculation.

Table 4 Summary of the outcome of previous studies about postoperative residual astigmatism.

Title	Publication year	Authors	Comparison of …	Lowest prediction error
Prediction of refractive outcomes with toric …	2015	Abulafia A, and …	Barret, Alcon and Holladay toric calculators	Barret toric calculator
Clinical outcomes with toric	2016	Gundersen KG, Potvin R	Barret and Panacea toic calculators	Barret toric IOL calculator

intraocular lenses…				
Comparison of astigmatic prediction errors…	2017	Ferreira TB and …	Barret, Alcon and Holladay toric calculators	Barret and Alcon toric IOL calculator

5. CONCLUSION

The Bausch and Lomb enVista toric calculator, Barrett toric calculator, and the Panacea toric intraocular lens calculator using total cornea astigmatism mode, are not significantly different in predicting the residual astigmatic outcome after implanting toric IOLs in cataract surgery; however, the Barrett toric calculator formula seems to predict postoperative astigmatism better than the other two formulas.

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Conflict of interest
The authors declare that there is no conflict of interests.

Informed consent
Written and oral informed consent was obtained from all individual participants included in the study. Additional informed consent was obtained from all individual participants for whom identifying information is included in this manuscript.

Ethical approval for study protocol/study design/Methodology
The study was approved by the medical ethics committee of Isfahan University of medical sciences (Ethical approval code: IR.MUI.MED.REC.1398.015).

Data and materials availability
All data associated with this study are present in the paper.

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