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ORIGINAL ARTICLE

Impact of posterior corneal astigmatism on deviation in predicted residual astigmatism for toric IOL calculations in keratoconic eyes

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Abstract

Purpose: The objective of the study was to evaluate the error in predicted residual astigmatism (PRA) using measurements of corneal astigmatism obtained with IOLMaster-700 and Pentacam for toric intraocular lens (IOL) calculation in keratoconic eyes.

Methods: For toric IOL calculations, we used keratometric astigmatism obtained by IOLMaster-700 and total corneal refractive power (TCRP) values determined by Pentacam Scheimpflug system. Using an online toric IOL calculator, PRA for keratometric astigmatism and TCRP with a toric IOL model suggested for keratometric astigmatism values was recorded. We also calculated the error in PRA as the difference between PRA with keratometric astigmatism and TCRP. For all calculations, vector analysis was used.

Results: In our sample of 70 keratoconic eyes of 70 patients, the mean difference in PRA using TCRP instead of keratometric astigmatism measurements was −1.21±0.93 with a centroid of 0.85 at 25. The error in PRA was ≤1.0D in 36 eyes, between 1.0D and 3.0D in 26 eyes, and between 3.0D and 4.0D in eight eyes. Whereas 80% of eyes with with-the-rule astigmatism showed decreased cylindrical IOL power, 88.9% of eyes with against-the-rule astigmatism showed increased IOL power with TCRP instead of keratometric astigmatism.

Conclusion: Using TCRP measurements instead of keratometric astigmatism in toric IOL calculations caused a considerable deviation in eyes with keratoconus, most probably due to the posterior corneal astigmatism.

Keywords: IOLMaster 700; keratoconus; Pentacam; posterior corneal astigmatism; toric intraocular lenses.

Keratoconus is a non-inflammatory corneal ectasia that typically emerges in early adulthood followed by a gradual progression that often stabilizes later in life. A proportion of patients with keratoconus eventually develops cataracts, which further impair vision in already disabled patients, even in younger ages than the normal population. Several studies have suggested that patients with stable keratoconus might benefit from toric intraocular lenses (IOLs) when undergoing cataract surgery.[1–6] In such studies, authors have always calculated the extent of the cylinder and its axis that need correction on the basis of keratometric astigmatism, yet without any direct measure-

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ment of the posterior or total corneal astigmatism. However, the outcomes of toric IOL implantation are better with cylinder calculations derived from total instead of anterior corneal power, even in eyes without keratoconus.[7] In eyes with keratoconus, as Savini et al.[8] have reported, posterior corneal astigmatism achieves large, variable values and cannot be neglected when planning astigmatism correction with toric IOLs, given the influence of posterior corneal astigmatism on total corneal astigmatism.

Although conventional keratometers cannot measure posterior corneal curvature, incorporating the mathematical assumption of an index of refraction can compensate for that lack of data. By contrast, the Scheimpflug analysis system can image both the anterior and posterior corneal surfaces to determine the total corneal astigmatism. In response, the purpose of this study was to evaluate the prediction error of estimated residual astigmatism using corneal astigmatism measurements obtained with an IOLMaster 700 conventional keratometer (Carl Zeiss Meditec AG, Jena, Germany) and a Pentacam Scheimpflug analysis system (Oculus, GmBH, Wetzlar, Germany) for toric IOL calculations in eyes with keratoconus.

Materials and Methods

Participants

This cross-sectional study received approval of by the Ethics Committee of SANKO University and was adherent to the tenets of the Declaration of Helsinki. Before being included in the study, each patient provided written consent.

The same experienced clinician diagnosed keratoconus using Pentacam Scheimpflug imaging system in light of evident findings characteristic of keratoconus (e.g., corneal topography with an asymmetric bow-tie pattern with or without skewed axes) and at least one sign of keratoconus (e.g., stromal thinning, conical protrusion of the cornea at the apex, Fleischer ring, Vogt Striae, or anterior stromal scar) during slit-lamp examination.[9] We categorized keratoconic eyes according to the Amsler–Krumeich classification based on astigmatism, corneal power, corneal transparency, and corneal thickness,[10] all of which we obtained using the rotating Scheimpflug analysis system and slit-lamp biomicroscopy. If both eyes exhibited keratoconus, then we selected only one at random. Participants also received a comprehensive ophthalmologic examination to rule out any other ocular disease. We asked participants who wore rigid gas permeable and soft contact lenses to stop using them for 3 and 2 weeks before assessment, respectively.

From our sample, we excluded any eyes with corneal scarring or history of surgery, including cross-linking, and eyes with keratoconus suspects.[11]

Devices and Measurements

We used the IOLMaster 700 version 1.8 for biometry measurements, as well as to determine values of flat keratometry, steep keratometry, and their corresponding axes. The device uses swept-source optical coherence tomography technology (i.e., a laser of variable wavelength) to generate optical B-scans or cross-sections to determine biometric eye data.[12] We calculated IOL power with the Holiday II formula using a target refraction of–0.25 D. The auto-keratometry feature of the IOLMaster 700 uses six light projections reflected of the anterior cornea at a diameter of 2.5 mm. To calculate corneal power, the device uses the anterior corneal radius and standardized keratometric index of 1.3375. To obtain the total corneal refractive power (TCRP) calculated using ray tracing, which sends parallel light beams to the cornea that refracts according to the correct refractive index (1.376/1.336), the slope of the surfaces, and the exact location of the refraction. Corneal power distribution display in Pentacam software permits the evaluation of the TCRP values in preferred zones or rings.

To minimize variation in the results, we took Pentacam and IOLMaster 700 measurements in random order in the same dimly lit room with a 10 min rest period from 9:00 am to 12:00 pm.

We obtained measurements of flat and steep keratometry and their corresponding axes for a 2.5–mm ring in the TCRP map from a power distribution display by centering X- and Y-axis at 0.0 mm and selecting the 2.5 mm ring diameter option.

To calculate IOL cylinder power and axial alignment, we used the online toric calculator [A]. Axial length, anterior chamber depth, and spherical IOL power measurements of IOLMaster 700 were used for calculation. For toric IOL calculation, we applied a surgically induced corneal astigmatism of 0.25 D for a 2.4 mm superior-temporal clear corneal incision based on the surgeon's personal data. The online calculator automatically selected the toric IOL model according to the lowest predicted residual astigmatism (PRA). For calculation, we used values of flat and steep keratometry, as well as of their corresponding axes, obtained by IOLMaster 700 and Pentacam measurements for a 2.5 mm ring in the TCRP map, respectively. In the process, we first recorded the suggested toric IOLs and their PRA values for the IOLMaster 700, after that PRA with TCRP measurements also recorded applying the same toric IOL model suggest-

Table 1. The mean keratometry measurements, astigmatic magnitudes of corneal astigmatism, and predicted residual astigmatism for conventional keratometer and Scheimpflug TRCP measurements

	Conventional keratometer	Scheimpflug TRCP	Difference	p
	Mean±SD (range)	Mean±SD (range)	Mean±SD	
Flat K (D)	44.81±3.32 (41.11–47.54)	44.39±3.9 (40.89–47.23)	0.43±0.92	0.212
Steep K (D)	48.52±4.06 (45.42–54.63)	48.33±3.85 (44.96–54.10)	0.19 ±0.46	0.336
Corneal astigmatism (D)	3.85±4.03 (0.15–10.40) c: 2.58 at 26	3.24±1.91 (0.12 to 10.55) c: 1.89 at 38	0.61±0.60 c: 0.49 at 30	0.072
Predicted residual astigmatism (D)	0.50±0.29 (0.15–2.15) c: 0.35 at 15	¥1.71±0.68 (0.65–3.98) c: 1.15 at 29	−1.21±0.93 (0.75–4.75) c: 0.85 at 25	0.006*

c: Centroid; D: Diopters; K: Keratometry; SD: Standard deviation; TRCP: Total corneal refractive power. *Paired t-test, ¥predicted residual astigmatism when total refractive corneal power measurements substituted for conventional keratometer values for the determined toric intraocular lens model for conventional keratometer measurements.

ed for IOLMaster 700. We next calculated the error in PRA as the difference between the PRAs and IOLMaster 700 and with the Pentacam by selecting the same toric IOL model determined by the toric IOL calculator according to conventional keratometer values. In all calculations, we used vector analysis.[13]

According to keratometric astigmatism obtained from conventional keratometry, we classified eyes as with-the-rule (WTR) when the steep meridian was within 60–120° and as against-the-rule (ATR) when the steep meridian was within 0–30° or 150–180°. Finally, we classified the remaining astigmatism as oblique astigmatism.

Statistical Analysis

We assessed data for normality using the Kolmogorov–Smirnov test and a paired t- test or Wilcoxon non-parametric test as appropriate. The Chi-square test was also used to test for equality of proportions. Differences were considered statistically significant when p<0.05 was considered statistically significant. We performed statistical analyses with the Statistical Package for the Social Sciences version 23.0 (SPSS Inc., Chicago, IL, USA). The double-angle plots were prepared using the double-angle plot tool for astigmatism available on the American Society of Cataract and Refractive Surgery website. We conducted a sample size calculation to detect an astigmatic prediction error of more than 0.25 D and an SD of 0.40 D. For a significance level (α) of 0.05 and test power of 0.80, 34 eyes were necessary in the sample.

Results

We evaluated 70 keratoconic eyes of 70 patients, 42 of whom were men and 28 of whom were women, with a mean age of 38.5±9.2 years (range 22–47 years). The mean axial length was 24.93±1.38 mm (range 22.25–27.11 mm) and the mean IOL power 17.2±4.5 D (range 8.50–25.0 D). Twenty-two eyes exhibited Grade 1 keratoconus, 40 exhibited Grade 2 keratoconus, and eight exhibited Grade 3 keratoconus. When we classified keratometric astigmatism with conventional keratometry as WTR, ATR, or oblique astigmatism, 30 eyes (42.8%) had WTR, 18 (25.8%) had ATR, and 22 (31.4%) had oblique astigmatism. Table 1 shows the mean keratometry measurements and astigmatic magnitudes of corneal astigmatism and PRA for the conventional and Scheimpflug TCRP keratometry measurements. The mean difference in PRA when Scheimpflug TCRP measurements substituted for the conventional keratometer was–1.21±0.93 D (−1.75 to −0.26 D) with a centroid of 0.85 at 25. The estimated error in PRA was <1.0 D in 36 eyes (51%), between 1.0 and 3.0 D in 26 eyes (37%), and between 3.0 and 4.0 D in eight eyes (12%). Eyes with estimated error in PRA >3.0 D had Grade 3 keratoconus. Table 2 presents the change in cylinder IOL power when TCRP measurements substituted for conventional keratometer values.

Table 2. The change in cylinder IOL power when total refractive corneal power measurements substituted for conventional keratometer values

Cylinder IOL power	WTR	ATR	Oblique
	n (%)	n (%)	n (%)
Increase	2 (6.6)	16 (88.9)	6 (27.2)
Decrease	24 (80)	0 (0)	6 (27.2)
No change	4 (13.4)	2 (11.1)	10 (45.6)
P	0.001*	0.001*	0.262

IOL: Intraocular lens; WTR: With-the-rule astigmatism; ATR: Against-the-rule astigmatism; n: Eye. *Chi-square test.

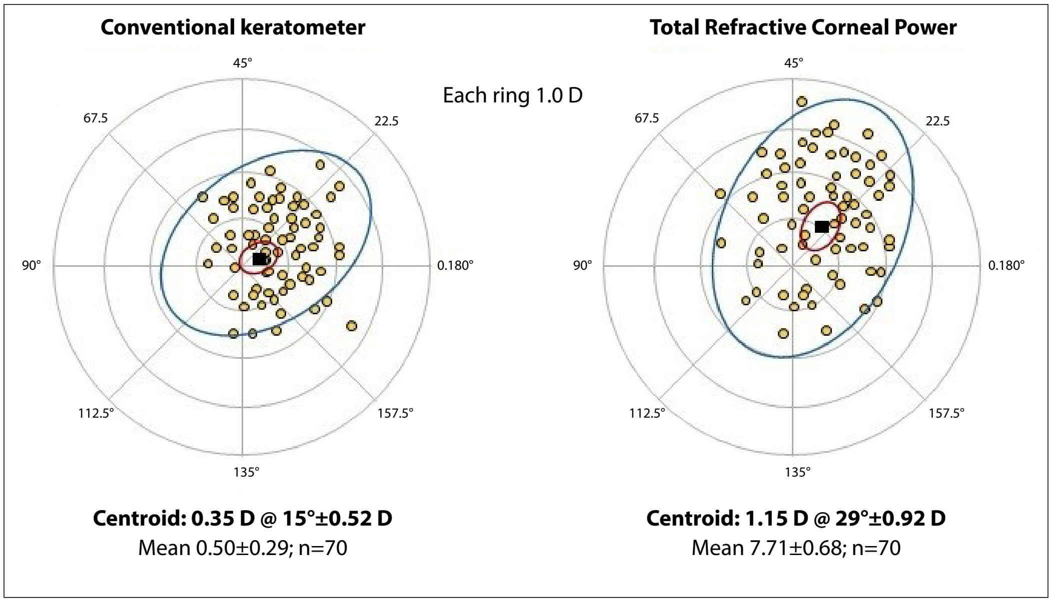

Fig. 1. Double-angle plots of error in predicted residual astigmatism using measurements of conventional keratometer and total refractive corneal power measurements.

When we used TCRP measurements, 80% of WTR eyes had decreased cylinder IOL power, whereas 88.9% of ATR eyes had increased cylinder IOL power. No significant difference emerged in eyes with oblique astigmatism regarding the change in cylinder IOL power. Figure 1 shows double-angle plots of PRA using measurements of the conventional keratometer and Scheimpflug devices for the determined toric IOL model for conventional keratometer measurements.

Discussion

The outcomes of toric IOL implantation depend on the accurate estimation of corneal astigmatism, which includes a contribution from the posterior corneal surface.[14] Our results demonstrate that posterior corneal astigmatism can cause a deviation of −1.21 D in PRA when posterior corneal astigmatism in keratoconic eyes is ignored. The error in PRA was >1.0 D in 49% of keratoconic eyes. Toric IOL cylinder power decreased in 80% of eyes with WTR and increased in 88.9% of eyes with ATR when TCRP measurements substituted for conventional keratometer values.

Studies have shown that toric IOL implantation is effective for correcting astigmatic errors in keratoconic patients with cataract.[2,4–6] Refractive lens exchange with toric IOL was also presented as a therapeutic option for non-progressive keratoconus patients.[1,3] Posterior corneal astigmatism is not taken into consideration for toric IOL implantation, despite its being a possible source of residual refractive astigmatism after surgery. Studies have also demonstrated the overestimation of the cylinder power of toric IOLs with WTR and its underestimation in eyes with ATR when calculation is only based on measurements of an automated keratometer in eyes without keratoconus.[15,16] In keratoconic eyes, Savini et al.[8] reported that keratometric astigmatism overestimated total corneal astigmatism in eyes with WTR astigmatism by 0.16 D and underestimated it in eyes with ATR astigmatism by 0.22 D. Similarly, our measurements found with the conventional keratometer overestimated the cylinder IOL power in WTR eyes and underestimated it in ATR eyes. The change in the posterior corneal surface plays a more subtle role than change in the anterior corneal surface in optical performance given the smaller change in the refractive index between the cornea and aqueous humor than the change between the cornea and the air. At the same time, considering that posterior corneal astigmatism in keratoconic eyes is far greater than that in normal eyes, the presence of posterior corneal astigmatism reported to be 0.77±0.43 D with a range of 0.0–3.10 D in eyes with keratoconus cannot be ignored for toric IOL calculation, especially in eyes with keratoconus.[8,16–18]

The online calculator that we used for toric IOL calculation includes the Barrett toric algorithm, which is designed to provide more accurate preoperative prediction of residual astigmatism by accounting posterior corneal astigmatism theoretically and calculating customized effective lens position. In normal eyes, a standard correction factor is applicable to the radius of the curvature of the anterior corneal surface to derive total corneal power. However, it is invalid if the normal relationship is distorted or changed, as is the case in keratoconus. In addition, to evaluate the effective lens position can be challenging in eyes with keratoconus given the variability of biometric measurements, which could also affect the final refractive outcome.

Other than cylinder error in toric IOL, error in the prediction of spherical IOL power in eyes with keratoconus is another consequence of keratometry measurements and IOL formula that are not exactly specified for keratoconic eyes. In general, a hyperopic refractive outcome is likely to occur in most keratoconus patients. Therefore, a myopic refraction target can be applicable, especially in severe keratoconus. Hashemi et al.[6] reported that the lowest mean absolute error in IOL power surfaced at all stages of keratoconus (i.e., mild, moderate, and severe) with corneal topography-derived keratometry and SRK/T formula. Savini et al.[19] found that the formula yielding an acceptable percentage of patients (61.9%) for the mean refractive prediction error (within ± 0.50 D) was SRK/T in only cases of Stage I keratoconus; in cases of Stages II and III keratoconus, the mean refractive prediction error was reported worse. SRK/T formula indirectly determines the effective lens position. Hence in eyes with longer axial length and a steep K measurement which a deeper anterior chamber is expected, IOL is considered to have a more posterior effective lens position. The 4th generation formulas are theoretically considered an improvement over the previous formulas to calculate IOL power in all eyes but especially in abnormal ones. Holladay II formula adjusts the recommended IOL power more by including factors such as axial length, corneal power, white to white, anterior chamber depth, lens thickness, age, and pre-operative refraction data. It has been reported Holladay II formula to be more accurate than other formulas when effective lens position is variable.[20] In keratoconic eyes, there are no established calculation formulas so far. Our study sample was formed of Stages I, II, and III keratoconic eyes, therefore, we used a 4th generation formula like Holladay II to determine IOL power with both conventional keratometer and Scheimpflug TCRP measurements by contributing of many ocular parameters. We did not compare spherical errors or IOL formulas, because the main focus of the present study was to reveal any the deviation in PRA between conventional keratometry and TCRP measurements for toric IOL calculations.

We used the Pentacam and IOLMaster 700 devices, both of which have highly reproducible and comparable corneal power measurements.[21–23] In addition to variability in keratometry, axial length measurement can also be challenging to evaluate in keratoconus. Since the decentered apex of keratoconic corneas creates unpredictable parallax errors in visual axis estimation, optical measurements are often preferable to other manual or ultrasound techniques to easily ensure patient's fixation. Alió et al.[5] found that axial length showed a stronger correlation with the final spherical equivalent than with pre-operative keratometry, which suggests that axial length readings might have an even greater influence in post-operative refractive results in keratoconic patients than expected.

Our study had some limitations. First, we did not investigate eyes with subclinical or with severely advanced keratoconus. Second, we did not perform subgroup analysis according to the Amsler–Krumeich classification for error in PRA. Finally, we did not validate the outcomes of actual residual astigmatism of toric IOL calculation results following cataract surgery in a clinical setting. However, we revealed the difference in PRA for toric IOL calculation considering the posterior corneal astigmatism in keratoconus in a preclinical setting.

Conclusion

In sum, using TCRP measurements instead of keratometric astigmatism in toric IOL calculations caused a considerable deviation in eyes with keratoconus, most probably due to the posterior corneal astigmatism. Considering TCRP measurements as well as conventional keratometry might be helpful for selecting a more appropriate toric IOL model that can yield more a precise astigmatism correction for eyes with keratoconus. However, further studies in a clinical setting with post-operative refractive results of keratoconic eyes after cataract surgery are necessary to confirm these preclinical setting findings.

Ethics Committee Approval: This study was approved by SANKO University Ethics Committee (2021/15-01).

Peer-review: Externally peer-reviewed.

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