Which Keratometer is Most Reliable for Correcting Astigmatism with Toric Intraocular Lenses?

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A significant number of patients who undergo cataract surgery have a varying degree of preexisting corneal astigmatism. An estimated 15% to 29% of patients with cataracts have more than 1.50 diopters (D) of preexisting astigmatism [1,2], and approximately 2% of all cataract patients have astigmatism of more than 4.00 D [1].

Astigmatism can be reduced or eliminated with several techniques, which include selective positioning of the phacoemulsification incision, corneal relaxing incisions, limbal relaxing incisions, excimer laser keratectomy and toric intraocular lens (IOL) implantation. Several reports have shown that toric IOL implantation during cataract surgery is an effective and safe method to reduce corneal astigmatism [3-9].

The optical effect that results from toric IOL implantation depends on the accurate measurement of the preoperative corneal astigmatism. Inaccurate measurements may result in failure to reduce the astigmatism or it may even result in worsened corneal astigmatism. Alcon, the manufacturer of the AcrySof toric IOLs, recommends the use of a manual keratometer to measure preoperative corneal astigmatism, but no studies have actually compared the accuracy of the various keratometric instruments. The purpose of this study was to evaluate the accuracy of the various keratometers that are used to make preoperative measurements prior to cataract surgery with toric IOL.

Materials and Methods

This prospective clinical study included 25 eyes from 23 patients who had received AcrySof toric IOL implantation between the dates of April 2008 and April 2009. Inclusion criteria were the presence of cataracts, less than 80 years of age, having a preoperative regular corneal astigmatism greater than 1.50 D, and a normal macular finding. Exclu-
sion criteria were having an irregular corneal astigmatism, a regular astigmatism greater than 5.00 D, tear-film abnormalities, or extensive macular disease. Informed consent was obtained from all of the patients after the nature and possible consequences of both the study and the surgery were fully explained. Patients received a complete preoperative ophthalmic examination, including slit lamp examination, IOP measurement using Goldmann applanation tonometry, preoperative manifest refraction, keratometry, and fundus examination.

Preoperative corneal astigmatism was evaluated by a single trained examiner using four different keratometers: a SO-21 manual keratometer (Shin-Nippon, Tokyo, Japan), a 420 auto keratometer (Allergan Humphrey, San Leandro, CA, USA), a Pantacam (Oculus, Wetzlar, Germany), and an IOL master (Zeiss, Jena, Germany). Intra-grader repeatability was evaluated and the coefficient of repeatability (COR) for the mean keratometric power was calculated. Axial length was measured with the IOL master and the Humphrey A-scan. Calculation of the IOL axis placement was performed using a toric IOL calculator program (http://www.acrysoftoriccalculator.com). Preoperative keratometry, biomeetry data, incision location, and the surgeon-estimated surgically-induced corneal astigmatism were used to determine the appropriate AcrySof toric IOL model, spherical equivalent lens power, and axis of placement in the eye. The SRK/T formula was used for spherical IOL power calculation. The targeted refraction was emmetropia.

All of the surgeries were performed by the same surgeon using topical anesthesia. With the patient seated at the slit lamp and with a coaxial thin slit adjusted to the 0- to 180-degree axis, the corneal limbus was marked at the 0- and 180-degree positions with a sterile marker after vertical alignment with the patient’s head. Next, with the patient lying on the surgical table, the steep corneal meridian was identified and marked using a Marquez gauge with the aid of the preplaced reference points. Phacoemulsification was performed through a 2.75 mm temporal corneal incision. After phacoemulsification, a foldable AcrySof toric IOL (AcrySof SA60AT; Alcon Laboratories, Fort Worth, TX, USA) was inserted into the capsular bag using a Monarch II injector (Alcon Laboratories), which was then rotated approximately 15 degrees off-axis before the ophthalmic viscosurgical device (OVD; sodium hyaluronate 1%, Provisc) was removed. After the OVD removal, the IOL was rotated to the final position by aligning the toric reference marks. A corneal suture was then made that was scheduled to be removed one week after surgery. Postoperative examinations were performed one day, one week, and one and three months after surgery. The manifest refraction (MR) and keratometric value were measured at the one month follow-up appointment, and all of the patients had a complete postoperative ophthalmic examination. Toric IOL rotation was measured using the slit lamp in one-degree steps through pupils that were dilated with tropicamide. A thin coaxial slit was projected in front of the eye and rotated until the thin slit projection overlapped with the axis marks of the IOL.

MR was performed in order to evaluate residual astigmatism. The residual corneal astigmatism that was based on the MR measurement was compared to the anticipated residual astigmatism, which is calculated using an online program. We defined the keratometric error (KE), as follows: KE = (actual postoperative astigmatism – anticipated residual astigmatism) / toricity of implanted IOL. We calculated KE using the vector calculator program VECTrAK version 1.5. An example of how the KE was calculated is as follows: preoperative corneal astigmatism as measured by manual keratometer (OD): 2.20 × 99°; surgically-induced astigmatism: 0.50 × 90°; crossed cylinder result (corneal plane): 2.68 × 97°; AcrySof Toric IOL: SN60T5 (cylinder power at corneal plane 2.06 D); axis of IOL placement: 97°; anticipated residual astigmatism: 0.62 × 97°; IOL rotation one month after surgery: 3°; loss of toric IOL effect to correct astigmatism: 10 percent of the toricity; corrected anticipated residual astigmatism: 2.68 – (2.06 × 0.9) = 0.82 × 97°; actual residual astigmatism (MR at one-month after surgery): 1.25 × 90°; difference between the two values of astigmatism: 0.50 × 78° (by vector calculator); KE = 0.50 / 2.06 = 0.24

Statistical analysis was performed using the SPSS ver. 12.0 (SPSS Inc., Chicago, IL, USA). One way ANOVA and Tukey’s b-test were used for performing comparative statistics. A p-value less than 0.05 were considered significant in our analyses.

Results

The COR of the mean keratometric power was ±0.21 D

Table 1. Patient demographics and characteristics

|                          | Average (±SD) |
|--------------------------|---------------|
| Age (yr)                 | 71.0 ± 5.15   |
| Eye (OD / OS / OU)       | 12 / 13 / 2   |
| Gender (M / F)           | 9 / 16        |
| Pre-operative UCVA (logMAR) | 0.57 ± 0.40 |
| Pre-operative BCVA (logMAR) | 0.37 ± 0.30 |
| Pre-operative cornea astigmatism (D, average) | 1.93 ± 0.67 |
| Pre-operative spherical equivalent | 0.61 ± 2.29 |
| IOL (D)                  | 21.4 ± 1.67   |
| Toricity (T3 / T4 / T5)  | 10 / 7 / 8    |

SD = standard deviation; OD = right eye; OS = left eye; OU = both eyes; UCVA = uncorrected visual acuity; logMAR = logarithm of the minimum angle of resolution; BCVA = best corrected visual acuity; D = diopter; IOL = intraocular lens.
for the auto keratometer, ±0.20 D for the manual keratometer, ±0.32 D for the Pentacam, and ±0.22 D for the IOL master. The demographic and clinical characteristics of the patients are shown in Table 1. The average preoperative corneal astigmatism was 2.18 ± 0.67 D by the auto keratometer, 1.68 ± 0.55 D by the manual keratometer, 1.74 ± 0.63 D by the Pentacam, and 1.90 ± 0.63 D by the IOL master. Average astigmatism as measured by the auto keratometer appeared to be higher than what was measured with the other instruments, but this difference was not significantly different ($p = 0.06$) (Fig. 1).

Postoperative results are shown in Table 2. The differences between postoperative residual corneal astigmatism and the anticipated residual astigmatism are listed in Table 3. T5 IOL showed the largest differences, which were then followed by T4 and T3, although these were not significant, and to reduce the confounding factors we divided the differences by the toricities of the implanted IOL. Comparison KE as toricity showed no significant differences (Table 4). The average KE was 0.59 D (0.08-0.94) by the auto keratometer, 0.52 D (0.17-1.17) by the manual keratometer, 0.61 D (0.08-1.52) by the Pentacam, and 0.62 D (0-1.31) by the IOL master. The median KE value was 0.54 D by the auto keratometer, 0.45 D by the manual keratometer, 0.46

### Table 2. Visual acuity and manifest refraction before and three months after AcrySof toric IOL implantation

|                      | Pre-operative | 3 mon post-operative | $p$-value |
|----------------------|---------------|----------------------|-----------|
| UCVA (logMAR)        | 0.57 ± 0.40   | 0.06 ± 0.10          | 0.00      |
| BCVA (logMAR)        | 0.37 ± 0.30   | 0.007 ± 0.02         | 0.00      |
| Corneal astigmatism (D) | 2.18 ± 0.67   | 2.34 ± 0.68          | 0.662     |
| Refractive cylinder (D) | 1.44 ± 0.87   | 0.46 ± 0.29          | 0.00      |

UCVA = uncorrected visual acuity; logMAR = logarithm of the minimum angle of resolution; BCVA = best corrected visual acuity; D = diopter.

### Table 3. Comparison of the differences between the residual corneal astigmatism and the anticipated residual astigmatism

|                      | T3 (n = 10) | T4 (n = 7) | T5 (n = 8) | $p$-value$^*$ |
|----------------------|------------|------------|------------|---------------|
| Auto (D)             | 0.65 ± 0.28| 0.92 ± 0.36| 1.10 ± 0.60| 0.186         |
| Manual (D)           | 0.62 ± 0.38| 0.77 ± 0.36| 1.12 ± 0.46| 0.108         |
| Pentacam (D)         | 0.73 ± 0.51| 0.91 ± 0.69| 1.04 ± 0.61| 0.611         |
| IOL master (D)       | 0.67 ± 0.44| 1.03 ± 0.43| 1.15 ± 0.33| 0.211         |

Values are presented as mean ± SD. D = diopter; SD = standard deviation; IOL = intraocular lens. $^*$One way ANOVA.

### Table 4. Comparison of the KE with regard to toricity

|                      | T3 (n = 10) | T4 (n = 7) | T5 (n = 8) | $p$-value$^*$ |
|----------------------|------------|------------|------------|---------------|
| Auto (D)             | 0.63 ± 0.27| 0.59 ± 0.23| 0.53 ± 0.29| 0.795         |
| Manual (D)           | 0.60 ± 0.37| 0.50 ± 0.24| 0.54 ± 0.22| 0.830         |
| Pentacam (D)         | 0.70 ± 0.49| 0.59 ± 0.45| 0.51 ± 0.30| 0.696         |
| IOL master (D)       | 0.65 ± 0.42| 0.66 ± 0.28| 0.56 ± 0.16| 0.856         |

Values are presented as mean ± SD. KE = (actual postoperative astigmatism − anticipated residual astigmatism) / toricity of implanted IOL. KE = keratometric error; SD = standard deviation; D = diopter; IOL = intraocular lens. $^*$ANOVA.
Shin-Nippon NVision-K 5001 autorefractor was similar to evaluate the preoperative keratometry [5,21,22], which may determine which keratometer was most accurate and to also determine the degree of error for each of the instruments. The difference between the two astigmatic values was then divided by the toricity in order to allow for comparisons of KE across different toricities.

This formula had its limitations, since the postoperative astigmatism can be influenced by not only the IOL toricity, but also by the IOL rotation, which is not considered in the formula we used. We also assumed that the astigmatism was not induced by the IOL itself.

In spite of these limitations, the comparison of KEs from different keratometers was meaningful since the four keratometers were evaluated under the same environment and conditions. This was the first study to evaluate the reliability of keratometers in correcting astigmatism with toric IOL. The results show that the manual keratometer was the most accurate of the ones tested, but the differences between the instruments were not significant. Bauer et al. has reported that manual keratometry (Javal), automated keratometry by optical biometry (IOL Master), and corneal topography all gave comparable results in regards to measuring corneal astigmatism [5]. This is consistent with our findings, with the exception that Bauer only compared preoperative astigmatic values. The manual keratometry was mandatory practice in the AcrySof clinical trial [23], and the three other methods were found to be equally competent at determining corneal astigmatism.

In conclusion, manual keratometry was found to be the most accurate in this study, although the other methods that were studied were equally suitable for determining corneal astigmatism for implanting toric IOL. We suggest that a study should be done to validate our findings by having longer follow-up times and a larger number of samples.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.
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