Total corneal astigmatism in older adults taking into account posterior corneal astigmatism by ray tracing

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PURPOSE: To study the composition of corneal astigmatism in older adults, evaluating the difference made by the inclusion of posterior corneal astigmatism in a ray tracing calculation of total corneal astigmatism.

SETTING: Ophthalmology clinic.

METHODS: One hundred consecutive patients aged between 60 and 80 years were included in a prospective descriptive study. Their right eye was analysed by an integrated Placido disk and rotating Scheimpflug camera topographer (CSO™ Sirius). Several parameters were measured: anterior corneal astigmatism (ACA) and posterior corneal astigmatism (PCA), total astigmatism based on anterior topographic data (SimK) and total corneal astigmatism (TCA) by merging anterior and posterior astigmatism using ray tracing.

RESULTS: Mean ACA was 1.51 diopters (D) and PCA was 0.38D. ACA was aligned 47% with-the-rule and PCA 87% against-the-rule. Cases with against-the-rule ACA showed low magnitude correlation between anterior and posterior surfaces. TCA had a mean deviation of 0.30D @ 3 over SimK in a vector calculation. Eighteen percent (18%) of cases differed by 0.50 D or more between SimK and TCA magnitude, and 53% had 10 or more degrees of axis discrepancy, the difference being higher at lower magnitudes of astigmatism.

CONCLUSIONS: Anterior WTR astigmatism tends to be compensated by posterior ATR astigmatism in older patients. Nevertheless, the high number of cases largely justifies the use of tomographic technology that takes into account the posterior corneal surface for managing individual total corneal astigmatism.

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Corneal astigmatism is gaining importance in cataract surgery planning as new correction methods appear. Although toric intraocular lenses (IOL) offer a more predictive intervention than the incision techniques used previously1, accurate calculation of corneal astigmatism is essential for choosing the correct lens. While there are many methods available for this purpose, Javal and Schiotz designed the first reliable astigmatic keratometer based on the anterior corneal surface. This value was adapted to represent the total corneal astigmatism using the keratometric index, and from then on, all new topographers used that shortcut. More recently, the posterior corneal surface has been measured with slit-lamp, optical coherence tomography (OCT) and Scheimpflug camera technology2-4. The combination of anterior and posterior corneal astigmatism has been calculated by vector analysis5-6 but only the ray tracing method, used here and in one previous study2, obtains the total corneal astigmatism based on an exact calculation and avoiding paraxial assumptions.

This paper aims to work in the same research line as recent publications emphasizing the importance of the posterior corneal surface in calculating the total astigmatism.

In our setting, astigmatism was scanned with an integrated Placido disk and rotating Scheimpflug camera topographer (CSO™ Sirius). We evaluated the correlation of posterior astigmatism in magnitude and axis with the anterior astigmatism. We accounted for the difference found by including the posterior corneal astigmatism into a ray tracing method to calculate the total corneal astigmatism (TCA) versus SimK.
PATIENTS AND METHODS

A prospective descriptive design was used to measure astigmatism values from 100 consecutive patients at our private practice who met the inclusion criteria. These were patients aged between 60 and 80 years, with no previous ocular surgery nor morbidity, and no contact lens usage. Subjects were informed about the use of their personal information, giving written consent. All research and data collection followed the tenets of the Declaration of Helsinki.

An integrated Placido disk and rotating Scheimpflug camera topographer (CSO™ Sirius) was used. This device was validated in a previous study and was calibrated by the company. A green check mark in the results display was required to guarantee the quality of each scan.

Only right eyes were analysed in a single measurement for each patient; complete analysis was then performed by the software. Four values were noted:

1. ACA: Anterior corneal astigmatism calculated by a combination of Placido disk image and Scheimpflug camera. Air (1.0) and true corneal refraction index (1.376) are used for Gaussian optics calculation.

2. PCA: Posterior corneal astigmatism is evaluated by the rotating Scheimpflug camera. True corneal (1.376) and aqueous refraction index (1.336) are used for Gaussian optics calculation.

3. SimK: Simulated keratometry uses the ACA information but includes a lower refraction index (keratometric index: 1.3375) to account for the posterior divergent effect.

4. TCA: A ray tracing formula integrating pachymetry, and anterior and posterior corneal information. It accurately calculates how light rays impact the refractive surfaces and obtains an exact corneal astigmatism value. We chose the value for central 3 mm analysis.

A descriptive analysis was conducted to obtain the mean values for each parameter and their standard deviation (SD). Percentages showing the steep meridian orientation were also calculated. A vertical anterior steep meridian will generate a with-the-rule (WTR) astigmatism, whereas a posterior one will add an against-the-rule (ATR) astigmatism.

Vector analysis was performed to show the difference between simK and TCA.

We also defined 1 D of astigmatism as the clinical threshold above which a toric IOL may be necessary, so this subgroup was analysed separately. A Chi-square test was used to search for significant differences in axis alignment of cylinder magnitude between simK and TCA. Vector calculation and graph plotting was performed using Eye Pro 2012©. All statistics were performed using IBM SPSS Statistics 21.00 for Windows.

RESULTS

Our patient sample had a mean age of 70 years ± 4 (SD).

Mean astigmatism magnitude for anterior cylinder was 1.51 ± 1.28 D, posterior cylinder 0.38 ± 0.20 D, simK 1.16 ± 1.16 D and TCA 1.32 ± 1.11 D (Table 1). Results are always stated in positive cylinder notation.

ACA was more frequently oriented WTR (47%) whereas PCA was mostly ATR (87%). The most prevalent combination was a corneal WTR anterior astigmatism and posterior ATR astigmatism (45%; Figure 1).

Anterior and posterior astigmatic magnitudes were well correlated in the case of an anterior WTR (R² = 0.587) or oblique astigmatism (R² = 0.462). However, an anterior ATR astigmatism appeared to be always related to a lower power posterior astigmatism, thus showing poor correlation (R² = 0.084; Figure 2).

The mean vector for the calculated simK was 0.25 @ 75 (Figure 3), and 0.20 @ 26 for the TCA (Figure 4). Vector difference showed that simK tended to underestimate TCA by 0.34 @ 3 (Figure 5).

We plotted the difference in the corneal astigmatism axis calculated by simK and TCA. Below 1 D of cylinder, the agreement was shown to be inferior to that obtained for the higher astigmatism values. Therefore,

| Table 1. Descriptive statistics (cylinder in diopters) |
|---|---|---|---|---|---|
|   | N  | Min | Max | Mean | SD  |
| Age       | 100 | 60  | 80  | 69.70 | 4.21 |
| ACA cylinder | 100 | 0.08 | 6.20 | 1.51 | 1.28 |
| PCA cylinder | 100 | 0.05 | 1.07 | 0.38 | 0.20 |
| SimK cylinder | 100 | 0.14 | 5.29 | 1.16 | 1.16 |
| TCA cylinder | 100 | 0.19 | 5.57 | 1.32 | 1.11 |

ACA, anterior corneal astigmatism; PCA, posterior corneal astigmatism; TCA, total corneal astigmatism
due to the clinical interest, we analysed the differences between simK and TCA by subgroups in patients with more than 1 diopter of astigmatism measured by TCA (Figure 6).

SimK and TCA had an astigmatism magnitude disagreement of more than 0.5D in 25.5% of patients with 1 D or higher astigmatism. Magnitude disagreement was lower in the less than 1 D astigmatism group (11.3%), but was not enough to indicate a significant difference (p = 0.065; Table 2).

SimK and TCA had a > 10 degree disagreement in 29.8% of the more than 1 D astigmatism group. This disagreement reached 73.6% and was significantly higher (p < 0.05) in the lower astigmatism group (Table 3).
Figure 5. Vector difference: simK-TCA. TCA shows a general tendency to be 0.34 @ 3 higher than simK, which would account for posterior corneal astigmatism.

Figure 6. Steep axis difference between simK and TCA. The horizontal line divides the cases with astigmatism over 1 D, which show better simK and TCA steep axis correlation (p = 0.05). Even in those cases, 29.79% show a more than 10 degree difference between simK and TCA.

Table 2. Cylinder magnitude difference SimK versus TCA considering TCA above 1D as clinically significant in a subgroup analysis.

<table>
<thead>
<tr>
<th>Count</th>
<th>TCA cylinder</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>&lt; 1 D</td>
<td>≥ 1 D</td>
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<td>Cylinder difference SimK versus TCA</td>
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<tr>
<td>&lt; 0.5 D</td>
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<td>35</td>
</tr>
<tr>
<td>≥ 0.5 D</td>
<td>6</td>
<td>12</td>
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<tr>
<td>Total</td>
<td>53</td>
<td>47</td>
</tr>
</tbody>
</table>

TCA, total cornea astigmatism. Chi-square test p = 0.065

Table 3. Steep axis difference SimK versus TCA considering TCA above 1D as clinically significant in a subgroup analysis.

<table>
<thead>
<tr>
<th>Count</th>
<th>TCA cylinder</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>&lt; 1 D</td>
<td>≥ 1 D</td>
</tr>
<tr>
<td>Steep axis difference SimK versus TCA</td>
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<tr>
<td>&lt; 10°</td>
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<td>33</td>
</tr>
<tr>
<td>≥ 10°</td>
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<td>14</td>
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Chi-square test p<0.05
DISCUSSION

Astigmatism is a low order aberration in an optical system. In the eye, it is defined by the difference in optical power between two orthogonal meridians of any of the optical surfaces in the cornea and lens. These four surfaces determine the astigmatism in the phakic eye, which is correctable by a toric-shaped lens. However, in pseudophakic eyes, the cornea alone determines the refractive astigmatism, as some authors have described.

In the quest for emmetropia, corneal astigmatism must be neutralised during cataract surgery. Several methods have been proposed in this respect, mainly limbal and corneal relaxing incisions, as well as toric IOL.

Regardless of the method chosen for the correction, precise pre-surgical corneal astigmatism measurement is required. Since the introduction of the first Javal manual keratometer, devices have been developed to measure the total astigmatism from anterior surface measurements through keratometric index conversion. This thick-lens calculation of the ray passing the cornea through convergent (anterior) and divergent (posterior) corneal surfaces is replaced by a thin lens calculation in which a keratometric index is employed (1.3375). Automatic keratometers are based on a projection of several points on the corneal surface; analysis of their separation will determine the anterior corneal curvature. While this is good for regular surfaces, later Placido-based topography enabled complete analysis of the anterior corneal surface, building a reconstruction from thousands of measured points. Different software was implemented to process that information, and to give an approximation of the keratometric corneal power, which was called simulated K (simK). Srivannaboon et al. recently published an article on the similarity and comparability between simK and auto refractometer keratometry.

In our study, we decided to take the simK measurement from the same topographer as the TCA, avoiding the use of any other keratometer in order not to add any inter-device variability.

All previous devices have lacked the technology for posterior corneal power measurement. Fortunately, Scheimpflug camera devices have been designed to measure the anterior and posterior curvature separately, allowing independent analysis. This is a key input for reproducing the ray behaviour through the cornea and, logically, the way to obtain the total corneal astigmatism. Some authors began this trend with a vector summation of anterior and posterior astigmatism, but later devices incorporated ray tracing technology. This latter optical analysis has two main advantages: it incorporates pachymetry and the real angle of incidence of light for each point on the cornea. It is also known to be an exact calculation; opposing the paraxial optics that keratometry had employed to simplify the formula.

With the technology available through the CSO Sirius topographer, based on Placido disk and a Scheimpflug camera, we decided to determine the importance of PCA and its relationship to ACA. We were particularly concerned about the impact that obviating posterior astigmatism could have in the overall astigmatism obviation if starting from anterior information only.

Ho et al. confirmed that astigmatism varies throughout life, so our patient selection was restricted to older adults attending our clinic for cataract surgery, obtaining a mean age of 69.7 ± 4.21 in our sample. This is the age at which most patients will undergo cataract surgery, so we focused on that astigmatism.

We were pleased to confirm that our mean posterior astigmatism results (0.38 ± 0.20) were consistent with previous studies using Pentacam and Galilei topographers regarding a 0.29 D and 0.30 D, respectively. Our results also agreed in axis distribution, showing a vertical posterior steeper meridian in 87% (Figure 1).

We concur with the paper by Koch et al. in concluding that an anterior ATR astigmatism seems to be poorly correlated with PCA magnitude, whereas WTR and oblique astigmatism have a direct correlation between anterior and posterior magnitudes (Figure 2). This is important for refuting some studies regarding a constant relationship between anterior and posterior astigmatism in normal eyes.

Focusing now on the difference between the astigmatism calculated for the anterior information (simK) and that obtained through ray tracing from the joint information from anterior and posterior surfaces and pachymetry (TCA), there was a tendency by simK towards underestimation of TCA by 0.34 @ 3, as shown by a vector difference (Figure 5). Unfortunately, the SD was high and we were unable to find a significant difference in the mean due to the insufficient sample size.

The next step in the analysis was aimed at detecting clinical differences in axis and magnitude of the astigmatism measured by simK or TCA. This would mean that a different toric IOL would have been selected with a more than 0.5 D difference or a different implantation axis would have been selected with a more than 10-degree difference. Below 1 D of TCA cylinder, agreement was lower in magnitude and axis between simK and TCA, but it lacked clinical interest, as toric IOL implantation is not frequently indicated for such cases.

For patients with astigmatism more than 1 D, TCA gave a significantly different axis in 25% and a non-significantly different magnitude in 28% of the sample, although it did show a trend.
Conclusions should be interpreted with caution as the sample size is small and most results show a tendency rather than a significant difference.

Nevertheless, we believe that this finding should encourage the surgeon to enter the TCA into the toric IOL calculation, but further clinical studies should be conducted to confirm this hypothesis.

We conclude that posterior corneal astigmatism distribution in our population measured by the Sirius topographer is comparable to that described in previous studies with other topographers. A method that includes pachymetry and anterior and posterior corneal astigmatism in a ray tracing calculation results in differences in axis and magnitude compared to the traditional astigmatism calculation based on anterior keratometry. It remains to be investigated in a clinical setting whether treatment guided by TCA provides a better refractive outcome for the patient.

REFERENCES


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