The popularity of toric IOLs has grown rapidly over the past decade. This article details four tips for obtaining the most accurate results when implanting these lenses in patients with corneal astigmatism and sheds light on areas in which further study is warranted.

1. **Consider Posterior Corneal Astigmatism**

   Traditional keratometers, both manual and automated, and corneal topographers measure only the radius of curvature of the anterior corneal surface (in millimeters). They calculate—or, better, estimate—the power of the whole cornea. Because these devices cannot measure the curvature of the posterior corneal surface, they must make assumptions to account for its power and thus obtain the total corneal power and total corneal astigmatism.

   The most important of these assumptions is the use of the so-called keratometric index, which is usually equal to 1.3375 and, less commonly, to 1.3315. The keratometric index is a fictitious value that does not correspond to the refractive index of any corneal layer. It is nevertheless used to calculate the power of the whole cornea without knowing the curvature of the posterior corneal surface.

   Use of this index leads to some errors. First, the estimated spherical corneal power is higher than the actual total corneal power by about 0.70 D, as measured by ray tracing through both corneal surfaces. This error has no effect on the calculation of the spherical power of IOLs for unoperated eyes, as most formulas were developed to be used with corneal power values derived from the keratometric index. However, this error negatively affects the calculation of corneal astigmatism and toric IOLs.

   Several studies have shown that posterior corneal astigmatism displays a vertical steep meridian in most eyes. Unlike the anterior corneal surface, which is in contact with air and has a positive refractive power, the posterior corneal surface is in contact with aqueous and has a negative refractive power. Hence, a vertically aligned steep meridian on the posterior corneal surface generates against-the-rule (ATR) rather than with-the-rule (WTR) astigmatism. The average power of posterior corneal astigmatism is approximately 0.50 D, and this value should be added to anterior ATR astigmatism and subtracted from anterior WTR astigmatism to determine the total corneal astigmatism.

   This average 0.50 D value is not fixed but rather proportional to the amount of anterior corneal astigmatism; therefore, a greater posterior contribution can be expected with increasing values of anterior corneal astigmatism. Because the corneal astigmatism calculated with the keratometric index (ie, the keratometric astigmatism) neglects information about posterior corneal astigmatism, it tends to overestimate total corneal astigmatism in eyes with WTR astigmatism and underestimate total corneal astigmatism in eyes with ATR astigmatism (Figure 1).

   We have found that, when calculating cylinder power for toric IOLs, the use of total corneal astigmatism leads to more accurate predictions than keratometric astigmatism, as it reduces astigmatism overcorrection in WTR eyes and astigmatism undercorrection in ATR eyes. On the Pentacam (Oculus Optikgeräte), using the value for Total Corneal Refractive Power (ie, the total corneal astigmatism), we were able to reduce residual error in refractive astigmatism after cataract surgery when compared with calculations based on keratometric astigmatism. In eyes with WTR astigmatism, keratometric

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**AT A GLANCE**

- The first step in improving toric IOL outcomes is to rely on total corneal astigmatism rather than keratometric astigmatism.
- It is not accurate to use a single ratio to convert IOL cylinder into corneal cylinder, as some toric IOL power calculators do.
- Future studies to investigate the influence of SIA and the effect of lens tilt on refractive astigmatism after toric IOL implantation are warranted.
astigmatism generated an overcorrection of 0.59 ± 0.34 D, and this decreased to 0.13 ± 0.42 D when total corneal astigmatism was used instead (Figure 2). In eyes with ATR astigmatism, keratometric astigmatism generated an undercorrection of 0.32 ± 0.42 D, and this decreased to 0.07 ± 0.59 D when total corneal astigmatism was used.

Minor and clinically insignificant differences were observed in the torsional component of astigmatism, meaning that differences in axis orientation between keratometric astigmatism and total corneal astigmatism are less important than differences in magnitude. Similar results have been confirmed by other investigators.7-9 Therefore, the first step to improve toric IOL outcomes is to rely on total corneal astigmatism rather than keratometric astigmatism.

Something more, however, can be done. In a study that is soon to be published, we observed that the use of total corneal astigmatism is not able to fully eradicate cylinder overcorrection in WTR eyes and undercorrection in ATR eyes.10 Using linear regression to correlate the error in refractive astigmatism to the keratometric astigmatism and total corneal astigmatism as measured preoperatively, we were able to describe equations to optimize these measurements and achieve even better results. With these equations, we were able to raise the percentage of eyes with a refractive error of 0.50 D of astigmatism or less from around 40% to almost 60%.

For this reason, we now rely on what we call optimized keratometric astigmatism to calculate cylinder for toric IOLs and to predict postoperative refractive astigmatism. Similar results can be obtained with the Barrett (unpublished data) and Abulafia-Koch calculators.11 Unfortunately, errors in the prediction of refractive astigmatism will still occur in a considerably large percentage of eyes; this must be taken into account when planning surgical procedures that target plano refraction.

CALCULATE YOUR SIA

Each surgeon should calculate the effect of his or her incision on corneal astigmatism; this value is known as the individual’s surgically induced corneal astigmatism (SIA). Although today cataract surgery through sub-3-mm incisions leads to small variations in corneal astigmatism (usually less than 0.20 D), we suggest calculating the average value for each surgeon. Calculations must be performed through vector analysis. The prediction of SIA, however, can still be inaccurate in some eyes, which can lead to refractive surprises. For this reason, further investigation of SIA is warranted.
surprises can still occur after toric IOL implantation. An error in refractive astigmatism (ie, a difference between the actual and the expected refractive astigmatism) of more than 0.50 D can be found in at least 40% of eyes.

To achieve more accurate results, future research efforts should be focused on multiple issues. First, we hope that better measurements of corneal curvature can be obtained with newer technologies such as OCT, which may be superior to Scheimpflug imaging. Second, the influence of SIA requires further investigation, as previous studies evaluated only anterior corneal curvature changes (with no attention paid to posterior corneal curvature), did not evaluate the influence of measurement repeatability (how much of the observed changes are due to the variability of measurements), and paid little attention to other factors such as the influence of the steep meridian's orientation. Third and last, no author has yet investigated the effect of lens tilt on refractive astigmatism after toric IOL implantation. These issues will likely all be the subjects of important studies yet to come.