Impact of axis misalignment of toric intraocular lenses on refractive outcomes after cataract surgery

Haiying Jin, MD, Il-Joo Limberger, MD, Angela Ehmer, MSc,
Haike Guo, MD, Gerd U. Auffarth, MD

PURPOSE: To theoretically and clinically evaluate the impact of axis misalignment of toric intraocular lenses (IOLs) on postoperative refraction.

SETTING: International Vision Correction Research Center, University of Heidelberg, Heidelberg, Germany.

DESIGN: Case series.

METHODS: A method based on mathematical solutions to obliquely crossed spherocylinders was derived according to the pseudophakic refractive properties and used to analyze the impact of toric IOL misalignment on postoperative refraction. The refractive outcomes were theoretically analyzed and actual postoperative outcomes assessed to confirm the theoretically identified impact.

RESULTS: The mean IOL misalignment was 12.5 degrees $\pm$ 6.7 (SD). Three main factors had an impact on refractive outcomes: hyperopic change in refractive sphere, reduction in astigmatic correction, and rotation of the astigmatic axis. The mean calculated spherical change was 0.32 $\pm$ 0.23 diopters (D) and the actual change, 0.36 $\pm$ 0.71 D. The mean calculated reduction in astigmatic correction was 0.65 $\pm$ 0.45 D and the actual reduction, 0.95 $\pm$ 0.54 D, indicating undercorrection of preexisting astigmatism. The mean calculated absolute astigmatic rotation was 32.7 $\pm$ 13.2 degrees (range 8 to 55 degrees) and the actual rotation, 29.1 $\pm$ 17.4 degrees. There was a correlation between the calculated and actual reduction ($r^2 = 0.51$; $P = .001$) and between the calculated and actual rotation ($r^2 = 0.86$; $P<.001$).

CONCLUSION: In addition to a reduction in astigmatic correction, misalignment of toric IOLs induced hyperopic spherical change and astigmatic rotation.

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Toric intraocular lenses (IOLs) were developed to neutralize preexisting corneal astigmatism in cataract patients.[1,2] Good outcomes depend on precise axis alignment of the toric IOL. Axis misalignment occurs from incorrect positioning at the time of surgery, postoperative rotation, or a combination, and it is still a limitation of toric IOL implantation. Alignment (positioning and rotational stability) remains an important topic in the evaluation of various toric IOL models.[1–12] Reduction in astigmatic correction caused by toric IOL misalignment has been theoretically documented[1,3,4] and confirmed in clinical research.[5–12] Several studies[9–12] report that excessive misalignment is a major complication that requires repositioning of the IOL; however, the subsequent impact of toric IOL misalignment on refractive outcomes has not been clinically studied.

A pseudophakic eye with a misaligned toric IOL can be regarded as a thin-lens system composed of 2 obliquely crossed spherocylinders, cornea, and the toric IOL. According to mathematical solutions to obliquely crossed spherocylinders published by Holladay et al.[13] (Holladay-Cravy-Koch method), the crossed-cylinder result of the cornea and toric IOL is a new spherocylinder.[14] Therefore, the spherical and cylindrical powers and cylindrical axis in

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a pseudophakic eye with a misaligned toric IOL are discordant with the intended targets. Apart from the reduction in astigmatic correction, 2 additional factors that have an impact on refractive outcomes after toric IOL misalignment can be theoretically identified. One is the change in the pseudophakic astigmatic axis (ie, astigmatic rotation); the other is the change in refractive sphere, resulting in a hyperopic spherical change. These factors may lead to a more complex postoperative refractive status, such as compound, oblique, and high residual astigmatism. This astigmatism can negatively affect postoperative visual quality.

Recently, we presented mathematical solutions to analyze the impact of toric IOL misalignment in a case in which the toric IOL was misaligned by 58 degrees.[14] Pseudophakic astigmatic rotation of 12 degrees due to the misalignment was observed. To our knowledge, a clinical study further investigating the effect of misalignment has not been published. The purpose of this study was to further assess the impact of toric IOL misalignment on the refractive outcomes after astigmatism-correcting cataract surgery using theoretical analysis and clinical study.

PATIENTS AND METHODS

Theoretical Mathematical Study

The spherocylindrical power of the pseudophakic eye can be analyzed by a mathematical method based on the Holladay-Cravy-Koch method.[13] Because the method to calculate the combining effect of the 2 obliquely crossed spherocylinders is performed at the same theoretical plane, the following vertex distance formula is used to vertex the lens (es) to the intended plane[15]:

$$F2 = \frac{F}{1 - \frac{d}{1000 \times n} \times F}$$

where F is the dioptric power of the lens, F2 is the effective power at a new position, d is the distance between the 2 positions in millimeters, and n is the refractive index of the refractive media between the 2 positions.

Following are the calculation procedures:

Step 1. *Calculate corneal refractive power*. Because the standard keratometric index of 1.3375 overestimates corneal refractive power, the calibrated index of 1.3288 found in previous research[16] is used to transform corneal radius to corneal power. Corneal power is described as

$$K_{steep}@A_{steep}/K_{flat}@A_{flat}$$

where K_{steep} is the corneal power along the steep meridian, A_{steep} is the corneal steep meridian, K_{flat} is the corneal power along the flat meridian, and A_{flat} is the corneal flat meridian.

Step 2. *Estimate the effective lens position (ELP)*. The ELP of the IOL was estimated by the ELP algorithm of Holladay formula.[17]

Step 3. *Calculate effective corneal power along the 2 orthogonal meridians at the theoretical plane of IOL (lens plane, LP) by the vertex distance formula*

$$K_{steep}LP = \frac{K_{steep}}{1 - \frac{ELP}{1000 \times n_a} \times K_{steep}}$$

$$K_{flat}LP = \frac{K_{flat}}{1 - \frac{ELP}{1000 \times n_a} \times K_{flat}}$$

where n_a is the refractive index of the aqueous (1.336) and the abbreviation following the subscript refers to the theoretical plane (eg, $K_{steep}LP$ means effective corneal power along corneal steep meridian at lens plane). The plus-cylinder form of effective corneal power at LP is expressed as

$$K_{flat}LP = \left(K_{steep}LP - K_{flat}LP\right) \times A_{flat}$$

Step 4. *Analyze the combining effect of the raw cornea and the toric IOL (cornea & IOL) at the lens plane.* According to Holladay-Cravy-Koch method[13]:

$$\alpha = A2 - A1$$

$$2\beta = \arctan\frac{C2(\sin 2\alpha)}{C1 + C2(\cos 2\alpha)}$$

$$\theta = \frac{2\beta + 180}{2}$$

$$SC = C1\sin^2\theta + C2\sin^2(\alpha - \theta)$$

$$S3 = S1 + S2 + SC$$

$$C3 = C1 + C2 - 2SC$$

$$A3 = A1 + \theta$$

Referring to a pseudophakic eye with a misaligned toric IOL, the 2 spherocylinders are toric IOL

$$(S_{IOL}C_{IOL} \times A_{IOL})$$

and the effective corneal power at lens plane

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From Guangdong Eye Institute (Jin, Guo), Guangdong Academy of Medical Sciences, Guangzhou, China; the International Vision Correction Research Centre (Jin, Limberger, Ehmer, Auffarth), Department of Ophthalmology, University of Heidelberg, Heidelberg, Germany.

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Corresponding author: Haike Guo, MD, Guangdong Eye Institute, Guangdong Academy of Medical Sciences, 510080, Guangzhou, China. E-mail: guohaike@medmail.com.cn.