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Residual astigmatism with toric intraocular lens misalignment

We read with surprise the discussion indicating that 1 degree of misalignment does not lead to a 3.3% effect decrease after implantation of a toric intraocular lens (IOL) and feel that there were several statements that were incorrect and need clarification.[1] One of us (J.T.H.) recently published the exact and complete methodology for determining the predicted refraction after implantation of a toric IOL and the postoperative back calculation of the necessary rotation for a misaligned toric IOL in the article titled, "Calculation of Total Surgically Induced Astigmatism with a Toric Intraocular Lens."[2] The original description showing the residual astigmatism for a specific angular error of a toric IOL is shown in Figure 2 of the 2001 article by Holladay et al.[3] We will only discuss the pertinent points in this letter and recommend accessing these references for any further details.

The forward toric vergence IOL calculation is similar to the spherical equivalent (SEQ) calculation with 2 major differences: (1) the total corneal power (SEQ and cylinder) must be predicted from the effect of the cataract incision using the preoperative measurements and (2) the calculation for IOL power must be determined in the flat and steep meridians of the predicted total corneal power. The predicted total corneal power must include any posterior corneal surface effects and other contributions, such as physiologic IOL tilt or decentration, refractive changes in the anterior and posterior corneal surfaces from the cataract incisions, and systematic differences in measured keratometric vs actual corneal refractive astigmatism.[4] With the predicted total corneal power, the exact meridional powers of the toric IOL can be determined. The nearest available SEQ power and toricity to the exact might then be chosen, and the resulting meridional refractions from the available meridional powers of the IOL might be calculated, yielding the predicted postoperative refraction.

Postoperatively, if the toric IOL is misaligned from the ideal axis, the amount of rotation necessary to achieve ideal alignment can be calculated from the postoperative refraction, the axial length, the actual effective lens position and the SEQ power, IOL toricity, and observed axis of the IOL (not intended). This calculation requires detailed knowledge of vector algebra, trigonometry, and the crossed-cylinder solution.[2,5] An example calculation with the specific equations is provided in the article and is accurate to 6 decimal places for validation.[2]

Although the actual calculation for the necessary rotation is tedious and complicated, it might be simplified conceptually to the problem of 2 equal-magnitude crossed cylinders of opposite sign. Consider a +1.0 diopter (D) cylinder and a −1.0 D cylinder, which are both aligned @ 90 degrees. When perfectly aligned, the residual cylinder is 0, but when the −1.0 D cylinder is rotated to 180 degrees (angle between of 90 degrees), the resulting residual cylinder is 2.0 D @ 90 degrees with an SEQ = 0 D. The magnitude of the residual astigmatism for orientations of the −1.0 D cylinder between 90 degrees and 180 degrees are given by 2 times the sine of the angle between the 2 IOLs:

$$\text{Residual cylinder} = 2 \times \sin(\text{angle between})$$

Table 1 summarizes the values for the residual magnitude for a misalignment from 0 to 90 degrees for the +1.0 D and −1.0 D cylinders. You can verify the values yourself on any lensometer by using these cylinders from a trial lens set. For any other magnitudes, the percentages might be multiplied by the original cylinder.

Most toric IOL misalignments are less than 30 degrees, so teachers and clinicians have simplified the relationship and said 100%/30 degrees is 3.3% per degree. We observe from Table 1, that, up to 30 degrees, this is approximately true: for every degree of misalignment, there will be an increase in the residual cylinder of 3.3% of the original. We also see from Table 1 that this 3.3% approximation becomes progressively less accurate above 40 degrees.

Therefore, assertions of the study by Nemeth that "only a 45-degree toric IOL misalignment leads to the total effect loss of cylindrical correction" and that "the first 10 degrees

Table 1. Residual cylinder for angular misalignment for +1.0 D and −1.0 D crossed cylinders.

Angular Misalignment (Degrees)	Residual Cylinder (D)*	% of Original Cylinder (D)
0	0.00	0
10	0.35	35
20	0.68	68
30	1.00	100
40	1.29	129
45	1.41	141
50	1.53	153
60	1.73	173
70	1.88	188
80	1.97	197
90	2.00	200

*Residual cylinder = 2 × sine (angle between).

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leads to a minimal to moderate effect loss" are both incorrect. At 30 degrees misalignment, the magnitude of the residual astigmatism is equal to the magnitude of the original astigmatism, so the patient sees no improvement. Above 30 degrees, the residual astigmatism exceeds the original astigmatism. In addition, the slope of the error curve is in fact steeper in the first 10 degrees and gradually diminishes; so, in fact, there is more, not less, effect per degree of misalignment at lower values. Again, this can be easily verified using plus and minus toric trial IOLs in a lensometer.

In addition, the toric IOL is almost never the perfect toricity (step sizes are usually 0.75 D of cylinder), so the residual cylinder will often be slightly larger for a given misalignment. The effect on visual quality (blur or defocus equivalent)[3,6] from the residual cylinder depends on not only the angle of misalignment but also the toricity of the IOL (amount of original astigmatism). The residual astigmatism is 6 times more for the same angular misalignment for 6 D of IOL toricity compared with 1 D of toricity.

We hope that this discussion clarifies the subject of residual astigmatism for toric misalignment. The open-access website for the preoperative toric calculator and the postoperative toric misalignment calculator implement all of the above-mentioned considerations.[A]

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Disclosures: *Neither author has a financial or proprietary interest in any material or method mentioned.*

Reply: I would like to thank Holladay and Koch for their valuable comments on my correspondence. I see that there are data in your material that are contradictory to my argument and that the interpretation looks slightly different.

The first criticism of my correspondence was that only a 45-degree toric IOL misalignment leads to a total effect loss of the cylindrical correction; however, 30-degree data are presented as fact in many scientific articles and brochures of toric IOLs. The second contentious point in my text was that the relationship between the toric IOL misalignment and the effect loss of the cylinder is nonlinear. The third point was that the first 10 degrees of misalignment lead to a minimal-to-moderate effect loss.

In the work by Alpins,[1] there is an outstanding theoretical description of the outcome of a thin-lens optical system of 2 cross-cylinders in such a situation of rotation. In that study, a graph shows that a 30-degree angle error leads to a 50% flattening index, and this index is 0 at only a 45-degree angle of error. However, if the relationship is described as the angle of error and the magnitude of the remaining astigmatism (as a percentage of preoperative magnitude), it can be seen that the value of the *y* axis is 100% at a 30-degree angle of error. In paper presented at the 2015 ESCRS Congress, George Beiko showed that the effect of misalignment can be different among different types of toric IOLs. For example, at 10 degrees of misalignment, an 18% loss was presented in the case of a specially designed toric IOL (Precizon, Ophtec), whereas, at 6 degrees of misalignment, the observed loss was 15% with a standard toric IOL (LENTIS, Oculentis). These measurements were performed using an objective intraoperative aberrometric tool, the ORA System (Alcon Laboratories, Inc.).

Tognetto et al. used an interesting objective measurement on an experimental eye model and presented a nonlinear relationship between the reduction of the quality of the image and the toric IOL rotation.[2] Their results showed that, after 30 degrees of toric IOL rotation, the reduction of the image quality was less than 50% and only reached the same image quality as that of no toric correction at 45 degrees. In the study by Tognetto et al., the authors call attention to the fact that their results are contrary to the suggested 100% reduction of image quality caused by toricity of IOL at 30 degrees misalignment and paralleled the vectorial 50% astigmatic loss at 30 degrees and a 100% loss at 45 degrees.

It seems that the strict "3.3% loss per 1 degree of misalignment" rule does not always hold true in objectively measured circumstances in relation to misalignment of a toric IOL. Of course, I can imagine that the "quality of image" or the "optical performance" in the work by Tognetto et al., the "flattening index" in the article by Alpins, the theoretical "tolerance in diopters" in your cited paper, and the "effect loss" are not all referring to exactly the same things in connection with this topic.

In most theoretical calculations, the cross-cylinders used to demonstrate the effect of misalignment are equal in diopters and have opposite powers. In addition, these cylinders are in the same optical plane. In an eye implanted with a toric IOL, that is, in a thick-lens system, the 2 main toric surfaces are the cornea and the toric IOL, separated by the anterior chamber. The toricities of the cornea and the toric IOL are obviously not equal in most clinical cases. Therefore, surely, the above-

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