

Efficacy evaluation of toric intraocular lens rotation after cataract surgery

In general, a 30-degree misalignment in rotation of a toric intraocular lens (IOL) results in a 100% residual astigmatism error in the magnitude of astigmatism, or in other words, there is no efficacy of the toric IOL in astigmatism correction.¹⁻³ On the other hand, there are reports that the efficacy of astigmatism correction becomes zero at 45 degrees misalignment.⁴⁻⁷ Based on an experiment by Tognetto et al.⁴ and the flattening index by Alpíns⁵, Németh⁷ stated that the efficacy of astigmatism correction could be zero at 45 degrees misalignment instead of 30 degrees misalignment. In this report, the effect on the efficacy of astigmatism correction caused by misalignment in rotation of the toric IOL was evaluated analytically, and the results were compared with simulation images.

The angular changes of corneal astigmatism and toric IOL occur in the form of a sinusoidal wave at 180-degree cycle. Figure 1 shows a graphical summation with no rotation, 30 degrees, and 45 degrees rotation to correct the entire -2 diopter (D) with-the-rule astigmatism.

The blue line shows the angular changes in corneal astigmatism, the yellow line shows the

angular changes in toric IOL correction, and the red line shows the angular changes in residual astigmatism after correction by the toric IOL. The residual astigmatism was linear when there was no postoperative misalignment (Figure 1A). When the postoperative misalignment was 30 degrees, the preoperative astigmatism of -2 D remained (Figure 1B). This means that the efficacy of astigmatism correction becomes zero with a 30-degree misalignment. It was also observed that the axial direction of the astigmatism changed. With-the-rule astigmatism turned into oblique astigmatism (30-degree astigmatism axis) with the same magnitude of astigmatism. Furthermore, when the postoperative misalignment was 45 degrees (Figure 1C), the residual astigmatism was -2.83 D at the astigmatic axis of 22.5 degrees, which was 1.41 times higher than preoperative astigmatism. The graphical analysis showed that postoperative astigmatism could be higher than preoperative corneal astigmatism at more than 30 degrees of IOL misalignment in rotation.

The formula for calculating the residual astigmatism caused by misalignment can be obtained using the vector summation method .³

$$C_R = \sqrt{C_P^2 + C_T^2 + 2C_P C_T \cos(2\alpha)}$$

$$y = \frac{C_R}{C_P} = \frac{\sqrt{C_P^2 + C_T^2 + 2C_P C_T \cos(2\alpha)}}{C_P}$$

If $C_T = AC_P$, then

$$y = \frac{\sqrt{C_P^2 + (AC_P)^2 + 2AC_P C_P \cos(2\alpha)}}{C_P}$$

C_R : Postoperative residual astigmatism (D)

C_P : Preoperative corneal astigmatism (D)

C_T : Cylinder power of toric IOL (D)
(at corneal plane)

α : Angle between corneal astigmatism axis
and IOL steepest meridian (°)

α of astigmatism correction is $90^\circ + \theta$

θ : Misalignment of toric IOL

A : Astigmatism correction rate

y : Ratio of postoperative residual astigmatism
and preoperative corneal astigmatism

$$y = \sqrt{A^2 + 1 + 2A \cos(2\alpha)}$$

$$y = \sqrt{(A - 1)^2 + 4A \cos^2(\alpha)}$$

In a special case when $C_P = C_T$ or $A = 1$, then

$$y = \sqrt{4 \cos^2(\alpha)}$$

The effectiveness of toric IOL correction is defined (Figure 1D) using the following equation:

$$Eff = (1 - y) \times 100\%$$

In the case of toric IOL to correct -2 D corneal astigmatism with 30 degrees misalignment and $y = 1$, the residual astigmatism remains -2 D and $Eff = 0\%$. There was no astigmatism correction. With 45 degrees misalignment, the residual astigmatism is -2.83 D and $Eff = -41.42\%$. The residual astigmatism increased 1.41 times higher than preoperative astigmatism.

In order to compare with the image of Tognetto et al.,⁴ we show the deterioration simulation image caused by rotational misalignment for a patient with -1.48 D with-the-rule astigmatism obtained using OPD SCAN (NIDEK) (Supplemental Figure 1, <http://links.lww.com/JRS/A205>).^A A toric IOL (Acrysof IQ SN6AT4 with 16.00 D) and a non-toric IOL (Acrysof SN60WF with 15.50 D) were simulated. At 30 degrees misalignment,

the image quality is equivalent to that of non-toric IOL (Non-toric IOL: -2.62 D, 30 degrees misalignment: -2.50 D). At 45 degrees misalignment, the image deteriorated further (Non-toric IOL: -2.62 D, 45 degrees misalignment: -3.51 D).

The simulation image using the artificial eye by Tognetto et al.⁴ became steeper in the rotation interval between 15 degrees and 20 degrees. 30 degrees of toric IOL rotation reduced the image quality to less than 50%, and 45 degrees of toric IOL rotation reduced the image quality to the same as no toric correction at all. This was contrary to the results of both our graphical analysis and image simulation.

In conclusion, from both the mathematical perspective and the results of image simulation, it is clear that the corrected astigmatism has no efficacy at 30 degrees misalignment, which indicates that postoperative residual astigmatism is equivalent to the value of astigmatism with non-toric IOL. Moreover, misalignment of over 30 degrees up to 90 degrees worsen residual astigmatism compared to the non-toric IOL.

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OTHER CITED MATERIAL

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Disclosures:

None of the authors has a financial or proprietary interest in any material or method mentioned.

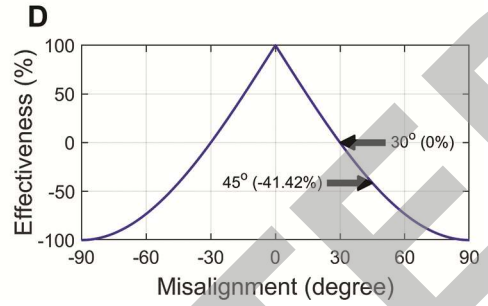
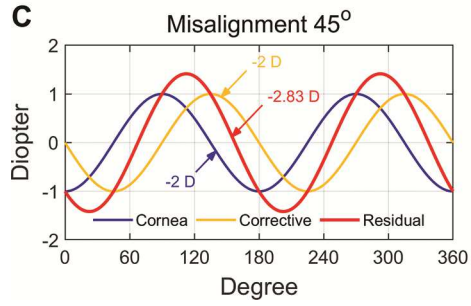
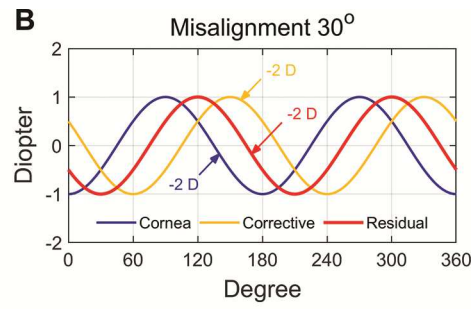
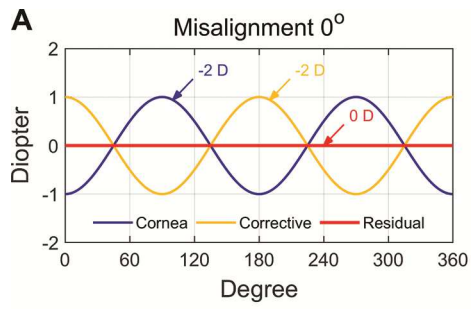
Figure Legends

Figure 1.

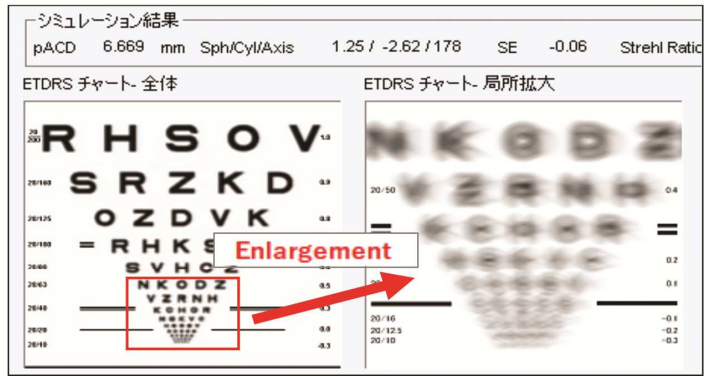
A: Graphical summation for toric IOL with no misalignment. B: Graphical summation for toric IOL with 30° misalignment. C: Graphical summation for toric IOL with 45° misalignment. D: Effectiveness of toric IOL as a function of misalignment angle when CP = CT (100% astigmatism corrections). Black arrows show the effectiveness with 30° and 45° misalignments.

Supplemental Figure 1.

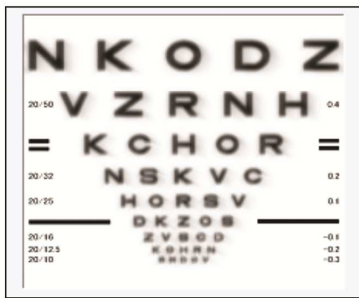
Deterioration of the simulated images caused by rotational misalignment for patient with with-the-rule astigmatism obtained using OPD scan.



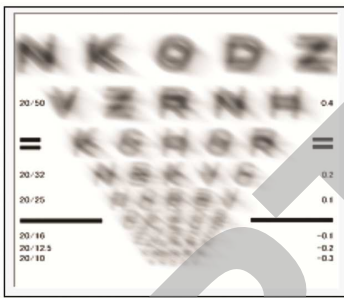
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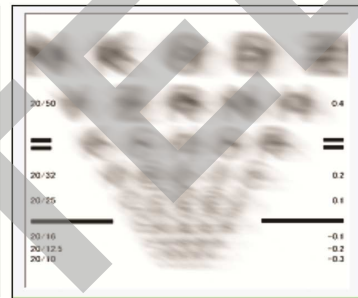
Non-toric
 178° (-2.62D)



No misalignment
 178° (-0.42D)



Misalignment 30°
 152° (-2.50D)



Misalignment 45°
 158° (-3.51D)

ACCEPTED