CORRESPONDENCE

Calculation of total surgically induced astigmatism with a toric intraocular lens

We previously published the formula and methodology for determining the total surgically induced astigmatism (SIA) for a nontoric intraocular lens (IOL).[1] It is also possible to determine the total SIA when a toric IOL is implanted, but the methodology requires use of the Gaussian vergence formula and usually involves cross-cylinder vector calculations. The following discussion provides the details for performing these calculations and determining the necessary rotation angle to the ideal orientation.

The first equation is the familiar thin lens Gaussian vergence equation for the power of the IOL from 5 other independent variables.[2]

$$IOL = \frac{1336}{AL_o - ELP_x} - \frac{1336}{\dfrac{1336}{\dfrac{1000}{\dfrac{1000}{DPostRx} - V} + K_r} - ELP_x} \qquad (1)$$

Here, IOL = intraocular lens power in diopters, AL_o = optical axial length in millimeter, ELP_x = expected lens position in millimeter (distance from the corneal vertex to the principal plane of the thin IOL, Holladay 1 formula used in Table 1),[3] DPostRx = desired postoperative refraction in diopters, V = vertex distance of refractions in millimeter, and K_r = net corneal power in diopters, K_r, the net corneal power varies depending on the IOL formula used. We use the original Binkhorst ratio of [(1000/3)/337.5] to compensate for the steeper posterior curve of the cornea that reduces the net power of the cornea by approximately 0.56 diopters compared with its keratometric front surface power (K_k).[2] AL_o, the optical axial length, is also the Binkhorst modification, which is the measured AL_m plus 0.2 mm. Although this should not be necessary with optical biometry (interferometry), because it includes retinal thickness, the instrument was calibrated using immersion A-scan to preserve the lens constants, so the adjustment is still valid. We can rearrange equation 1, solving for DPostRx, which allows us to predict the exact refraction from available IOL powers (Equation 2).

$$DPostRx = \frac{1000}{\dfrac{1000}{\dfrac{1336}{\dfrac{1336}{\dfrac{1336}{AL_o - ELP_x} - IOL} + ELP_x} - K_r} + V} \qquad (2)$$

The determination of the total SIA for a toric IOL requires solving the vergence equation for K_r.

$$K_r = \frac{1336}{\dfrac{1336}{\dfrac{1336}{AL_o - ELP_x} - IOL} + ELP_x} - \frac{1000}{\dfrac{1000}{APostRx} - V} \qquad (3a)$$

Table 1. Numeric example.

Parameter	Description	Value
IOL	Spherical equivalent intraocular lens power (D)	30.000000
Al_m	Measured axial length (AL_o = AL_m + 0.2 mm)	21.100000
AL_o	Optical axial length (mm)	21.300000
ELP_x	Effective lens position (mm), Holladay 1 formula used	4.973701
DPostRx	Desired postoperative refraction (D)	−0.009214
V	Vertex distance of refraction (mm)	12.000000
K_k	Keratometric power of the cornea (D)	44.000000
K_r	Spherical equivalent net power of the cornea (D)	43.456790
$\overrightarrow{IOL}$	Actual SEQ power (D), toricity (D), and observed axis (°)	30.000000 3.000000 × 180.000000°
$\overrightarrow{APostRx}$	Actual postoperative refraction vector at V (D)	+1.360960 −2.797141 × 21.612421°
$\overrightarrow{\text{Pre-op } K_k}$	Actual preoperative keratometry vector (D)	42.920000 @ 45.000000° 45.080000 @ 135.000000°
Act $\overrightarrow{\text{back-calc } K_k}$	Actual back-calculated K_k vector (D)	43.030131 @ 46.063639° 44.969869 @ 136.063639°
$\overrightarrow{\text{Total SIA}}$	Total surgically induced astigmatism vector at V (D)	+0.116502 −0.233004 @ 126.000000°
Predicted $\overrightarrow{\text{back-calc } K_k}$	Predicted back-calculated K_k vector (D)	43.030131 @ 46.063639° 44.969869 @ 136.063639°
Rotation angle	Necessary rotation angle (°) to ideal orientation	43.936361° clockwise

IOL = intraocular lens; SEQ = spherical equivalent

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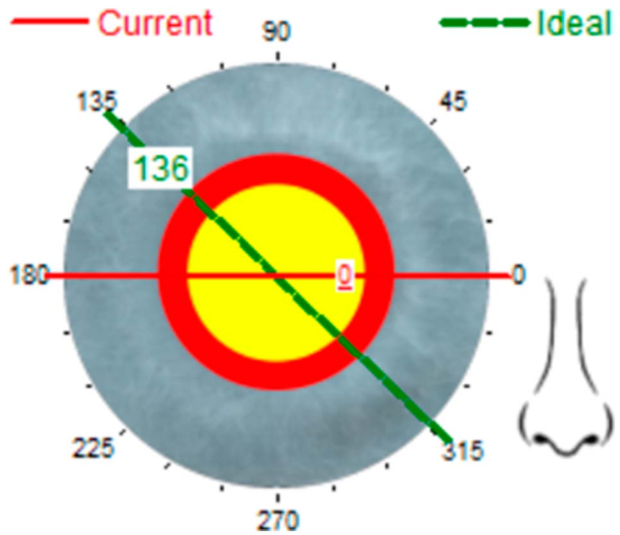

Figure 1. Current (180°) in *red* and ideal (136°) axis in *green* of the intraocular lens after 44° clockwise rotation.

This equation uses the actual postoperative refraction (APostRx) and actual implanted IOL power to determine the back-calculated K_r. It is the back-calculated K_r that is consistent with the other 5 variables. It is the K_r that predicts the actual postoperative refraction for a given IOL, AL_o, and ELP_x.

Although the vergence equations are usually written with scalar values (spherical equivalent powers), they may also be written as vectors for K_r, toric IOL, and APostRx using doubled angles for the meridian or axes.[4,5]

$$\overrightarrow{\text{Actual back-calc } K_r} = \frac{1336}{\dfrac{1336}{\dfrac{1336}{AL_o - ELP_x} - \overrightarrow{IOL}} + ELP_x} - \frac{1000}{\dfrac{1000}{\overrightarrow{APostRx}} - V} \quad (3b)$$

When the actual toric IOL (magnitude, toricity, and observed orientation) and the actual postoperative refraction are aligned (same axis or 90° apart), then the calculation may be done in both principal meridians using the scalar values in each meridian. In most cases, however, the 2 vectors are not aligned, and the calculation must be done using a cross-cylinder calculation. Once the actual back-calculated K_r vector is determined, the actual back-calculated K_k is simply the magnitudes of the K_r vector multiplied by [337.5/(1000/3)], the inverse of the net K calculation.

$$\overrightarrow{\text{Back-calc } K_k} = \overrightarrow{\text{back-calc } K_r} \times 337.5/(1000/3) \quad (4)$$

It is important to note that the actual back-calculated K_k is derived from the actual observed axis of the toric IOL (not the intended) and the actual postoperative refraction. It is the only K_k that is consistent with these values. Once the actual back-calculated K_k vector is determined, the actual total SIA is the difference between these 2 vectors. The total SIA is akin to a Jackson cross-cylinder, that is, it has a spherical equivalent of zero and the cylinders are orthogonal, equal power and opposite sign.

$$\overrightarrow{\text{Total SIA}} = \overrightarrow{\text{back-calc } K_k} - \overrightarrow{\text{pre-op } K_k} \quad (5a)$$

When a dataset of values is available (including the observed axis of the IOL), the cases may be grouped by the magnitude and meridian of the preoperative keratometry and the centroid (mean vector) may be calculated for each group, thus generating a total SIA vector, specific for every patient.[1] This centroid or mean vector is then used to calculate the predicted back-calculated K_k, which is used in the forward toric IOL calculation for a new patient.

$$\text{Predicted } \overrightarrow{\text{back-calc } K_k} = \overrightarrow{\text{pre-op } K_k} + \overrightarrow{\text{total SIA}} \quad (5b)$$

The total SIA is the vector that when added to the pre-op K_k predicts the back-calculated K_k and, in turn, the predicted ideal axis of the toric IOL (Figure 1) and predicted postoperative refraction. Postoperatively, the difference in the observed axis and the ideal axis is how much the toric IOL must be rotated to achieve the minimum residual astigmatism. The residual refraction at the ideal axis may be determined from Equation 2 and does not require a vector calculation because it is assumed that the toric IOL will be aligned with the steep axis of the back-calculated K_k and a scalar calculation in each principal meridian is all that is necessary.

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