Digital overlay technique for documenting toric intraocular lens axis orientation

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ABSTRACT

Purpose: To describe a digital overlay technique for documenting toric intraocular lens (IOL) axis alignment.

Setting: Jules Stein Eye Institute and the Department of Ophthalmology, University of California at Los Angeles School of Medicine, Los Angeles, California, USA.

Methods: Digital overlay imaging was used to evaluate the alignment of Staar toric IOLs in 4 eyes of 3 patients who had regular corneal astigmatism at the time of cataract surgery. Lens axes were determined by computerized analysis of digitally scanned retroillumination photographs. A stock digital image of a Staar AA4203TF toric IOL was superimposed on corneal topography images to document IOL alignment with the steep corneal meridian.

Results: Digital overlay images demonstrated that 3 IOLs in the sample group were within 5 degrees and 1 was within 20 degrees of the intended axis at the time of the final postoperative examination. Slitlamp lens axis estimations were 3 to 18 degrees different from that determined by this technique.

Conclusion: Digital overlay imaging of correctly oriented toric IOLs on computerized corneal topography maps represents an intuitive, accurate, and visually appealing method of documenting toric IOL axis alignment. *J Cataract Refract Surg 2000; 26: 1496–1504 © 2000 ASCRS and ESCRS*

With the widespread availability of toric intraocular lenses (IOLs), it is possible to correct astigmatism in many cataract patients and achieve better spectacle-free distance vision through a single small incision procedure. Accurate axis alignment and rotational stability of the toric IOLs are critical to the efficacy of surgery. Optimal astigmatic correction requires precise IOL axis alignment with the steep corneal meridian. Any degree of IOL axis misalignment will lead to a suboptimal result.

Theoretical and experimental evidence indicates that the maximum acceptable limit for toric IOL axis rotation is 30 degrees from the intended axis.[1] Beyond this amount, the axis of manifest residual astigmatism rotates while the magnitude stays the same or increases. Studies of 3-piece poly(methyl methacrylate) IOLs found that rotation seldom occurs beyond the immediate postoperative period.[2] However, given that lens encapsulation and lens rotational stability may vary with lens material and design, similar stability may not necessarily apply to the foldable single-piece silicone lenses used in our current study.

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Although no scientific data on the rotational stability of the Staar Surgical single-piece toric IOL (Staar AA4203TF) have been published, unpublished data from Staar's prospective multicenter clinical study found that 76% of lenses remained within 10 degrees, while 92% remained within 30 degrees of the intended axis. The Staar study also found that axis misalignment within 30 degrees resulted in partial astigmatism reduction. Axis misalignment of 45 degrees or more occurred in only 5% of study eyes and resulted in significantly increased residual cylinder. The AA4203TF has a 10.8 mm haptic diameter. Recently, a Staar toric IOL with a longer haptic diameter of 11.2 mm (Staar AA4203TL) was introduced to, theoretically, increase rotational stability (unpublished results, Staar Surgical Co.).

Currently, toric IOL orientation is assessed strictly by rough estimation of IOL position during a dilated slitlamp examination. Although this technique in the eyes of an experienced clinician may closely approximate the relation between the actual and the desired IOL orientation, it is inherently subjective. Moreover, this technique does not assess IOL alignment with respect to postoperative shift in the steep corneal meridian as a result of surgically induced changes in corneal astigmatism. In this article, we describe a method for accurately determining toric IOL alignment by overlaying a stock toric IOL image on preoperative and postoperative corneal topography maps.

Patients and Methods

To demonstrate the use of the digital overlay technique, we selected 4 eyes of 3 patients with regular preexisting corneal astigmatism who had cataract extraction and implantation of a Staar toric IOL (model AA4203TF). These single-piece, plate-haptic, foldable, posterior chamber silicone IOLs have varying spherical power, an overall diameter of 10.8 mm, and a cylinder power of +2.00 diopters (D) or +3.50 D. The lenses are designed with large positioning holes to decrease IOL decentration and dislocation.[3,4]

Precisely oriented lenses with cylindrical powers of +2.00 D and +3.50 D neutralize +1.40 D and +2.30 D of astigmatism in the corneal plane, respectively. The lenses are designed for implantation with their axis tick marks aligned with the steep axis of corneal astigmatism. Rotation from this position decreases the cylindrical correction as previously described.[1] Eyes with +1.50 to +2.25 D of corneal astigmatism are implanted with +2.00 D toric IOLs, while eyes with greater than +2.25 D of corneal astigmatism are implanted with +3.50 D toric IOLs.

For each patient, corneal topography was recorded 1 to 4 weeks preoperatively, 2 weeks postoperatively, and 2 weeks after repositioning (if applicable) using a computer-assisted videokeratoscope, the Topographic Modeling System-1 (TMS-1, Computed Anatomy Inc.). Computerized videokeratography (CVK) was performed by an experienced ophthalmic technician. Preoperative planning relied on CVK to determine the axis and power of corneal astigmatism to be corrected.

The patients had uneventful cataract extraction and IOL implantation under monitored topical anesthesia by a single surgeon (K.M.M.). The operative procedure consisted of a 2.6 mm clear corneal incision, circular tear capsulorhexis, Kelman phacoemulsification, IOL injection into the capsular bag, and sutureless wound closure. Clear corneal incisions were placed in the steep axis of corneal astigmatism (patients 1 and 3, left eyes) unless narrow lid fissures or deep-set eyes made a temporal approach more practical (patients 2 and 3, right eyes). The axis marks on the toric IOLs were aligned with the steep corneal meridian, determined by CVK.

Evaluation 2 weeks after surgery included manifest refraction, corneal topography, dilated slitlamp examination, and slitlamp retroillumination photography. Intraocular lenses significantly off axis during the examination were repositioned by reopening the clear corneal incision, freeing the capsular synechias, and reorienting the IOL in the new intended axis, determined by postoperative CVK. Eyes that had repositioning surgery had another evaluation 2 weeks postoperatively.

To document IOL orientation, retroillumination photographs were scanned digitally, and the IOL axes were determined using Adobe PhotoShop® 5.0 software (Figure 1). The TMS-1 corneal topography maps were converted to graphics files using Pizazz Plus 227 Computed Anatomy software. A stock digital image of a Staar AA4203TF toric IOL was oriented in the measured axis and superimposed on the appropriate preoperative and postoperative corneal topography maps. A graphic artist unfamiliar with the purpose of the study

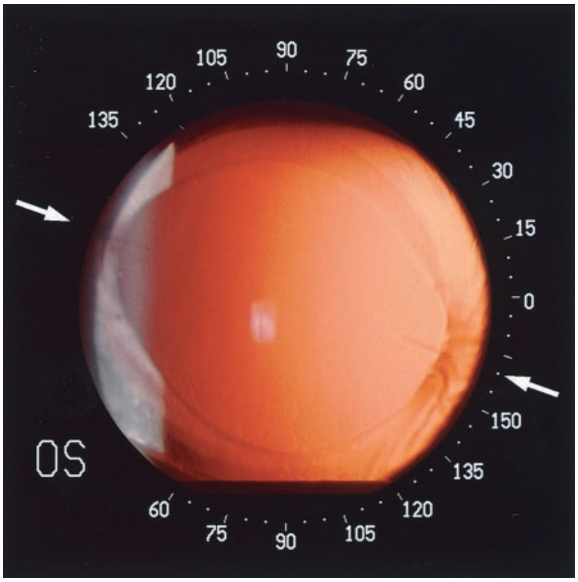

Figure 1. (Nguyen) A digitally scanned retroillumination photograph shows peripheral IOL axis marks in relation to the axis scale. Computer-assisted axis determination identified this lens angle to be at 162 degrees.

performed the digital imaging and computer-assisted axis determinations.

Patient 1

A 74-year-old woman with preexisting against-the-rule (ATR) astigmatism had cataract extraction and Staar toric IOL implantation in her left eye in January 1999. Preoperative manifest refraction was +2.00 +1.75 × 16, resulting in a best corrected visual acuity (BCVA) of 20/25. Preoperative corneal topography revealed the steep meridian to be at 165 degrees. Simulated keratometry values were 44.4/46.2 × 153, indicating +2.20 D of corneal astigmatism. The IOL had a spherical power of 21.50 D and a cylinder power of +2.00 D. Postoperative BCVA improved to $20/20^{+3}$ with a manifest refraction of −0.25 +0.50 × 154. Postoperative corneal topography revealed an 0.80 D decrease in cylinder power with no change in axis. Upon dilated slitlamp examination, the IOL axis was estimated by the surgeon to be at 165 degrees.

Patient 2

A 74-year-old woman with preexisting with-the-rule (WTR) astigmatism had cataract surgery in her left eye in January 1999. Her preoperative BCVA was $20/25^{-1}$ with a manifest refraction of −7.00 +2.00 × 105. Preoperative corneal topography revealed the steep meridian at 95 degrees. Simulated keratometry values were 44.7/46.8 × 112, indicating +2.10 D of corneal astigmatism. The IOL had a spherical power of 15.50 D and a cylinder power of +2.00 D. Postoperative BCVA improved to $20/20^{-3}$ with a manifest refraction of −0.75 +0.50 × 140. Postoperative corneal topography revealed a 0.70 D increase in cylinder power but no change in axis. Upon dilated slitlamp examination, the IOL axis was estimated by the surgeon to be in the 95 degree meridian.

Patient 3

A 78-year-old man with preexisting WTR astigmatism had cataract surgery in his right eye in March 1999 and in his left eye in April 1999. The patient's history was complicated by age-related macular degeneration and, more important, severe keratoconjunctivitis sicca that improved only after bilateral upper and lower canalicular electrocauterization in January 1999. Moreover, the postoperative course of each eye was complicated by significant IOL rotation, resulting in substantial residual astigmatism.

Right eye. Preoperative BCVA in the right eye was $20/70^{-1}$ with a manifest refraction of +1.25 +2.00 × 75. Preoperative corneal topography revealed the steep meridian at 85 degrees. Simulated keratometry values were 42.2/45.0 × 97, indicating +2.80 D of corneal astigmatism. The IOL had a spherical power of 22.00 D and a cylinder power of +3.50 D. It was positioned in the eye in the 85 degree meridian. Postoperative BCVA improved to $20/50^{-2}$ with a manifest refraction of −1.50 +2.50 × 103. Postoperative corneal topography demonstrated an 0.80 D decrease in cylinder power and a slight shift in axis toward the 90 degree meridian. On dilated slitlamp examination 2 weeks postoperatively, the IOL was approximately 40 degrees off axis in the 45 degree meridian. This malrotation accounted for the measured increase in refractive astigmatism.

The patient had successful IOL repositioning into the 90 degree axis 3 weeks after the initial surgery. Manifest refraction 3 weeks after repositioning was −1.00 +1.00 × 110, resulting in a BCVA of 20/50 (limited by macular degeneration). Repeat corneal topography demonstrated a 1.80 D increase in cylinder power (over preoperative astigmatism) and an axis shift back toward the 85 degree meridian. Upon dilated slitlamp examination, the IOL was estimated by the surgeon to be in the 85 degree meridian, 5 degrees from the intended axis.

Left eye. Preoperative BCVA in the left eye was $20/40^{-2}$ with a manifest refraction of -2.25 $+4.00$ $\times$ 97. Preoperative corneal topography revealed the steep meridian to be near the 105 degree axis. Simulated keratometry values were 41.8/45.9 $\times$ 111, indicating $+4.10$ D of corneal astigmatism. The IOL had a spherical power of 19.00 D and a cylinder power of $+3.50$ D. It was positioned in the eye at 105 degrees. Postoperative manifest refraction yielded a BCVA of $20/25^{+}$ with a manifest refraction of -2.00 $+4.25$ $\times$ 95. Postoperative corneal topography showed an axis shift toward the 90 degree meridian but no significant change in cylinder power. On dilated slitlamp examination 2 weeks postoperatively, the IOL was rotated approximately 85 degrees off axis into the 20 degree meridian, accounting for the increase in residual astigmatism.

The patient had IOL repositioning 3 weeks after initial implantation. Capsule synechias and contraction prevented precise IOL repositioning at 105 degrees, and the IOL was left in the overrotated axis of 120 degrees after some effort. Manifest refraction 2 weeks after the repositioning resulted in a BCVA of $20/20^{-2}$ with a refraction of plano $+1.25$ $\times$ 60. Repeat topography demonstrated a 1.60 D decrease in corneal astigmatism over preoperatively but no further change in axis. Two weeks after the IOL was repositioned, the surgeon estimated the IOL to be in the 105 degree meridian.

Results

Composite digital images were produced showing a stock toric IOL image overlaid on preoperative and postoperative corneal topography maps in the measured axis orientation. Composite images after repositioning were produced for the right eye of patient 3.

Patient 1

Computer-assisted axis determination revealed the IOL to be oriented in the 162 degree axis. Digital overlay images (Figure 2) demonstrated excellent alignment (within 5 degrees) of the toric IOL with the steep corneal meridian. The reduction in refractive cylinder was further evidence of proper IOL alignment. Slitlamp estimation of the IOL axis was within 3 degrees of the computer-assisted axis determination.

Patient 2

Computer-assisted axis determination revealed the IOL to be oriented in the 92 degree axis. Digital overlay images (Figure 3) documented excellent IOL alignment (within 5 degrees) with the steep corneal meridian. Slitlamp estimation of the IOL axis was within 3 degrees of the computer-assisted axis determination.

Patient 3

Right eye. Computer-assisted axis determinations of the IOLs before and after they were repositioned were 27 and 78 degrees, respectively. Digital overlay images of the toric IOL in the axes before and after repositioning showed misalignment (60 degrees off axis) and proper alignment (within 5 degrees), respectively (Figure 4). Although the IOL rotated slightly from the repositioned axis of 90 degrees, the modest IOL rotation was partially offset by a concomitant surgically induced shift in the axis of corneal astigmatism. These concomitant changes in IOL orientation and corneal topography resulted in excellent axis alignment. Slitlamp estimations of the IOL axes before and after repositioning were within 18 and 7 degrees of the computer-assisted axis determinations, respectively.

Left eye. Computer-assisted axis determinations of IOLs before and after repositioning IOLs were 9 and 110 degrees, respectively. Digital overlay images of the toric IOL axes before and after repositioning showed the misalignment (85 degrees off axis) and approximate alignment (within 20 degrees), respectively (Figures 5). In contrast to the outcome in the right eye, a postoperative shift in the steep axis of corneal astigmatism resulted in a final axis deviation of 20 degrees versus a potential deviation of 5 degrees. These 2 examples show the importance of serial corneal topography in documenting IOL axis alignment. Slitlamp estimations of IOL axes before and after repositioning were within 11 and 5 degrees of the computer-assisted axis determinations, respectively.

Discussion

Essential to the effectiveness of toric IOLs are precise alignment and rotational stability. The conven-

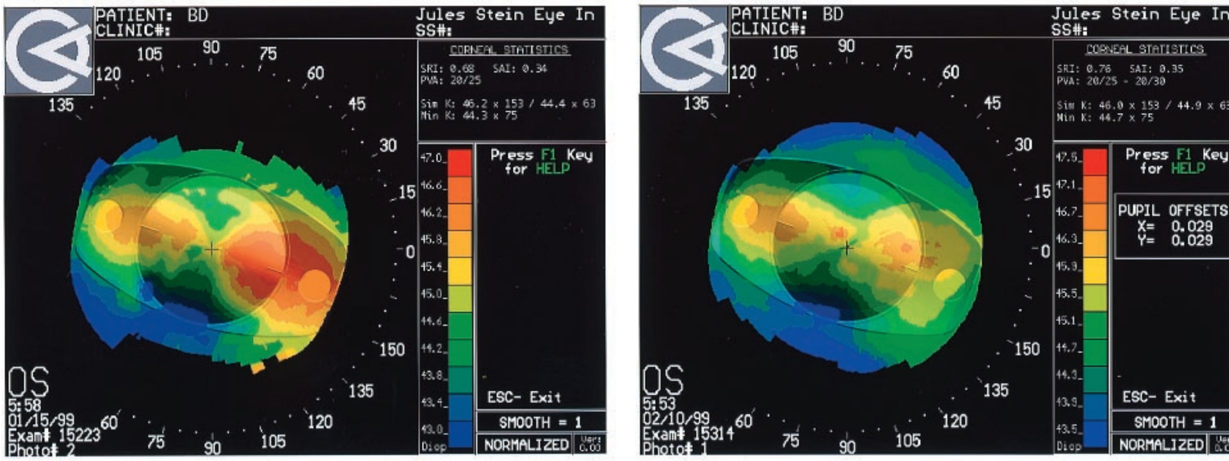

Figure 2. (Nguyen) Digital overlay images of the left eye of patient 1 show excellent IOL axis alignment (within 5 degrees) with the preoperative (*left*) and postoperative (*right*) steep corneal meridian.

tional method of evaluating postoperative IOL orientation is careful estimation of the IOL axis during dilated slitlamp examination. The relative accuracy of this technique, however, is subject to the observer's experience and bias and has inherent precision limits. In our 4 eyes, slitlamp estimations by an experienced clinician differed 3 to 18 degrees from computer-assisted axis determinations. Although manifest refraction may help assess IOL axis alignment indirectly, residual cylinder on manifest refraction is actually the vector sum of lens astigmatism and postoperative corneal astigmatism. Calculating lens astigmatism by working backward from manifest astigmatism and corneal astigmatism is computationally difficult and subject to errors of central adaptation.

Our computer-assisted technique of determining the IOL axis and the method of superimposing the image of a stock IOL on the preoperative and postoperative corneal topographies represent a direct, visual, and intuitive means of assessing IOL axis orientation with the steep corneal meridian. This method allows rapid, precise, and accurate interpretation of IOL axis orientation and can be used to document proper IOL alignment or guide necessary IOL realignment. Overlaying the toric IOL on both preoperative and postoperative corneal topographies shows the IOL position in relation to both the planned and resulting axes. Including the postoperative topography map in the analysis makes it possible to account for surgically induced changes in corneal astigmatism and their effect on IOL efficacy.

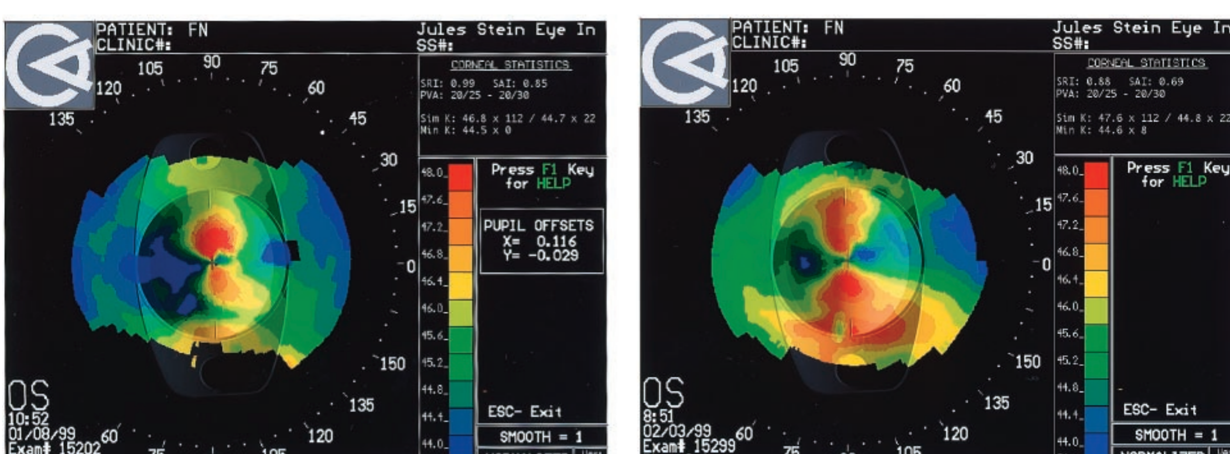

Figure 3. (Nguyen) Digital overlay images of the left eye of patient 2 show excellent IOL axis alignment (within 5 degrees) with the preoperative (*left*) and postoperative (*right*) steep corneal meridian.

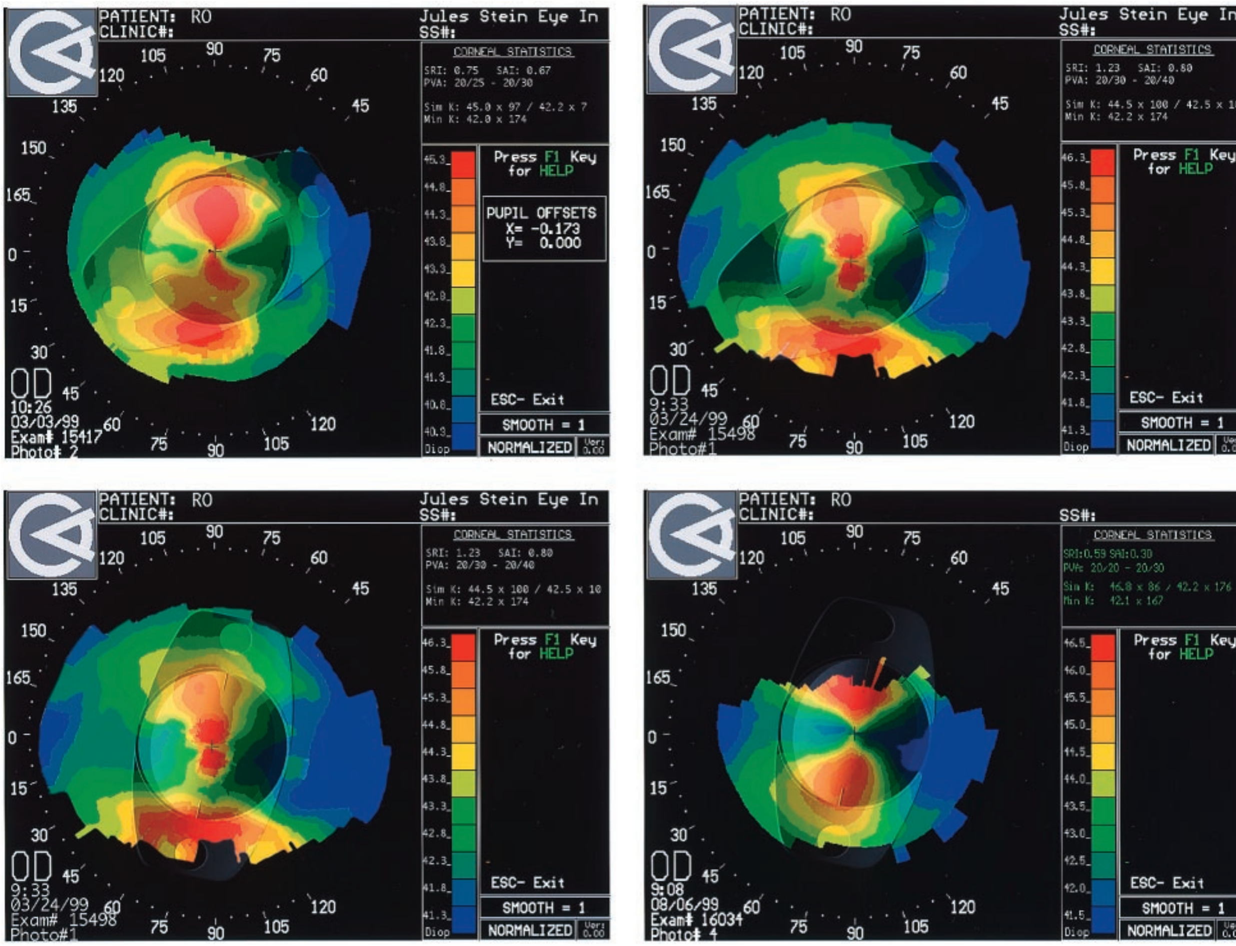

Figure 4. (Nguyen) Digital overlay images of the right eye of patient 3 show IOL axis misalignment (60 degrees off axis) with the preoperative (*top left*) and postoperative (*top right*) steep corneal meridian. Digital overlay images using the repositioned IOL axis show approximate alignment (within 10 degrees) and excellent alignment (within 5 degrees) with the initial postoperative (*bottom left*) and postrepositioning (*bottom right*) steep corneal meridian, respectively.

In our study, CVK rather than keratometry was used to plan toric IOL placement. Computerized videokeratography maps the entire corneal surface using more than 6500 data points, while keratometry only measures 4 points on the central 3.0 mm of the cornea.[5–8] Computerized videokeratography-derived simulated keratometry values closely correlate with measurements derived from conventional keratometry.[5] Although the relative merits of CVK and keratometry in calculating IOL power are still disputed,[6,7] the increased data, broader area of study, and lack of false assumptions regarding corneal symmetry make CVK theoretically superior to keratometry in assessing corneal astigmatism.[5–8] Moreover, corneal topography allows rapid visual assessment of the steep corneal meridian and of surgically induced changes in astigmatism.

Corneal, rather than refractive, astigmatism is used in selecting the cylinder power of the IOL to avoid lenticular astigmatism and vertex distance variability.[9] A 2.6 mm corneal incision and sutureless wound closure minimize surgically induced astigmatism[10–12] and ensure relatively predictable postoperative corneal astigmatism. Of the 4 eyes studied, only 1 had an appreciable change in axis of corneal astigmatism, as seen on corneal topography. Although this shift may truly represent surgically induced astigmatic changes, it may simply reflect distortion from this patient's severe corneal dryness. Regardless of the etiology, this topographic change illustrates the aforementioned importance of serial corneal topography in documenting any postoperative change in corneal astigmatism and its effect on IOL alignment.

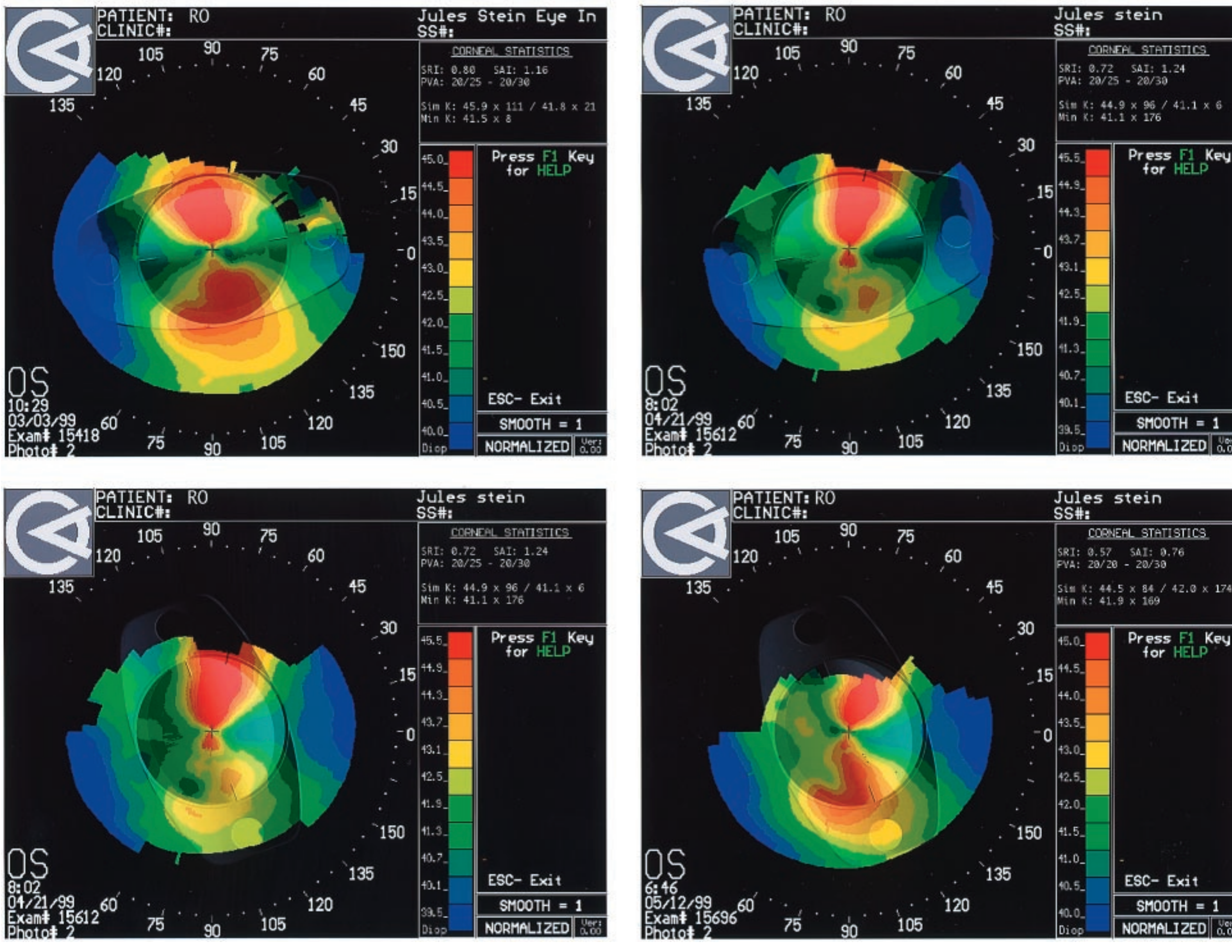

Figure 5. (Nguyen) A digital overlay image of the left eye of patient 3 shows IOL axis misalignment (more than 80 degrees off axis) with the preoperative (*left*) and postoperative (*right*) steep corneal meridian. Digital overlay images using the repositioned IOL axis show improved alignment (within 20 degrees) with the initial postoperative (*bottom left*) and postrepositioning (*bottom right*) steep corneal meridian.

The efficacy of toric IOLs depends on the accuracy of the axis alignment. The unpublished Staar U.S. Food and Drug Administration study reports that axis misalignment within 30 degrees results in partial cylinder reduction, while axis misalignment of 45 degrees or more exacerbates residual astigmatism. These findings are consistent with those of Guyton's classic guidelines on prescribing spectacle cylinder correction.[13] Essentially, the magnitude of residual astigmatism is unchanged when the correcting cylinder is rotated 30 degrees from the intended axis and doubled when rotated 90 degrees. Using the mathematics of obliquely crossed cylinders, the amount of residual astigmatism can be calculated to be approximately equal to $2C\sin\theta$, where C is the dioptric value of corrective cylinder and θ is the angle of axis malrotation.[13]

The efficacy of toric IOLs also depends on their rotational stability. If lenses rotate off axis in the long term, repositioning in the immediate postoperative period may be counterproductive. Although studies of 3-piece IOLs suggest long-term rotational stability[2] and a maximum tolerable axis shift of less than 30 degrees,[1] there are no published reports on the characteristics of single-piece toric IOLs. The Staar report maintains that 76% of lenses (Staar AA4203TF) remained within 10 degrees and 92% remained within 30 degrees of the intended axis.

Because the amount of meridional magnification and distortion from cylindrical lenses is a function not only of cylindrical power but also of distance from the entrance pupil,[13] the close proximity of the IOL virtually eliminates these problems. Toric IOLs, therefore, have the potential to correct postoperative astigmatism fully without the use of spectacles and thus without meridional magnification or distortion. In addition, inherent advantages over astigmatic keratotomy or limbal relaxing incisions are greater patient comfort and better refractive stability.

Intraocular lens axis errors produce residual astigmatism of altered axis and power. Therefore, although IOL axis rotations alone do not produce appreciable distortion, they may give rise to a new problem of correcting residual oblique astigmatism, a task less favorable than that of correcting original pre-existing WTR or ATR astigmatism. As a result of the dominant effect of vertex distance on distortion, the direction and amount of meridional magnification and distortion are determined primarily by the axis and power of the spectacle lens itself.

Binocular visual distortion tends to be worst when the correcting cylinder axis is at 45 or 135 degrees.[13] Because oblique distortion disturbs binocular vision more than vertical or horizontal distortion, in affected spectacle wearers, the power of the cylinder correction should be reduced or the axis of the correction rotated toward 90 or 180 degrees. These maneuvers, while reducing distortion, may increase blur from residual astigmatism and decrease visual acuity. Hence, while toric IOLs may correct preexisting astigmatism without meridional magnification or distortion when oriented properly, they may induce more severe residual oblique astigmatism when oriented incorrectly. Additional studies are necessary to determine how much IOL rotation will be tolerated, on average, before residual oblique astigmatism is a clinical problem.

Other important issues in toric lens positioning are centration and tilt. Recent studies suggest that plate-haptic single-piece silicone IOLs with the larger 1.15 mm positioning holes may be more resistant to decentration than 3-piece IOLs.[3,4] Although IOL decentration can easily be measured and demonstrated using our digital overlay technique, we currently have no rapid visual means of displaying IOL tilt. However, documentation of IOL tilt is likely to be of less significance. Others have shown that IOL tilt of 20 degrees or more is required before significant astigmatism is induced, making such tilt an unlikely source of unwanted postoperative astigmatism.[14]

The digital overlay technique represents a direct, accurate, and visual means of documenting IOL alignment, but problems remain. Potential errors in lens angle calculations as well as in corneal axis determinations may arise from head tilt during slitlamp photography or CVK. Werblin[2] studied this source of error and found an overall range of 6 degrees of variation in lens orientation. He also suggests that the tendency for patients to blink their eyes when photographed may invoke Bell's phenomenon, which has a torsion component. Error may further arise from imprecise framing of the photographic slides or from imprecise alignment during digital scanning. Despite these inherent problems, digital overlay of stock toric IOLs on corneal topography appears to represent an accurate, visual method of evaluating and documenting IOL axis alignment.

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Dr. Miller owns stock in Staar Surgical Co. Dr. Nguyen has no financial interest in any product mentioned.