ARTICLE

Accuracy of toric intraocular lens implantation in cataract and refractive surgery

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PURPOSE: To determine the accuracy of a commonly used 3-step procedure for toric pseudophakic and phakic intraocular lens (IOL) implantation.

SETTING: University Eye Clinic, Maastricht University Medical Centre, Maastricht, The Netherlands.

DESIGN: Cohort study.

METHOD: In this analysis of toric IOL implantation, 6 preoperative images of the eye per patient and the surgery video were obtained using a digital imaging system. All 3 steps for toric IOL implantation were analyzed as follows: reference axis marking, alignment axis marking, and IOL alignment. In addition, vector analysis was used to calculate the errors in toric IOL alignment.

RESULTS: Forty eyes (26 pseudophakic, 14 phakic) were analyzed. The mean errors in reference axis marking, alignment axis marking, and toric IOL alignment were 2.4 degrees $\pm$ 0.8 (SD), 3.3 $\pm$ 2.0 degrees, and 2.6 $\pm$ 2.6 degrees, respectively. Together, these 3 errors led to a mean total error in toric IOL alignment of 4.9 $\pm$ 2.1 degrees. Subgroup analysis showed no significant difference in mean error between pseudophakic IOL and phakic toric IOL alignment ($P = .501$). Vector analysis showed a mean angle or error of -2 ± 8 degrees (pseudophakic IOLs) and 6 ± 14 degrees (phakic IOLs).

CONCLUSIONS: A commonly used 3-step ink-marker procedure to implant toric IOLs led to a mean error in IOL placement of approximately 5 degrees. The error was especially relevant in cases in which higher cylinder power IOLs were implanted. Orienting the toric IOL with great accuracy is necessary in all patients to achieve the best cylinder correction.

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Toric pseudophakic intraocular lenses (IOLs) and toric phakic IOLs (pIOLs) are increasingly used in cataract and refractive surgery. They provide the opportunity to correct preexisting astigmatism, offering patients optimum distance vision without the use of spectacles or contact lenses. Among the options of regularly used toric pseudophakic IOLs are the Acrysof (Alcon Laboratories, Inc.), the Acri.Comfort and Acri.Lisa multifocal (both Carl Zeiss Meditec AG), and the T-flex and multifocal M-flex T (both Rayner Intraocular Lenses, Ltd). The options for toric pIOLs include the Artisan and foldable Artiflex (Ophtec BV) and the toric Implantable Collamer Lens (Staar Surgical Co.).

Crucial to the efficacy of all toric IOLs is the position of the IOL with regard to the intended alignment axis because every degree of misalignment leads to residual astigmatism. Misalignment of the IOL can be caused by inaccurate placement of the IOL, rotation of the IOL, or both. Rotational stability used to be an issue in toric pseudophakic IOLs made of silicone.[1–4] However, many currently used pseudophakic IOLs are acrylic and the reported postoperative rotation rate of these IOLs is less than 1 degree.[5] Because of their design and fixation technique, rotation appears not to be an issue with iris-fixated toric pIOLs.[6] This indicates that with both toric pseudophakic and pIOLs, accurate placement of the IOL is the most important factor in avoiding misalignment.

There are several methods to align the toric IOL at the intended axis.[2,7–11] However, most methods follow a 3-step procedure. First, the horizontal axis (0 to 180 degrees) of the eye is marked preoperatively with the patient sitting upright to correct for cyclotorsion. This is usually done using a reference marker or

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a slitlamp with a rotating slit. Next, intraoperatively, the desired alignment axis for the toric IOL is marked with an angular graduation instrument. Finally, the toric IOL is implanted and rotated until the IOL markings agree with the alignment marks.

The purpose of this study was to determine the accuracy of a commonly used 3-step ink marker procedure for toric pseudophakic and pIOL implantation using a new digital imaging system. In addition, vector analysis was performed to provide parallel mathematic confirmation of the physical accuracy of toric IOL alignment.

PATIENTS AND METHODS

Study Design and Patient Population

In this prospective study, patients had cataract extraction with implantation of a toric pseudophakic IOL (Acrysof toric SN60T3-T9) or a toric pIOL (Artisan or Artiflex). Two experienced surgeons (R.N., N.B.) performed all surgeries at Maastricht University Medical Centre, The Netherlands, between July 2009 and July 2010. All patients provided informed consent, and the tenets of the declaration of Helsinki were followed.

Preoperatively, patients had a complete ophthalmic evaluation including manifest refraction, slitlamp examination, fundoscopy, applanation tonometry, partial coherence interferometry (PCI) optical biometry (IOLMaster Carl Zeiss Meditec AG), corneal topography (Atlas, Carl Zeiss Meditec AG), and manual keratometry (K) (Javal-Schiotz, Rodenstock GmbH). Patients having toric pIOL implantation also had noncontact specular microscopy (Noncon Robo SP-9000, Konan Medical) and anterior segment optical coherence tomography (Visante, Carl Zeiss Meditec AG). Three months postoperatively, manifest refraction was performed in all cases.

Inclusion criteria for toric pseudophakic IOL implantation were regular corneal astigmatism of 1.25 diopters (D) or more and cataract. Exclusion criteria were tear-film abnormalities, Fuchs endothelial dystrophy (more than 2+ guttata), and extensive visual loss due to macular disease or glaucoma. Inclusion criteria for toric pIOL implantation were a subjective refractive astigmatism of 1.50 D or more, a stable refractive error during the previous 2 years, and unsatisfactory correction with spectacles or contact lenses. Exclusion criteria were an anterior chamber depth (ACD) less than 3.2 mm (measured from the epithelium to the crystalline lens), an endothelial cell count less than 2000 cells/mm^2, an abnormal iris or pupil, a history of glaucoma, and chronic or recurrent uveitis.

Toric Intraocular Lens Implantation

The toric pseudophakic IOL cylinder power and alignment axis were calculated using an online calculator.[A] This program takes into account the patient's K values, the astigmatism meridians, and the expected surgically induced astigmatism (SIA). The K values obtained from the PCI optical biometer and the astigmatism steep and flat meridians from the PCI optical biometer, corneal topographer, or manual keratometer were used. If the values from the PCI optical biometer and corneal topographer were consistent within ±5 degrees, the meridians obtained from the optical biometer were used. If the discrepancy was more than ±5 degrees, the meridians obtained with the manual keratometer were used. An expected amount of incision-induced astigmatism of 0.5 D (2.2 mm superior incision) was incorporated in the IOL calculation.

The refractive spherical equivalent, subjective refractive cylinder power, ACD, and corneal curvature (optical biometer) were inserted into the van der Heijde formula to calculate the power of the toric pIOL.[12] The axis of surgical enclavation was derived from the subjective refraction. The Artiflex toric IOL was implanted through a 3.4 mm and the Artisan toric IOL through a 5.4 mm superior corneoscleral incision, respectively, as described earlier.[13,14] All power calculations were performed by Ophtec.

The marking steps for toric pseudophakic and toric pIOL implantation were identical. Preoperatively, after topical anesthesia was administered, the patient was positioned upright to correct for cyclotorsion and asked to fixate on an object at distance. Limbal reference marks were placed at 0 degrees, 180 degrees, and 270 degrees (3 o'clock, 6 o'clock, and 9 o'clock, respectively) using a Nuijts-Lane toric reference marker with bubble level (AE-2791TBL, American Surgical Instruments Corp.). Intraoperatively, the limbal reference marks were used to mark the alignment axis with a Mendez degree gauge (AE-2765N, American Surgical Instruments Corp.) and a Nuijts toric axis marker (AE-2740, American Surgical Instruments Corp.). In cases of cataract extraction with toric pseudophakic IOL implantation, standard phacoemulsification was performed. Finally, the toric IOL was implanted and rotated to its final position by aligning the marks on the toric IOL with the alignment axis marks on the cornea.

Accuracy of Toric Intraocular Lens Implantation

The accuracy of toric IOL implantation was evaluated using the Surgery Guidance SG3000 system (Sensomotoric Instruments GmbH), which consists of a reference unit and a surgery pilot. The reference unit is a noncontact device that acquires a digital image of the eye (1.3 mega-pixel resolution), in which the limbal vessels, scleral vessels, and iris are shown in detail (Figure 1, *A*). Simultaneously, the unit performs keratometry using the optical reflections of 12 light-emitting diodes arranged in a 1.9 mm diameter ring. The keratometry results (including the steep and flat meridians of corneal astigmatism) and the position and diameter of the limbus and pupil are shown in an overlay on the digital

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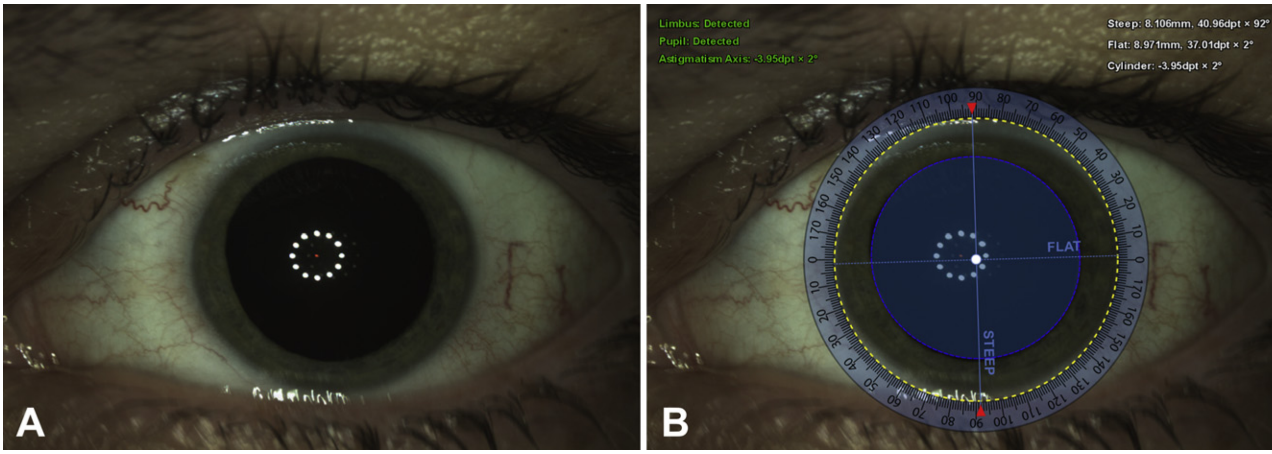

Figure 1. Example of an image obtained with the reference unit. *A*: Detailed image of the eye in which the limbal vessels, scleral vessels, and iris characteristics are visible. Simultaneously, when the preoperative image is being captured, keratometry is performed and those results and the position and diameter of the limbus and pupil are shown in an overlay (*B*).

image (Figure 1, *B*). The reference unit is calibrated horizontally.

At the time of this study, the surgery pilot consisted of a microscope camera adapter connected to a personal computer (PC). The preoperative image is loaded into the PC, and the rotation angle between the preoperative image and the microscope image is automatically detected (based on the limbal and scleral vessels and on iris characteristics) and overlaid on the camera image. Intraoperatively, the eye tracker provides a real-time update of all overlaid features relative to the camera image. The video of the surgery was recorded using the surgery unit.

Analysis of Errors in Toric Intraocular Lens Implantation

Using the reference unit, 6 images (3 before and 3 after limbal reference marks were applied) were obtained per patient. Between these measurements, the patient left the device, had reference axis marking, and sat down again. The accuracy of the reference-axis marking was assessed by evaluating 2 potential errors; that is, cyclotorsion of the eye (error A) and the horizontal placement of the reference axis (error B). Error A was defined as the cyclotorsion (rotation) of the eye between the preoperative image without reference marks and the preoperative image with reference marks. The rotation angle between these 2 images was determined manually using at least 6 reference points of blood vessel or iris landmarks on opposite sides of the pupil (error A) (Figure 2). Error B was defined as the deviation (in degrees) of the center of the reference marks with regard to the calibrated horizontal line of the reference unit (Figure 3).

The accuracy of the alignment axis marking was determined using intraoperative images obtained from the surgery video. The angle between the marked reference axis and the marked alignment axis was determined (Figure 4). Subsequently, the difference between this angle and the intended alignment axis (obtained from the IOL calculation) was determined (error C).

The accuracy of the IOL alignment along the marked alignment axis was evaluated using intraoperative images from the surgery video. The angle between the center of the IOL marks and the center of the alignment axis marks was determined (error D) (Figure 5).

A semiautomatic software tool was used to determine the rotation angle between 2 images (error A) and the angle between 2 lines (errors B, C, and D). To determine rotation, 2 images were shown on a monitor next to each other. The examiner (N.V.) determined matching blood vessel and iris features in both images (at least 6) and marked these features by manually clicking on them. To determine the angle between 2 lines, the examiner manually clicked on the center of the relevant axes marks or IOL marks. The software tool automatically calculated the rotation between 2 images, or angle between 2 lines, based on the manually marked features.

The mean total error ± standard deviation (SD) of the 4 individual errors (errors A, B, C, and D) was calculated using the following formula for mean total error:

$$Y = \sqrt{\text{Mean}_A^2 + \text{Mean}_B^2 + \text{Mean}_C^2 + \text{Mean}_D^2}$$

and the formula below for the SD of the total error.

Astigmatism Analysis by Alpins Method

The overall accuracy of the astigmatism correction was calculated using vector analysis according to Alpins.[15] The Alpins method uses 3 astigmatism parameters: preoperative

$$SDy = \sqrt{\left(\frac{\text{Mean}_A \times SD_A}{Y}\right)^2 + \left(\frac{\text{Mean}_B \times SD_B}{Y}\right)^2 + \left(\frac{\text{Mean}_C \times SD_C}{Y}\right)^2 + \left(\frac{\text{Mean}_D \times SD_D}{Y}\right)^2}$$

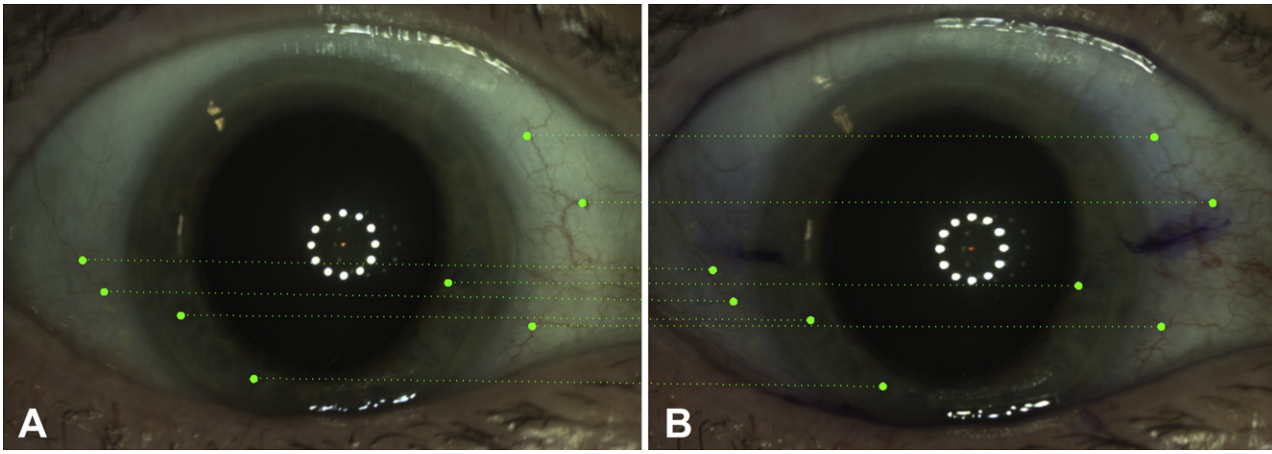

Figure 2. Cyclotorsion of the eye between 2 measurements (error A). First, image *A* was obtained. Next, the patient left the device and reference marks were applied. Finally, image *B* was obtained after the patient sat down again. The rotation angle between image A and image B was assessed using blood vessel and iris landmarks (indicated by the *green dots*).

astigmatism, target astigmatism, and achieved astigmatism. In patients with a toric pseudophakic IOL,the postoperative refractive astigmatism was compared with the preoperative keratometric astigmatism (from PCI optical biometry). In patients with a toric pIOL, the postoperative refractive astigmatism was compared with the preoperative refractive astigmatism. The target astigmatism was zero because emmetropia was the goal in all patients.

Refractive astigmatism data were calculated to the corneal plane by adjusting for a back vertex distance of 12.0 mm. Individual magnitude (diopters) and axis (degrees) values were transformed into rectangular x and y coordinates and used to calculate the following vectors: target-induced astigmatism (TIA) vector, which represents the change (by magnitude and axis) the surgery was intended to induce; the SIA vector, which is the astigmatic change the surgery actually induced; and the difference vector, which represents the astigmatic change between the achieved astigmatic outcome and the target astigmatic outcome. The difference vector is an absolute measure of success and is preferably zero. The magnitude of error is defined as the arithmetic difference between the magnitudes of the SIA and the TIA. The magnitude of error is positive for overcorrection and negative for undercorrection. The angle of error is the angle between the SIA vector and the TIA vector. The angle is positive if the achieved correction is counterclockwise to the intended axis and negative if the achieved correction is clockwise to the intended axis. The flattening effect is the amount of astigmatism reduction achieved at the intended meridian (TIA meridian). The flattening index is calculated by dividing the flattening effect by the TIA and is preferably 1.0. The correction index was calculated by the ratio of the magnitude of SIA to the magnitude of TIA. The correction index is preferably 1.0. It is greater than 1.0 if overcorrection occurred and

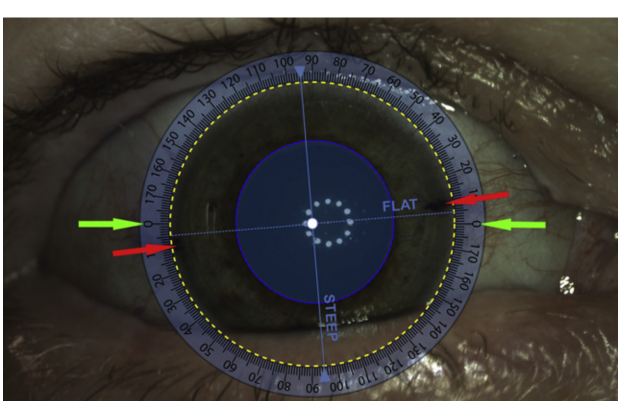

Figure 3. The horizontal placement of the reference axis marks was evaluated by determining the deviation (in degrees) of the reference marks (*red arrows*) with regard to the (calibrated) horizontal line (*green arrows*) of the Reference Unit (error B).

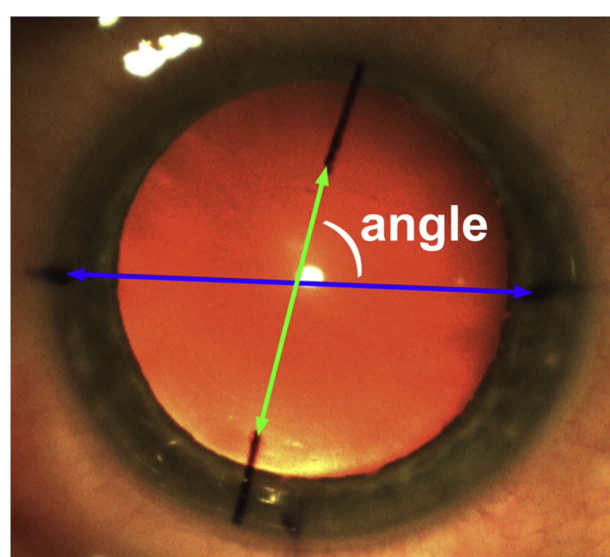

Figure 4. The accuracy of marking the alignment axis was determined by calculating the angle between the marked reference axis (*blue arrow*) and marked alignment axis (*green arrow*). Subsequently, the difference between this angle and the intended alignment axis was calculated (error C).

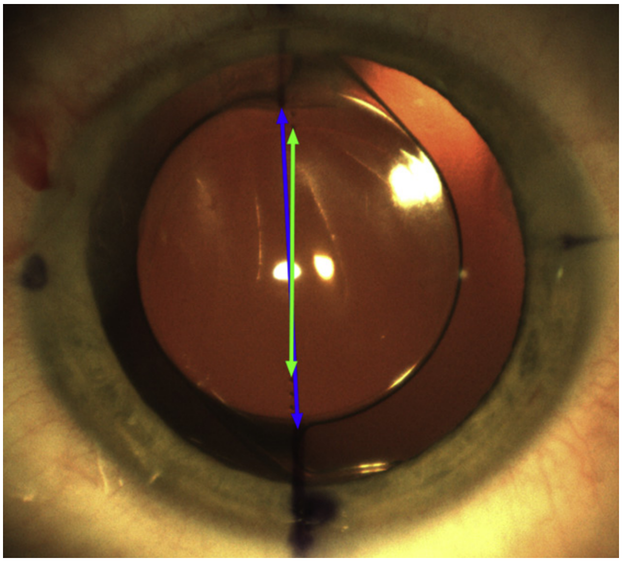

Figure 5. The accuracy of the IOL alignment was evaluated by determining the angle between the center of the IOL marks (*green arrow*) and the center of the alignment axis marks (*blue line*) (error D).

less than 1.0 if undercorrection occurred. The index of success was calculated by dividing the difference vector by the TIA. This is a relative measure of success and is preferably zero.

Statistical Analysis

All data were collected in an Excel database (Microsoft Office 2003). Data analysis using SPSS for Windows (version 16.0, SPSS Inc.) showed a normal distribution and allowed the use of parametric tests. A *P* value less than 0.05 was considered statistically significant.

RESULTS

The study enrolled 40 eyes of 31 patients; 26 eyes had implantation of an Acrysof toric SN60T3-T9 IOL; 8, a toric Artiflex pIOL; and 6, a toric Artisan pIOL. Table 1 shows the patients' demographics. Patients in the pIOL subgroup were significantly younger than patients in the pseudophakic IOL subgroup ($P = .001$).

Table 2 shows the results of the analysis of the individual steps in toric IOL implantation. The mean cyclotorsion of the eye between images with and without reference marks (error A) was not more than 5 degrees in any case. The reference marks were more than 5 degrees off the calibrated horizontal axis (error B) in 1 eye. Together, errors A and B caused a mean error in reference axis marking of 2.4 $\pm$ 0.8 degrees. The mean difference between the marked alignment axis and the intended alignment axis (error C) was more than 5 degrees in 6 eyes (15%); no eye had a difference greater than 10 degrees. The mean error in IOL alignment (error D) was more than 5 degrees in 4 eyes (10%) and more than 10 degrees in 1 eye (2%). Together, errors A, B, C, and D led to a mean total error in toric IOL alignment of 4.9 $\pm$ 2.1 degrees. There was no statistically significant difference in the mean total error between the toric pseudophakic IOL subgroup and the toric pIOL subgroup ($P = .501$; independent-samples *t* test).

Table 3 shows the results of the vectorial astigmatism analysis. The mean angle of error indicated that the mean angle of the SIA vector was −2 $\pm$ 8 degrees clockwise to the TIA vector in the toric pseudophakic IOL group and 6 $\pm$ 14 degrees counterclockwise to the TIA vector in the toric pIOL group.

DISCUSSION

Accurate positioning of a toric IOL is the most important factor determining the efficacy of the astigmatism

Table 1. Patient demographics and preoperative characteristics.

Parameter	All Toric IOLs	Toric IOL Subgroup: Pseudophakic	Toric IOL Subgroup: Phakic
Eyes (n)	40	26	14
Patients (n)	31	18	13
Female (%)	63	69	93
Age (y)	52.3 ± 19.1	58.8 ± 18.2	40.1 ± 14.7
Corneal astigmatism (D)*			
Arithmetic mean magnitude (D) ± SD	2.30 ± 1.13	2.17 ± 0.82	2.54 ± 1.56
Vector mean (D @ degrees)	1.24 @ 93	1.04 @ 95	1.63 @ 90
Refractive astigmatism (D)†			
Arithmetic mean magnitude (D) ± SD	−2.49 ± 1.34	−2.18 ± 1.11	−3.05 ± 1.58
Vector mean (D @ degrees)	1.02 @ 94	0.63 @ 94	1.73 @ 95

IOL = intraocular lens
*Determined by partial coherence interferometry keratometry
†Determined by manifest refraction

Table 2. Physical errors in toric IOL implantation.

Step in Toric IOL Implantation	Mean ± SD (Maximum)		
		Toric IOL Subgroup	
	All Toric IOLs (40 Eyes)	Pseudophakic (26 Eyes)	Phakic (14 Eyes)
1. Reference axis marking: error A + error B	2.4 ± 0.8	2.6 ± 0.9	2.0 ± 0.4
Cyclotorsion: error A	1.5 ± 1.2 (5.0)	1.6 ± 1.4 (5.0)	1.2 ± 0.8 (2.4)
Horizontal placement: error B	2.0 ± 1.8 (8.7)	2.0 ± 1.9 (8.7)	1.6 ± 1.2 (2.9)
2. Alignment axis marking: error C	3.3 ± 2.0 (7.7)	3.5 ± 1.8 (7.7)	3.0 ± 2.3 (7.3)
3. IOL alignment: error D	2.6 ± 2.6 (10.5)	2.5 ± 2.7 (10.5)	3.2 ± 2.4 (6.4)
Sum of errors	4.9 ± 2.1	5.0 ± 2.1	4.8 ± 2.2

IOL = intraocular lens

correction. In this study, we analyzed the accuracy of a commonly used 3-step (ink marker–based) method of toric IOL implantation. As far as we are aware, no previous studies have examined the accuracy of positioning toric IOLs. Furthermore, we describe a new device that combines eye-tracking technology with keratometry measurement, providing the opportunity to align the toric IOL in real time during surgery.

Table 3. Astigmatism analysis by Alpins method.

Parameter	Toric IOL Subgroup	
	Pseudophakic (26 Eyes)	Phakic (14 Eyes)
Target induced astigmatism		
Arithmetic mean magnitude (D) ± SD	2.17 ± 0.82	3.05 ± 1.58
Vector result (D @ degrees)	1.04 @ 5	1.73 @ 5
Surgically induced astigmatism		
Arithmetic mean magnitude (D) ± SD	2.18 ± 1.04	2.78 ± 2.22
Vector result (D @ degrees)	1.25 @ 3	1.74 @ 11
Difference vector		
Arithmetic mean magnitude (D) ± SD	0.46 ± 0.40	1.00 ± 0.96
Vector result (D @ degrees)	0.24 @ 81	0.38 @ 142
Mean magnitude of error (D) ± SD	0.00 ± 0.47	0.09 ± 0.86
Mean angle of error (degrees) ± SD	−2 ± 8	6 ± 14
Mean flattening effect (D) ± SD	2.11 ± 1.04	2.46 ± 2.22
Mean flattening index ± SD	0.96 ± 0.28	0.86 ± 0.45
Mean correction index ± SD	0.99 ± 0.27	0.98 ± 0.40
Mean index of success ± SD	0.23 ± 0.24	0.40 ± 0.28

IOL = intraocular lens

We found a mean total error of 4.9 ± 2.1 degrees in the alignment of toric IOLs in cataract and refractive surgery. Every degree of misalignment contributes to residual astigmatism. At present, there are 2 views currently in the literature regarding the effect of toric IOL misalignment on remaining astigmatism (Figure 6). The first approach is based on the flattening effect. Vector analysis is used to determine the amount of astigmatism reduction achieved at the intended meridian of treatment (Figure 6, *A*).[16] Using this method, an error of 4.9 degrees would lead to 1.5% of preoperative astigmatism remaining at the intended meridian of treatment (the TIA meridian). The second approach determines the overall magnitude of astigmatism remaining. It is calculated by determining the vector difference between the target and achieved astigmatic outcomes (Figure 6, *B*).[17,18] Using this method, an error of 4.9 degrees would result in a remaining astigmatism magnitude of 17% of the preoperative astigmatism magnitude. The effect of a mean error of 4.9 ± 2.1 degrees may be especially relevant when implanting a toric IOL with a high cylinder power. In addition, the alignment error may be larger in individual cases due to fading out of the ink markings, horizontal or vertical translocation of the ink marks, or even complete washout of the ink marks at the time of surgery.[19] We did not have problems with fading out or disappearing of ink marks because the preoperative bubble marker also leaves slight impressions on the cornea.

We determined the physical accuracy of a commonly used 3-step method for toric IOL implantation by examining each step as follows: reference axis marking, alignment axis marking, and IOL alignment. The accuracy of reference axis marking is affected by the

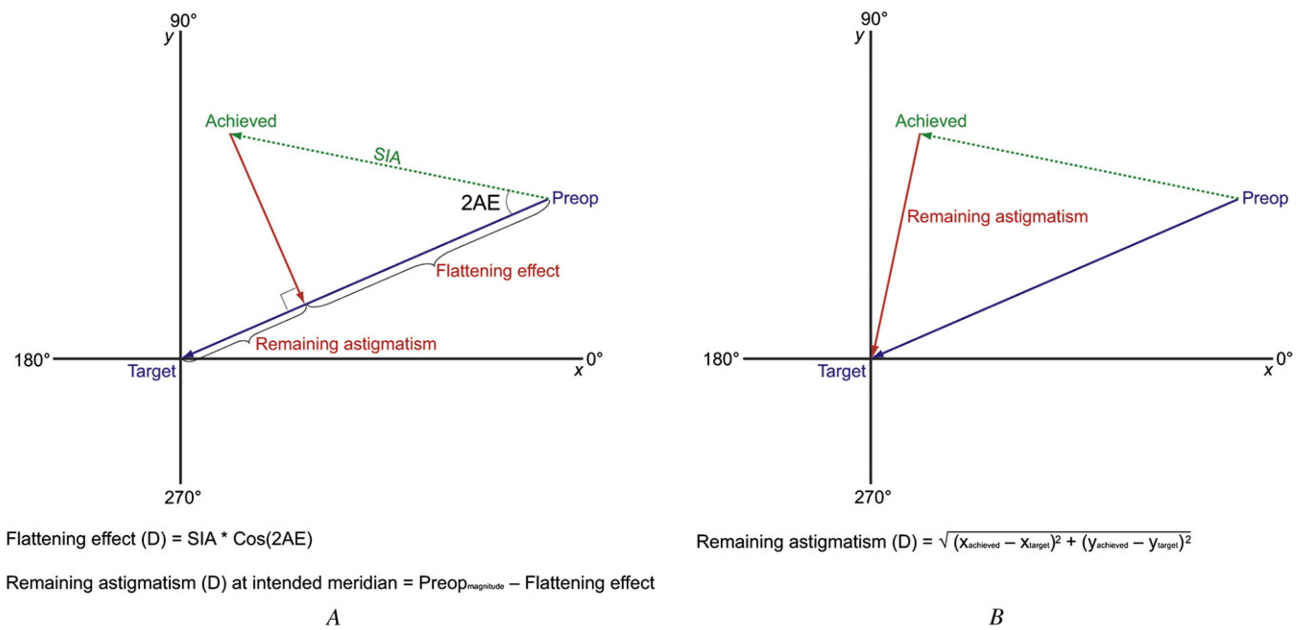

Figure 6. Two views in the current literature regarding the effect of toric IOL misalignment on remaining astigmatism. *A*: Method 1. Remaining astigmatism is determined by the amount of astigmatism reduction achieved at the intended meridian of treatment (flattening effect). *B*: Method 2. Remaining astigmatism magnitude is determined by the magnitude of the vector between the achieved and target astigmatism (AE = angle of error; SIA = surgically induced astigmatism).

cyclotorsion (rotation) of the eye between 2 separate measurements (between which the patient left the device and sat down again) (error A). The mean cyclotorsion of the eye between 2 measurements was 1.5 ± 1.2 degrees. Cyclotorsion of the eye from the upright to supine position is a well-known aspect and generally compensated for during refractive surgery. Studies examining upright-to-supine cyclotorsion generally report values ranging from 2 to 4 degrees, although the value may be larger.[20–22] However, cyclotorsion of the eye between 2 measurements, both with the patient in upright position, is less well established. This was recently examined by Wolffsohn and Buckhurst[23] in 107 eyes using conjunctival vessels and iris features as landmarks. They found a mean rotation of 2.2 ± 1.8 degrees. In addition, Viestenz et al.[24] used standard fundus photography to examine eye rotation between 2 measurements in 400 eyes with the patient upright and found a mean rotation of 2.3 ± 1.7 degrees. We found a mean rotation value of 1.5 ± 1.2 degrees, which is slightly lower than the values reported in the above-mentioned studies. This could be an underestimation because we measured patients within a time frame of approximately 5 minutes, whereas the other studies used time frames of 6 months.[23,24] In addition, patients in our study were measured with their head fixated in a headrest and were able to look at a fixation light binocularly, which has been shown to reduce cyclotorsion.[25,26] Cyclotorsion of the eye between the preoperative visit, where the biometry measurements are performed, and the surgery visit may introduce errors in the alignment axis marking. A second factor that influences the accuracy of reference axis marking is the horizontal placement of the marks (error B). In our study, the mean error was low (2.0 ± 1.8 degrees), indicating that the reference marker (with the bubble level) used in this study is effective in placing the marks horizontally. The mean error in marking the alignment axis (error C) was 3.3 ± 2.0 degrees, which is relatively small considering that the Mendez gauge used to mark the alignment axis uses 10-degree steps. The IOL alignment along the marked alignment axis (error D) was off axis by a mean of 2.6 ± 2.6 degrees. We believe this is reasonable considering that the marks on the IOL are generally much smaller than the dimensions of the marks on the cornea.

We performed vector analysis to provide a parallel mathematic confirmation to the physical accuracy of toric IOL alignment. In this analysis, we used the postoperative refractive astigmatism to determine the overall accuracy of toric IOLs in the correction of astigmatism. The mean angle of error between the SIA vector and the TIA vector was −2 ± 8 degrees in patients with a toric pseudophakic IOL and 6 ± 14 degrees in patients with a toric pIOL. The angle of error obtained in the vector analysis is not directly comparable to the physical error in toric IOL alignment because of the subjective component of the refractive outcome, the influence of the incision, and possibly the effect of other refractive surfaces of the eye (posterior corneal surface and vitreous). However, the relatively large SDs of the calculated angles of error indicate that this angle of error was much larger in individual patients.

Alpins astigmatism analysis provides several indices to determine the overall success of astigmatism correction. The correction indices in our study indicate that 99% of astigmatism was corrected in the toric pseudophakic IOL group and 98% in the toric pIOL group. The mean flattening index was 0.96 in the toric pseudophakic IOL group and 0.86 in the toric pIOL group, indicating that the toric pseudophakic IOL was more effective in reducing astigmatism at the intended meridian of treatment. In addition, the index of success showed that the toric pseudophakic IOL was more successful than the toric pIOL in correcting astigmatism. We believe this may be the result of not incorporating the flattening effect of the incision in the pIOL power calculation. The exact effect of the incision on corneal astigmatism is difficult to predict and depends on the amount of preoperative corneal astigmatism, incision location, incision width, suture use, and patient age.[27–29] Pseudophakic IOLs may be implanted through a 2.2 mm sutureless corneal incision, which has been shown to induce 0.24 to 0.52 D of flattening at the incised meridian.[30–32] When performing the toric pseudophakic IOL power calculation, we incorporated an incision-induced astigmatism of 0.50 D into the IOL power calculation. Toric pIOLs, however, require a much larger incision. The 3.4 mm and 5.4 mm incisions required for toric Artiflex IOL and Artisan IOL implantation, respectively, require sutures for wound closure. The incision-induced astigmatism for Artisan implantation is reported to be 0.74 D.[33] However, the pIOL calculations are performed by the manufacturer and the effect of the incision is not incorporated into the pIOL power calculation. Future studies should be performed to determine the effect of the 3.4 mm and 5.4 mm incisions on corneal astigmatism to incorporate it in the pIOL power calculation.

The success of toric IOLs also depends on accurate preoperative measurements of corneal astigmatism (pseudophakic IOLs) and refractive astigmatism (pIOLs). Accurate astigmatism measurements using keratometry or subjective refraction for pseudophakic IOLs and pIOLs, respectively, must be obtained. Our preferred method for pseudophakic IOLs is to measure corneal astigmatism with the IOLMaster PCI device and a corneal topographer. If these values are consistent within 5 degrees, we use the meridians obtained from the PCI device. If the discrepancy is more than 5 degrees, we use the meridians obtained with manual keratometry. For pIOLs, we used the cylinder values obtained from the subjective refraction. We believe that using the Jackson cross-cylinder, the refractive cylinder axis can be refined with a precision of less than 5 degrees.

Digital imaging techniques using iris and blood vessel characteristics have been used in previous studies.[5,19,23] One report[19] describes the acquisition of a preoperative digital image of the iris, in which the horizontal axis and the alignment axis are shown in an overlay. A printout of this image is used during surgery to align the toric IOL. Wolfsohn and Buckhurst[23] used a digital imaging technique with blood vessel landmarks and iris features to determine the rotation and centration of toric IOLs. The repeatability of this technique was high, with an SD of intrasession repeatability of $\pm$0.79 degrees. The combination of iris features and blood vessel characteristics is, in our opinion, an optimal combination. Iris features can alter between the undilated and dilated state of the pupil. Due to the anesthesia, a subconjunctival hemorrhage may occur, which can obliterate the vascular landmarks. This occurred in 2 patients in our study but did not lead to problems with eye tracking. Thus, we believe that eye tracking based on iris and blood vessel characteristics is the most accurate. By combining eye-tracking technology with keratometry, toric IOL alignment can be performed in real time during surgery, making the manual marking steps obsolete. Furthermore, it will be possible to use the preoperative keratometry results for both toric IOL calculation and IOL alignment during surgery. This will further minimize errors introduced by separate keratometry measurements performed, for example, with the IOLMaster, Javal manual keratometry, and corneal topography. In addition, eye-tracking technology may also be used for other aspects in IOL implantation surgery, including planning of the incisions and capsulorhexis and optimal centration of multifocal IOLs.

In conclusion, a commonly used 3-step manual (ink marker) procedure for toric IOL implantation led to a mean error in IOL placement of approximately 5 degrees. However, the error may be higher in individual cases as a result of problems with the ink marks. This error is especially relevant in cases in which higher cylinder power IOLs are implanted. Orienting the toric IOL with great accuracy is necessary in all patients to achieve the most optimum cylinder correction.

REFERENCES

1. Chang DF. Early rotational stability of the longer Staar toric intraocular lens; fifty consecutive cases. J Cataract Refract Surg 2003; 29:935–940
2. De Silva DJ, Ramkissoon YD, Bloom PA. Evaluation of a toric intraocular lens with a Z-haptic. J Cataract Refract Surg 2006; 32:1492–1498
3. Dick HB, Krummenauer F, Tröber L. Ausgleich des kornealen Astigmatismus mit torischer Intraokularlinse: Ergebnisse der Multicenterstudie [Compensation of corneal astigmatism with

toric intraocular lens: results of a multicentre study]. Klin Monatsbl Augenheilkd 2006; 223:593–608
4. Till JS, Yoder PR Jr, Wilcox TK, Spielman JL. Toric intraocular lens implantation: 100 consecutive cases. J Cataract Refract Surg 2002; 28:295–301
5. Weinand F, Jung A, Stein A, Pfützner A, Becker R, Pavlovic S. Rotational stability of a single-piece hydrophobic acrylic intraocular lens: new method for high-precision rotation control. J Cataract Refract Surg 2007; 33:800–803
6. Tehrani M, Dick HB, Schwenn O, Blom E, Schmidt AH, Koch H-R. Postoperative astigmatism and rotational stability after Artisan toric phakic intraocular lens implantation. J Cataract Refract Surg 2003; 29:1761–1766
7. Ahmed IIK, Rocha G, Slomovic AR, Climenhaga H, Gohill J, Grégoire A, Ma J; Canadian Toric Study Group. Visual function and patient experience after bilateral implantation of toric intraocular lenses. J Cataract Refract Surg 2010; 36:609–616
8. Bauer NJC, de Vries NE, Webers CAB, Hendrikse F, Nuijts RMMA. Astigmatism management in cataract surgery with the AcrySof toric intraocular lens. J Cataract Refract Surg 2008; 34:1483–1488
9. Carey PJ, Leccisotti A, McGilligan VE, Goodall EA, Moore CBT. Assessment of toric intraocular lens alignment by a refractive power/corneal analyzer system and slitlamp observation. J Cataract Refract Surg 2010; 36:222–229
10. Leyland M, Zinicola E, Bloom P, Lee N. Prospective evaluation of a plate haptic toric intraocular lens. Eye 2001; 15:202–205
11. Zuberbuhler B, Signer T, Gale R, Haefliger E. Rotational stability of the AcrySof SA60TT toric intraocular lenses: a cohort study. BMC Ophthalmol 2008; 8:8. Available at: http://www.biomedcentral.com/content/pdf/1471-2415-8-8.pdf. Accessed March 5, 2011
12. van der Heijde GL, Fechner PU, Worst JGF. Optische Konsequenzen der Implantation einer negativen Intraokularlinse bei myopen Patienten [Optical consequences of implantation of a negative intraocular lens in myopic patients]. Klin Monatsbl Augenheilkd 1988; 193:99–102
13. Doors M, Cals DWJK, Berendschot TTJM, de Brabander J, Hendrikse F, Webers CAB, Nuijts RMMA. Influence of anterior chamber morphometrics on endothelial cell changes after phakic intraocular lens implantation. J Cataract Refract Surg 2008; 34:2110–2118
14. Tahzib NG, Nuijts RM, Wu WY, Budo CJ. Long-term study of Artisan phakic intraocular lens implantation for the correction of moderate to high myopia: ten-year follow-up results. Ophthalmology 2007; 114:1133–1142
15. Alpins NA. New method of targeting vectors to treat astigmatism. J Cataract Refract Surg 1997; 23:65–75
16. Alpins NA. Vector analysis of astigmatism changes by flattening, steepening, and torque. J Cataract Refract Surg 1997; 23:1503–1514
17. Ma JJK, Tseng SS. Simple method for accurate alignment in toric phakic and aphakic intraocular lens implantation. J Cataract Refract Surg 2008; 34:1631–1636
18. Shimizu K, Misawa A, Suzuki Y. Toric intraocular lenses: correcting astigmatism while controlling axis shift. J Cataract Refract Surg 1994; 20:523–526
19. Osher RH. Iris fingerprinting: new method for improving accuracy in toric lens orientation. J Cataract Refract Surg 2010; 36:351–352
20. Arba-Mosquera S, Merayo-Lloves J, de Ortueta D. Clinical effects of pure cyclotorsional errors during refractive surgery. Invest Ophthalmol Vis Sci 2008; 49:4828–4836. Available at: http://www.iovs.org/cgi/reprint/49/11/4828. Accessed March 5, 2011
21. Chernyak DA. Cyclotorsional eye motion occurring between wavefront measurement and refractive surgery. J Cataract Refract Surg 2004; 30:633–638
22. Swami AU, Steinert RF, Osborne WE, White AA. Rotational malposition during laser in situ keratomileusis. Am J Ophthalmol 2002; 133:561–562
23. Wolffsohn JS, Buckhurst PJ. Objective analysis of toric intraocular lens rotation and centration. J Cataract Refract Surg 2010; 36:778–782
24. Viestenz A, Seitz B, Langenbucher A. Evaluating the eye's rotational stability during standard photography; effect on determining the axial orientation of toric intraocular lenses. J Cataract Refract Surg 2005; 31:557–561
25. Becker R, Krzizok TH, Wassill H. Use of preoperative assessment of positionally induced cyclotorsion: a video-oculographic study. Br J Ophthalmol 2004; 88:417–421. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1772033/pdf/bjo08800417.pdf. Accessed March 5, 2011
26. Tjon-Fo-Sang MJ, de Faber J-THN, Kingma C, Beekhuis WH. Cyclotorsion: a possible cause of residual astigmatism in refractive surgery. J Cataract Refract Surg 2002; 28:599–602
27. Oshika T, Nagahara K, Yaguchi S, Emi K, Takenaka H, Tsuboi S, Yoshitomi F, Nagamoto T, Kurosaka D. Three year prospective, randomized evaluation of intraocular lens implantation through 3.2 and 5.5 mm incisions. J Cataract Refract Surg 1998; 24:509–514
28. Storr-Paulsen A, Madsen H, Perriard A. Possible factors modifying the surgically induced astigmatism in cataract surgery. Acta Ophthalmol Scand 1999; 77:548–551. Available at: http://onlinelibrary.wiley.com/doi/10.1034/j.1600-0420.1999.770513.x/pdf. Accessed March 5, 2011
29. Tejedor J, Pérez-Rodríguez JA. Astigmatic change induced by 2.8-mm corneal incisions for cataract surgery. Invest Ophthalmol Vis Sci 2009; 50:989–994. Available at: http://www.iovs.org/content/50/3/989.full.pdf. Accessed March 5, 2011
30. Can İ, Takmaz T, Yıldız Y, Bayhan HA, Soyugelen G, Bostancı B. Coaxial, microcoaxial, and biaxial microincision cataract surgery; prospective comparative study. J Cataract Refract Surg 2010; 36:740–746
31. Lee K-M, Kwon H-G, Joo C-K. Microcoaxial cataract surgery outcomes: comparison of 1.8 mm system and 2.2 mm system. J Cataract Refract Surg 2009; 35:874–880
32. Wang J, Zhang E-K, Fan W-Y, Ma J-X, Zhao P-F. The effect of micro-incision and small-incision coaxial phaco-emulsification on corneal astigmatism. Clin Exp Ophthalmol 2009; 37:664–669
33. Bartels MC, Saxena R, van den Berg TJPT, van Rij G, Mulder PGH, Luyten GPM. The influence of incision-induced astigmatism and axial lens position on the correction of myopic astigmatism with the Artisan toric phakic intraocular lens. Ophthalmology 2006; 113:1110–1117

OTHER CITED MATERIAL

A. Alcon, Inc. AcrySof® Toric IOL Web Based Calculators. Available at: http://www.acrysoftoriccalculator.com. Accessed March 5, 2011

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