ARTICLE

Cyclorotation during femtosecond laser–assisted cataract surgery measured using iris registration

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Purpose: To assess ocular cyclorotation of eyes having femtosecond laser–assisted cataract surgery using iris registration.

Setting: Eye Institute of West Florida, Largo, Florida, USA.

Design: Retrospective cases series.

Methods: Charts of patients who had femtosecond laser–assisted cataract surgery with preoperative and intraoperative iris registration in 1 or 2 eyes between November 2015 and March 2016 were reviewed. Cyclorotation was assessed via iris-registration acquired preoperatively using the Cassini topographer (patient in upright position) and intraoperatively using the iris registration option of the Lensar laser system (patient in supine position) acquired immediately before the laser treatment.

Results: The study comprised 241 patients (337 eyes). The mean age of the 107 men and 134 women was 68.0 years ± 9.0 (SD) (range 37 to 90 years). The mean absolute value of cyclorotation was 5.81 ± 4.20 degrees (range 0 to 17 degrees), which was statistically significant when comparing the preoperative axis with the intraoperative axis deviation ($P < .0001$). Overall, incyclorotation (67.4%) was more common than excyclorotation (30.9%). In patients having bilateral femtosecond laser–assisted cataract surgery, bilateral incyclorotation (47.37%) was the most common occurrence.

Conclusions: During femtosecond laser–assisted cataract surgery, clinically significant cyclotorsion that might influence astigmatism correction outcomes can occur in patients having cataract extraction. Iris registration was useful in accounting for cyclorotation during this procedure when corneal or intraocular lens–based forms of astigmatic corrections will be used.

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Ocular cyclorotation and its implications during the correction of refractive errors, especially astigmatism, were initially encountered in corneal excimer laser refractive treatments; previous studies measuring cyclorotation during laser in situ keratomileusis (LASIK) and photorefractive keratectomy found a mean cyclorotation of 0.4 to 4.0 degrees.[1–5] At present, the development of femtosecond laser platforms and toric intraocular lenses (IOLs) offer both corneal (astigmatic keratotomies [AK] and limbal relaxing incisions [LRIs]) and IOL-based astigmatism correction during cataract surgery. This not only allows surgeons to remove a patient's cataract, it also gives them a means of decreasing or eliminating a patient's need for spectacle dependence. Achieving this goal also involves significantly reducing corneal astigmatic errors as well as spherical errors (myopia and hyperopia).

More than 50% of patients having cataract surgery have corneal astigmatism in the 0.5 diopters (D) to 1.5 D range.[6] To ensure full astigmatic correction, proper alignment in the axis of astigmatism for corneal-based and IOL-based approaches is essential. If not accounted for intraoperatively, cyclotorsion can cause rotational errors in this alignment and might lead to suboptimum correction of astigmatism. Ocular cyclorotation during femtosecond laser–assisted cataract surgery might be attributed to a combination of factors that could be categorized as (1) patient dependent: supine position during surgery, head position during surgery; (2) surgeon dependent: suboptimum preoperative axis marking, ocular position influenced by a surgeon's handling of the eye during femtosecond laser–assisted cataract surgery (patient interface using suction is maneuvered by surgeon); and (3) other extrinsic: free-floating surgical beds.

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This study assessed ocular cyclorotation in eyes having femtosecond laser–assisted cataract surgery using iris registration and the possible influence that cyclorotation might have on corneal- or lens-based astigmatism correction during cataract surgery.

PATIENTS AND METHODS

Patient Population

This was a single-center (Eye Institute of West Florida, Largo, Florida, USA) retrospective case series. The chart review included patients who had femtosecond laser–assisted cataract surgery with placement of a posterior chamber IOL between November 2015 and March 2016 using a femtosecond laser platform (Lensar) with Streamline 2 software (both Lensar, Inc.) and iris registration coupled with the Cassini topographer (iOptics Corp.).

All patients were informed of the risks and benefits before cataract surgery, and they gave their written informed consent in accordance with institutional guidelines. Institutional review board approval was obtained before the study was performed.

Inclusion and Exclusion Criteria

Patients were eligible for inclusion in the review if they were older than 18 years and had a diagnosis of 2+, 3+, and 4+ nuclear sclerotic, cortical, or posterior subcapsular cataract limiting vision. Patients were excluded if they had a history of pseudoexfoliation syndrome, corneal edema, Fuchs endothelial dystrophy, or previous surgery in the operative eye. Eyes that failed iris registration and had a cyclorotation above 17 degrees (the femtosecond laser platform's software is unable to measure cyclorotation above 17 degrees) were excluded from the study.

Image Acquisition and Docking Process

The Cassini topography platform combines light-emitting diode ray tracing and second Purkinje imaging technology, allowing for corneal astigmatism axis repeatability of 3 degrees. Furthermore, the topograper offers iris registration and allows for image acquisition to be coupled with the Lensar femtosecond laser platform on which astigmatism correction is based during cataract surgery. All patients in this study were evaluated preoperatively (seated upright position) using the Cassini topography platform. Then, the image was matched to the iris infrared image acquired via the Lensar femtosecond laser platforms using the Streamline 2 software (Figure 1). The Lensar image was acquired with the patient after the patient's eye was docked to the laser system. Docking was achieved using a plastic patient interface ring (centered around the corneal limbus) that is affixed to the eye using suction. A balanced salt solution was then placed in the patient interface and the laser was docked to the eye and locked into position. Incyclorotation and excyclorotation were measured, and their values were generated by the femtosecond laser platform's software. These values and the magnitude of the cyclorotation were generated by the laser and corrected for during corneal astigmatism correction. All femtosecond laser procedures were performed by 1 of 2 experienced surgeons (C.D.H., R.J.W.), each of whom performed more than 500 femtosecond laser cases before the case studies.

Statistical Analysis

Excel software (2007, Microsoft Corp.) and a custom Ophthalmic Data Analysis Software[A] were used for data collection and analysis. The cyclorotation data were tested to determine whether they followed a normal distribution according to the Shapiro-Wilks test with a P value less than 0.0001. An evaluation for power analysis was performed using post hoc power assessment. A P value less than 0.05 was considered statically significant.

Post hoc power analysis showed a power of 1 (100%); to test the null hypothesis that the mean value was not statistically different than the constant value of zero, a nonparametric test (Wilcoxon signed-rank test) was used.

RESULTS

The retrospective chart review identified 354 eyes of 253 patients who had femtosecond laser–assisted cataract surgery using the femtosecond laser platform. Of the 354 eyes, 3 eyes failed iris registration, and 14 eyes showed cyclorotation greater than 17 degrees for which the femtosecond laser platform could not measure total rotation with the current software. This resulted in 337 eyes of 241 patients (164 right eyes, 174 left eyes; 107 men and 134 women, aged 68.0 years $\pm$ 9.0 (SD) [range 37 to 90 years]) available for analysis. A further subanalysis of all patients receiving bilateral femtosecond laser treatment (190 eyes of 95 patients) was performed.

Of the 337 eyes that were analyzed, the mean absolute value of cyclorotation was 5.81 $\pm$ 4.20 degrees (range 0 to 17 degrees) (Table 1). Cyclorotation was statistically significant when comparing the preoperative axis with the intraoperative axis deviation ($P < .0001$). Overall, incyclorotation (227 eyes) was more common than excyclorotation (104 eyes) (Figure 2). In total, there were 8 eyes that did not show cyclorotation. In the right eyes, incyclorotation was significantly more common than excyclorotation. In the left eyes, incyclorotation was slightly more common than excyclorotation. The amount of cyclorotation was most commonly between 0 degree and 3 degrees (Figure 3). More than 39% of eyes (133/337) showed cyclorotation greater than 6 degrees (Figure 3).

A subanalysis of all patients having bilateral femtosecond laser–assisted cataract surgery (190 eyes of 95 patients) was performed to assess the congruency of cyclorotation between eyes. Bilateral incyclorotation was the most common occurrence (45 patients). Table 2 shows the results of the subanalysis.

DISCUSSION

Theoretic modeling indicates that residual astigmatism induced from axis error can be calculated via the formula $C = 2F \times \sin\alpha$, where C is residual astigmatism, F is the original astigmatic error, and α is the axis misalignment.[1] Using this equation, it can be calculated that a 10-degree error results in an approximately 34% decrease in astigmatic correction. Thus, iris registration and cyclotorsion correction has become the standard of care in modern refractive corneal surgery. It is reasonable to assume that cyclorotation also occurs during femtosecond laser–assisted cataract surgery AKs. In addition to cyclorotation induced purely by the patient lying supine as well as by the head positioning (as in refractive surgery), the manual handling of the patient interface applied during the docking of the femtosecond laser and other factors, such as the free-floating beds that some femtosecond lasers use, can induce cyclorotation. These factors might not be controlled during surgery, and a registration system that combines preoperative axis determination and intraoperative application of

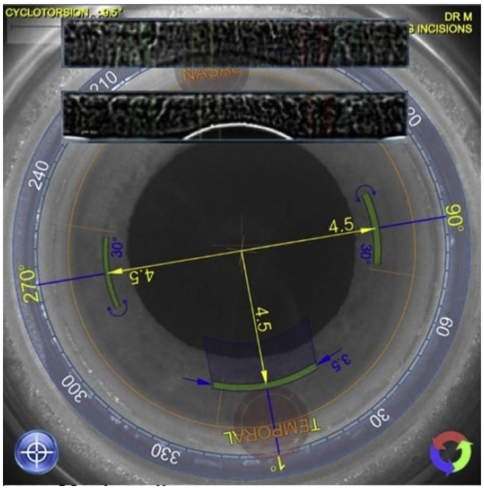

Figure 1. An image from the femtosecond laser system showing the iris-registration image overlay and cyclotorsion calculations.

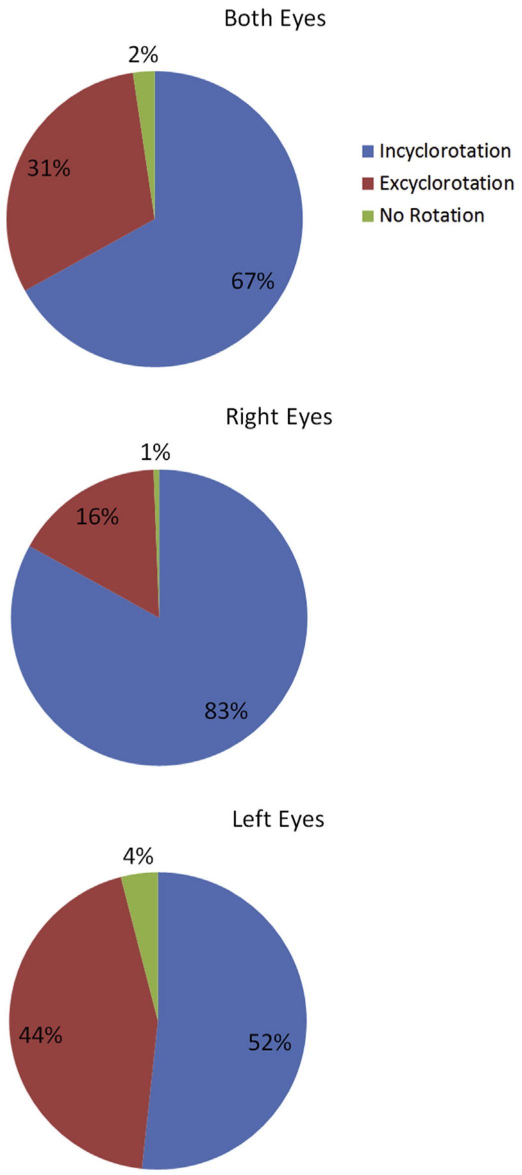

Figure 2. Distribution of incyclorotation, excyclorotation, and no rotation in left eyes and right eyes.

Table 1. Measurements of cyclorotation.

Parameter	Right Eyes (N = 177)	Left Eyes (N = 177)
Mean correction (degrees)	7.13	4.55
Mean incyclorotation (degrees)	−7.88	4.74
Mean excyclorotation (degrees)	3.46	−4.75
Requiring incyclorotation (n)	137	90
Requiring excyclorotation (n)	27	77
No rotation required (n)	1	7
Could not be measured (n)*	11	3
Iris registration failed (n)	2	1

*Cyclorotation was greater than 17 degrees

astigmatic treatment in accordance to that registration process is required.

Traditionally, cyclotorsion was accounted for during placement of toric IOLs and corneal-based astigmatism correction by marking the patient while he or she is sitting upright. Several marking techniques have been used for this purpose, including slitlamp markers, pendular markers, bubble markers, and tonometer markers. One study[7] found that these marking devices can result in rotational misalignments of up to 5.6 to 9.3 degrees and in vertical misalignments of up to 0.6 to 1.3 mm. They also have several drawbacks, including inaccurate placement, fading or bleeding of the mark, and even blocking of laser energy. New technology has incorporated iris registration into a femtosecond laser system. This decreases the need for corneal marking and ensures that cyclorotation is accounted for during the placement of corneal astigmatic incisions (AKs and LRIs). This also allows for the placement of intrastromal marks during toric IOL placement, which is especially useful when intraoperative aberrometry is not available or is unable to take a measurement.

This study showed that significant cyclotorsion can occur during femtosecond laser–assisted cataract surgery. Previous LASIK studies[1,2] have suggested that an excyclotorsion error averaging approximately 2 degrees occurs in both eyes with the patient supine. Previous studies[8] have also reported binocular excyclorotation as the dominant trend. In our study, there was a significant difference in average

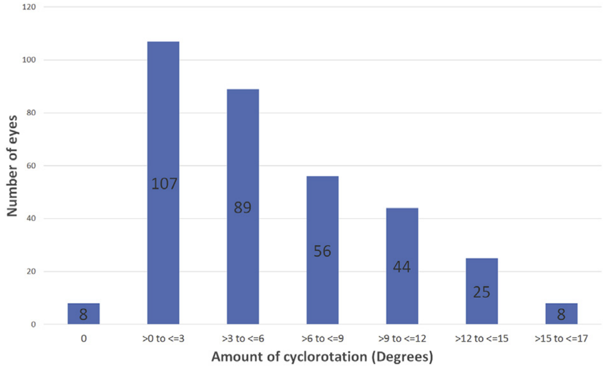

Figure 3. Frequency of cyclorotation.

Table 2. Incidence of bilateral rotation by direction.

Rotation type	Incidence (%)
Bilateral clockwise rotation	8.42
Bilateral counter-clockwise rotation	32.63
Bilateral incyclorotation	47.37
Bilateral excyclorotation	8.42
No rotation in 1 eye	3.16

magnitude and direction of cyclorotation error between right eyes and left eyes. Bilateral incyclorotation was the most common occurrence. We believe these differences are attributable to the docking system that is used and are likely user dependent. The handle of the patient interface likely experiences slight clockwise or counterclockwise rotation during docking because of hand positioning in the temporal position. There would likely be a difference between right-handed and left-handed surgeons. It is also possible that because of the free-standing bed, bed positioning under the laser could affect cyclorotation. Iris-registration failures were very rare (3 of 354 eyes [$<$1%]); they are usually caused by corneal opacities obstructing iris details.

Overall, average cyclotorsion error would result in an error of astigmatic correction of approximately 17% using the mathematic model for cylindrical correction presented earlier in this paper. For patients with small amounts of corneal astigmatism, the clinical significance of this error is undetermined. For patients having corneal-based astigmatic correction for 1.5 D of corneal astigmatism, the residual astigmatism might be more significant with average values of 0.3 D. Patients with greater than 17 degrees of cyclorotation could experience more than 0.9 D of residual astigmatism. By using iris registration during femtosecond laser–assisted cataract surgery procedures, residual cylindrical error can be minimized. The use of iris registration during femtosecond laser–assisted cataract surgery treatments also allows for the precise positioning of intrastromal marks to aid in placement of toric IOLs in patients with even higher magnitudes of corneal astigmatism. This technique has several benefits over traditional toric marking techniques, including increased accuracy and a decreased risk for bleeding or spreading of the marks. Toric IOLs might correct corneal astigmatic errors in excess of 4.0 D. For the 14 patients in this study who had cyclorotation greater than 17 degrees, this would result in more than 2.25 D of residual astigmatism. Therefore, we recommended that iris registration and cyclotorsion correction be used for refractive cataract surgery to minimize residual astigmatism. However, because it is always possible for laser marking or iris-registration technologies to fail, manual marking is still advised for toric IOL cases. Further studies analyzing the outcomes of patients with and without cyclorotation correction are required to identify the visual effect of these errors.

WHAT WAS KNOWN

- Previous studies showing cyclorotation occurs during cornea refractive surgery have resulted in the incorporation of iris registration as a standard of care in excimer laser treatments.

WHAT THIS PAPER ADDS

- The amplitude and direction of cyclorotation in femtosecond laser–assisted cataract surgery varied from that previously measured during corneal refractive surgery. This might be caused by the docking mechanism of the femtosecond laser and might vary from system to system and surgeon to surgeon.
- The occurrence of ocular cyclorotation during femtosecond laser–assisted cataract surgery was significant and could affect corneal-based and IOL-based astigmatism correction, leading to suboptimal visual and refractive outcomes of cataract surgery.
- Iris registration might overcome the uncontrolled intraoperative factors that lead to cyclorotation and could offer on-axis astigmatic treatments.

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Disclosures: *Dr. Desai is a consultant to Abbott Medical Optics, Inc., Alcon Laboratories, Inc., Allergan, Inc., Bio-Tissue, Inc., Lensar, Inc., and Valeant Pharmaceuticals International, Inc. Dr. Weinstock is a consultant to Abbott Medical Optics, Inc., Alcon Laboratories, Inc., Bausch & Lomb, Inc., Calhoun Vision, Inc., Doctor's Allergy, Healthe LLC, i-Optics Corp., Lensar, Inc., Omeros Corp., Rapid Pathogen Screening, Inc., Staar Surgical Co., and Truvision Systems, Inc. None of the other authors has a financial or proprietary interest in any material or methods mentioned.*