

Comparison of Astigmatism Correction in Cataract Surgery Between Simultaneous Femtosecond Laser-Assisted Intrastromal Arcuate Keratotomy and Toric Intraocular Lens Implantation

Hye Ji Kwon

Asan Medical Center

Hun Lee

Asan Medical Center

Jin Ah Lee

Asan Medical Center

Jae Yong Kim

Asan Medical Center

Hungwon Tchah (✉ hwtchah@amc.seoul.kr)

Asan Medical Center, University of Ulsan College of Medicine

Research article

Keywords: Femtosecond laser-assisted cataract surgery, femtosecond laser-assisted intrastromal arcuate keratotomy, toric intraocular lens implantation, astigmatism, cataract surgery

Posted Date: August 18th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-58747/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at BMC Ophthalmology on August 14th, 2021. See the published version at <https://doi.org/10.1186/s12886-021-02059-2>.

Abstract

Objectives

To compare the efficacy of astigmatic correction between simultaneous femtosecond laser-assisted intrastromal arcuate keratotomy (AK) combined with femtosecond laser-assisted cataract surgery (FLACS) and toric intraocular lens (IOL) implantation during cataract surgery in moderate astigmatism.

Design:

Retrospective observational study, tertiary care medical center

Methods

We retrospectively reviewed medical records of patients who underwent astigmatic correction via femtosecond laser-assisted intrastromal AK (AK group; 27 eyes of 27 patients) with FLACS or toric IOL implantation (toric IOL group; 21 eyes of 21 patients). All patients had senile cataracts with corneal astigmatism ranging from + 1.00 to + 2.00 diopters (D) before cataract surgery. We measured visual acuity, intraocular pressure, automated keratometry, manifest refraction and topography preoperatively and at 1-day, 1-month, 3-month, and 6-month postoperatively.

Results

Refractive astigmatism was significantly decreased in both groups. The mean preoperative and 6-month postoperative refractive astigmatism were 1.85 ± 1.07 and 0.99 ± 0.51 D, respectively, in the AK group ($P=0.028$), and 1.84 ± 0.81 and 0.68 ± 0.21 D, respectively, in the toric IOL group ($P<0.001$). There was no significant difference in refractive astigmatism between the two groups at 6-month postoperatively (0.99 ± 0.51 vs 0.68 ± 0.21 D, $P=0.057$). At 6-month postoperatively, parameters for vector analysis of refractive astigmatism showed no statistical difference between the two groups. Corneal astigmatism was significantly decreased in the AK group. There was significant difference in corneal astigmatism from topography and automated keratometer between the two groups at 6-month postoperatively (0.94 ± 0.40 vs 1.53 ± 0.46 D, $P=0.018$ for topography and 0.98 ± 0.69 vs 1.37 ± 0.41 D, $P=0.032$ for automated keratometer).

Conclusions

Femtosecond laser-assisted intrastromal AK in FLACS could be an effective procedure for reducing astigmatism as well as toric IOL implantation in cataract surgery.

Introduction

A significant number of patients undergoing cataract surgery tend to have a varying degree of corneal astigmatism.[1, 2] Approximately, a third of cataract patients have more than 1.25 diopters (D) of preexisting corneal astigmatism, whereas approximately 10% have 2.00 D or higher.[1–6] The reduction of refractive astigmatism after cataract surgery can result in a significant improvement in visual quality, but remaining astigmatism decreases visual acuity and quality of vision.[7, 8] Postoperative astigmatism is an important cause for the lack of achieving emmetropia even after successful cataract surgery.[9, 10]

Over the past decade, various approaches, including limbal relaxing incisions, corneal incision on the steep axis, astigmatic refractive keratectomy, and toric intraocular lens (IOL) implantation, have been employed to reduce preexisting astigmatism during cataract surgery.[10–12] However, limbal relaxing incisions have limitations that include restricted predictability, induced irregular astigmatism, induced ocular aberrations, and abnormal wound healing.[11, 12] Excimer laser procedures after cataract surgery are useful for eliminating remaining astigmatism but are rarely used because of high cost and ocular surface problems following excimer laser treatment.[13] Toric IOL implantation during cataract surgery allows better management of astigmatism, leading to better uncorrected visual acuity.[14, 15]

Recently, femtosecond laser-assisted intrastromal arcuate keratotomy (AK), demonstrating higher precision, safety, and reproducibility in reducing refractive astigmatism, has been suggested as an alternative to these surgical techniques.[16, 17] Along with the introduction of femtosecond laser-assisted cataract surgery (FLACS), cataract surgeons could perform femtosecond laser-assisted intrastromal AK during FLACS to reduce corneal astigmatism.[18–22] In the present study, we aim to compare the efficacy of astigmatic correction between femtosecond laser-assisted intrastromal AK and toric IOL implantation during cataract surgery in patients with moderate astigmatism.

Methods

We conducted this retrospective study with the approval of the Institutional Review Board of the Asan Medical Center and the University of Ulsan College of Medicine, Seoul, South Korea (2019 – 1244). The study adhered to the tenets of the Declaration of Helsinki and followed good clinical practice. All patients were informed of risks and benefits of the surgery and provided written consent for surgery.

This retrospective study included 48 patients who underwent cataract surgery by one surgeon (HT) at the cataract and refractive clinic of Asan Medical Center from November 2016 to July 2018. Patients who met the following inclusion criteria were included: older than 18 years, with preexisting corneal astigmatism between + 1.00 and + 2.00 D by simulated keratometry (Sim K) of topography, and agreement of femtosecond laser-assisted intrastromal AK with FLACS or toric IOL implantation during cataract surgery. Patients were excluded from the analyses if they had any optical opacities or pathologies on slit-lamp examination, previous corneal surgeries, ocular trauma, intraocular surgery, severe dry eye, corneal disease, ocular infection, or collagen vascular/autoimmune diseases. Among 48

patients, 27 patients had FLACS and femtosecond laser-assisted intrastromal AK (AK group) and 21 patients underwent conventional cataract surgery with toric IOL implantation (toric IOL group).

All surgeries were performed by one surgeon using topical anesthesia (0.5% proparacaine hydrochloride). Cataract surgeries were performed with phacoemulsification and implantation of a foldable IOL with 2.2 mm limbal incision. The incisions were located at the steep axis of cornea measured by automated keratometry. All non-toric or toric IOLs were injected into the capsular bag. Main incisions were sealed with anterior stromal hydration without corneal sutures. Topical antibiotics and steroid eyedrops were used for 1-month after surgery.

In the AK group, all 27 patients underwent cataract surgery using the Catalys femtosecond laser platform (Abbott Medical Optics, Inc, Santa Ana CA, USA). Horizontal limbal marker was done in sitting position prior to the laser to avoid cyclotorsion. After the patient lies supine, a suction ring with vacuum was aligned with corneal marks, and a safe distance for the docking interface was controlled with a joystick by the surgeon. After surgical site and depth was confirmed using the incorporated optical coherence tomography cross section, anterior capsulotomy and lens fragmentation were performed, followed by the intrastromal AK. The programmed anterior capsulotomy size was 4.8 mm in diameter. Crystalline lens fragmentation was done using a standard template with a pattern described as “lens softening: quadrants” in the system.

Intrastromal AK nomogram of paired symmetric (same length) incisions centered on the steep corneal axis was done, with 8.0 mm in diameter and central 60% of total corneal thickness in depth remaining upper 20% and lower 20% without penetration. The arc length was determined by intrastromal AK nomogram calculator v3, which is provided on the website. The length was proportional to preoperative corneal cylindrical power and was adjusted by the age and type of astigmatism, i.e., against-the-rule, with-the-rule, or oblique astigmatism. Foldable aspheric IOL (TECNIS 1-piece ZCB00 or PCB00 IOL; Abbot Medical Optics, Inc.) was implanted in patients of the AK group. The target of reduction in femtosecond laser-assisted intrastromal AK is corneal astigmatism.

In the toric IOL group, horizontal corneal-limbal marks using a sterile pen was made in each patient, while each was in a sitting position to avoid cyclotorsion. After a patient lied in a supine position in the operating room with aseptic drape, intraoperative markings were made under a surgical microscope with guidance from preoperative horizontal markings. After successful phacoemulsification, toric IOL (TECNIS Toric IOL; Abbott Medical Optics, Inc.) was implanted. The goal of toric IOL implantation is to reduce the refractive astigmatism. The appropriate cylindrical power and axis placement of the toric IOL to be implanted were determined with a program available from the IOL manufacturer and the Barrett toric calculator. After the implantation of IOL, IOL alignment and axis were re-checked.

The preoperative and postoperative (1-day, 1-month, 3-month, and 6-month) ophthalmic examinations included uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA), autorefractometry, manifest refraction, IOP measurements (non-contact tonometer; NT-530, NCT Nidek Co. Ltd., Aichi, Japan), dilated fundus examinations, and slit-lamp examinations (Haag-Streit,

Gartenstadtstrasse, Köniz, Switzerland). Corneal astigmatism was measured by corneal topographies with the Orbscan (Bausch & Lomb, Rochester, NY, USA) and automated keratometer (KR-8800, Topcon Europe Medical BV). Additionally, for measuring ocular biometry such as axial length and anterior chamber depth, IOL Master 500 (Carl Zeiss Meditec, Oberkochen, Germany) was used.

Vector analysis of refractive astigmatism is based on the definitions and formulas given by Eydelman MB.[23, 24] We analyzed the intended refractive correction, surgically induced refractive correction, error ratio, correction ratio, error of magnitude, and error of angle. The intended refractive correction is the vector difference between the preoperative and the target postoperative cylinder vector. Assuming that target refractive state is emmetropia, it is equal to the preoperative astigmatism. The surgically induced refractive correction is defined as an amount and axis of astigmatism change achieved by surgery. The error ratio is the proportion of the intended correction that was not successfully corrected. The correction ratio is the ratio of the achieved correction magnitude to the targeted correction magnitude; whereas the error of magnitude is the difference in magnitudes between the surgically induced refractive correction and intended refractive correction. Finally, the error of angle is the angular difference between the achieved correction and the intended correction. Double-angle plots of preoperative corneal astigmatism and postoperative refractive astigmatism (3-month and 6-month) are drawn. The double-angle plot tool used in this paper is provided in the American Society of Cataract and Refractive Surgery website.[25]

The Mann–Whitney U test, Wilcoxon signed-rank test, and Chi-square test were used for statistical analyses using the SPSS software version 21.0 (SPSS, Inc., Chicago, IL, USA). Differences were considered to be statistically significant for P values less than 0.05. Data from automated keratometer and topography were analyzed using vector analysis.

Results

Demographics of the AK and toric IOL groups are summarized in Table 1. There were no significant differences in the mean age, preoperative UDVA, preoperative corneal astigmatism, and refractive astigmatism between the two groups. Preoperative CDVA was different between the two groups. No ocular complications, such as corneal ectasia or epithelial ingrowth, were reported in all cases.

Table 1
Demographics and clinical characteristics of the participants

	AK group	toric IOL group	<i>P</i> *
Number of eyes (n)	27	21	
Male/Female (% women)	9/18 (66.7)	8/13 (61.9)	0.732
Right/Left	18/9	10/11	0.184
Age (years)	69.4 ± 12.1 (39 to 89)	67.4 ± 12.5 (41 to 86)	0.581
ATR/WTR/Oblique	15/8/4	12/6/3	0.994
Preoperative UDVA (logMAR)	0.67 ± 0.442 (0.1 to 2.0)	0.43 ± 0.29 (0.15 to 1.3)	0.077
Preoperative CDVA (logMAR)	0.43 ± 0.39 (0.1 to 2.0)	0.22 ± 0.13 (0.1 to 0.6)	0.038 [†]
Corneal astigmatism from topography (D)	1.49 ± 0.36 (1.3 to 2.0)	1.60 ± 0.47 (1.2 to 2.0)	0.235
Corneal astigmatism from automated keratometer (D)	1.44 ± 0.39 (1.0 to 2.0)	1.50 ± 0.37 (0.87 to 2.0)	0.505
Refractive astigmatism (D)	1.85 ± 1.07 (0.87 to 3.50)	1.84 ± 0.81 (0.75 to 3.50)	0.723
D = diopters; AK = arcuate keratotomy; IOL = intraocular lens; ATR = against-the-rule; WTR = with-the-rule; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; logMAR = logarithm of the minimum angle of resolution			
Values are presented as mean ± standard deviation (range) or number.			
*Differences of categorical variables assessed by Pearson's chi-square test; continuous variables assessed by Mann-Whitney <i>U</i> test			
†Statistically significant (<i>P</i> < .05)			

Table 2 demonstrates the results of refractive astigmatism and corneal astigmatism for both AK and toric IOL group. Significant reduction of refractive astigmatism was observed in both groups at 1-month, 3-month, and 6-month after the surgery, when compared with preoperative refractive astigmatism (1.85 ± 1.07 preoperatively, 0.96 ± 0.37 at 1-month, 0.76 ± 0.42 at 3-month, 0.99 ± 0.51 at 6-month postoperatively, *P* = 0.001, *P* < 0.001, *P* = 0.028, respectively, in AK group, and 1.84 ± 0.81 preoperatively, 0.63 ± 0.32 at 1-month, 0.67 ± 0.34 at 3-month, 0.68 ± 0.21 at 6-month postoperatively, *P* = 0.001, *P* = 0.001, *P* = 0.001,

respectively, in toric IOL group) (Table 2). There was no significant difference of refractive astigmatism between the two groups at 3-month and 6-month after surgery (0.76 ± 0.42 in AK group vs 0.67 ± 0.34 in toric IOL group, $P = 0.483$, at 3-month, and 0.99 ± 0.51 in AK group vs 0.68 ± 0.21 in toric IOL group, $P = 0.057$, at 6-month postoperatively) (Table 2). The corneal astigmatism was significantly reduced only in the AK group at 1-month, 3-month, and 6-month after the surgery, when compared with preoperative corneal astigmatism (1.49 ± 0.36 preoperatively, 0.93 ± 0.44 at 1-month, 1.02 ± 0.52 at 3-month, 0.94 ± 0.40 at 6-month postoperatively, $P < 0.001$, $P = 0.003$, $P = 0.010$, respectively, from topography, and 1.44 ± 0.39 preoperatively, 0.91 ± 0.37 at 1-month, 0.99 ± 0.67 at 3-month, 0.98 ± 0.69 at 6-month postoperatively, $P = 0.001$, $P = 0.009$, $P = 0.013$, respectively, from automated keratometer, in AK group) (Table 2). Between two groups, significant difference of corneal astigmatism at all of each postoperative follow-up period was observed (Table 2).

Table 2
Results of corneal astigmatism refractive astigmatism

	AK group	<i>p</i> ^a	toric IOL group	<i>p</i> ^a	<i>p</i> ^b
Manifest refractive astigmatism (D)					
Baseline	1.85 ± 1.07		1.84 ± 0.81		0.723
1-month postop	0.96 ± 0.37		0.62 ± 0.32		0.024 [†]
3-month postop	0.76 ± 0.42		0.67 ± 0.34		0.483
6-month postop	0.99 ± 0.51		0.68 ± 0.21		0.057
1-month vs baseline		0.001 [†]		0.001 [†]	
3-month vs baseline		0.000 [†]		0.001 [†]	
6-month vs baseline		0.028 [†]		0.001 [†]	
Corneal astigmatism from topography (D)					
Baseline	1.49 ± 0.36		1.60 ± 0.47		0.235
1-month postop	0.93 ± 0.44		1.40 ± 0.50		0.011 [†]
3-month postop	1.02 ± 0.52		1.50 ± 0.47		0.010 [†]
6-month postop	0.94 ± 0.40		1.53 ± 0.46		0.018 [†]
1-month vs baseline		0.000 [†]		0.048 [†]	
3-month vs baseline		0.003 [†]		0.058	
6-month vs baseline		0.010 [†]		0.149	
Corneal astigmatism from automated keratometer (D)					
Baseline	1.44 ± 0.39		1.50 ± 0.37		0.505
1-month postop	0.91 ± 0.37		1.22 ± 0.47		0.045 [†]

D = diopters; AK = arcuate keratotomy; IOL = intraocular lens

Values are presented as mean ± standard deviation (range) or number.

^aComparison with baseline within groups assessed by Wilcoxon signed-rank test

^bComparison between groups assessed by Mann-Whitney *U* test

†Statistically significant (*P* < .05)

	AK group	<i>P</i> ^a	toric IOL group	<i>P</i> ^a	<i>P</i> ^b
3-month postop	0.99 ± 0.67		1.35 ± 0.33		0.021 [†]
6-month postop	0.98 ± 0.69		1.37 ± 0.41		0.032 [†]
1-month vs baseline		0.001 [†]		0.114	
3-month vs baseline		0.009 [†]		0.306	
6-month vs baseline		0.013 [†]		1.000	
D = diopters; AK = arcuate keratotomy; IOL = intraocular lens					
Values are presented as mean ± standard deviation (range) or number.					
^a Comparison with baseline within groups assessed by Wilcoxon signed-rank test					
^b Comparison between groups assessed by Mann-Whitney <i>U</i> test					
[†] Statistically significant (<i>P</i> < .05)					

Table 3 demonstrates the results of vector analysis of refractive astigmatism. There was no significant difference in all vector analysis parameters (surgically induced refractive correction, error ratio, correction ratio, error of magnitude, and error of angle) between the two groups at 1-month, 3-month, and 6-month after surgery (all *P* values > 0.05) (Table 3) except error ratio at 1-months postoperatively (0.66 ± 0.44 in AK group vs 0.31 ± 0.21 in toric IOL group, *P* = 0.011) (Table 3). In the AK group, there was no significant difference between the 1-month, 3-month, and 6-month postoperative vector analysis parameters (all *P* values > 0.05) (Table 3). In the toric IOL group, there were significant differences between 1-month and 3-month and between 1-month and 6-month postoperatively in surgically induced refractive correction, correction ratio, and error of magnitude (1.69 ± 0.84 vs 1.49 ± 0.75, 1-month vs 3-month, 1.69 ± 0.84 vs 1.40 ± 0.87, 1-month vs 6-month, *P* = 0.006 and *P* = 0.009, respectively, in surgically induced refractive correction, 0.99 ± 0.25 vs 0.81 ± 0.23, 1-month vs 3-month, 0.99 ± 0.25 vs 0.78 ± 0.32, 1-month vs 6-month, *P* = 0.004 and *P* = 0.013, respectively, in correction ratio, and 0.05 ± 0.55 vs 0.34 ± 0.51, 1-month vs 3-month, 0.05 ± 0.55 vs 0.44 ± 0.69, 1-month vs 6-month, *P* = 0.006 and *P* = 0.009, respectively, in error of magnitude) (Table 3).

Table 3
Vector analysis of refractive astigmatism

	AK group	<i>p</i> ^a	toric IOL group	<i>p</i> ^a	<i>p</i> ^b
Surgically induced refractive correction (D)					
1-month postop	1.49 ± 1.12		1.69 ± 0.84		0.211
3-month postop	1.57 ± 1.51		1.49 ± 0.75		0.465
6-month postop	1.36 ± 0.93		1.40 ± 0.87		0.973
1-month vs 3-month		0.884		0.006 [†]	
3-month vs 6-month		0.794		0.807	
1-month vs 6-month		0.401		0.009 [†]	
Error ratio					
1-month postop	0.66 ± 0.44		0.31 ± 0.21		0.011 [†]
3-month postop	0.60 ± 0.44		0.37 ± 0.10		0.071
6-month postop	0.69 ± 0.58		0.39 ± 0.30		0.105
1-month vs 3-month		0.469		0.552	
3-month vs 6-month		0.222		0.965	
1-month vs 6-month		0.463		0.414	
Correction ratio					
1-month postop	0.80 ± 0.40		0.99 ± 0.25		0.108
3-month postop	0.82 ± 0.54		0.81 ± 0.23		0.465
6-month postop	0.78 ± 0.43		0.78 ± 0.32		0.840
1-month vs 3-month		0.931		0.004 [†]	
3-month vs 6-month		0.809		0.650	

D = diopters; AK = arcuate keratotomy; IOL = intraocular lens

Values are presented as mean ± standard deviation (range) or number.

^aComparison between follow-up period within groups assessed by Wilcoxon signed-rank test

^bComparison between groups assessed by Mann-Whitney *U* test

[†]Statistically significant (*P* < .05)

	AK group	<i>p</i> ^a	toric IOL group	<i>p</i> ^a	<i>p</i> ^b
1-month vs 6-month		0.681		0.013 [†]	
Error of magnitude (D)					
1-month postop	0.31 ± 0.62		0.05 ± 0.55		0.194
3-month postop	0.24 ± 1.18		0.34 ± 0.51		0.808
6-month postop	0.47 ± 0.70		0.44 ± 0.69		0.813
1-month vs 3-month		0.884		0.006 [†]	
3-month vs 6-month		0.794		0.807	
1-month vs 6-month		0.401		0.009 [†]	
Error of angle (°)					
1-month postop	15.13 ± 67.82		7.01 ± 75.03		0.820
3-month postop	-0.03 ± 75.59		-4.42 ± 82.27		0.697
6-month postop	6.00 ± 65.83		-12.96 ± 74.47		0.522
1-month vs 3-month		0.426		0.594	
3-month vs 6-month		0.968		0.650	
1-month vs 6-month		0.575		0.221	
D = diopters; AK = arcuate keratotomy; IOL = intraocular lens					
Values are presented as mean ± standard deviation (range) or number.					
^a Comparison between follow-up period within groups assessed by Wilcoxon signed-rank test					
^b Comparison between groups assessed by Mann-Whitney <i>U</i> test					
[†] Statistically significant (<i>P</i> < .05)					

Figures show double-angle plots of preoperative corneal astigmatism and postoperative refractive astigmatism at 3-month and 6-month after surgery in both AK group (Fig. 1, 2) and toric IOL group (Fig. 3, 4). Effective postoperative astigmatism reduction was observed in all of the double-angle plots.

There was no intraoperative complication requiring secondary operation in both groups. In the AK group, no case of corneal ectasia or corneal perforation was occurred. There was no instance of IOL misalignment more than 10° in the toric IOL group.

Discussion

Cataract surgery has evolved into a refractive procedure during which spherical and cylindrical errors are minimized, finally resulting in satisfactory spectacle-free visual outcomes. However, accurate surgical planning and perfect correction of astigmatism have been challenging for cataract surgeons. Many previous studies compared several options during cataract surgery to correct astigmatism, including opposite clear corneal incisions, limbal relaxing incisions, manual AK, and toric IOL implantation. The implantation of toric IOL is considered as an effective surgical option to reduce refractive astigmatism. [14, 26, 27] Additionally, recently introduced FLACS showed comparable results with conventional cataract surgery.[28] Furthermore, simultaneous astigmatism correction with femtosecond laser-assisted intrastromal AK combined with FLACS is reported to be adjustable for managing astigmatism in cataract surgery.[29] To the best of our knowledge, no comparison between femtosecond laser-assisted intrastromal AK and toric IOL implantation in the aspect of astigmatism correction was reported yet. In the present study, we aim to compare the effectiveness of astigmatism reduction in cataract surgery between the two procedures: simultaneous femtosecond laser-assisted intrastromal AK combined with FLACS and toric IOL implantation.

In this study, significant correction of refractive astigmatism was derived by both femtosecond laser-assisted intrastromal AK and toric IOL implantation. Our previous study suggested that the femtosecond laser-assisted AK following conventional cataract surgery is comparable to implantation of toric IOL in patients with preoperative astigmatism between + 1.00 and + 3.00 D.[19] However, there are some important differences between the current study and our previous study. That is, whereas femtosecond laser-assisted trans-epithelial AK was performed for patients who were not satisfied with their remaining astigmatism, following conventional cataract surgery in our previous study,[19] femtosecond laser-assisted intrastromal AK was performed simultaneously with FLACS in patients with lower preexisting astigmatism up to + 2.00 D in the present study. In addition, intrastromal AK was performed in this study, while trans-epithelial AK was done previously. Intrastromal AK with central 60% of total corneal thickness in depth remaining upper 20% and lower 20% without penetration could be safer than trans-epithelial AK which includes Bowman's layer incision followed by anterior stromal inflammation with epithelial hyperplasia.[30] According to our previous study, in cases of lower magnitude of preoperative astigmatism, there was comparable effect between femtosecond laser-assisted trans-epithelial AK and toric IOL implantation with regards to postoperative astigmatism correction. In the current study, also, comparable astigmatism correction was noted between simultaneous femtosecond laser-assisted intrastromal AK combined with FLACS and toric IOL implantation in terms of refractive astigmatism reduction. Both femtosecond laser-assisted intrastromal AK and toric IOL implantation could effectively reduce refractive astigmatism postoperatively.

By performing femtosecond laser-assisted intrastromal AK during cataract surgery, corneal astigmatism was effectively corrected postoperatively. Significant reduction in corneal astigmatism was made in the AK group at all of each postoperative follow-up period. Principle of the toric IOL implantation does not affect corneal astigmatism. However, for the reason that on-axis clear corneal incision may alter postoperative surgically induced astigmatism in cataract surgery, corneal astigmatism as well as refractive astigmatism was also compared between the two groups. Obviously, compared to baseline

preoperative levels, the amount of reduction was not significant in the toric IOL group, while significant reduction of corneal astigmatism was noted in the AK group.

In femtosecond laser-assisted intrastromal AK group, no significant change was seen in vector analysis during each follow-up period of 1-month, 3-month, and 6-month postoperatively. In line with our results, previous study reported that the reduced corneal astigmatism after intrastromal AK showed a stable course during 6-month postoperatively.[16] Reported stability in astigmatism correction could be attributed to the fact that femtosecond laser-assisted intrastromal AK is performed with optical coherence tomography-guided computer software with calculated nomogram. Considering that there was no ocular complication such as corneal ectasia or epithelial ingrowth, albeit short term follow-up period, femtosecond laser-assisted intrastromal AK with FLACS can be an effective, reproducible, and precise alternative procedure not only to remove cataract, but also decrease astigmatism.

With the passage of follow-up period, tendency of undercorrection of astigmatism was noted in the toric IOL group. Surgically induced refractive correction, correction ratio, and error of magnitude was significantly changed at 3-month and 6-month postoperatively in the toric IOL group compared to 1-month after surgery. Previous studies suggest that the rotation of toric IOL contributes to the reduced correction of astigmatism.[26, 31] Considering that 1° of off-axis IOL rotation is estimated to cause a reduction of up to 3.3% of IOL cylindrical power, rotation of toric IOL is very crucial to maintain UCVA and visual quality. In one study, toric IOLs continue to show some tendency to rotate for about 2 years postoperatively, although IOL rotation was usually less than 10° .[31] One previous study showed that postoperative rotation was within 5° in 95% of cases and within 2° in 68% of eyes after 3-month postoperatively.[26] In our study, about 0.2 D of cylindrical power correction was reduced from 1-month to 3-month postoperatively in the toric IOL group, which corresponds to approximately 10% of preoperative cylindrical power. Roughly 3° rotation can be presumed, which corresponds to similar outcomes with the study by Miyake T *et al* [26], which suggests a 2.2° rotation 1-week to 3-month postoperatively. Clinically, this minimal rotation may not significantly affect UCVA or patients' satisfaction. Nevertheless, careful routine check-up is needed in patients with toric IOL implantation.

The present study had several limitations, including its retrospective design and relatively short-term follow-up period. A prospective randomized clinical trial study with an appropriate sample size would allow a more thorough comparison with regards to astigmatism correction between the femtosecond laser-assisted intrastromal AK and implantation of toric IOL during cataract surgery.

In conclusion, femtosecond laser-assisted intrastromal AK in FLACS, as well as toric IOL implantation, is a comparable procedure in terms of reducing astigmatism in cataract surgery for patients with moderate astigmatism.

Declarations

Declaration of Conflicting Interests

The authors declare that there is no conflict of interest.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology(2016R1A2B1011341) and by a grant from the Asan Institute for Life Sciences, Asan Medical Center, Seoul, Korea (2020IP0088, 2020IT0004-1). We would like to thank Editage (www.editage.co.kr) for English language editing.

References

1. Hoffmann PC, Hutz WW: **Analysis of biometry and prevalence data for corneal astigmatism in 23,239 eyes.** *J Cataract Refract Surg* 2010, **36**(9):1479-1485.
2. Hoffer KJ: **Biometry of 7,500 cataractous eyes.** *Am J Ophthalmol* 1980, **90**(3):360-368.
3. Khan MI, Muhtaseb M: **Prevalence of corneal astigmatism in patients having routine cataract surgery at a teaching hospital in the United Kingdom.** *J Cataract Refract Surg* 2011, **37**(10):1751-1755.
4. Ferrer-Blasco T, Montes-Mico R, Peixoto-de-Matos SC, Gonzalez-Meijome JM, Cervino A: **Prevalence of corneal astigmatism before cataract surgery.** *J Cataract Refract Surg* 2009, **35**(1):70-75.
5. Chen W, Zuo C, Chen C, Su J, Luo L, Congdon N, Liu Y: **Prevalence of corneal astigmatism before cataract surgery in Chinese patients.** *J Cataract Refract Surg* 2013, **39**(2):188-192.
6. Lekhanont K, Wuthisiri W, Chatchaipun P, Vongthongsri A: **Prevalence of corneal astigmatism in cataract surgery candidates in Bangkok, Thailand.** *J Cataract Refract Surg* 2011, **37**(3):613-615.
7. Visser N, Bauer NJ, Nuijts RM: **Residual astigmatism following toric intraocular lens implantation related to pupil size.** *J Refract Surg* 2012, **28**(10):729-732.
8. Wolffsohn JS, Bhogal G, Shah S: **Effect of uncorrected astigmatism on vision.** *J Cataract Refract Surg* 2011, **37**(3):454-460.
9. Behndig A, Montan P, Stenevi U, Kugelberg M, Zetterstrom C, Lundstrom M: **Aiming for emmetropia after cataract surgery: Swedish National Cataract Register study.** *J Cataract Refract Surg* 2012, **38**(7):1181-1186.
10. Lee H, Kim TI, Kim EK: **Corneal astigmatism analysis for toric intraocular lens implantation: precise measurements for perfect correction.** *Curr Opin Ophthalmol* 2015, **26**(1):34-38.
11. Fouda S, Kamiya K, Aizawa D, Shimizu K: **Limbal relaxing incision during cataract extraction versus photoastigmatic keratectomy after cataract extraction in controlling pre-existing corneal astigmatism.** *Graefes Arch Clin Exp Ophthalmol* 2010, **248**(7):1029-1035.
12. Bayramlar H, Daglioglu MC, Borazan M: **Limbal relaxing incisions for primary mixed astigmatism and mixed astigmatism after cataract surgery.** *J Cataract Refract Surg* 2003, **29**(4):723-728.
13. Kamiya K, Umeda K, Ando W, Igarashi A, Shimizu K: **Clinical outcomes of photoastigmatic refractive keratectomy for the correction of residual refractive errors following cataract surgery.** *J Refract Surg*

- 2011, **27**(11):826-831.
14. Kessel L, Andresen J, Tendal B, Erngaard D, Flesner P, Hjortdal J: **Toric Intraocular Lenses in the Correction of Astigmatism During Cataract Surgery: A Systematic Review and Meta-analysis.** *Ophthalmology* 2016, **123**(2):275-286.
 15. Hayashi K, Kondo H, Yoshida M, Manabe S, Hirata A: **Higher-order aberrations and visual function in pseudophakic eyes with a toric intraocular lens.** *J Cataract Refract Surg* 2012, **38**(7):1156-1165.
 16. Ruckl T, Dexl AK, Bacherneegg A, Reischl V, Riha W, Ruckhofer J, Binder PS, Grabner G: **Femtosecond laser-assisted intrastromal arcuate keratotomy to reduce corneal astigmatism.** *J Cataract Refract Surg* 2013, **39**(4):528-538.
 17. Nubile M, Carpineto P, Lanzini M, Calienno R, Agnifili L, Ciancaglini M, Mastropasqua L: **Femtosecond laser arcuate keratotomy for the correction of high astigmatism after keratoplasty.** *Ophthalmology* 2009, **116**(6):1083-1092.
 18. Wetterstrand O, Holopainen JM, Krootila K: **Treatment of postoperative keratoplasty astigmatism using femtosecond laser-assisted intrastromal relaxing incisions.** *J Refract Surg* 2013, **29**(6):378-382.
 19. Yoo A, Yun S, Kim JY, Kim MJ, Tchah H: **Femtosecond Laser-assisted Arcuate Keratotomy Versus Toric IOL Implantation for Correcting Astigmatism.** *J Refract Surg* 2015, **31**(9):574-578.
 20. Nejima R, Terada Y, Mori Y, Ogata M, Minami K, Miyata K: **Clinical utility of femtosecond laser-assisted astigmatic keratotomy after cataract surgery.** *Jpn J Ophthalmol* 2015, **59**(4):209-215.
 21. Day AC, Lau NM, Stevens JD: **Nonpenetrating femtosecond laser intrastromal astigmatic keratotomy in eyes having cataract surgery.** *J Cataract Refract Surg* 2016, **42**(1):102-109.
 22. Chan TC, Cheng GP, Wang Z, Tham CC, Woo VC, Jhanji V: **Vector Analysis of Corneal Astigmatism After Combined Femtosecond-Assisted Phacoemulsification and Arcuate Keratotomy.** *Am J Ophthalmol* 2015, **160**(2):250-255 e252.
 23. Eydelman MB, Drum B, Holladay J, Hilmantel G, Kezirian G, Durrie D, Stulting RD, Sanders D, Wong B: **Standardized analyses of correction of astigmatism by laser systems that reshape the cornea.** *J Refract Surg* 2006, **22**(1):81-95.
 24. Reinstein DZ, Archer TJ, Randleman JB: **JRS standard for reporting astigmatism outcomes of refractive surgery.** *J Refract Surg* 2014, **30**(10):654-659.
 25. Dupps WJ, Jr., Kohnen T, Mamalis N, Rosen ES, Srinivasan S, Koch DD, Obstbaum SA: **The Journal of Cataract & Refractive Surgery: 2018 in Review.** *J Cataract Refract Surg* 2018, **44**(12):1411-1412.
 26. Miyake T, Kamiya K, Amano R, Iida Y, Tsunehiro S, Shimizu K: **Long-term clinical outcomes of toric intraocular lens implantation in cataract cases with preexisting astigmatism.** *J Cataract Refract Surg* 2014, **40**(10):1654-1660.
 27. Roberts TV, Sharwood P, Hodge C, Roberts K, Sutton G: **Comparison of Toric Intraocular Lenses and Arcuate Corneal Relaxing Incisions to Correct Moderate to High Astigmatism in Cataract Surgery.** *Asia Pac J Ophthalmol (Phila)* 2014, **3**(1):9-16.

28. Chan TC, Ng AL, Cheng GP, Wang Z, Woo VC, Jhanji V: **Corneal Astigmatism and Aberrations After Combined Femtosecond-Assisted Phacoemulsification and Arcuate Keratotomy: Two-Year Results.** *Am J Ophthalmol* 2016, **170**:83-90.
29. Wang J, Zhao J, Xu J, Zhang J: **Evaluation of the effectiveness of combined femtosecond laser-assisted cataract surgery and femtosecond laser astigmatic keratotomy in improving post-operative visual outcomes.** *BMC Ophthalmol* 2018, **18**(1):161.
30. Gray B, Binder PS, Huang LC, Hill J, Salvador-Silva M, Gwon A: **Penetrating and Intrastromal Corneal Arcuate Incisions in Rabbit and Human Cadaver Eyes: Manual Diamond Blade and Femtosecond Laser-Created Incisions.** *Eye Contact Lens* 2016, **42**(4):267-273.
31. Gyongyossy B, Jirak P, Schonherr U: **Long-term rotational stability and visual outcomes of a single-piece hydrophilic acrylic toric IOL: a 1.5-year follow-up.** *Int J Ophthalmol* 2017, **10**(4):573-578.

Figures

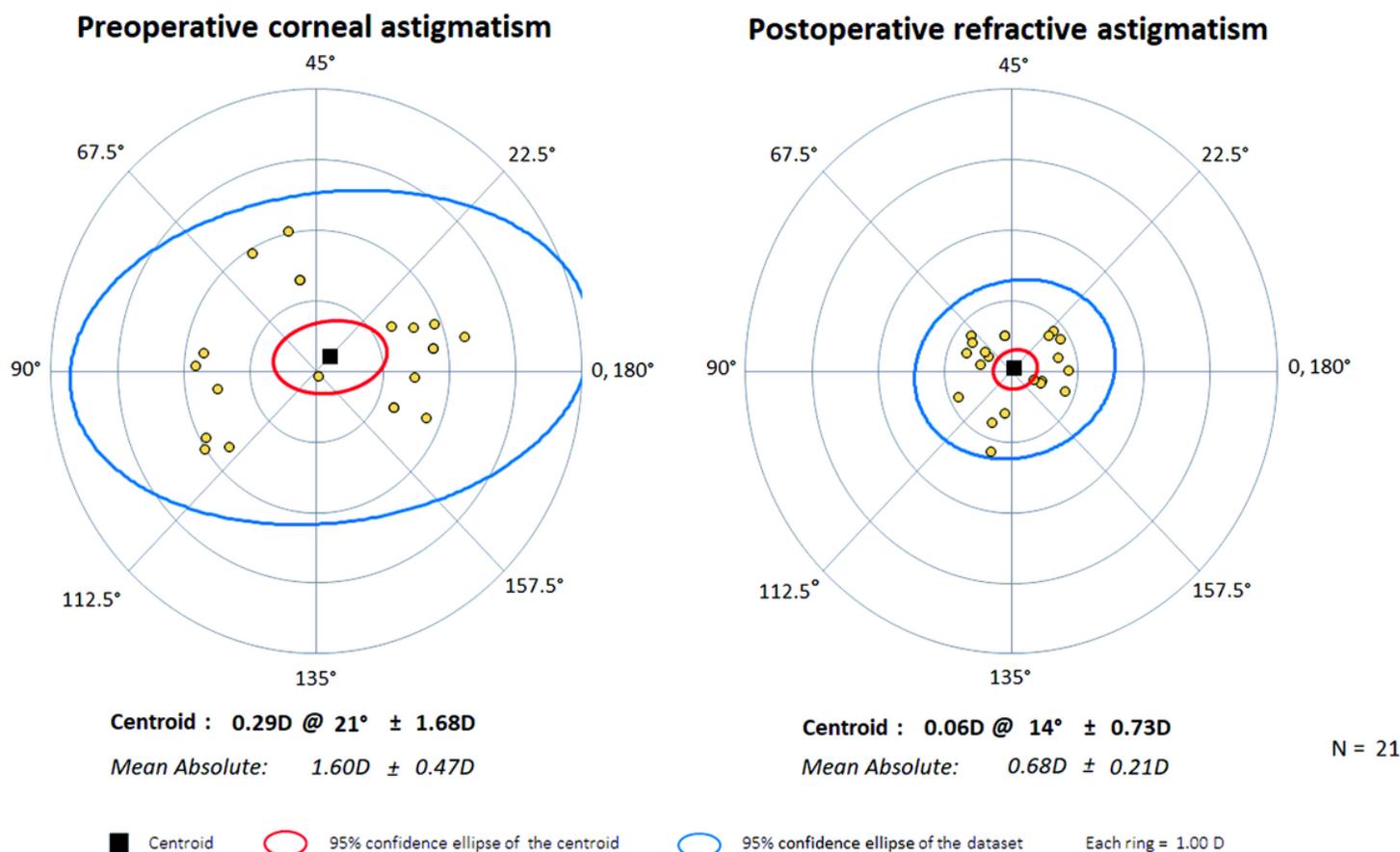


Figure 1

Double-angle plots of preoperative corneal astigmatism and 3-month postoperative refractive astigmatism in patients who underwent femtosecond laser-assisted intrastromal arcuate keratotomy with femtosecond laser-assisted cataract surgery.

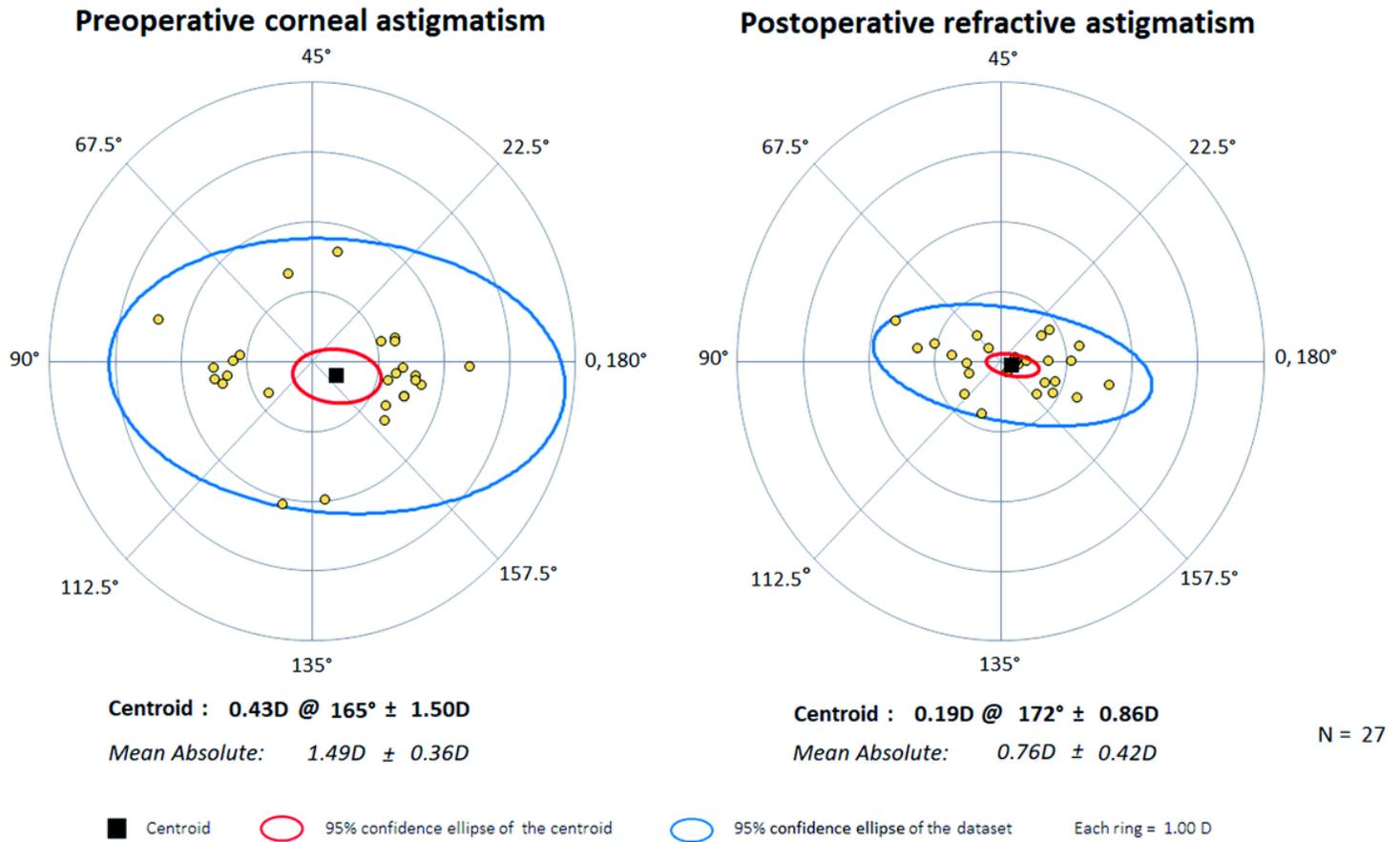


Figure 2

Double-angle plots of preoperative corneal astigmatism and 6-month postoperative refractive astigmatism in patients who underwent femtosecond laser-assisted intrastromal arcuate keratotomy with femtosecond laser-assisted cataract surgery.

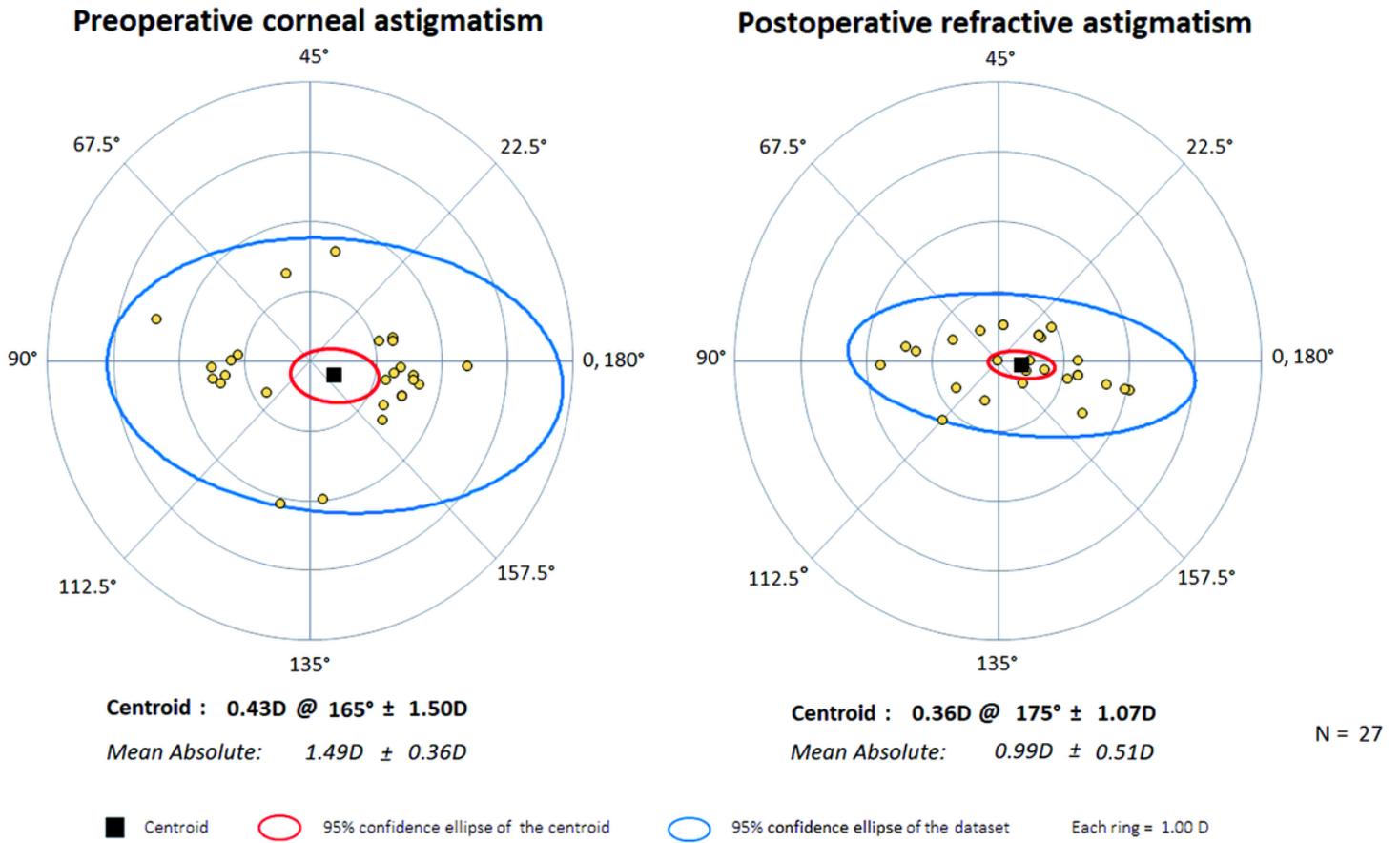


Figure 3

Double-angle plots of preoperative corneal astigmatism and 3-month postoperative refractive astigmatism in patients who underwent cataract surgery with toric IOL implantation.

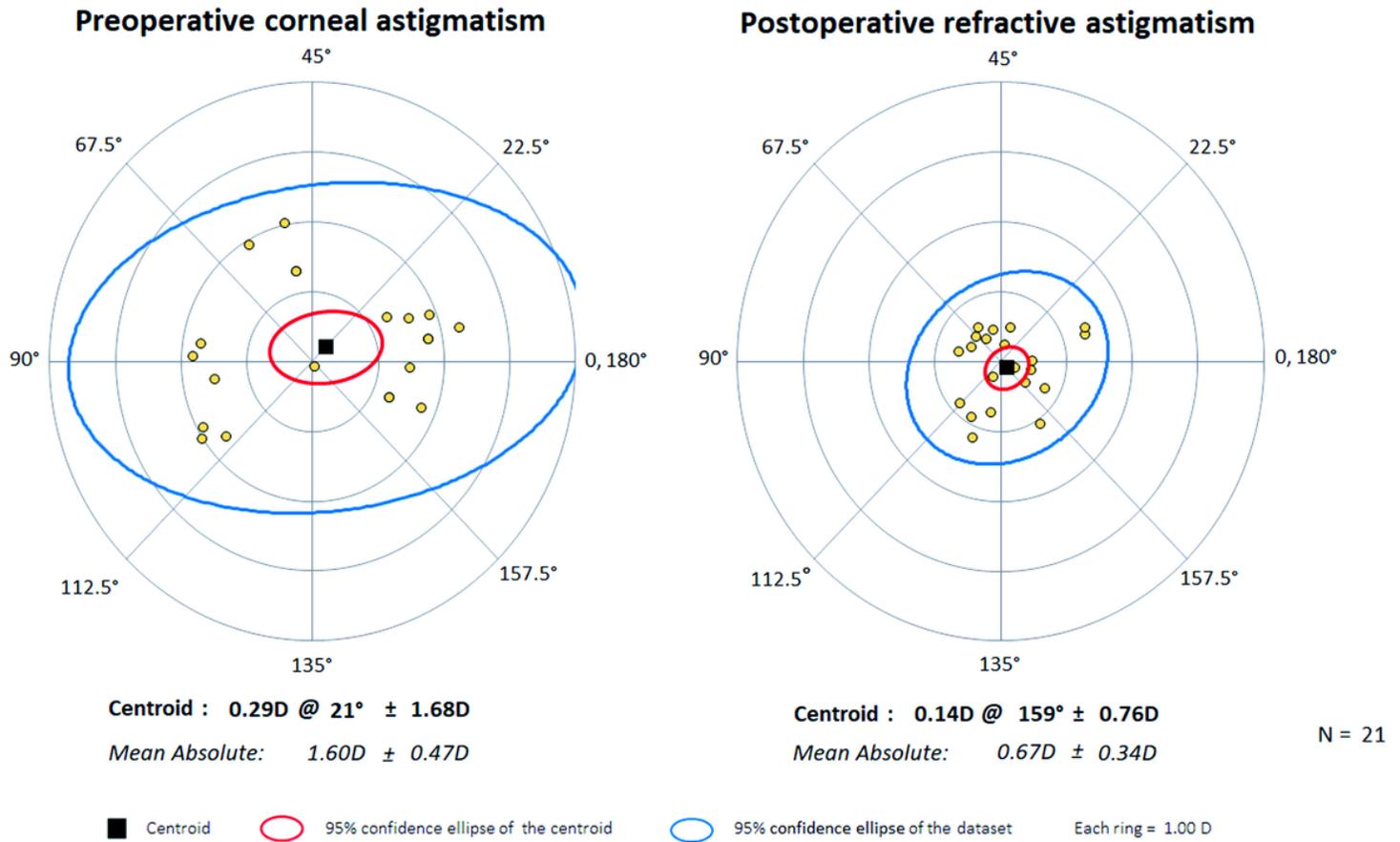


Figure 4

Double-angle plots of preoperative corneal astigmatism and 6-month postoperative refractive astigmatism in patients who underwent cataract surgery with toric IOL implantation.