Two Different Corneal Incision Designs for Correcting Corneal Astigmatism During Cataract Surgery With Multifocal Intraocular Lens Implantation

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Abstract

Background: Multifocal intraocular lenses (IOLs) is very intolerant to residual corneal astigmatism and patients with more than 1.0 D of residual corneal astigmatism are not suitable candidates for implantation of multifocal IOLs. The purpose of this study was to evaluate the efficacy of a single clear corneal incision (CCI) or an opposite clear corneal incision (OCCI) made on a steep meridian for correction of low to moderate corneal astigmatism during implantation of multifocal IOLs.

Methods: This is a retrospective cohort study. A total of 80 patients with pre-operative total corneal astigmatism, ranging between 0.5 and 2.0 diopters (D), who underwent cataract surgery and received multifocal IOLs were included. Correction of corneal astigmatism was done via single CCIs on steep meridians in patients with 0.5–1.2 D total corneal astigmatism, and OCCIs in patients with 1.3–2.0 D total corneal astigmatism. Visual acuity, corneal astigmatism, ocular aberrations, corneal aberrations, and subjective vision quality were evaluated after surgery.

Results: At 12-weeks post-surgery, the mean uncorrected distance vision acuity (UDVA) was 0.06 ± 0.09 logarithm of the minimum angle of resolution (logMAR) and 0.03 ± 0.09 logMAR, and the mean uncorrected near vision acuity (UNVA) was 0.08 ± 0.11 logMAR and 0.09 ± 0.09 logMAR in the CCI and OCCI groups, respectively. The change in corneal astigmatism was 0.52 ± 0.22 D and 1.06 ± 0.23 D in the CCI and OCCI groups, respectively ($P < 0.001$). Total corneal higher-order aberrations (HOAs) and trefoil increased in both groups ($P < 0.05$); however, there was no difference in the change in total corneal HOAs between the two groups ($P > 0.05$).

Conclusions: CCI and OCCI made on a steep axis could be an option for correction of mild-to-moderate astigmatism during cataract surgery with multifocal IOL implantation.

Introduction

Residual astigmatism after cataract surgery can significantly compromise vision in patients, causing symptomatic blur and a reduction in uncorrected vision, thus affecting quality of life. Unaided visual acuity in patients with 1.0 D or more of residual refractive astigmatism after monofocal intraocular lens (IOL) may not be acceptable.¹ Multifocal IOLs are even less forgiving for corneal astigmatism, and patients receiving multifocal IOLs can be affected by as little as 0.5 D of residual refractive astigmatism.^{1–2} It is estimated that 50% of cataract patients in America and 43% in China exhibit more than 1.0 D of astigmatism.^{3–4} Therefore, managing preexisting corneal astigmatism at the time of cataract surgery is critical for achieving excellent visual outcomes, especially when implanting multifocal IOLs.

Several methods have been employed to correct corneal astigmatism, including corneal or limbal relaxing incisions, clear corneal incision (CCI) and opposite clear corneal incision (OCCI) applied on a steep axis, as well as implantation of toric IOLs.^{5–11} Among these methods, CCI and OCCI made on a steep meridian are widely used in patients with low to moderate corneal astigmatism since this technique is simple and

requires no additional skill or instrumentation.^{8–11} Previous studies have reported the use of CCI and OCCl to correct corneal astigmatism in eyes with monocular IOLs.^{8–11} To our knowledge, there is no report examining the use of OCCl or CCI applied on a steep meridian to correct astigmatism when multifocal IOLs are implanted. Since a growing number of multifocal IOLs, which are less tolerant to residual corneal astigmatism than monocular IOLs,^{1,2} are being used in cataract patients, it is important to evaluate whether CCI and/or OCCl are effective for correcting astigmatism in patients undergoing multifocal IOL implantation. In this study, CCI or OCCl on a steep meridian were used to correct total corneal astigmatism ranging between 0.5 and 2.0 D, during implantation of multifocal IOLs. Visual quality of life was then evaluated in patients that underwent CCI or OCCl with implantation of multifocal IOL at 12 weeks post-surgery.

Patients And Methods

Study design

This study is a retrospective cohort study that was performed at the Eye Center of Xiangya Hospital, Central South University, Changsha, China. Patients who underwent cataract surgery in our department were consecutively included from October 2018 to October 2020. Inclusion criteria were as follows: 1) total corneal astigmatism ranging between 0.5 D and 2.0 D preoperatively; 2) implantation of ZMB00 multifocal IOLs (Abbott Medical Optics, Inc., California, USA); and 3) a single CCI or OCCl was made on the steepest meridian. Exclusion criteria were as follows: 1) corneal astigmatism greater than 2.0 D or irregular astigmatism; 2) presence of eye disease other than cataract; 3) a history of eye trauma and/or previous ocular surgery; and 4) intra-operative complications.

Eighty eyes of 80 patients, ranging in age from 37 to 81 years, were included. One eye per one patient was used in this study. If both eyes that underwent cataract surgery were eligible for this study, the first surgical eye was selected.

Corneal astigmatism was measured with Scheimpflug topography (Pentacam; Oculus, Inc, Wetzlar, Germany), and patients were divided into a CCI group and an OCCl group by pre-operative total corneal astigmatism. Patients with 0.5–1.2D pre-operative corneal astigmatism were included in the CCI group and received a single CCI on the steep meridian, and patients with 1.3–2.0 D were included in the OCCl group and received OCCl on the steep meridian. A total of 41 patients were included in the CCI group and 39 patients were included in the OCCl group. Both groups consisted of superior, temporal, and oblique subgroups on the basis of the steepest corneal meridian. The orientation of corneal astigmatism was regarded as against-the-rule astigmatism (ATR) in the case of the steepest keratometric readings being between 0–30 and 150–180 degrees, oblique astigmatism was between 30–60 and 120–150 degrees, and with-the-rule astigmatism (WTR) was 60–120 degrees. The pre-operative clinical data of patients in the CCI and OCCl groups is described in Table 1.

Table 1
Pre-operative baseline clinical data of patients.

		CCI group	OCCI group	P
No.		41	39	/
Age (year)		64.9 ± 9.1	58.9 ± 12.4	0.09
Female/Male		21/20	20/19	0.78
Right eye/Left eye		19/22	21/18	0.57
Nuclear opalescence grade		2–4	2–4	/
Mean corneal astigmatism(D)		0.98 ± 0.22	1.63 ± 0.27	<0.001
Mean corneal power(D)		43.87 ± 1.76	43.84 ± 1.70	0.97
The orientation of corneal astigmatism	WTR	17	15	0.78
	ATR	19	19	
	oblique	5	5	
Corneal Total HOAs		0.092 ± 0.014	0.140 ± 0.018	<0.001
Ocular Total HOAs		0.232 ± 0.042	0.286 ± 0.023	0.62
UDVA(logMAR)		0.98 ± 0.04	1.06 ± 0.08	0.53
VF-14score		65.12 ± 1.78	67.23 ± 3.14	0.98
WTR: with-the-rule; ATR:against-the-rule; UDVA:uncorrected distance visual acuity				

The study was approved by the Xiangya Hospital ethics committee and was performed in accordance with the tenets of the Declaration of Helsinki. All patients signed informed consent forms before cataract surgery, and data were collected anonymously.

Intraocular lens

The TECNIS ZMB00 is a UV-blocking, hydrophobic, acrylic, single-piece IOL. It has a C-loop haptic with near power added (+ 4.0 D) at the IOL optic plane. The IOL is designed as biconvex and consists of a wavefront-designed, anterior aspheric surface (negative spherical aberration – 0.27 μm) and posterior diffractive surface with 22 diffractive rings. The IOL power was calculated by the same technician using an IOL Master 500 optical biometer (Carl Zeiss Meditec AG, Jena, Germany) using the Haigis formula. Parameters included axial length, corneal power and anterior chamber depth.

Surgical Technique

All surgeries and corneal meridian markings were performed by the same surgeon (J.J). The steep corneal meridian was marked prior to surgery using a slit lamp. Briefly, the patient's head was positioned on the slit lamp and the patient was asked to keep the contralateral eye open and to look forward. The slit beam was narrowed to a thin slit, centered on the pupil and aligned with the 0°–180° marks of the calibrator. Then, using a sterile 30-gauge needle, two small superficial incisions were made at the periphery of the cornea where the slit beam cut the limbus at the 0°–180° position. Care was taken to keep the slit beam on the center of the pupil for alignment. Incisions were fixated with a sterile marker pen for easier intraoperative recognition. Finally, the correct position markings were verified at the slit lamp (Fig. 1).

Surgery was performed using topical anesthesia in both groups. After the Mendez-style corneal marking ring was aligned to the two preoperative markings, dots were made using a blue pen on the planned meridian (Fig. 1). A self-sealing 3.0 mm CCI was made 1 mm anterior to the limbus on a steep meridian using a 3.0 mm keratome (Alcon Laboratories, Inc. Fort Worth, USA). There is a 2 mm marking line on the surface of the keratome so that we can ensure that the tunnel length is 2 mm. The standard phacoemulsification procedure was performed via 2 incisions. Routine phacoemulsification was performed using a standard ultrasound technique (Centurion, Alcon Laboratories, Inc. Fort Worth, USA), followed by insertion of a foldable multifocal IOL (ZMB00). The OCCI was made on the opposite steep meridian 1 mm anterior to the limbus using the same keratome prior to removal of viscoelastic material; the length of corneal tunnel was also 2 mm. Only the phacoemulsification incision was hydrated at the end of surgery. All patients received routine postoperative topical steroids for 4 weeks and antibiotic eye drops for 2 weeks.

Main Outcome Measures

Uncorrected distance visual acuity (UDVA) and uncorrected near visual acuity (UNVA) were evaluated by an optometrist; the patients and optometrists were masked during vision testing. The decimal visual acuity was then converted to a logMAR scale for statistical analysis. Corneal astigmatism was assessed using Scheimpflug topography (Pentacam ; Oculus, Inc, Wetzlar, Germany), and the root mean square (RMS) of ocular and corneal HOAs, including total HOAs, coma (Z_3^{-1} and Z_3^1), spherical aberration (Z_4^0), secondary astigmatism (Z_4^{-2} and Z_4^2), and trefoil (Z_3^{-3} and Z_3^3), were assessed with the Zernike coefficient (iTrace, Tracey Technologies Inc., Houston, USA) in a 3.0 mm diameter central area. Astigmatic change was calculated as the difference between mean preoperative and postoperative topographic readings. Surgically induced astigmatism (SIA) was evaluated using the vector analysis on Dr. Warren Hill's website ([https:// sia-calculator.com/](https://sia-calculator.com/)). To determine whether different location of CCI and OCCI can induce different corneal astigmatism, we compared SIA, corneal astigmatic change between patients with WTR and ATR astigmatism. Five patients with oblique astigmatism in CCI or OCCI group were excluded from this comparison.

The Visual Function scale-14 (VF-14) was used to evaluate postoperative visual quality. The scale included 4 items: subjective vision, visual adaptation, peripheral vision and stereoscopic vision¹². Each

item was graded from 1 to 5 points, and a higher score indicated higher visual satisfaction. The final score was the average value times 20; higher scores indicated better postoperative life and visual quality.

UDVA, UNVA, total corneal astigmatism and HOAs were recorded before surgery. UDVA and UNVA were observed at 1, 4, and 12 weeks post-surgery. The HOAs were determined 12-weeks post-surgery. The VF-14 questionnaire, glare, halos, and the need for spectacles were recorded at 12 weeks post-surgery.

Statistical Analysis

Statistical analysis was performed using SPSS software (version 21.0; SPSS, Inc.). Categorical variables were compared with use of the Fisher's exact test. A Wilcoxon Signed Ranks test was used to analyze preoperative and postoperative data. A Mann–Whitney test was used to analyze the data between the two groups. A p value less than 0.05 was considered statistically significant.

Results

Visual Acuity

UDVA and UNVA were significantly improved at 1, 4 and 12 weeks post-surgery in both groups compared to pre-operative values ($P < 0.001$). There was no difference in UDVA and UNVA between the two groups post-surgery (Table 2).

Table 2
Mean preoperative and postoperative UDVA and UNVA in two groups.

		OCCI group	CCI group	P
UDVA (logMar)	Pre-op	1.06 ± 0.08	0.98 ± 0.04	0.53
	Post-1 week	0.12 ± 0.02*	0.10 ± 0.02*	0.26
	Post-4 weeks	0.09 ± 0.02*	0.05 ± 0.02*	0.87
	Post-12 weeks	0.06 ± 0.02*	0.03 ± 0.01*	0.24
UNVA (logMar)	Pre-op	0.92 ± 0.05	0.97 ± 0.06	0.89
	Post-1 week	0.10 ± 0.04*	0.09 ± 0.02*	0.92
	Post-4 weeks	0.09 ± 0.01*	0.09 ± 0.02*	0.20
	Post-12 weeks	0.08 ± 0.01*	0.09 ± 0.01*	0.81
UDVA: uncorrected distance visual acuity; UNVA:uncorrected near visual acuity; OCCI:opposite clear corneal incision; CCI:clear corneal incision.				
* Values are statistically significant compared with preoperative values ($P < 0.001$).				

Residual Corneal Astigmatism

Residual corneal astigmatism at 12 weeks post-surgery is shown in Fig. 2. Residual total corneal astigmatism was 0.2–0.8 D in the CCI group and 0.2–1.1 D in the OCCI group. In the CCI group, 14 of 41 patients (34.1%) had more than 0.5 D residual astigmatism and no patients had more than 1.0 D residual astigmatism. In the OCCI group, 13 of 24 patients (54.2%) had more than 0.5 D residual astigmatism, and 3 of 24 patients (7.6%) had more than 1.0 D residual astigmatism. Among the three patients, 2 patients had ATR astigmatism and 1 patient had WTR astigmatism and their preoperative mean astigmatism was 1.9D. The mean change in corneal astigmatism was 0.52 ± 0.22 D and 1.06 ± 0.23 D in the CCI and OCCI groups, respectively ($P < 0.001$).

Surgically Induced Astigmatism

The mean SIA was 0.62 ± 0.16 D and 1.23 ± 0.24 D in the CCI and OCCI groups, respectively, indicating that OCCIs caused significantly greater SIA than single CCIs ($P < 0.001$).

The impact of CCI and OCCI on WTR and ATR astigmatism

Compared to patients with ATR astigmatism, both the SIA and corneal astigmatic change were slightly higher in patients with WTR astigmatism in both CCI group and OCCI group, but there was no statistical difference($P = 0.38, P = 0.91, P = 0.49, P = 0.08$). (Table 3)

Table 3
The impact of CCI and OCCI on WTR and ATR astigmatism

	CCI		P	OCCI		p
	WTR	ATR		WTR	ATR	
Pre-operative CA	0.96 ± 0.22	1.02 ± 0.22	0.69	1.67 ± 0.26	1.56 ± 0.26	0.28
SIA	0.70 ± 0.15	0.64 ± 0.20	0.38	1.39 ± 0.21	1.37 ± 0.28	0.91
change of CA	0.52 ± 0.18	0.52 ± 0.16	0.49	1.12 ± 0.17	1.01 ± 0.28	0.08
CA:corneal astigmatism; SIA:surgically induced astigmatism; CCI:clear corneal incision; OCCI:apposite clear corneal incision; WTR:with the rule; ATR:against the rule.						

Corneal and ocular HOAs

After cataract surgery, ocular HOAs were significantly decreased in both the OCCI and CCI groups ($P < 0.05$) 12 weeks post-surgery. Corneal HOAs, total HOAs and trefoil increased in both groups ($P < 0.05$). Spherical aberration and secondary astigmatism increased in the CCI group ($P < 0.05$), but not in the OCCI group ($P > 0.05$) (Table 4, Fig. 3). Compared to the CCI group, the change in trefoil was larger and the change in secondary astigmatism was smaller in the OCCI group, which demonstrated a similar change in total HOAs in the two groups(Figure 3).

Table 4

Mean preoperative and 3-month postoperative corneal and ocular HOAs in the CCI and OCCl groups.

	Cornea		Ocular	
	OCCl	CCI	OCCl	CCI
Total HOA				
preoperative	0.140 ± 0.018	0.092 ± 0.014	0.286 ± 0.023	0.232 ± 0.042
postoperative	0.176 ± 0.018*	0.127 ± 0.016*	0.167 ± 0.018*	0.128 ± 0.020*
P	<0.001	<0.001	<0.001	<0.001
Coma				
preoperative	0.065 ± 0.011	0.052 ± 0.011	0.124 ± 0.021	0.140 ± 0.032
postoperative	0.063 ± 0.012*	0.050 ± 0.010	0.065 ± 0.010*	0.071 ± 0.012*
P	<0.001	0.182	<0.001	<0.001
Spherical Aberration				
preoperative	0.023 ± 0.008	0.027 ± 0.006	0.049 ± 0.012	0.062 ± 0.014
postoperative	0.024 ± 0.007	0.031 ± 0.006*	0.028 ± 0.006*	0.038 ± 0.006*
P	0.226	<0.001	<0.001	<0.001
Secondary Astigmatism				
preoperative	0.023 ± 0.007	0.022 ± 0.005	0.029 ± 0.008	0.032 ± 0.006
postoperative	0.023 ± 0.006	0.025 ± 0.005*	0.023 ± 0.005*	0.028 ± 0.011*
P	0.797	<0.001	<0.001	<0.001
Trefoil				
preoperative	0.038 ± 0.008	0.041 ± 0.009	0.070 ± 0.011	0.618 ± 0.009
postoperative	0.065 ± 0.010*	0.059 ± 0.010*	0.058 ± 0.010*	0.056 ± 0.010*
P	<0.001	<0.001	<0.001	<0.001
HOA: total higher-order aberrations; CCI: clear corneal incision; OCCl: opposite clear corneal incision				
* Values are statistically significant compared with preoperative examinations (P < 0.05).				

Visual quality

The VF-14 scores were significantly higher in both groups at 12-weeks post-surgery (both P < 0.001, Table 5). All patients reported that they were not wearing spectacles most of the time; although 10

patients (12.5%) needed spectacles when reading for long periods of time. A total of 12 patients (15%) reported glare and 9(11.2%) reported halos, but only 3 (3.8%) patients reported being bothered by these phenomena when driving at night.

Table 5
Mean preoperative and 3-month postoperative VF-14 scores in the two groups.

	Preoperative	Postoperative	P
CCI group	65.12 ± 1.78	88.87 ± 2.13	< 0.001*
OCCI group	67.23 ± 3.14	86.47 ± 4.25	< 0.001*
CCI: clear corneal incision; OCCI: opposite clear corneal incision			

Discussion

In this study, two different corneal incisions (CCI and OCCI) made at the steepest meridian were used to reduce corneal astigmatism during cataract surgery. Because the corrective effect of a single CCI made at the steepest meridian is limited, and astigmatism has not been fully corrected after CCI in eyes with more than 1.2 D of astigmatism prior to surgery,¹³ CCI at the steepest meridian was only used in patients with astigmatism between 0.5 and 1.2 D, and OCCI was used in patients with astigmatism between 1.3 and 2.0 D. It has been reported that the mean astigmatism correction with CCI is about 0.5 D,^{9,11,14,15} and the mean astigmatism correction with OCCI varies from 0.50 to 2.06 D, depending on the preoperative corneal astigmatism, as well as the location and length of the incisions.^{10,11,15} In the current study, a 3.0 mm OCCI on the steep corneal meridian reduced astigmatism by 1.06 D, and single CCI reduced astigmatism by 0.52 D. The results obtained herein are within the range reported previously.^{9–11, 14,15,16}

Since vision can be affected by as little as a 0.5 D residual astigmatism with multifocal IOL implantation, patients with more than 1.0 D residual astigmatism are not recommended for multifocal IOL implantations^{1,2}. In this study, patients with more than 0.5 D or 1.0 D residual corneal astigmatism were counted post-surgery. Half of the patients had less than 0.5 D residual astigmatism and almost all patients had less than 1.0 D residual astigmatism postoperatively, resulting in most patients reporting satisfaction with UDVA and UNVA after multifocal IOL implantation. At 12 weeks post-surgery, UDVA was 0.06 and 0.03 logMAR, and UNVA was 0.08 and 0.09 logMAR in the CCI and OCCI groups, respectively. This finding is consistent with the visual improvement reported by others using multifocal IOLs in patients with less than 1.0 D preoperative corneal astigmatism.^{17–19} However, there were still three patients in OCCI group had more than 1.0D residual astigmatism at 12 weeks post-surgery. We thought the reason why postoperative residual astigmatism was still high was the high preoperative corneal astigmatism (mean 1.9D) in these three patients, so multifocal toric IOLs may be more suitable for these patients.

The location of the corneal incisions was a factor that affect the corneal astigmatism after cataract surgery. Many studies have demonstrated that a temporally located incision induces less astigmatism than other types of incisions^{20,21}. But such alterations have not been reported in CCI or OCCl which was made on the steep meridian. In previous studies, the rate of SIA showed no statistical difference between superior, temporal, and oblique OCCl^{22,23}. Similar to previous studies, the rate of SIA in our study was detected slightly higher in the case of superior incisions, but the difference was not statistically significant. Further investigations should be carried out to explain the similarity in the rates of SIA detected in superior and temporal OCCl incisions.

Wavefront analysis is an objective measurement of visual quality and may predict visual complaints. Although approximately 93% of the aberration in a normal eye is known to be attributable to lower-order aberrations, HOAs are important for achieving the best optical quality in pseudophakic eyes.²⁴⁻²⁶ In this study, the ocular HOAs decreased significantly after surgery, which indicated an increase of visual quality with multifocal IOL implantation.

It has been shown that corneal incisions can increase the values of the root mean square (RMS) of corneal HOAs²⁷⁻³⁰; thus, we assessed the changes in corneal aberrations after surgery. The wavefront parameters of total HOAs, trefoil, coma, spherical aberrations, and secondary astigmatism were compared, since these aberrations constitute the major components of HOAs. In this study, both CCI and OCCl caused an increase in postoperative corneal HOAs, which is consistent with results of previous research.²⁷⁻³⁰ The change in the trefoil aberration increases significantly the larger the corneal incision.^{30,31} The current study found that the change of trefoil aberration was larger in the OCCl group than in the CCI group, which may be related to the additional surgical incision. However, the change in secondary astigmatism was smaller in the OCCl group than in the CCI group; thus, the change in total HOA was similar between the two groups. These findings show that compared with CCI, OCCl can increase astigmatism correction, but it does not increase the total corneal HOA.

Subjective vision quality is also an essential component for assessing visual performance. In this study, subjective vision quality was assessed using the VF-14 questionnaire. The questionnaire was used to evaluate near and far vision after cataract surgery. The findings showed that quality of life was significantly improved in both groups. Patients in our study who selected multifocal IOLs do not want to wear reading glasses after surgery. Since all patients in the current study had good UCNV and were spectacle-free most of the time after surgery, our procedure met the expectations of these patients. Glare and halo are common optical side effects after cataract surgery, especially when multifocal IOLs are inserted, and can significantly affect the visual performance and satisfaction of patients. Overall, 10 patients (12.5%) reported glare and 9 (11.2%) reported halos, while only 3 (3.8%) patients reported being bothered by these phenomena when driving at night.

This study had some limitations. First, this was a retrospective study and did not compare different methods for correcting corneal astigmatism. Second Moreover, the 12 weeks follow-up time was relatively

short; therefore, research into long-term outcomes is necessary. Furthermore, the limited number of patients enrolled reduced the statistical power of the analysis.

In conclusion, patients in this study had satisfactory vision quality after surgery. As for the correction of corneal astigmatism, CCI/OCCI requires no additional skill or instrumentation when 3.0 mm phacoemulsification incisions are used. Therefore, for patients with mild-to-moderate corneal astigmatism who elect to undergo implantation of a multifocal IOL during cataract surgery, CCI/OCCI is a recommended method for correcting corneal astigmatism

Declarations

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Compliance with Ethical Standards:

Conflict of interest : All authors declares that they have no conflict of interest.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the Xiangya Ethics Committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study. The data used to support the findings of this study are included within the article. The article has not been presented in a meeting.

References

1. Hayashi K, Hayashi H, Nakao F, Hayashi F (2000) Influence of astigmatism on multifocal and monofocal intraocular lenses. *Am J Ophthalmol* 130:477–482
2. Hayashi K, Manabe S-I, Yoshida M, Hayashi H (2010) Effect of astigmatism on visual acuity in eyes with a diffractive multifocal intraocular lens. *J Cataract Refract Surg* 36:1323–1329
3. Vitale S, Ellwein L, Cotch MF, Ferris FL, Sperduto R (2008) Prevalence of refractive error in the United States, 1999–2004. *Arch Ophthalmol* 126:1111–1119
4. Chen W, Zuo C, Chen C (2013) Prevalence of corneal astigmatism before cataract surgery in Chinese patients. *J Cataract Refract Surg* 39(2):188–192
5. Rubenstein JB, Raciti M (2013) Approaches to corneal astigmatism in cataract surgery. *Curr Opin Ophthalmol* 24(1):30–34
6. Kessel L, Andresen J, Tendal B, Erngaard D, Flesner P, Hjortdal J (2016) Toric Intraocular Lenses in the Correction of Astigmatism During Cataract Surgery: A Systematic Review and Meta-analysis.

7. Carvalho MJ, Suzuki SH, Freitas LL, Branco BC, Schor P, Lima AL (2007) Limbal relaxing incisions to correct corneal astigmatism during phacoemulsification. *J Refract Surg* 23(5):499–504
8. Rho CR, Joo CK (2012) Effects of steep meridian incision on corneal astigmatism in phacoemulsification cataract surgery. *J Cataract Refract Surg* 38(4):666–671
9. Song W, Chen X, Wang W (2015) Effect of steep meridian clear corneal incisions in phacoemulsification. *Eur J Ophthalmol* 25(5):422–425
10. Qammar A, Mullaney P (2005) Paired opposite clear corneal incisions to correct preexisting astigmatism in cataract patients. *J Cataract Refract Surg* 31(6):1167–1170
11. Khokhar S, Lohiya P, Murugiesan V, Panda A (2006) Corneal astigmatism correction with opposite clear corneal incisions or single clear corneal incision: comparative analysis. *J Cataract Refract Surg* 32(9):1432–1437
12. Steinberg EP, Tielsch JM, Schein OD, Javitt JC, Sharkey P, Cassard SD, Legro MW, Diener-West M, Bass EB, Damiano AM et al. The VF-14(1994). An index of functional impairment in patients with cataract. *Arch Ophthalmol* 112:630–638
13. Matsumoto Y, Hara T, Chiba K, Chikuda M (2001) Optimal incision sites to obtain an astigmatism-free cornea after cataract surgery with a 3.2 mm sutureless incision. *J Cataract Refract Surg* 27(10):1615–1619
14. Kaufmann C, Peter J, Ooi K, Phipps S, Cooper P, Goggin M (2005) Limbal relaxing incisions versus on-axis incisions to reduce corneal astigmatism at the time of cataract surgery. *J Cataract Refract Surg* 31:2261–2265
15. Can T, Takmaz Y, Yıldız H, Bayhan A, Soyugelen G, Bostancı B (2010) Coaxial, microcoaxial, and biaxial microincision cataract surgery. *J Cataract Refract Surg* 36:740–746
16. Ren Y, Fang X, Fang A, Wang L, Jhanji V, Gong X (2019) Phacoemulsification With 3.0 and 2.0 mm Opposite Clear Corneal Incisions for Correction of Corneal Astigmatism. *Cornea* 38(9):1105–1110
17. Cezón Prieto J, Bautista MJ(2010). Visual outcomes after implantation of a refractive multifocal intraocular lens with a 3.00 D addition. *J Cataract Refract Surg* 2010; 36:1508–1516
18. Alfonso JF, Puchades C, Fernández-Vega L, Montés-Micó R, Valcárcel B, Ferrer-Blasco T (2009) Visual acuity comparison of 2 models of bifocal aspheric intraocular lenses. *J Cataract Refract Surg* 35(4):672–676
19. Alió JL, Plaza-Puche AB, Piñero DP (2011) Optical analysis, reading performance, and quality-of-life evaluation after implantation of a diffractive multifocal intraocular lens. *J Cataract Refract Surg* 37(1):27–37
20. Altan-Yaycioglu R, Akova YA, Akca S, Gur S, Oktem C (2007) Effect on astigmatism of the location of clear corneal incision in phacoemulsification of cataract. *J Refract Surg* 23(5):515–518
21. Hashemi H, Khabazkhoob M, Soroush S, Shariati R, Miraftab M, Yekta A (2016) The location of incision in cataract surgery and its impact on induced astigmatism. *Curr Opin Ophthalmol* 27(1):58–

22. Tadros A, Habib M, Tejawani D, Von Lany H, Thomas P. Opposite clear corneal incisions on the steep meridian in phacoemulsification: early effects on the cornea. *J Cataract*
23. Refract S 2004;30:414-7. Nemeth G, Kolozsvari B, Berta A, Laszlo M. Paired opposite clear corneal incision: time-related changes of its effect and factors on which those changes depend. *Eur J Ophthalmol*. 2014;24(5):676–681
24. Nanavaty MA, Spalton DJ, Marshall J (2010) Effect of intraocular lens asphericity on vertical coma aberration. *J Cataract Refract Surg* 36:215–221
25. Song IS, Park JH, Park JH (2015) Corneal coma and trefoil changes associated with incision location in cataract surgery. *J Cataract Refract Surg* 41:2145–2151
26. Rocha KM, Soriano ES, Chalita MR (2006) Wavefront analysis and contrast sensitivity of aspheric and spherical intraocular lenses: a randomized prospective study. *Am J Ophthalmol* 142:750–756
27. Park YM, Choi BJ, Lee JS (2016) Effect of incision types for Artisan phakic intraocular lens implantation on ocular higher order aberrations. *Int J Ophthalmol* 9:1785–1789
28. Jiang Y, Le Q, Yang J, Lu Y (2006) Changes in corneal astigmatism and high order aberrations after clear corneal tunnel phacoemulsification guided by corneal topography. *J Refract Surg* 22(9 Suppl):1083–1088
29. Villegas EA, Alcón E, Rubio E, Marín JM, Artal P (2019) One-year follow-up of changes in refraction and aberrations induced by corneal incision. *PLoS ONE* 14(11):e0224823
30. Wang L, Zhao L, Yang X, Zhang Y, Liao D, Wang J(2019). Comparison of Outcomes after Phacoemulsification with Two Different Corneal Incision Distances Anterior to the Limbus. *J Ophthalmol* 2019:1760742
31. Tong N, He JC, Lu F, Wang Q, Qu J, Zhao YE (2008) Changes in corneal wavefront aberrations in microincision and small-incision cataract surgery. *J Cataract Refract Surg* 34:2085–2090

Figures

Figure 1

(A) Two marks placed at the limbus on the horizontal axis (0° and 180°) under slit lamp observation. (B) CCI was made at a planned meridian.

Figure 2

Figure 3

Mean change in corneal aberration in the CCI and OCCI groups.