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Original Article

Comparison of Postoperative Corneal Astigmatism Induced by Two Different Corneal Incisions during Microincisional Cataract Surgery

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Abstract

Objectives: Clear corneal incision (CCI) architecture in modern microincision cataract surgery (MICS) plays an undeniable role in postoperative refraction. The goal of this study was to evaluate the effect of hinge incision prior to two-step CCI on postoperative refractive astigmatism after cataract surgery and to demonstrate the schematic presentation of these postoperative astigmatic changes via double-angle polar plots.

Methods: This study involved a consecutive case series of patients who had MICS. The first incision was performed as a two-step CCI, whereas the second was made as a hinge incision prior to 2-step CCI. The preoperative corneal and postoperative refractive astigmatism and surgically induced astigmatism (SIA) were calculated by vectorial analysis. Hotelling's T2 test was performed to compare the centroid values of preoperative and postoperative corneal astigmatism.

Results: A total of 63 eyes from 57 subjects were evaluated. Group I consisted of 27 eyes with the two-step CCI, and Group II included 36 eyes with the hinge incision prior to two-step CCI. No significant difference was found between the groups in terms of age, sex, axial length, keratometry readings, implanted intraocular lens power, and postoperative spherical equivalent. The centroids of corneal astigmatism postoperatively increased to 0.21 D at 87.6°±0.61 with no significance in Group I ($p=0.525$) and to 0.70 D at 90.6°±0.47 with significance in Group II ($p=0.032$). The difference in postoperative centroids between the two groups was also significantly different ($p=0.043$). Finally, the centroids of SIA were 0.12 D at 85.5°±0.50 and 0.22 D at 91.1°±0.49 for Group I and Group II, respectively, with no significance.

Conclusion: A hinge incision did not have an unfavorable effect on postoperative refractive astigmatism; therefore, it may be preferred for controlled entrance to the anterior chamber.

Keywords: Centroid value, incision architecture, microincision cataract surgery, surgically induced astigmatism, vectorial analysis

Introduction

Modern microincision cataract surgery (MICS) has been developed in the last decades and has been increasingly preferred worldwide in clinical use with reduced surgical trauma and expeditious postoperative visual satisfaction (1). The incision architecture, including the width, length, distance to the limbus, and the configuration of the incision, has an undeniable impact not only on the relative stability in terms of resistance to external pressure (2) but also on the induced postoperative astigmatism (3).

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It has been proven that well-structured clear corneal incisions (CCIs) in MICS are watertight enough, and consequently, the risk of endophthalmitis is low (4). Also, the types of CCI, namely, beveled, stepped, and hinged, have been investigated to evaluate the wound integrity. The hinged incision was found to be the best to get a clear corneal construction (2) although additional astigmatism was induced minimally (5).

In addition, the side of the incision significantly affects postoperative astigmatism, that is, the temporal clear corneal approach is much more applicable and results in lesser postoperative astigmatism compared to superior CCIs (6).

Every surgeon is thought to induce postoperative astigmatism, which is defined as surgically induced astigmatism (SIA). SIA is a form of astigmatism caused by wound healing and scar formation that takes place at the incision site and is affected not only by the architecture of the wound but also by the surgeon's habitual preferences (7). With the increasing patient demands, the surgeons aimed to reduce postoperative refractive errors. As the primary goal is to provide a successful visual rehabilitation, SIA is still a challenge in the postoperative period. It is well known that only patients who have 0.50 or less diopters (D) of astigmatism are free of the need for spectacles for distance activities (8), and with the increase in each diopter of astigmatism, the need for spectacles increased significantly (9). Earlier, the effect of CCI on postoperative astigmatism was calculated using different mathematical formulas (10–12). However, the astigmatic changes of hinge incision have not been evaluated yet with the double-angle polar plots which allow one to determine the distribution of the astigmatic changes through its schematic presentation on centroids whether towards with-the-rule (WTR), against-the-rule, or oblique axes. Moreover, in literature, there is a tendency to use those double-angle vectorial diagrams (DAVDs) in studies investigating postoperative refraction after cataract surgery (13).

The principal aim of the present study was to compare two different corneal incision architectures in terms of postoperative corneal astigmatism using double-angle vectorial analysis.

Methods

This study was approved by the institutional review board (IRB) of Koc University Committee on Human Research (2020. 295. IRB1.103) and all the methods adhered to the tenets of the Declaration of Helsinki, and informed consent was obtained from all subjects. We reviewed consecutive cases of MICS in the eyes between March 2019 and January 2020 at Koc University Hospital. The demographics, including age and sex, the axial length (AL) at the time of cataract surgery, the keratometry (K) readings, implanted intraocular lens power, and postoperative refraction, were evaluated retrospectively. An autorefractometer (Topcon KR-800, Canon Inc., Japan) and a partial coherence laser interferometry (IOLMaster, Carl Zeiss Meditec AG) were used in recording AL, K readings, and corneal astigmatism.

Surgical Technique in Phacoemulsification

All surgeries were performed by a right-handed surgeon under topical proparacaine hydrochloride (Alcaine®) anesthesia. Centurion® phaco machine was used for phacoemulsification, and the same acrylic hydrophilic foldable intraocular lenses were implanted. The surgeon sat at the 9 o'clock position for the right eye and at the 3 o'clock for the left eye. The two side ports were made with 20-gauge angled MVR blades at 90° to the planned main CCI, at 12 o'clock and 6 o'clock in both eyes. Except for the architecture of CCI, there was no difference between the two surgical techniques.

In both groups, the two-step incision configuration was made as follows: First, an initial incision 0.5 mm deep and 2.2 mm wide was constructed perpendicular to the corneal surface. Then, the keratome was diverted parallel to the course of the cornea at the same depth, and an intracorneal tunnel of approximately 2.5 mm was achieved. Finally, the keratome slit knife was inserted to the full depth of the cornea at an angle in the direction of the center of the pupil to enter the anterior chamber.

As described, for Group I, a two-step, square and horizontal shaped main CCI was carried out with a 2.2-mm keratome slit knife about 1 mm inside the limbus as shown in Figure 1b and c. Differently, for Group II, a hinge incision as shown in Figure 1a was performed first with the base of the facet of the 2.2-mm keratome as defined earlier (14), then configured the same two-step CCI about 1 mm inside the limbus as shown in Figure 1b and c.

The technique used for nuclear fragmentation was the "divide and conquer approach," and the rest of the surgical steps were performed in the same manner as in routine phacoemulsification. No intraoperative complications were experienced. Patients were recommended the same topical antibiotic eye drops (moxifloxacin 0.5% ophthalmic solution, 5 times a day for 7 days) and topical steroid eye drops (dexamethasone 0.1%, 5 times a day for a month) for the postoperative treatment regimen.

Astigmatic Vectorial Analysis

Astigmatic vector parameters were defined as baseline corneal astigmatic vector (BV), postoperative corneal astigmatic vector at the last visit (LV), and SIA. The meridional and torsional astigmatic power vector components of BV and LV were calculated by converting their polar astigmatic values (cylinder @ axis) to Cartesian coordinates as follows:

Meridional power = Cylinder × cos 2α,

Torsional power = Cylinder × sin 2α.

In this measure, the meridional (M), torsional (T) power vectors, and the magnitude of SIA were calculated accordingly:

$$\mathrm{SIA_M} = \mathrm{LV_M} - \mathrm{BV_M},$$

$$\mathrm{SIA_T} = \mathrm{LV_T} - \mathrm{BV_T},$$

$$\mathrm{SIA_{mag}} = \sqrt{(\mathrm{SIA_M})^2 + (\mathrm{SIA_T})^2}.$$

DAVDs proposed by Holladay et al. (15) were used for vectorial presentations. In DAVDs, the overall astigmatic vector was depicted as an ellipsoid with the centroid representing the mean magnitude and axis of the vector and the horizontal and vertical radii representing standard deviations of meridional and torsional components, respectively.

Statistical Analysis

All vectorial calculations and double-angle polar plots are performed in Microsoft Excel software (Microsoft, Redmond, WA, USA), and statistical analysis was performed using SPSS software (version 20.0, IBM, Armonk, NY, USA). Data distribution was determined with the Shapiro–Wilk test. The Mann–Whitney U test was performed to compare mean magnitude, meridional power, and torsional power values of corneal astigmatism between two groups. The Wilcoxon signed rank test was performed to compare preoperative and postoperative parameters within each group. The Hotelling T2 test was performed to compare the centroid values of preoperative and postoperative corneal astigmatism between two groups and within each group separately. A p value less than 0.05 was statistically significant.

Results

Demographics and Clinical Characteristics

A total of 63 eyes from 57 subjects were included in the study. Group I consisted of 27 eyes with the two-step CCI, and Group II included 36 eyes with the hinge incision. The demographics and clinical characteristics of eyes are shown in Table 1. The mean age at the time of cataract surgery was 66.6±9.3 years for Group I and 65.5±8.3 years for Group II (p=0.631). There was no significant difference between the groups in terms of sex (p=0.79). The differences in AL, flattest and steepest keratometry readings, implanted intraocular lens power, and postoperative spherical equivalent values were also insignificant between the two groups as shown in Table 1 (All p>0.05).

Corneal Astigmatic Parameters

The preoperative astigmatic magnitudes were 0.66±0.32 D and 0.70±0.42 D for Group I and Group II, respectively. No significant difference was found in preoperative astigmatic magnitudes and both its meridional and torsional components between two groups (All p>0.05, as shown in Table 2). The postoperative astigmatic magnitudes were 0.89±0.46 D and 0.85±0.53 D for Group I and Group II, respectively, showing no significant difference between the groups (p=0.707). However, the mean meridional LV values were −0.13±0.87 D for Group I and −0.70±0.56 D for Group II, which were significantly different (p=0.014), indicating a WTR astigmatic shift, whereas no difference was found in SIA parameters between two groups as shown in Table 2.

Double-Angle Vectorial Analysis

The double-angle vectorial analysis is shown in DAVD plots in Figures 1–4, and the results are given in Tables 3 and 4. The centroids of preoperative corneal astigmatisms, which were 0.09 D at 90.5°±0.50 and 0.48 D at 90.4°±0.52 for Group I and Group II, respectively, with no significant difference between groups (p=0.526), are shown in Figure 1 and Table 3. The difference in postoperative centroids between the two groups was significantly different (p=0.043), indicating that Group II had higher WTR astigmatism than Group I, as demonstrated in Figure 2 and Table 3. Finally, the centroids of SIA were 0.12 D at 85.5°±0.50 and 0.22 D at 91.1°±0.49 for Group I and Group II, respectively, with no significant difference between groups (p=0.291). The centroids are

Table 1. Demographics and clinical characteristics of the study

Parameters	Group I (n=27)	Group II (n=36)	p
Age	66.6±9.3	65.5±8.3	0.569
Sex (F/M)	16/11	16/14	0.790
Axial length (mm)	23.78±1.01	23.82±1.66	0.854
Flattest K (D)	43.36±2.39	42.94±1.44	0.571
Steepest K (D)	44.02±2.43	43.65±1.47	0.704
Implanted IOL power (D)	20.9±3.4	22.2±2.3	0.328
Postoperative SE (D)	−0.35±0.65	−0.27±0.58	0.645

p<0.05 is statistically significant. F: Female; M: Male; D: Diopter; K: Keratometry; IOL: Intraocular lens; SE: Spherical equivalent; n: Number.

Table 2. Corneal astigmatism findings

Parameters	Group I (n=27)	Group II (n=36)	p
BV			
Magnitude (D)	0.66±0.32	0.70±0.42	0.975
Meridional (D)	−0.07±0.63	−0.33±0.62	0.213
Torsional (D)	0.00±0.38	0.00±0.44	0.823
LV			
Magnitude (D)	0.89±0.46	0.85±0.53	0.707
Meridional (D)	−0.13±0.87	−0.70±0.56	0.014
Torsional (D)	0.06±0.50	−0.02±0.47	0.620
SIA			
Magnitude (D)	0.60±0.58	0.73±0.64	0.415
Meridional (D)	−0.05±0.77	−0.36±0.71	0.213
Torsional (D)	0.06±0.35	−0.02±0.58	0.362

p<0.05 is statistically significant. BV: Baseline astigmatism vector; LV: Last visit astigmatism vector; SIA: Surgically induced astigmatism; D: Diopter; n: number.

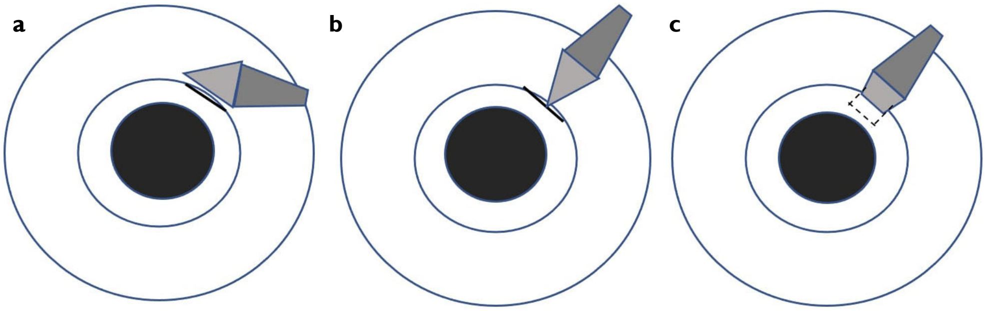

Figure 1. Schematic presentation of CCI with hinge incision. First, a hinge incision was performed parallel to the limbus with the base of the facet of the 2.2-mm keratome **(a)**. Then, a 2.2-mm wide, square and horizontal two-step main CCI was performed just through the hinge incision **(b, c)**.

demonstrated in Figure 3 and the detailed data are shown in Table 3. The centroids of corneal astigmatism also postoperatively increased to 0.21 D at 87.6°±0.61 with no significance within Group I (p=0.525) and to 0.70 D at 90.6°±0.47 with significance within Group II (p=0.032) as shown in Table 4.

Discussion

In this study, the baseline and postoperative astigmatism and SIA were compared in eyes with two different CCI architecture, one with a two-step CCI and the other with a hinge incision prior to two-step CCI. Not enough data are available in the literature about the effect of hinge on SIA. We found that the planar differences in the architecture of CCI did not significantly affect SIA as much as we expected although the WTR astigmatism was found higher in eyes with the hinge incision than those without.

CCI techniques have been investigated in many studies over a quarter century (2, 5, 14, 16, 17). Ernest et al. (2) researched the critical incision width for three incision types (beveled, stepped, and hinged) at which resistance to external pressure and stated that hinged incision had the best wound configuration. They also determined that the width of the beveled incision should be 3.0 mm or less but for stepped or hinged CCI, the value should be 3.5 mm or less. Now in MICS, there is no need to think about the incision type to be used in terms of wound strength and integrity because the widest width of CCI is 2.8 mm or less. Today, postoperative refractive perfection has come to the fore.

Residual astigmatism following cataract surgery is highly important in terms of the postoperative quality of life of the patients. Day et al. (18) first reported the astigmatism distribution in a large series including 31,898 eyes, undergoing cataract surgery in the UK. A power vector analysis, defined by Thibos et al. (19), was used in this retrospective cohort study, and similar to our study, the Hotelling T2 test was performed comparing vectorial values. They pointed out the high

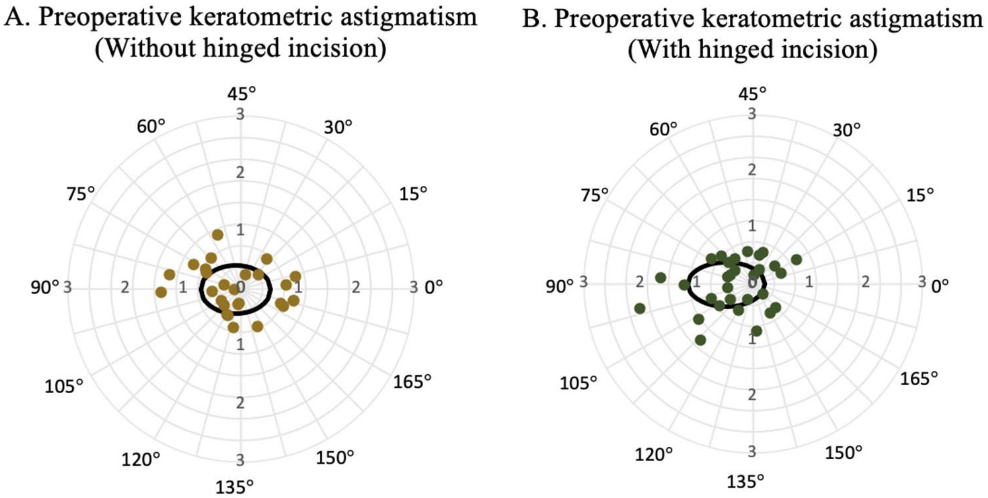

Figure 2. Astigmatic centroid analysis of preoperative corneal astigmatism in double-angle vectorial diagrams for Group I without hinge incision (centroid: 0.09 × 90.5°±0.50 D; p=0.48) **(a)** and for Group II with hinge incision (centroid: 0.48 × 90.4°±0.52 D; p=0.33) **(b)**. The centroid represented the mean magnitude and axis of the vector, and the horizontal and vertical radii represented standard deviations of meridional and torsional components, respectively. No significant difference was found in preoperative astigmatism between the two groups in centroid analysis (p=0.526).

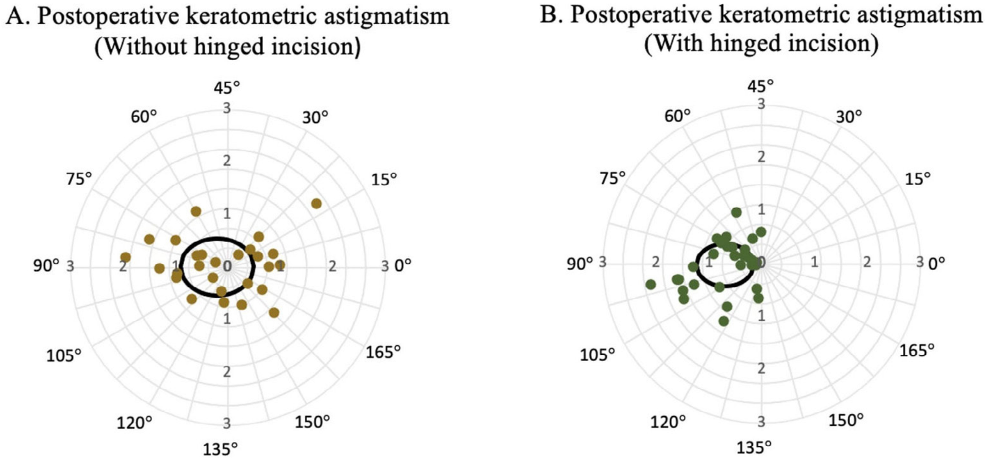

Figure 3. Astigmatic centroid analysis of postoperative corneal astigmatism in double-angle vectorial diagrams for Group I without hinge incision (centroid: 0.21 × 87.6°±0.61 D; p=0.60) **(a)** and for Group II with the hinge incision (centroid: 0.70 × 90.6°±0.46 D; p=0.55) **(b)**. A significant difference was found between two groups in meridional component (p=0.014), indicating that a with-the-rule astigmatic shift was seen in eyes with the hinge incision in centroid analysis (p=0.043).

prevalence of preoperative astigmatism in the UK cataract population and indicated that the implantation of standard monofocal intraocular lenses was inefficient to correct postoperative astigmatism and improve visual performance.

SIA is a type of astigmatism that is thought to be induced by the surgeon postoperatively. CCIs are one of the determining parameters in SIA development. Although many studies in the literature have investigated the effect of the width and location of main CCIs on SIA (20–23), the effect of other ocular parameters is still less well known. The influence of corneal biomechanics on SIA was discussed by Denoyer et al. in a prospective clinical study (24). In this study, the corneal thicknesses, incision width, length and architecture, the corneal hysteresis (CH), and the corneal resistance factor (CRF) were evaluated in 40 eyes undergoing MICS or small-incision cataract surgery. They reported that SIA depends not only on the incision size but also on the preoperative CH. In their study, in patients who had higher preoperative CH, despite a large incision, lower final SIA values were determined, whereas in patients with lower preoperative CH, despite a microincision, the final SIA values were found higher.

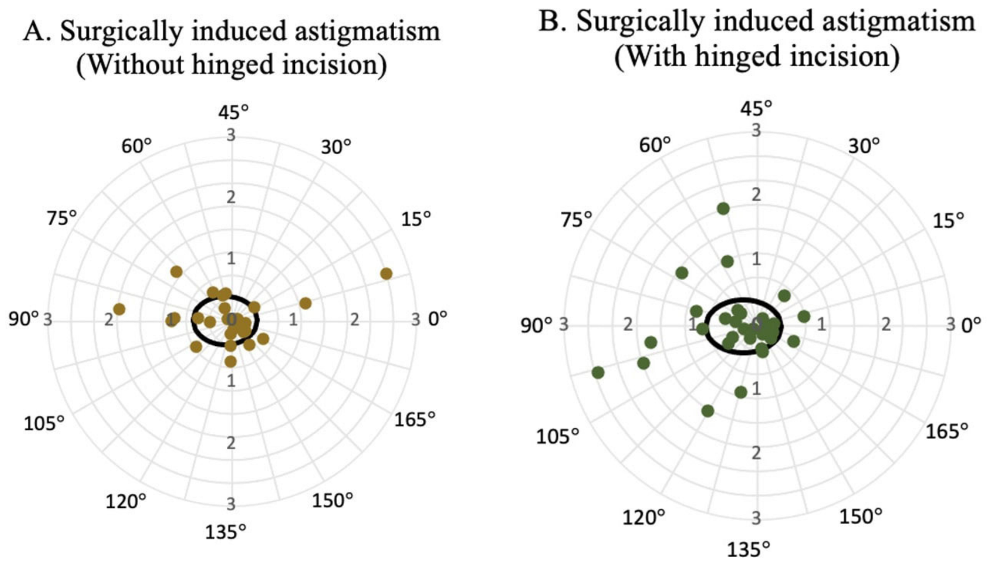

Figure 4. Astigmatic centroid analysis of surgically induced astigmatism (SIA) in double-angle vectorial diagrams for Group I without hinge incision (centroid: 0.12 × 85.5°±0.45 D; p=0.56) **(a)** and for Group II with hinge incision (centroid: 0.22 × 91.1°±0.49 D; p=0.47) **(b)**. No significant difference was found in SIA between the two groups in centroid analysis (p=0.291).

Table 3. Astigmatic centroid analysis and comparison between preoperative and postoperative centroids between the study groups

Centroid (mean D ×axis ± SD)	Group I (n=27)	Group II (n=36)	p
BV	0.09 × 90.5±0.50	0.48 × 90.4±0.52	0.526
LV	0.21 × 87.6±0.61	0.70 × 90.6±0.47	0.043
SIA	0.12 × 85.5±0.50	0.22 × 91.1±0.49	0.291

p<0.05 is statistically significant. BV: Baseline astigmatism vector; LV: Last visit astigmatism vector; SIA: Surgically induced astigmatism; D: Diopter; n: Number.

Table 4. Comparison of preoperative and postoperative astigmatic centroids within the groups

	Centroid (mean D × axis±SD)		p
	BV	LV	
Group I (n=27)	0.09 × 90.5±0.50	0.21 × 87.6±0.61	0.525
Group II (n=36)	0.48 × 90.4±0.52	0.70 × 90.6±0.47	0.032

p<0.05 is statistically significant. BV: Baseline astigmatism vector; LV: Last visit astigmatism vector; SIA: Surgically induced astigmatism; D: Diopter; n: Number.

Unlike our study, Theodoulidou et al. investigated SIA among four different surgeons who had performed the three-stepped, 3.0-mm sized, identic main CCIs from superotemporal and superonasal, for the right and left eyes, respectively (3). At the end of the assessment of 275 eyes undergoing phacoemulsification, no significant difference was found in SIA between the surgeons. They concluded that SIA is more dependent on incision architecture and prior astigmatism, rather than the surgeon. In our study, even though the main incision characteristics were different in our study groups, we found no significant difference in SIA. However, the increase in the LV values in Group II was found statistically significant in vectorial analysis, compared with LV values in Group I and the BV values in Group II. We considered that the hinge incision performed caused these results, but it could not affect SIA significantly. A significant difference was found between two groups in meridional component, indicating that a WTR astigmatic shift was seen in eyes with the hinge incision in centroid analysis. The higher WTR astigmatism we found in Group II was consistent with the literature, which was reported by Zanini et al in patients who had hinge incision (16).

In the past decade, the femtosecond laser has been used in cataract surgery to provide an almost perfect CCI, as well as capsulotomy and lens fragmentation (25). Ferreira et al. compared SIA, flattening effect, torque, and wound architecture developing after femtosecond laser and manual phacoemulsification surgery (26). In this study, Alpins method (27), which is a widely accepted method in the literature for astigmatic vectorial analysis, was used in a large number of patients (600 eyes of 361 patients). Although higher values of mean SIA and flattening effect were calculated in the manual surgery group, the difference compared to the femtosecond laser group did not reach statistical significance. In the light of their results, Ferreira et al. showed that slight differences in CCI technique might not cause significant changes in postoperative astigmatism. Similar to Ferreira's study (26), we also found that the mean SIA was higher in eyes with hinge incision but this difference was not statistically significant.

In a prospective clinical study, including 40 eyes of 40 patients, Aykut et al. (28) previously compared the postoperative keratometric corneal changes after phacoemulsification surgery in eyes that underwent single-stepped CCI with or without pre-incision. They performed the pre-incision with the side edge of a 2.8-mm slit knife parallel to the limbus, similar to the hinge incision technique performed in our study. Differently, they evaluated astigmatic changes in magnitude by keratometry examination rather than in direction by vectorial analysis. Three months postoperatively, they found no significant difference in postoperative keratometry readings, and hence in corneal refractive power. Based on the satisfying results achieved in postoperative refraction, the authors highlighted that the pre-incision technique might facilitate the entry to the anterior chamber and to create a more controlled corneal tunnel and a more controlled CCI extension when needed, especially for inexperienced surgeons. Similarly, we found no significant difference in mean SIA among the eyes with or without hinge incision. We conclude that minimal manipulations on CCI can bring more benefit than harm and make the inexperienced surgeon's work easier in terms of the uncomplicated entrance to the eye.

Our study has a few limitations. First, a relatively small sample of subjects was evaluated. The other limitation was the absence of corneal topography imaging in the study subjects. In our clinical practice, corneal topography imaging is not routinely performed before the cataract surgery because we use a T-con attached optic biometry. Also, we perform automated keratometry readings. Since the design of our study was retrospective, we processed the data achieved from the biometry and the autorefractometry. Another drawback was that the patients had not been evaluated via an ocular response analyzer for a better understanding of corneal biomechanics, namely, the CH and CRF.

In summary, in the light of double-angle vectorial analysis, we found that hinge incision prior to two-step CCI did not have an unfavorable effect on postoperative refractive astigmatism. For this reason, we consider that hinge incision can be preferred by well-experienced surgeons optionally or by inexperienced surgeons when necessary, as it provides a more controlled entrance to the anterior chamber. Certainly, these results should be confirmed with larger series.

Disclosures

Ethics Committee Approval: Koc University Committee on Human Research (2020. 295. IRB1.103), July 10, 2020.

Peer-review: Externally peer-reviewed.

Conflict of Interest: None declared.

Authorship Contributions: Involved in design and conduct of the study (MZK, OM, AS); preparation and review of the study (MZK, MH, AS); data collection (MZK, CK, AYT); and statistical analysis (CK, MH, OM).

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