Asymmetric Corneal Flattening Effect After Small Incision Cataract Surgery

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ABSTRACT

PURPOSE: To determine whether the flattening effect of corneal incisions differs between the right and left eye.

METHODS: A retrospective study of preoperative and postoperative corneal astigmatism was performed for patients who had bilateral cataract surgery by a right-handed surgeon. The change in corneal astigmatism was attributed to the 2.2-mm phacoemulsification incision, and the incisional flattening effect was calculated. The incisions were grouped by position on the eye and whether they were performed on the preoperative steep corneal meridian.

RESULTS: A total of 1,298 eyes of 649 patients were evaluated. The flattening effect of temporal 2.2-mm incisions performed on the preoperative corneal steep meridian was different for right eyes (0.53 diopters [D]) and left eyes (0.34 D) ($P = .017$). The flattening effect of superior 2.2-mm incisions performed on the preoperative corneal steep meridian was equivalent in the two eyes.

CONCLUSIONS: The flattening effect of a corneal incision may depend on whether it has been performed on the right or the left eye.

[*J Refract Surg.* 2016;32(9):598-603.]

The astigmatic effect of corneal incisions has been investigated in previous studies. Many of these studies analyze only one eye per patient when investigating the effect of incision type or position.[1-9] However, some studies have used a bilateral design, with one type of treatment on one eye and a different treatment on the other eye.[10-12] This assumes that the astigmatic effect of a certain type and size of incision is independent of whether it has been performed on the right eye or the left eye. This assumption seems not to have been explicitly examined in the literature.

We performed a retrospective analysis to see whether the flattening effect of a corneal incision is dependent on which eye has been treated.

PATIENTS AND METHODS

Calculation of Flattening Effect

The total astigmatic effect of an incision on the corneal astigmatism is quantified by its surgically induced astigmatism vector (SIA).[13] It can be calculated as a double angle vector difference between the postoperative astigmatism and the preoperative astigmatism at the corneal plane. This SIA can be decomposed into a component with a pure flattening/steepening effect, which changes the magnitude of the astigmatism, and a component that induces torque, which changes the orientation of the preoperative astigmatism.[14]

The flattening effect is the component of the SIA that acts at the reference meridian,[14] in this case the incision meridian. For SIA with magnitude C and axis A and an incision meridian of M, the steepening effect is calculated as C cos 2(A-M); the flattening effect is the negative of the steepening effect.

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Submitted: December 29, 2015; Accepted: May 27, 2016

Dr. Alpins and Mr. Stamatelatos have a financial interest in the ASSORT software program used to support the planning and analysis of astigmatic correction. Dr. Ong is an employee of ASSORT, NewVision Clinics.

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doi:10.3928/1081597X-20160608-01

The flattening effect can also be measured clinically by aligning a manual keratometer with the intended incision meridian postoperatively and performing a simple arithmetic subtraction with the preoperative measure at the same meridian.

Retrospective Analysis

A retrospective analysis of the flattening effect of 2.2-mm phacoemulsification incisions created as part of cataract surgery was conducted. All cataract surgeries were performed on virgin eyes between July 2006 and August 2015 using a 2.2-mm phacoemulsification incision and no limbal relaxing incisions were included in this study. Manual keratometry measurements (OM-4 keratometer; Topcon Corporation, Tokyo, Japan) from preoperative and 1 month postoperative visits were used. We restricted our data set to include only patients who had bilateral cataract surgery.

All surgeries were performed by the same experienced right-handed surgeon (NA). For each surgery, a 2.2-mm one-step clear corneal phacomulsification incision was made in the prelimbal region using a diamond trapezoidal blade (Mastel Inc., Rapid City, SD). A 1-mm side port incision was made with a Triamond blade (Mastel Inc.) approximately 70° clockwise of the primary incision. The surgeon was seated in a position approximately 20° clockwise of the primary incision to allow a right-handed phacoemulsification incision. If the amount of corneal astigmatism was greater than 0.25 diopters (D) and the steep meridian was ergonomically accessible (right eye: 70° to 120° and 170° to 210°, left eye: 0° to 30° and 70° to 120°, eye not deep set), the primary incision was performed on the steep preoperative corneal meridian; otherwise, a temporal incision was performed. No nasal incisions were performed. The intraocular lens was injected using a cartridge injector in a wound-assisted manner so that the surgeon was stabilizing the side port incision with a phacoemulsification chopper (wound-assisted by side port) and pushing with the cartridge injector creating counter traction. The primary incision was self-sealing with some balanced salt insufflation and no suture was used.

Statistical Analysis

Descriptive statistics of the flattening effects for each eye are presented initially at bands of 10° intervals around the eye. Data were grouped by whether the incision position was temporal (right eye: 150° to 210°, left eye: 330° to 30°) or superior (60° to 120°), which allowed for comparison with previous studies. Oblique incisions were not studied due to their scarcity.

It is also possible that incisional flattening effect is dependent on whether an incision has been performed on or off the preoperative steep meridian. Almost all of the superior incisions in our study were performed on the preoperative steep meridian. However, less than half of the temporal incisions were performed on the preoperative steep meridian because this was the default position for eyes with low corneal astigmatism or where the preoperative steep meridian was not ergonomically accessible. Thus, the data for temporal incisions were further divided up according to whether the incision was on or off the preoperative steep meridian and whether the preoperative corneal astigmatism was high (≥ 0.50 D) or low.

Student's *t* tests were performed to determine whether there was a significant difference in the flattening effects between the two eyes for those incisions performed on the preoperative steep meridian, either superior or temporal. The preoperative astigmatism was required to be high (> 0.50 D) so that the preoperative steep meridian was unambiguous. In addition, paired *t* tests comparing the two eyes of each patient were performed for the subgroup where both incisions were temporal or both incisions were superior.

RESULTS

A total of 1,298 eyes of 649 patients (43% male and 57% female; age range: 33 to 98 years) were included in this study.

A summary of flattening effects at 10° intervals around each eye is shown in **Table 1** and **Figure 1**. In **Table 2**, the flattening effects are grouped according to their position, namely temporal or superior. Oblique incisions were excluded due to their scarcity.

Table 3 shows a further breakdown of incisions based on whether they were temporal or superior and performed on or off the preoperative corneal steep meridian and whether the preoperative corneal astigmatism was high or low. Note that there were only a handful of cases of superior incisions performed away from the steep meridian, so we omitted those from this analysis.

In a comparison of the temporal incisions performed on-axis where there was more than 0.50 D of preexisting corneal astigmatism, the flattening effect in the right eye was larger than the flattening effect in the left eye and the difference was statistically significant (unadjusted $P = .017$). The analogous comparison of superior incisions performed on-axis where there was more than 0.50 D of preexisting corneal astigmatism showed no significant difference (unadjusted $P = .10$).

In the subgroup of patients where both incisions were temporal (n = 428), the difference observed above was also observed in the paired difference (unadjusted $P = .021$). In the subgroup where both incisions were superior (n = 115), there was no significant paired difference between the eyes (unadjusted $P = .16$).

TABLE 1

Flattening Effect (Mean [Range]) of 2.2-mm Phacoemulsification Incisions at Various Corneal Meridians

Incision Meridian (degrees)	OD Flattening Effect (D)	No. of OD Incisions	OS Flattening Effect (D)	No. of OS Incisions
330	–	–	1.03 (1.03 to 1.03)	1
340	–	–	0.41 (-0.38 to 1.21)	6
350	–	–	0.74 (-0.07 to 2.30)	8
0	–	–	0.15 (-2.80 to 2.68)	205
10	–	–	0.32 (-1.15 to 2.86)	37
20	–	–	0.12 (-1.91 to 1.39)	189
30	–	–	0.37 (-0.49 to 1.15)	22
40	–	–	0.40 (0.05 to 0.64)	4
50	–	–	0.00 (0.00 to 0.00)	1
60	0.48 (0.48 to 0.48)	1	0.95 (0.87 to 1.03)	2
70	0.34 (-0.39 to 0.92)	10	0.69 (-0.23 to 2.04)	17
80	0.66 (-0.06 to 2.04)	18	0.40 (-0.73 to 1.74)	26
90	0.39 (-0.52 to 1.75)	54	0.46 (-0.72 to 1.89)	51
100	0.35 (-1.54 to 1.47)	34	0.58 (-1.35 to 1.69)	40
110	0.32 (-0.68 to 0.94)	24	0.55 (-0.82 to 1.77)	25
120	0.80 (-0.30 to 2.52)	9	0.42 (-0.48 to 1.01)	13
130	0.56 (-0.18 to 0.83)	5	0.75 (0.75 to 0.75)	2
140	0.64 (0.04 to 2.09)	4	–	–
150	0.50 (0.50 to 0.50)	1	–	–
160	0.04 (-1.37 to 0.81)	10	–	–
170	0.46 (-0.53 to 1.81)	29	–	–
180	0.28 (-1.87 to 4.95)	178	–	–
190	0.42 (-0.75 to 2.57)	48	–	–
200	0.23 (-1.82 to 2.64)	195	–	–
210	0.37 (-0.45 to 1.02)	26	–	–
220	0.00 (-0.41 to 0.41)	3	–	–

OD = right eye; D = diopters; OS = left eye

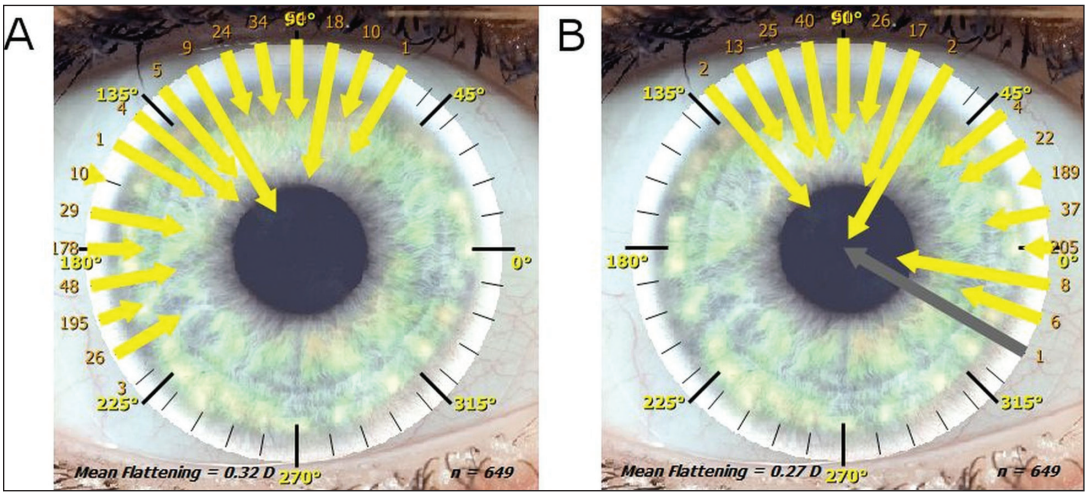

Figure 1. Graphical display of the flattening effect of 2.2-mm phacoemulsification incisions. (A: right eye, B: left eye) Arrows pointing toward the center of the pupil demonstrate flattening. The longer the arrow, the greater the amount of flattening, and the distance from the limbus to the pupil center represents 1 diopter of flattening. The grey arrow indicates a flattening effect of greater than 1.00 diopter. The numbers around the limbus indicate the number of incisions performed at that meridian.

TABLE 2

Overall Flattening Effects (Mean ± SD) of Temporal and Superior Incisions for Each Eye

Incision Position	OD Flattening Effect (D)	OD No. of Eyes	OS Flattening Effect (D)	OS No. of Eyes
Temporal incision (330° to 30°, or 150° to 210°)	0.26 ± 0.59	487	0.17 ± 0.56	468
Superior incision (60° to 120°)	0.45 ± 0.54	150	0.54 ± 0.55	174

SD = standard deviation; OD = right eye; D = diopters; OS = left eye

TABLE 3

Amount of Flattening, SIA, and Torque (Mean ± SD) Induced by Temporal and Superior Incisions, Divided Into On-axis (±20°) and Off-axis, for High (> 0.50 D) and Low (≤ 0.50 D) Preoperative Keratometric Astigmatism

Group	Eye	No. of Eyes	Flattening Effect (D)	SIA Magnitude (D)	Torque (D)
Temporal, on steep meridian, high	OD	167	0.53 ± 0.71	0.78 ± 0.63	-0.05 ± 0.46
	OS	141	0.34 ± 0.70	0.76 ± 0.53	-0.09 ± 0.49
Temporal, on steep meridian, low	OD	123	0.23 ± 0.42	0.46 ± 0.33	-0.07 ± 0.29
	OS	119	0.21 ± 0.38	0.43 ± 0.33	-0.03 ± 0.33
Temporal, off steep meridian, low	OD	147	0.05 ± 0.41	0.44 ± 0.30	-0.05 ± 0.34
	OS	142	0.07 ± 0.40	0.43 ± 0.29	-0.10 ± 0.31
Temporal, off steep meridian, high	OD	50	0.01 ± 0.64	0.82 ± 0.49	0.03 ± 0.72
	OS	66	-0.04 ± 0.68	0.81 ± 0.54	-0.23 ± 0.66
Superior, on steep meridian, high	OD	129	0.49 ± 0.53	0.83 ± 0.47	0.33 ± 0.52
	OS	147	0.60 ± 0.55	0.85 ± 0.44	0.14 ± 0.49
Superior, on steep meridian, low	OD	18	0.26 ± 0.40	0.39 ± 0.41	0.16 ± 0.27
	OS	22	0.27 ± 0.32	0.48 ± 0.27	0.06 ± 0.36

SIA = surgically induced astigmatism; SD = standard deviation; D = diopters; OD = right eye; OS = left eye

Generally, incisions performed on corneas with low preoperative astigmatism tended to have less astigmatic effect (low astigmatism: 0.40 to 0.50 D SIA, high astigmatism: 0.70 to 0.90 D SIA).

The temporal incisions that were not on the preoperative steep meridian showed on average no flattening effect, but large SIA magnitudes. Taken together with the small mean but large standard deviation of the torque, this indicates that this case requires more detailed analysis. **Table 4** shows how the amounts of flattening, SIA, and torque depend on whether the incision is clockwise or counterclockwise of the preoperative steep meridian. Generally, the incisions clockwise of the steep meridian produce positive (counterclockwise) torque, whereas the incisions counterclockwise of the steep meridian produce negative (clockwise) torque.

DISCUSSION

Our results are consistent with previously published research: there may be slightly more flattening for superior incisions on the steep meridian than temporal incisions on the steep meridian (not obvious for right eye: 0.49 vs 0.53 D, more likely for left eye: 0.60 vs 0.34 D)[5,6,8] and superior incisions on the steep meridian induce more flattening than temporal incisions away from the steep meridian (right eye: 0.49 vs 0.01 D, left eye: 0.53 vs -0.04 D).[4] Furthermore, our results indicate that the flattening effect of temporal incisions depends on the magnitude and orientation of the preoperative corneal astigmatism; this differs from a previous study that showed no effect of the orientation of the preoperative steep meridian.[3] The most interesting finding is one that does not seem to have been considered previously: the induced astigmatism caused by temporal incisions may not be identical for the right and left eyes. The difference that we found may be due to ergonomic factors influenced by the surgeon, including the anterior-posterior position of the incision, the hand used to create the incision, and the physical orientation of the hand to the eye at the time of diamond blade penetration, as well as any alteration of the incision caused by insertion of the IOL. However,

TABLE 4

Amount of Flattening, SIA, and Torque (Mean ± SD) Induced by Temporal Off-axis (> 20° Away) Incisions for High (> 0.50 D) Preoperative Keratometric Astigmatism, Grouped by Whether the Incision Was Clockwise or Counterclockwise From the Preoperative Steep Meridian

Group	Eye	No. of Eyes	Flattening Effect (D)	SIA Magnitude (D)	Torque (D)
Incision clockwise of steep meridian	OD	26	-0.04 ± 0.54	0.73 ± 0.43	0.50 ± 0.44
	OS	13	0.18 ± 0.35	0.51 ± 0.28	0.24 ± 0.38
Incision counterclockwise of steep meridian	OD	22	0.11 ± 0.76	0.92 ± 0.58	-0.55 ± 0.57
	OS	48	-0.03 ± 0.72	0.87 ± 0.58	-0.38 ± 0.66

SIA = surgically induced astigmatism; SD = standard deviation; D = diopters; OD = right eye; OS = left eye

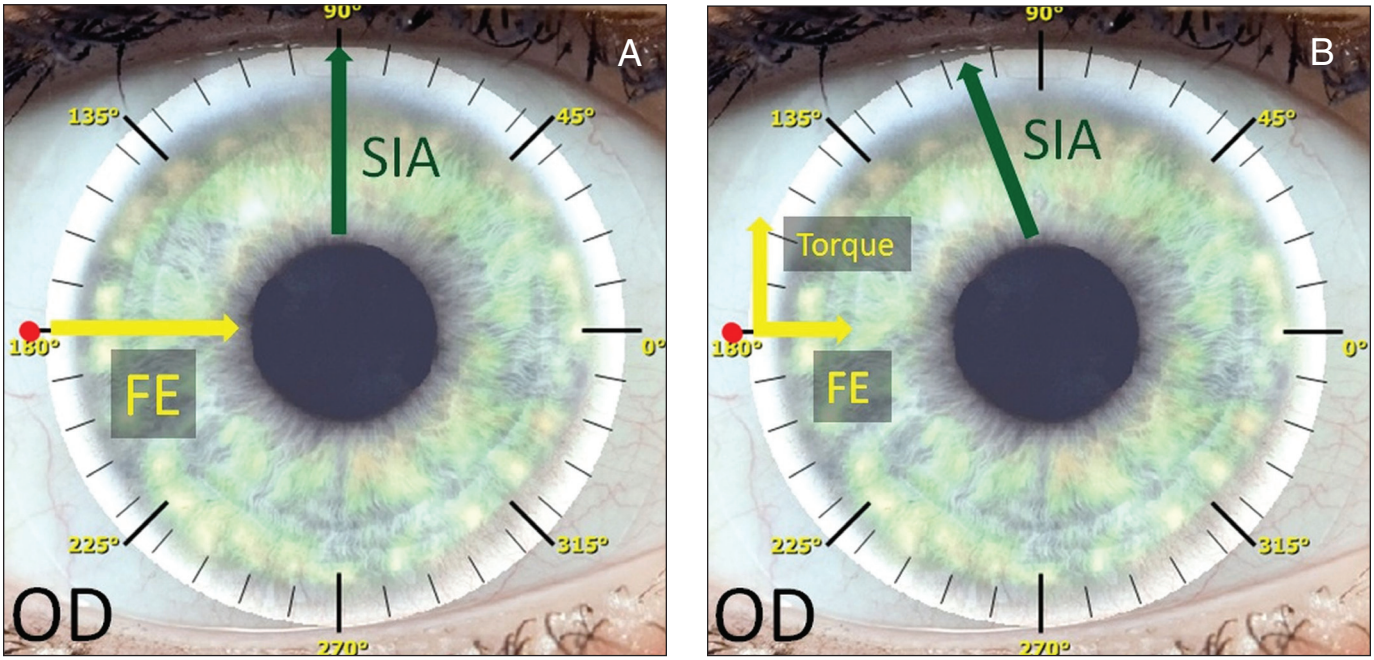

Figure 2. (A) Display of the flattening effect (FE) of a corneal incision that has been placed temporally at 180° as planned. The surgically induced astigmatism vector (SIA) is consequently 90° away from the incision meridian of 180° (indicated by the red circle) when the astigmatic affect occurs as predicted. In this case, the SIA equals the FE at its maximum and the torque is zero. (B) The FE of a corneal incision placed temporally. The SIA indicates that the incision is not functionally at the intended meridian and hence the FE at the intended incision meridian is reduced to less than the SIA and some of the SIA has dispersed to torque that rotates the preoperative corneal astigmatism, in a clockwise direction in this example. The SIA is a combination of the FE and the torque that, when 45° off-axis, at 45° or 135°, acts entirely as torque with no FE at the incision site.

there was no conscious intent on the part of the surgeon to perform surgery differently on the two eyes, so it is likely that other surgeons may also cause different flattening effects in the two eyes. It would be informative to replicate this study with the data of other surgeons to see whether specific surgical variables relate to the difference in flattening effect.

The difference in flattening effect between the eyes that we found (right eye: 0.53 D, left eye: 0.34 D) is small enough that it does not invalidate most previous bilateral studies. This difference was statistically significant and clinically relevant because it cannot be ignored when comparing small changes. However, it is a confounding factor that needs to be taken into account, especially for those studies where the effects are marginally statistically significant. It is important to note that there was no direct corneal marking of the steep meridian for corneal astigmatism of 0.75 D or less and computer alignment systems were not used for this cohort; therefore, one may expect the standard deviation of the flattening effect to be tighter if the steep meridian of the corneal astigmatism were more directly marked. For higher amounts of corneal astigmatism, ink marks at the limbus were used at

0° and 180° together with a Mendez ring to mark the steep meridian.

A further finding of interest is the difference in flattening effect between placing the incision on (right eye: 0.53 ± 0.71 D, left eye: 0.34 ± 0.70 D) and off (right eye: 0.01 ± 0.64 D, left eye: -0.04 ± 0.68 D) the steep meridian for temporal incisions in high astigmatism cases. This supports the principle of analyzing both the flattening effect of incisions and the total SIA for differing amounts and orientations of preoperative astigmatism for both right and left eyes.

We restricted most of our attention to the incisional flattening effect because this is the only component of the SIA that can decrease the corneal astigmatism. Any torque effect present will serve primarily to rotate the orientation of the corneal astigmatism, and as a side effect will also slightly increase the magnitude of the corneal astigmatism. Inclusion of the torque effect by employing the whole of the SIA in toric lens calculations would result in an overestimation of the incisional effect, with the result of a net underpowering of the implant's toric power (**Figure 2**). A consistent torque effect in a specific direction should prompt the surgeon to consider why this is occurring and how to correct this angular bias. Our results indicate that incisions occurring away from the preoperative steep meridian produce torque effects. However, it is likely that other factors, including anatomical and ergonomic factors, may also cause torque.

Precision in planning and analysis of incisions is achieved by examining the flattening effect of incisions at whatever meridian they are placed rather than the whole of the SIA. **Figure 1** displays the flattening effect for all incisions (both on and off the steep meridian) at 10° bands for both eyes. Our results show that it is prudent to further subdivide the data based on whether the incision has been placed on the preoperative corneal steep meridian or not. When planning and executing toric implant surgery with an incision placed at any meridian, steepest or otherwise, a surgeon should use historical flattening effects in a toric calculator to more accurately calculate the toric power of any implant after the corneal astigmatism has been adjusted for the incisional effect of the phacoemulsification incision.

Further studies are needed to elucidate the important variables that cause the asymmetry in incisional flattening effect. These would need to take into account surgeon technique and hand dominance or ambidexterity, and control for the type and size of corneal incision.

AUTHOR CONTRIBUTIONS

Study concept and design (NA, JKYO); data collection (GS); analysis and interpretation of data (JKYO); writing the manuscript (NA, JKYO); critical revision of the manuscript (NA, JKYO, GS); statistical expertise (JKYO); supervision (NA, GS)

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