Astigmatic Change Induced by 2.8-mm Corneal Incisions for Cataract Surgery

Jaime Tejedor1,2 and José A. Pérez-Rodríguez1

PURPOSE. To study the induced refractive change caused by different 2.8-mm corneal incision locations in phacoemulsification.

METHODS. One hundred ten patients were randomly assigned to nasal or temporal incision or to superior incision, depending on preexisting astigmatism. The authors fulfilled visual acuity, refraction, keratometry, and eye scanner analysis before and after phacoemulsification. Outcome measures were induced corneal refractive change (Fourier power vector analysis), index of surface variance (ISV) change, and visual acuity at 6 months. A comparative interventional case series was used for the study design.

RESULTS. Induced refractive change caused by different incision locations showed differences in parameter J0 (JCC at axis 0°), which was smaller after temporal than after nasal or superior incision, with marginal clinical significance and influence in uncorrected visual acuity. ISV changes did not differ between incisional groups.

CONCLUSIONS. Small differential effects of incisions by location may be useful, depending on preexisting astigmatism. Temporal incisions are recommended for negligible astigmatism, whereas nasal and superior incisions are preferable when the steep axis is located at approximately 180° and 90°, respectively. (ClinicalTrials.gov number, NCT00742950) (Invest Ophthalmol Vis Sci. 2009;50:989–994) DOI:10.1167/iovs.08-2778

STUDIES on the use of 3.5-mm to 4-mm corneal incisions in phacoemulsification have led to the conclusion that superior and nasal locations induce greater refractive changes than temporal corneal incision.1–6 and this effect could be intentionally used by the surgeon to reduce or treat preexisting astigmatism.5 Recent evidence indicates that a small 2.8-mm clear corneal incision induces little refractive change, at least in eyes with low preoperative corneal cylinder, regardless of incision site.7,8 However, a retrospective study describes larger changes induced by superior rather than temporal 2.8-mm incision, which had been considered nearly astigmatism neutral.9 Controversy about refractive changes caused by the use of this corneal incision size is of interest. With the introduction of toric IOLs for astigmatic correction, it is becoming increasingly important to predict accurately the amount of astigmatism induced with different corneal incisions to facilitate calculating the power of the toric IOL we insert in the phacoemulsification procedure. The potential role of customized IOLs to treat preoperative optical aberrations of the eye should also take into account the effect of corneal incision with as much precision as possible. In addition, in light of refractive changes caused by the extensively used 2.8-mm corneal incisions, the need for phacoemulsification devices introduced to reduce incision size further (to less than 2 mm) should be considered. Existing data on the refractive effect of 2.8-mm incisions are reported by nonrandomized7 or retrospective studies.8–9 In the present study, we assess in a controlled fashion the amount of surgically induced refractive change caused by different 2.8-mm clear corneal incision locations in phacoemulsification.

METHODS

This study received approval from the local institutional ethics committees, and all patients provided signed informed consent. The study adhered to the tenets of the Declaration of Helsinki. Eligibility criteria were visual impairment for daily tasks caused by cataract, age older than 50 years, steep axis of corneal astigmatism at 90° ± 20° or 180° ± 20° or negligible astigmatism (<0.5 diopters [D]), and ability to cooperate in the protocol procedures. Restrictions were few so that the sample would mimic a population of cataract patients undergoing surgery.

Preoperative evaluation included uncorrected and corrected visual acuity (ETDRS chart), refraction, manual keratometry (Bausch & Lomb, Rochester, NY), eye scanner (Pentacam; Oculus, Wetzlar, Germany) analysis, intraocular pressure, biomicroscopy, biomeetry, and intraocular lens calculation using SRK-T formula (IOLMaster; Carl Zeiss, Göttingen, Germany), and funduscopy. In postoperative examination, we repeated testing of visual acuity, keratometry, intraocular pressure, and biomicroscopy at 2 weeks and at 1, 3, and 6 months. Eye scanner (Pentacam; Oculus) analysis was repeated only at 6 months. Outcome measures were induced corneal refractive change, index of surface variance (ISV) change, and corrected and uncorrected visual acuity at 6 months (ISV is an output of the eye scanner [Pentacam; Oculus] system, which gives the deviation of individual corneal radii from the mean value and is elevated in all types of corneal surface irregularity). Subjects with visual acuity worse than 0.3 logMAR (Snellen equivalent 20/40) were excluded from visual acuity analyses. We used induced corneal refractive change as an outcome measure (refractive effect similar to placing an equivalent lens in front of the eye) because refractive state of the eye was not accurately estimated before surgery. The cornea was considered a lens from which a Fourier series could be obtained by conversion from diopters (determined on the 3-mm ring of the cornea using eye scanner [Pentacam; Oculus] because, in these meridians, orthogonality is easily established (Pentacam [Oculus] instruction manual, page 44) into a vector representation with three components: spherical lens (M), Jackson cross-cylinder (JCC) at axis 0° (J0), and JCC at axis 45° (J45). The last two components may be converted to a polar Fourier form as a single JCC lens of power J.10

From the 1Department of Ophthalmology, Hospital Ramón y Cajal, Madrid, Spain; and the 2Faculty of Medicine, Universidad Autónoma de Madrid, Madrid, Spain.

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Corresponding author: Jaime Tejedor, Department of Ophthalmology, Hospital Ramón y Cajal, C Colmenar km 9100, Madrid 28034, Spain; jtejedor.hrc@salud.madrid.org.
Postoperative and preoperative values of these components were subtracted to obtain a difference vector (post-pre). The components of the difference vectors were used for statistical procedures. They were converted again to a conventional, more meaningful, value of induced refractive change for the clinician (which could not be used for statistical analysis). Parameter P (an estimation of overall blurring effect, defined as the length of the power vector) may also be derived from the difference vector.

The eye scanner (Pentacam; Oculus) maintains a fixed point on the vertex of the cornea during the examination and maintains the central point of each meridian in the sample images. For this reason, and because any eye movement is detected by a second camera and corrected for in the process, it can compensate for eye movement. Measurements took place in ambient lighting conditions, with patients looking at the fixation target, in the automatic release mode. We considered a measurement valid only when the instrument’s quality specification registered the scan as acceptable. According to Shankar et al.,11 eye scanner (Pentacam; Oculus) corneal curvature measurements show excellent repeatability. We tested repeatability in six patients, with two measurements in each patient, 2 hours apart. Intraclass correlation was 0.98, with a standard deviation of difference between K measurements of 0.14 D (0.09–0.36; SE approximately 0.06). For K astigmatism, the standard deviation of difference was 0.05 D (0.03–0.36; SE approximately 0.03). Therefore, measurement error for the eye scanner (Pentacam; Oculus) was approximately 0.14 D, with accuracy to within 0.09 to 0.3 D, which is similar to Placido-disc based videokeratography.

Phacoemulsification was performed under topical anesthesia or retrobulbar block. After a three-step peripheral corneal incision (2.8-mm blade) and the introduction of viscoelastic, a 5-mm capsulorhexis was made, followed by hydrodissection, stop and chop technique, aspiration of cortical masses, and IOL implantation (Acrysof SN60AT [Alcon Laboratories, Fort Worth, TX] or Clariflex [Advanced Medical Optics, Santa Ana, CA]) through an IOL insertion cartridge (Monarch II; Alcon Laboratories).

Based on our previous experience with the 2.8-mm incision size, we used a superior incision when the steep axis of corneal astigmatism was located at 90°±20° and had at least 1 D preoperative corneal astigmatism. Patients with the steep axis at 90°±20° and less astigmatism, steep axis at 180°±20°, or negligible astigmatism were randomly assigned to nasal or temporal corneal incision.

For univariate comparisons, we used paired and unpaired Student’s t-tests. Regression and multivariate analyses (Hotelling T2)12 were also included. All statistical analyses were carried out using commercial software (NCSS, Kaysville, UT). To detect a difference of only 0.5 in power vector parameters with a SD of 0.3, at the 0.05 significance level, we needed 29 patients in each group to reach 99% of power in two-sample tests.

**RESULTS**

One hundred ten patients were included. Nasal incision was used in 44 patients, temporal incision in 45 patients, and superior incision in 21. Nasal incision (n = 44) induced an average corneal refractive change of 0.24, −0.5 × 76, whereas temporal incision (n = 45), induced an average corneal refractive change of 0.29, −0.06 × 35. The difference between temporal and nasal incision was not significant in parameters M (P = 0.37), J (P = 0.11), and J45 (power of the JCC at axis 0°) was significantly larger using nasal compared with temporal incision (95% confidence interval [CI], −0.31–0.13 D and −0.07–0.09 D, respectively; P < 0.01; mean, −0.22 D and 0.0102 D, respectively; Fig 1). The overall blurring effect P induced by the nasal and temporal incision was similar (95% CI, 0.37–0.53 D and 0.08–1.23 D, respectively; P = 0.49; mean, 0.45 D and 0.65 D, respectively).

Postoperative uncorrected visual acuity was similar using nasal or temporal incision (logMAR 95% CI: 0.11–0.22 and 0.16–0.27, respectively; P = 0.21; mean, 0.16 [Snellen equivalent, 0.69] and 0.21 [Snellen equivalent, 0.61]). Postoperative corrected visual acuity was also similar (logMAR 95% CI, 0.02–0.09 and 0.18–0.07, respectively; P = 0.55; mean, 0.05 [Snellen equivalent, 0.87] and 0.04 [Snellen equivalent, 0.9], respectively). ISV did not change significantly after surgery in any of the groups (for all patients; mean preoperative value, 21.36; mean postoperative value, 20.87), nor was ISV change significantly different in nasal versus temporal incision. Differences were not found by treatment group in age (P = 0.52) or IOL power (P = 0.21).

When only patients with the steep axis at 180°±20° were included in the analysis, the induced corneal refractive change was 0.37, −0.55 × 76 after nasal incision (n = 22), and it was 0.07, −0.21 × 60 after temporal incision (n = 23). Again, the difference in the spherical lens, M, between the two incisional locations was not significant, but parameters J and J0 differed significantly. J and J0 of the induced refractive corneal change were larger after nasal incision than after temporal incision, with marginal significance in the former (95% CI for J, 0.25–0.56 D and 0.17–0.52 D, respectively; P = 0.05; mean, 0.40 D and 0.25 D, respectively; 95% CI for J0: –0.4–0.08 D and −0.13–0.06 D; P = 0.02; mean, −0.24 D and −0.03 D, respectively), whereas J45 was not significantly different in the two groups (95% CI, −3.06–0.29 D and −1.64–0.19 D, respectively; P = 0.67; mean, 0.12 D and 0.09 D, respectively). The induced overall blurring effect, P, was similar in nasal and temporal approaches (95% CI, 0.32–0.63 D and 0.24–0.46 D, respectively; P = 0.16; mean, 0.48 D and 0.35 D, respectively).
Interestingly, postoperative uncorrected visual acuity (Fig. 2) was better in the nasal than in the temporal incision group (logMAR 95% CI, 0.09–0.21 and 0.20–0.40, respectively; \( P < 0.01 \); mean, 0.15 logMAR [Snellen equivalent, 0.7] and 0.30 logMAR [Snellen equivalent, 0.5]), probably in part because of a smaller, though not significantly different, refractive cylinder power in the nasal incision group (95% CI, −1.37–−0.56 D and −1.58–−0.86 D, respectively; \( P = 0.34 \); mean, −0.97 D and −1.22 D, respectively; Fig. 3). Corrected visual acuity was similar in the two groups (logMAR 95% CI, 0.002–0.09 and 0.017–0.12, respectively; \( P = 0.51 \); mean, 0.049 logMAR [Snellen equivalent, 0.89] and 0.07 logMAR [Snellen equivalent, 0.85]). ISV did not change significantly (data not shown).

The power of the tests in this group of patients varied between 64% and 78%.

Superior incision (\( n = 21 \)) induced a corneal refractive change of −0.24, −0.53 \( \times \) 175. Although the initial astigmatism pattern in these patients was different from that in patients who underwent horizontal meridian incision, parameters studied were not significantly different in superior incision when compared with nasal and temporal incision except for \( J_0 \) (M = −0.5 D; J = 0.27 D; \( J_{45} = 0.26 \) D [\( P < 0.01 \) for comparison with nasal and temporal incision], \( J_{45} = −0.04 \) D). P was also similar to that obtained in nasal and temporal incision (95% CI, 0.38–0.68 D; mean, 0.56 D). Postoperative uncorrected and corrected visual acuity did not differ significantly from that obtained in nasal and temporal approaches (uncorrected VA, logMAR 95% CI, 0.03–0.31; mean, 0.15 logMAR [Snellen equivalent, 0.7]; corrected VA, logMAR 95% CI, 0.02–0.11; mean, 0.045 logMAR [Snellen equivalent, 0.9]). ISV change was not significant after superior incision (mean preoperative, 34; mean postoperative, 29), and ISV change was not significantly different from that caused by other incision locations (data not shown). The power of tests for comparison between superior and nasal or temporal incision was greater than 80%.

### Table 1. Refractive Parameters of Difference Power Vectors

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<tr>
<th>Incision</th>
<th>( J_0 ) (multivariate analysis, Hotelling ( T^2 ))</th>
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<tbody>
<tr>
<td>Nasal</td>
<td>(-0.01 (−0.1−0.07))</td>
</tr>
<tr>
<td>Temporal</td>
<td>(0.25 (−0.34−0.85))</td>
</tr>
<tr>
<td>Superior</td>
<td>(-0.5 (−0.65−0.26))</td>
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\( P \) values are expressed as mean (95% CI). N/T, nasal/temporal; T/S, temporal/superior; N/S, nasal/superior.

Multivariate analysis of refractive parameters, listed in Table 1, demonstrates significant differences between different corneal incisions in which parameter \( J_0 \) mainly accounts for significance.

### DISCUSSION

Small 2.8-mm corneal incisions in phacoemulsification induced on average very small corneal refractive change, but differences were detected depending on the location of the incision. Although differences were not observed in most parameters, \( J_0 \) (representing the power of the JCC at axis 0° of the surgically induced corneal refractive change) was larger in nasal than in temporal incisions. The main functional consequence was that, in patients with the steep corneal meridian at or close to axis 180°, uncorrected visual acuity was significantly better when the nasal incision was used, although the difference was at the limit of clinical significance (0.15 logMAR). The effect of this incision size on the cornea was not different, depending on preexisting corneal astigmatism, but it influenced visual function differently because it could correct or increase preexisting corneal astigmatism, depending on the steep axis location.

The effect of superior incision on the cornea was significantly different from that caused by temporal and nasal approaches, again only in parameter \( J_0 \). This parameter in the power vector of change was larger than in the temporal incision and was approximately the same as that caused by nasal incision, but of a different sign. In other words, superior incision increased corneal power at axis 180°, and nasal incision decreased its power. Parameter \( J_0 \) was responsible for significant differences between incision locations detected in the multivariate analysis (Table 1).

Therefore, although the differences observed among incisional locations in parameter \( J_0 \) (\( \leq 0.5 \) D on average) may be considered of low clinical significance, depending on preexisting astigmatism, the effect on vision is sometimes determinant because it likely accounts for better uncorrected visual acuity in patients with preoperative steep axis at 180° treated using nasal incision.

The spherical component \( M \) of the power vector decreases on average after superior incision, whereas it increases or decreases slightly after temporal and nasal incisions. However, the variability of change is such that differences are not significant. If the coupling ratio is 1, a change in refractive power of a corneal meridian is accompanied by an opposite change in the axis at 90°, which keeps the spherical value constant. If this is not the case, spherical change may be induced. The smaller vertical compared with horizontal diameter of the cornea and nasal physiological displacement of the pupil (visual axis) might help explain these findings.

Our findings are in general agreement with previously reported data. Induced changes in \( J_0 \) were similar to those described by Giasanti et al. (−0.15–−0.32 D and 0.10–0.27 D). They only found differences in JCC<sub>0</sub> (here designated as \( J_0 \)) of...
statistical, but low clinical, significance between the superior and the 8 o’clock incision. In addition to the superior-nasal comparison difference, found by Giasanti et al.,7 we extended differences of significance in parameter J0 to comparison between nasal and temporal and between superior and temporal incision. The superior-temporal difference is supported by the study of Marek et al.9

According to the present findings, placing a 2.8-mm temporal incision is recommended in preexisting negligible corneal astigmatism. In patients with the steep axis at 180°, a nasal incision is recommended. Using a nasal incision (Fig. 4), the surgeon should not expect to correct more than 0.5 D of astigmatism. In patients with the steep axis at 90°, superior incision may be recommended for at least 0.75 D of astigmatism (correction of more than 0.75 D of astigmatism using this incision is unlikely). With less than 0.75 D of astigmatism, however, temporal incision is the best choice. In summary, temporal incisions should be used for negligible astigmatism, and nasal and superior incisions should be used when the steep axis is located at approximately 180° and 90°, respectively.

The preceding guidelines are based on a general trend, but it should be noted that individual variations in biomechanical response occur, so that in a particular case, steepness could paradoxically increase along the incision meridian (Fig. 5). Limitations of accuracy and reproducibility may explain these findings.

The advent of toric IOLs for cataract surgery demands precise knowledge of the induced refractive change caused by

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**Figure 4.** Preoperative (A) and postoperative (B) eye scanner analysis in a patient with presurgical steep corneal axis at 180°, operated through a nasal 2.8-mm corneal incision. Corneal astigmatism was slightly reduced after surgery (from 0.8 to 0.6 D), and ISV also decreased (from 18 to 15).
different locations of corneal 2.8-mm incisions to predict the final refractive outcome. Given that 2.8-mm corneal incisions, particularly superior and nasal, are not absolutely astigmatism neutral, a sub-2-mm incision (with presumed negligible influence on corneal refractive status) could be helpful when preexisting astigmatism is treated using a toric IOL. Refractive outcome may then be predicted more accurately, when only one factor (IOL) has to be taken into account. Depending on preoperative corneal astigmatism, a sub-2-mm incision may also be appropriate when a customized IOL to treat optical aberrations is used. Knowledge about the effect of 2.8-mm incisions on the refractive state is useful in all these situations.

References


