Clinical results of arcuate incisions to correct astigmatism

Kurt A. Buzard, MD, Eduardo Laranjeira, MD, Bradley R. Fundingsland, BS

ABSTRACT

Purpose: To evaluate the effectiveness of arcuate incisions for correcting congenital, post-cataract, post-radial keratotomy, and post-trapezoidal keratotomy astigmatism.

Setting: Buzard Eye Institute, Las Vegas, Nevada.

Methods: In this retrospective study, 46 eyes of 29 patients had arcuate incisions to correct astigmatism. The average age of patients was 52 years.

Results: Mean preoperative astigmatism was 3.51 ± 1.57 D (keratometric) and 3.41 ± 1.44 D (manifest). Mean preoperative uncorrected visual acuity was 20/80, ranging from 20/30 to 20/400. Thirty eyes had a pair of 45-degree arcuate incisions, 10 eyes had a pair of 60-degree arcuate incisions, and 6 eyes had a pair of 90-degree arcuate incisions. Mean follow-up was 6 months. Mean postoperative astigmatism was 1.46 ± 1.07 D (keratometric) and 1.05 ± 0.94 D (manifest), with a reduction of astigmatism in all operated eyes. Mean postoperative uncorrected visual acuity was 20/32, ranging from 20/20 to 20/60. The analysis of the vector astigmatic change showed that only two patients were overcorrected after the procedure.


The common view is that astigmatism can be easily corrected with spectacles or contact lenses. However, even when corrected by these devices, it may cause off-axis blur, eye strain, glare, and visual field restriction.

Surgical correction of astigmatism has been attempted since the last century. Transverse keratotomy was suggested by Snellen1 in 1869. Lans2 and Sato3 investigated the concept of relaxing incisions. In the 1970s, Trutman and Swinger4 introduced and popularized the use of corneal relaxing incisions and corneal wedge resection to correct postkeratoplasty astigmatism. In 1982, Ruiz described trapezoidal keratotomy,5 which was explored in a cadaver eye study performed by Lavery and Lindstrom.6 This study indicated that a simple pair of transverse incisions appeared to provide a considerable percentage of the effect of the full Ruiz procedure. Many authors7–10 have described potential complications of trapezoidal keratotomy, such as microperforations and macroperforations, large postoperative axis shifts, glare, overcorrections, and wound dehiscence. The main disadvantage is the excessive number of incisions in a limited area of the cornea, with subsequent
corneal instability. The same problem has been observed with other modalities of astigmatic surgery, such as the “I,” procedure and the Binder procedure.

Arcuate incisions have become popular as a means of correcting moderate and large amounts of astigmatism. Arcuate incisions were first performed to correct astigmatism after penetrating keratoplasty. In 1985, Tchah et al.12 introduced the bowrie procedure, which involves a four-incision radial keratotomy (RK) connected at the limbus by two arcuate incisions straddling the steep axis. This procedure was abandoned because of wound healing problems and block lift in the area in which the radial and arcuate incisions connect. The corneal topographic changes induced by arcuate incisions were first investigated in eye-bank eyes by Tripoli and coauthors.14 The first systematic use of arcuate incisions to correct congenital astigmatism was by Merlin, who investigated incisions ranging from 100 to 160 degrees and optical zones ranging from 5 to 7 mm. He found progressive diminished effect as the optical zone was shifted from 5 to 7 mm. The effect on spherical equivalent was null for 100 degree incisions and produced larger hyperopic effects as the incision length increased to 160 degrees. Duffey et al.16 performed a cadaver eye study to evaluate the effectiveness of arcuate incisions and found that longer paired arcuate incisions produced a predictable corneal flattening in the meridian centered over the incisions and a smaller corneal steepening 90 degrees away, making the procedure ideal for mixed astigmatism.

The study presents the clinical results of arcuate incisions performed to correct congenital, post-cataract, post-RK, and post-trapezoidal keratotomy astigmatism, using the Buzard nomogram.17,18 Few clinical studies of the effectiveness and predictability of astigmatic surgery have been published.19–21 We describe a method that uses shorter and more shallow incisions in the first procedure. This approach tends to avoid the serious problem of overcorrection while allowing for additional correction on follow-up visits, if necessary.

Subjects and Methods

Forty-six eyes of 23 patients (17 men and 12 women) had arcuate incisions to correct astigmatism. The surgeries were performed between October 1991 and November 1993. The average age of the patients was 52 years (range 23 to 90 years). The patients had four categories of astigmatism: congenital (28 eyes), post-cataract (15 eyes), post-RK (2 eyes), and post-trapezoidal keratotomy (1 eye). The mean time of astigmatic surgery after cataract extraction was 12 months (range 3 to 36 months). The two cases of arcuate incisions after RK and the only case after trapezoidal keratotomy were performed 5 years after the original procedure.

All procedures were performed by one surgeon (K.A.B.). Twenty-three were performed in the operating room and the other 23, at the slitlamp. All enhancement procedures were performed at the slitlamp. Keratometry, photokeratometry, and computed corneal topography were performed on all eyes at all preoperative and postoperative visits.

Just prior to surgery, the eye was marked at the 12, 6, 3, and 9 o’clock limbal positions with a skin marker or needle to prevent surgical problems with eye torsion at the time of the surgery. All cases were performed with topical anesthesia (tetracaine). Pachymetry was done at the locations contemplated for the incisions and the knife was set at 80% of the thinnest reading. A locking lid speculum was used to secure the lids, and an aximeter was used for patient fixation. The steep axis was verified by aligning a Mendez gauge with the previously placed major marks. The arcuate incisions were marked with the specialized Buzard/Friedlander astigmatic arcuate markers after they were dipped in methylene blue. The eye was stabilized using a ring fixation without teeth (a Buzard/Thornton ring).

Two arcuate incisions were performed at a 7.0 mm optical zone in all cases. Thirty patients had a pair of 45-degree arcuate incisions, 10 had a pair of 60-degree arcuate incisions, and 6 had a pair of 90-degree arcuate incisions. All surgeries were planned using the Buzard arcuate nomogram (Figure 1), placing incisions in the steep axis. In cases of doubt between two incision lengths, the smaller was chosen. The refraction was expressed in plus cylinder and the surgery performed on the plus cylinder axis. The incisions were made with a front-cutting motion of the knife, using the vertical cutting edge of the diamond. In cases of previous RK, the incisions were “jumped” or placed between the radial incisions. A Thornton 15-degree trifaceted diamond knife was used to perform the incisions. A disposable contact lens was placed on the eye after the procedure and removed that night by the patient. Postoperatively,
the patient used antibiotic-steroid drops four times a day and artificial tears every hour while awake.

Postoperatively, the undercorrected eyes were treated by making the incisions deeper and/or longer with enhancement surgery. Twenty-three eyes (50%) had enhancement procedures: 9 had one, 9 had two, and 5 had three. The number of reoperations was higher with longer arcuate incisions. Twelve eyes (40%) with 45-degree arcuate incisions and 6 (60%) with 60-degree arcuate incisions had enhancements, but 5 of the 6 eyes (83%) with 90-degree arcuate incisions had reoperations.

**Results**

Mean follow-up after surgery was 6 months (range 2 to 24 months). There was a reduction of both keratometric and manifest astigmatism in all eyes. The mean preoperative keratometric astigmatism was 3.5 ± 1.57 diopters (D) (range 1.37 to 8.75 D) and the mean manifest astigmatism, 3.41 ± 1.44 D (range 1.25 to 7.75 D). Before enhancement surgery, the mean postoperative keratometric astigmatism was 1.91 ± 1.60 D (range 0.37 to 9.50 D) and the mean postoperative manifest astigmatism, 1.30 ± 0.00 D (range 0.00 to 5.50 D). After enhancement surgery, the mean postoperative keratometric astigmatism was 1.46 ± 1.07 D (range 0.37 to 6.87 D) (Figure 2) and the mean postoperative manifest astigmatism, 1.05 ± 0.94 D (range 0.00 to 3.00 D) (Figure 3).

Analysis of the change in astigmatism achieved by the incisions shows that more astigmatism is corrected with longer incisions. At last follow-up, the mean change in keratometric astigmatism for the 45-, 60-, and 90-degree arcuate incisions was 1.66 ± 0.64 D, 2.69 ± 1.24 D, and 2.83 ± 1.04 D, respectively.

The mean difference between preoperative and final postoperative keratometric axis was 12.3 ± 16.6 degrees (Figure 4), and the mean difference between preoperative and final postoperative manifest axis, 10.7 ± 9.38 degrees (Figure 5). Two patients had axis changes greater than 25 degrees: one had an axis shift of 51 keratometric degrees and 50 manifest degrees after a pair of 90-degree arcuate incisions; the other had an axis shift of 105 degrees (keratometric and manifest) after a pair of 90-degree arcuate incisions. Analysis of the vector astigmatic change (Figure 6) shows that these two patients (4%) were the only cases of overcorrection in this series.
Vector astigmatic change was analyzed using the Holladay/Gravy/Koch formula.²² Roth cases were complicated by problems of wound dehiscence.

The average uncorrected visual acuity at last follow-up was 20/32 (range 20/20 to 20/60) (Figure 7). Postoperatively before enhancement surgery, 31 eyes
(67%) had 20/40 or better acuity. At last follow-up after enhancements, 35 (76%) had 20/40 or better. None of the eyes had a decrease of uncorrected visual acuity after surgery. The best corrected visual acuity remained the same or improved in all eyes.

The mean preoperative spherical equivalent was -0.09 ± 1.60 D (range -2.50 to +4.25 D) and the mean postoperative spherical equivalent at last follow-up, -0.27 ± 1.30 D (range -3.00 to +2.50 D) (Figure 8). The mean preoperative keratometry was 43.65 ± 1.60 D (range 38.18 to 47.43 D) and the mean keratometry after surgery, 43.75 ± 1.80 D (range 38.31 to 47.93 D) (Figure 9). The mean ratio of corneal flattening in the steep meridian to steepening in the flat meridian (F/S ratio) was 0.97 ± 0.9 (range 0.16 to 3.84). With 45-degree arcuate incisions the ratio was 1.05 ± 0.8. With 60- and 90-degree arcuate incisions, the F/S ratio was 0.81 ± 0.4 and 0.70 ± 0.3, respectively. Three patients had steepening of both steep and flat meridians, and three other patients had flattening of both meridians.

Two cases of wound dehiscence were observed. These patients were treated by suturing the wound with 11-O polyester fiber (Mersilene®) interrupted sutures. Final outcome data on these cases are presented after suture correction. We had no other complications such as microperforations and macroperforations, infection, or vascularization of the incisions.

**Discussion**

Astigmatism represents a refractive error that should be analyzed separately from myopia and hyperopia. Ruzard and coauthors’ have demonstrated that manifest refraction often underestimates true keratometric astigmatism. In a related study, Lakshminarayanan et al. found that a tilted or displaced intraocular lens induced a maximum astigmatism of 0.50 D. These studies support our opinion that most astigmatism in the human optical system resides in the cornea and that, therefore, astigmatic surgery should be based on keratometry, computed corneal topography, or both, instead of on manifest refraction. In cases in which there is a significant difference between manifest and keratometric astigmatism, it is often better to avoid the surgery, which may lead to a complex cross-cylinder effect, creating an astigmatic error at an entirely new axis.
Astigmatic surgery is distinguished from RK in many ways. In RK, the length of the incisions and optical zone are linked (i.e., the longer the incision, the smaller the optical zone), making nomograms very similar. In astigmatic keratotomy, incision length and optical zone are unlinked, resulting in many different nomograms to correct similar amounts of astigmatism.

In a recent article, 14 experts were asked to give their opinion about correcting astigmatism after cataract surgery. Each proposed a different approach, including transverse incisions, wedge resection, and resuturing the wound.

Arcuate incisions have the potential for greater effect because the chord length is the same as straight transverse incisions, but the actual length is about 10% longer on the curve. Moreover, the length of the incision is equidistant from the center of the cornea, cutting through tissue of approximately equal thickness. Arcuate incisions are, however, more difficult to perform. To avoid irregularities, the incision must be performed slowly and with a continuous movement, following the curved marks. Hanna et al. have developed an arcuate keratome for performing the incisions with a more uniform and accurate depth. A multiple-puncture technique has been proposed; it consists of successively deeper incisions to connect multiple punctures when creating arcuate incisions.

Hanna and coauthors have found that at an optical zone of 7.0 mm, arcuate transverse incisions show maximal effect at 100 degrees. Because of the potential for corneal instability and lack of additional effect, we do not recommend performing arcuate incisions over 100 degrees in length. Another important issue is the incision depth. We believe transverse incisions, whether straight or arcuate, should aim for significantly less than 100% of the thinnest paracentral corneal thickness to avoid the possibility of corneal instability, wound gape, and overcorrection. In this study we aimed for 80% depth, which could be deepened later if necessary. Finally, the effect of astigmatic incisions is dependent on age and increases 15% per decade according to the Buzard nomogram and 0.36 D per decade according to Price et al. One wound dehiscence case in this series consisted of a 70-year-old man with post-cataract astigmatism. He had a pair of 90-degree arcuate incisions and had an axis shift of 50 degrees, with wound dehiscence, which was corrected in the postoperative period with suturing. Although pilocarpine has been discussed as treatment for overcorrections associated with RK, it has been observed to worsen astigmatic overcorrections. Because of this case and the findings of the Buzard and Price nomograms, we suggest arcuate incisions be limited to 60 degrees in length in patients older than 60 years.

This conservative approach of short, shallow incisions, followed by enhancement if necessary, showed encouraging results and safety when compared with related studies. A reduction in astigmatism was observed in all operated eyes. The effectiveness of the procedure was reflected through the achievement of 20/40 or better uncorrected visual acuity in 35 eyes (76%) at last follow-up (Figure 7). In a study of 142 eyes, Price et al. achieved a mean postoperative refractive cylinder of 1.22 ± 0.85 D, whereas we achieved 1.30 ± 1.00 D before any enhancement surgery and 1.05 ± 0.94 D after enhancements.

With this technique, the majority of patients showed a tendency toward undercorrection. Undercorrection can be managed by enhancing the original surgical procedure-making the incisions deeper, longer, or both—which can be performed at the slitlamp. These
enhancements differ from traditional reoperations in that no new incisions are made. This enhancement philosophy follows that of the RK “tickle” in which incisions are reopened or lengthened for postoperative precision and to avoid overcorrections. Our results demonstrate that the enhancement procedures correct an additional 12% of keratometric astigmatism and an additional 7% of manifest astigmatism without additional complications.

Overcorrection is a much more serious problem. It leads to diminished best corrected vision, glare, diurnal variation, and wound dehiscence. A new set of incisions in the opposing axis must be made to correct significant overcorrections. Analysis of the vector astigmatic change in this study revealed two patients (4%) with overcorrections (Figure 6). The overcorrections were due to the two large axis shifts of 50 and 105 degrees, complicated by wound dehiscence problems. This 4% incidence is lower than the 18% reported by Price et al. and 19% reported by Neumann and coauthors. In addition, the mean coupling ratio of 0.97 (F/S) demonstrates less flattening than the 1.47 ratio reported by Duffey et al. and the 1.0 reported by Merlin, and the 2.0 reported by Lundergan and Rowsey.

Arcuate incisions couple in a more unpredictable manner, preserving spherical equivalent in some cases and making the patient more myopic or hyperopic in other cases (Figures 8 and 9). At a 7.0 optical zone with longer arcuate incisions (60 and 90 degrees), there is a tendency to make the cornea slightly steeper, which is supported by coupling ratio data in this and other studies. For this reason, we recommend that astigmatic corrections larger than 3.00 D be performed prior to RK to determine the actual spherical correction needed after astigmatic surgery.

In summary, arcuate incisions may be an effective treatment of astigmatic patients who do not have satisfactory results with spectacles or contact lenses. A conservative approach, making the incisions shallow and short, and deepening or extended later, eliminates a large amount of corneal astigmatism and tends to avoid the number of overcorrections observed with other techniques.

References
17. Troutman RC, Buzard KA. Corneal Astigmatism; Etiology, Prevention, and Management. St Louis, Mosby Yearbook, 1992; 11X1-36
21. Buzard KA. The surgical management of astigmatism. In:
34. Lundergan MK, Rowsey JJ. Relaxing incisions; corneal topography. Ophthalmology 1985; 92: 1226-1236