Circular Keratotomy to Reduce Astigmatism and Improve Vision in Stage I and II Keratoconus

Jorg H. Krumeich, MD; Guy M. Kezirian, MD, FACS

ABSTRACT

PURPOSE: To report the use of circular keratotomy in eyes with stage I and II keratoconus to reduce astigmatism.

METHODS: A retrospective analysis was performed of all eyes operated from 1993 to 2006 by one surgeon using circular keratotomy for stage I and II keratoconus. Results were evaluated for reduction of corneal astigmatism, refractive stability, and change in best spectacle-corrected visual acuity (BSCVA).

RESULTS: Forty-six eyes in 36 patients were evaluated. Corneal (keratometric) astigmatism and refractive astigmatism were significantly reduced, particularly in eyes with preoperative astigmatism ≥2.00 diopters (D). Preoperative astigmatism correlated with reduction of astigmatism (R=0.81). Astigmatism stabilized after 1 year in 64% of 28 eyes that were seen both within the first year after surgery and then at some time point ≥2 years after surgery. In this group, astigmatism changed ≤2.00 D in 94% of eyes between 1-year follow-up and the last examination. Mean BSCVA improved from 20/44 to 20/33 (P<.01), with 20 (43%) of 46 eyes gaining 2 lines or more, 22 (48%) of 46 eyes changing by less than 2 lines, and 4 (9%) of 46 eyes having a worse BSCVA at the last examination compared with preoperatively.

CONCLUSIONS: Circular keratotomy provides significant reduction in astigmatism, improved BSCVA, and stabilization of astigmatic changes in most eyes, although some eyes show limited benefit. Eyes with higher preoperative astigmatism appear to be more likely to benefit from the procedure than those with lower preoperative astigmatism. Circular keratotomy also resulted in reasonable clinical results for the treatment of stage I and II keratoconus. [J Refract Surg. 2009;25:357-365.]
Circular keratotomy attempts to isolate the central cornea from surrounding tissue, to allow Gauss’ observation to create a regular, spherical central surface. The circular keratotomy procedure consists of making a partial thickness circular cut, 7 mm in diameter, to 80% of the corneal depth. By mechanically isolating the central cornea from the surrounding tissue, intraocular pressure acts to fulfill Gauss’ observation and creates a spherical surface over the central cornea. When circular keratotomy was used to diminish postoperative keratoplasty astigmatism, the circular cut and scar led to a reduction of astigmatism, whereby the values of the spherical equivalent refraction remained constant in agreement with Gauss’ observation regarding the constant relationship of perpendicular radii. Furthermore, the scar seemed to act like a stabilizing ring within the stroma and is difficult to open once healed. This is different than the scars created by radial keratotomy, which often open easily even years after being created.

The current study reports on the use of circular keratotomy in eyes with stage I and II keratoconus in an attempt to reduce astigmatism. Refractive changes and stability over time are reported.

**Patients and Methods**

**Study Design and Patient Enrollment**

This is a retrospective, consecutive enrollment clinical outcomes report of circular keratotomy performed by one surgeon in one center. Entry criteria were keratoconus I and II according to the staging in Table 1 with worsening of the disease during the year prior to surgery. Additional criteria included loss of more than one line of best spectacle-corrected visual acuity (BSCVA) and increase in keratometric astigmatism of more than 1.00 diopter (D) accompanied by topographic changes showing extension of the cone toward the central cornea. Patient age was not considered an entry criterion.

All patients signed an informed consent that described the procedure, disclosed the novelty of the procedure, and stated that the outcome of the procedure was uncertain. Prior to performing the procedure, the Guided Trephine System (GTS; Polytech, Rossdorf, Germany) had been awarded CE mark with indications for partial or total trephination of the cornea. Consultation with the ethical committee of the University of Munster confirmed that no special permission of an ethical committee was required.

All eyes operated by one surgeon (J.H.K.) using circular keratotomy for stage I or II keratoconus from 1993 through May 2006 were enrolled (Table 1). A prerequisite for qualifying for the procedure was a minimum thickness of 400 µm at the site of the trephination. Patients were evaluated as a group and also subdivided into cohorts for purposes of further analysis. Stability was evaluated using the eyes that were examined both within the first year and again 2 or more years after surgery. Results over time (case study cohort) were evaluated using eyes that were seen at each annual interval from 1 to 5 years after surgery.

**Clinical Outcomes Measures**

Clinical outcomes measures included keratometry changes, refractive changes, and assessment of BSCVA. Keratometry was obtained using Bausch & Lomb (Rochester, NY) manual keratometer. Refractive analysis included evaluation of spherical equivalent refraction, astigmatism, and refractive stability.

**Surgical Procedure**

Procedures were performed using peribulbar anesthesia. Globes were fixated and a central mark created using Gentian violet with an 8-bar radial keratotomy marker. Prior to creating the keratotomy, the central cornea was molded against a rounded dome—obturator, which is a spherical body with a concave radius of 7.9 mm housed in the trephine (Fig 1A). In all cases the Guided Trephine System (Fig 1B) was used, which enables pressure of 800 m bars to fixate the suction ring outside the cornea. Intraocular pressure is not raised thereby due to the construction of the ring (Fig 1C). With the use of the obturator inside the trephine, the formation of a

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**Table 1**

**Clinical Classification of Keratoconus by Stage**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Eccentric steepening</td>
</tr>
<tr>
<td></td>
<td>Induced myopia and/or astigmatism of ≤5.00 D</td>
</tr>
<tr>
<td></td>
<td>K-reading ≤48.00 D</td>
</tr>
<tr>
<td></td>
<td>Vogt’s lines, typical topography</td>
</tr>
<tr>
<td>II</td>
<td>Induced myopia and/or astigmatism &gt;5.00 to ≤8.00 D</td>
</tr>
<tr>
<td></td>
<td>K-reading ≤53.00 D</td>
</tr>
<tr>
<td></td>
<td>Pachymetry &gt;400 µm</td>
</tr>
<tr>
<td>III</td>
<td>Induced myopia and/or astigmatism &gt;8.00 to ≤10.00 D</td>
</tr>
<tr>
<td></td>
<td>K-reading &gt;53.00 D</td>
</tr>
<tr>
<td></td>
<td>Pachymetry 200 to 400 µm</td>
</tr>
<tr>
<td>IV</td>
<td>Refraction not measurable</td>
</tr>
<tr>
<td></td>
<td>K-reading &gt;55.00 D</td>
</tr>
<tr>
<td></td>
<td>Central scars</td>
</tr>
<tr>
<td></td>
<td>Pachymetry ≤200 µm</td>
</tr>
</tbody>
</table>

*Stage is determined if one of the characteristics applies. Note. Pachymetry is measured at the thinnest site of the cornea.
spherical surface was mechanically established prior to the cut.

Circular keratotomy was performed to the depths of 90% of the 7-mm Orbscan (Bausch & Lomb) pachymetry values, corresponding to 80% of corneal thickness at the 7-mm site (Fig 2).

After creating the keratotomy, a double-running anti-torque suture was placed in all cases (see Fig 2) under keratoscopic control, with attempts to reduce astigmatism to a minimum.

Postoperative treatment consisted of application of a combination drop of dexamethasone, neomycin sulfate, and polymyxin B sulfate (Isopto Max; Alcon Laboratories Inc, Ft Worth, Tex) four times daily for 1 week, then three times a day for 2 additional weeks.

SUTURES
Because firm wall-to-wall adaptation was the basis of the concept, sutures were left in for a minimum of 6 months, but preferably 12 months.

STATISTICAL ANALYSIS
Statistical analysis was performed using the following methods:

- All refractions were converted to the corneal plane (vertex = 0) for calculations, and refractive results are reported at the corneal plane (vertex 0).
- Vector analysis performed according to the methods reported by Holladay et al.20,21
- Visual acuities calculations performed using logMAR equivalents.22
- Stability analysis was performed by
  1. Comparing the last examination occurring within 1 year of surgery to the last examination reported up to 5 years after surgery. A paired analysis was used for all stability calculations.
  2. Comparing results at each annual interval for eyes that were seen more than once beyond 1-year follow-up.
  3. Comparing results at each annual interval for eyes that were seen every year from 1 to 5 years after surgery.
- A “Last Visit” analysis was performed for most outcomes reports, including data from the last follow-up available for each eye.

Evaluations of comparative outcomes were performed using the Student’s t test for mean and an F-test for variance.
RESULTS

COHORT COMPOSITION

Results were evaluated for all eyes and for subgroups for ad hoc analysis. Overall, 46 eyes were operated over a 13-year period spanning from March 1993 through May 2006. Mean follow-up was 2.9±1.8 years (range: 11 months to >5 years) with 39 (84.7%) of 46 eyes having ≥1-year follow-up.

The female ratio was 14:32 (30.4%:69.6%, P<.01). Mean age was 42.9±13.4 years (range: 22 to 75 years). Surgery was performed on 1 eye of 36 patients and the remaining 5 patients underwent bilateral procedures.

Stability Cohort. Eyes used to evaluate stability included 28 (60.8%) of 46 eyes that were examined both within the first year and again ≥2 years after surgery. An analysis was performed to evaluate whether the 28 eyes included in the stability cohort differed from the 16 eyes that were not included. Comparison of the preoperative and 3-month postoperative refractive characteristics (sphere, cylinder, and spherical equivalent refraction) and mean keratometry values showed no statistically significant differences.

Case Study Cohort. Year-to-year variability was evaluated using 7 (15.2%) of 46 eyes that were seen at each annual interval from 1 to 5 years after surgery.

SUTURES

Sutures were left in place for at least 6 months following surgery to promote firm adhesion of the circular keratotomy interface. In 3 (6.5%) of 46 eyes, sutures spontaneously broke within 6 months and were replaced.

KERATOMETRY

Keratometry data are summarized in Table 2. The mean keratometry value did not change significantly with surgery; however, the cornea became significantly less astigmatic.

For all eyes, the mean preoperative keratometry was 46.01±3.56 D and mean postoperative keratometry was 45.84±2.76 (difference not significant, Student t test). However, a statistically significant reduction was noted in the steepest keratometry from a mean of 48.34±4.02 D to 47.14±3.10 D (P=.01). There was a corresponding reduction in the difference between

<table>
<thead>
<tr>
<th>Mean K</th>
<th>Steep K</th>
<th>Steep – Flat K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Mean</td>
<td>46.01</td>
<td>45.84</td>
</tr>
<tr>
<td>SD</td>
<td>3.56</td>
<td>2.76</td>
</tr>
<tr>
<td>Min</td>
<td>41.50</td>
<td>39.75</td>
</tr>
<tr>
<td>Max</td>
<td>57.85</td>
<td>51.75</td>
</tr>
</tbody>
</table>

Note. Mean K values did not change significantly, but the difference between steep and flat K was significantly reduced.

Figure 3. Corneal topography in the same postoperative eye taken approximately 5 years apart, showing no progression of keratoconus.
the steepest and flattest keratometry readings (corneal astigmatism) after surgery, from a mean of 4.66±2.74 D to 2.59±1.68 D (P<.001).

On average, the eyes experienced a reduction in keratometric astigmatism of 2.06±2.70 D. However, not all eyes were improved. Six (13%) of 46 eyes experienced an increase in corneal astigmatism of more than 1.00 D (range: 1.20 to 3.65 D). Eleven (23.9%) of 46 eyes experienced a change of less than 1.00 D, and the remaining 29 (63%) eyes had a reduction in corneal astigmatism of more than 1.00 D (range: 1.43 to 8.63 D). Figure 3 shows the keratometric appearance of one eye before and after surgery.

The reduction in corneal astigmatism positively correlated with the amount of preoperative corneal astigmatism (R=0.81) (Fig 4). No eye with <2.00 D preoperative corneal astigmatism improved, whereas all eyes with ≥5.00 D corneal astigmatism improved. Weaker correlations existed between the pre- and postoperative mean keratometry readings (R=0.55) and the preoperative mean keratometry and preoperative spherical equivalent refraction (R=0.53).

**REFRACTIVE OUTCOMES**

Refractive outcomes are summarized in Table 3.

**Spherical Equivalent Refraction Results.** The mean preoperative spherical equivalent refraction in this series varied widely from −13.25 to 5.89 D. The mean was slightly myopic at −1.17±4.51 D. Postoperative refractions were slightly less myopic with a mean of −1.02±2.80 D (range: −9.72 to 5.32 D). The mean differences were not statistically significant (t-test) but the variance was significantly reduced after surgery (P<.01, F-test).

**Astigmatic Results.** Refractive astigmatism was significantly reduced in this series. Absolute preoperative astigmatism averaged 3.56±1.78 D (range: 0 to 7.78 D), which was reduced postoperatively to 2.24±1.13 D (range: 0.48 to 5.73 D). Both the mean (t test) and variance (F-test) were significantly reduced after surgery (P<.01 for both tests). Figure 5 shows the doubled-angle plots for the preoperative and last postoperative astigmatism. Significant reduction in cylinder magnitudes can be seen.

Comparison of Table 3 and the results shown in Figure 6 shows the utility of evaluating astigmatism vectors. The absolute cylinder amounts were similar from the 1-year to the last follow-up for each group, whether the last examination occurred at the 2-, 3-, 4-, or 5-year time point. However, analysis of the cylinder vector magnitudes reveals a greater amount of cylinder...
change during the interval between 1 year and the last follow-up than is suggested by the absolute values (Table 5). Taken together, these data indicate that the cylinder axis was changing more than the cylinder magnitude over time.

Over time, the mean change in the astigmatism vector was $0.48\pm0.42$ D per year (range: 0.09 to 1.60 D per year). However, cylinder amounts in the 4 eyes examined 2 years after surgery were not significantly different from the 15 eyes seen 5 years after surgery ($2.18$ D vs $1.54$ D), suggesting that the changes after 1 year may not be progressive (Table 2). Figure 6 plots the changes in the absolute astigmatism amounts for this group, and shows that 64% experienced $\leq1.00$ D change in cylinder amount between 1 year and the last follow-up for each eye.

The limitation of two-observation stability analysis is that there is no information about trends within the interval. Serial observations are needed to determine whether stability is improving over time, and this is difficult with a retrospective analysis. To address this issue, an analysis was performed for the 28 eyes in the stability cohort that were seen at annual intervals from 1 to 5 years after surgery.

To further evaluate this issue, a case study cohort was established to evaluate changes in astigmatism over time in individual eyes. Of the overall group, 7 (15.2%) of 46 eyes were seen at annual intervals from 1 to 5 years after surgery and qualified for inclusion. From this group, it is possible to evaluate changes in astigmatism from year to year over a 5-year period. Table 4 shows the magnitude of the cylinder vector change from year to year for this group; results show that on average this group experience from 0.58 to 1.55 D in vector magnitude shifts each year.

Figure 7 graphs the absolute cylinder magnitudes in each of these seven eyes over time. As shown in Figure 7, the absolute cylinder was stable within 1.00 D from 1 to 5 years after surgery in four (57.1%) of seven eyes.
One of the seven eyes experienced an increase in astigmatism of approximately 1.50 D and one increased 2.15 D. The last eye (patient 27045 OS) had an unexplained sudden decrease in astigmatism from 5.50 to 1.50 D between the 3rd and 4th postoperative year.

**BEST SPECTACLE-CORRECTED VISUAL ACUITY**

When comparing the preoperative BSCVA to the BSCVA at the last follow-up, mean vision was significantly improved by the procedure (20/44 to 20/33, P < .01). Only 4 (9%) of 46 eyes had worse BSCVA at the last examination, whereas 20 (43%) eyes gained 2 lines or more. Best spectacle-corrected visual acuity was unchanged in 22 (48%) eyes. Table 6 reports BSCVA statistics for all eyes.

**COMPLICATIONS**

In 3 (6.5%) eyes, double running sutures became loose within 2 months due to pulling through the peripheral tissue. The wound was cleaned, washed with vancomycin, and re-sutured under the keratoscope. No other complications were observed. Specifically, there were no infections and no progression to keratoplasty in this series.

**DISCUSSION**

This report presents a retrospective analysis of clinical outcomes following circular keratotomy in 46 eyes of 41 patients with clinically diagnosed stage I and II keratoconus. Follow-up extended through 5 years in 15 (32.6%) eyes; 39 (84.7%) eyes were followed for ≥1 year after surgery.

The circular keratotomy procedure creates a circular cut to 80% of the thinnest pachymetric corneal depth, which correlates to 90% of the thinnest Orbscan measurement at a 7-mm diameter. Prior to creating the keratotomy, the central cornea is molded against a rounded dome using suction. The goal is to equalize the mechanical forces on the central cornea by eliminating the differences in the arc lengths, thereby reducing uneven biomechanical stress that may lead to irregular astigmatism.

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**TABLE 4**

<table>
<thead>
<tr>
<th>Last Examination Years from Surgery</th>
<th>Mean Absolute Cylinder (D)</th>
<th>Vector Change in Cylinder Amount Year 1 to Last Exam (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 1</td>
<td>Last Exam</td>
</tr>
<tr>
<td>2</td>
<td>−3.00</td>
<td>−2.26</td>
</tr>
<tr>
<td>3</td>
<td>−1.63</td>
<td>−1.71</td>
</tr>
<tr>
<td>4</td>
<td>−2.00</td>
<td>−1.95</td>
</tr>
<tr>
<td>5</td>
<td>−2.91</td>
<td>−2.39</td>
</tr>
</tbody>
</table>

*Eyes that were seen at multiple postoperative intervals.

**Figure 7.** Absolute cylinder magnitudes for the 7 eyes seen at annual intervals from years 1 to 5 after surgery.
Circular keratotomy relies on the faithful application of this principle during surgery. The obturator is used to round the deformed aspheric cornea before making the circular keratotomy cut, and a double running anti-torque suture is used to firmly appose the walls of the incision. If a conventional trephine is used instead of the obturator to create the cut, or if a standard running suture is used rather than an anti-torque suture, the procedure will fail. Heavy steepening of the radii and worsening of the cone will result.

Results show that the procedure does not significantly change the mean corneal curvature, on average. However, corneal (keratometric) astigmatism and refractive astigmatism were significantly reduced, particularly in eyes with ≥2.00 D preoperative astigmatism. Mean refractive astigmatism went from 3.56 ± 1.78 D (range: 0 to 7.78 D) preoperatively to 2.24 ± 1.13 D postoperatively ($P < .01$). Preoperative astigmatism showed the best correlation with procedure effectiveness in reducing astigmatism ($R=0.81$).

Astigmatism was stabilized after 1 year in 64% of the 28 eyes that were seen both within the first year after surgery and then at some time point ≥2 years after surgery. In this group, astigmatism changed ≤2.00 D in 94% of eyes between 1-year follow-up and the last examination.

The procedure also had a beneficial effect on BSCVA (Table 6). Mean BSCVA improved from 20/44 to 20/33 ($P < .01$), with 20 (43%) of 46 eyes gaining 2 lines or more, 22 (48%) eyes changing by less than 2 lines, and 4 (9%) eyes showing a worse BSCVA at the last examination compared with the preoperative visit.

Of the 46 eyes, 7 (15.2%) had data from annual examinations for 5 years (see Fig 7), permitting longitudinal evaluation of their astigmatic stability. Four of these eyes did well, with astigmatism stable within 1.00 D over the entire 5-year period. One eye showed significant reduction in astigmatism between 3- and 4-year follow-up, and 2 showed worsened astigmatism over time.

Circular keratotomy provides significant reduction in astigmatism, improved BSCVA, and stabilization of astigmatic changes in most eyes, whereas some eyes show limited benefit. The effect of the procedure on the overall corneal curvature was slight. Eyes with more preoperative astigmatism appear to be more likely to benefit from the procedure than those with low amounts of preoperative astigmatism. Circular keratotomy offers reasonable clinical results for the treatment of stage I and II keratoconus.

A remarkable feature of the eyes in this series is the lack of progression in corneal steepness after surgery. Over the observation period of up to 5 years, the astigmatic vector magnitude was stable within 1.00 D in 85% of eyes whereas 15% showed ≥1.00 D steepening. A controlled study is needed to determine whether circular keratotomy can halt the progression of keratoconus, but these results suggest that biomechanical isolation of the central cornea with circular keratotomy may permit some stabilization of the condition.

Further studies, preferably with prospective, controlled designs, are needed to compare this treatment against other modalities.

**AUTHOR CONTRIBUTIONS**

Study concept and design (J.H.K., G.M.K.); data collection (J.H.K.); data analysis and interpretation (J.H.K., G.M.K.); drafting of the manuscript (J.H.K., G.M.K.); critical revision of the manuscript (J.H.K., G.M.K.); statistical expertise (G.M.K.)

**REFERENCES**


