Treatment of Postoperative Keratoplasty Astigmatism Using Femtosecond Laser-Assisted Intrastromal Relaxing Incisions

Olli Wetterstrand, MD; Juha M. Holopainen, MD, PhD; Kari Kroo"{t}ila, MD, PhD

ABSTRACT

PURPOSE: To investigate the effectiveness of femtosecond laser-assisted intrastromal relaxing incisions for astigmatism management and establish laser treatment parameters.

METHODS: Sixteen eyes of 16 patients had regular astigmatism after penetrating keratoplasty. All sutures had been removed and the refraction was stabilized. Paired arcuate intrastromal incisions were made 180° apart within the graft stroma with a femtosecond laser preserving the epithelium. Follow-up examinations were performed at 1 week, 2 weeks, 1 month, and 3 months.

RESULTS: The logMAR corrected distance visual acuity (CDVA) improved from 0.50 ± 0.29 to 0.32 ± 0.23 (Snellen 20/63 to 20/40). Refractive and topographic anterior cylinders decreased from 6.8 ± 2.2 diopters (D) to 3.7 ± 1.7 D and from 9.5 ± 4.8 D to 4.4 ± 2.1 D, respectively. Stabilization of topographic cylinder was observed 1 month postoperatively. The worse the preoperative CDVA was and the higher the preoperative values for the refractive and topographic cylinders were, the higher the surgically induced changes were. Anterior side cut angles at 90° and 120° produced similar results. A bulge of incision occurred in one eye requiring compression sutures.

CONCLUSIONS: Significant improvement in CDVA and refractive and topographic cylinders indicated a good effect of femtosecond laser-assisted intrastromal relaxing incisions in reducing astigmatism. No advantage between 90° and 120° anterior side cut angles was found. No infections were recorded and no patient expressed discomfort.

and informed consent was obtained from all patients. After clinical evaluation consisting of biomicroscopy, intraocular pressure measurement using application tonometer, fundus examination, and topographic evaluation using anterior segment optical coherence tomography (OCT) (SS-1000 Casia; Tomey, Nagoya, Japan), the clinical decision was made to reduce corneal astigmatism by performing astigmatic keratotomy.

Sixteen eyes of 16 patients were treated between September 2010 and October 2011. All patients had regular astigmatism and all sutures were removed from the cornea a mean 9 ± 6 months earlier (range: 2.5 to 21 months). All patients were examined for 3 months.

**Intrastromal Relaxing Incisions**

Femtosecond laser-assisted relaxing incisions were made under topical 1% tetracaine hydrochloride anesthesia (Minims Tetracaine; Chauvin Pharmaceuticals Ltd., Kingston-Upon-Thames, UK). Corneal thickness was measured prior to surgery using ultrasound pachymeter (AL-3000; Tomey) from eight different points inside the graft–host wound at the presumed incision site. The center of the corneal graft was marked and the femtosecond laser was centered to the graft. The length of all paired arcuate incisions was 90° and incisions were made inside the graft using 60-kHz Intralase femtosecond laser (IntraLase Corp., Abbott Medical Optics, Irvine, CA) using keratoplasty mode and only the anterior side cut incision. The parameters for the laser were: energy 2.5 J, spot separation 3 μm, and layer separation 3 μm. The depth of the incisions was set to 90% of the measured thickness, the diameter of the incisions were 6.0 mm (n = 8), 6.5 mm (n = 6), or 7 mm (n = 2), and the side cut angle was 90° or 120°. To preserve the epithelium, the depth in glass was set to -90 μm. The epithelium was not opened with any instrument at any point of the treatment. The results of the incisions were confirmed immediately after the operation biromicroscopically. Postoperatively, one drop of antibiotic (levofloxacin) (Oftaquix; Santen, Tampere, Finland) was administered and prednisolone acetate 10 mg/mL (Allergan, Westport, County Mayo, Ireland) was applied three times a day for 1 week. Topical lubricants were used as needed.

Microsoft Excel software version 14.0.0 (Microsoft Corporation, Redmond, WA) and SPSS software version 20 (SPSS, Inc., Chicago, IL) were used for statistical analysis. Statistical significance was measured using the Wilcoxon and Mann–Whitney U tests. Correlations were examined using the Pearson correlation test for normally distributed variables. The coupling ratio was calculated as the ratio between flattening of the steep meridian and steepening of the flat meridian from the anterior topographic cylinder values. The surgically induced astigmatism was calculated using the Alpins method.23

**RESULTS**

Specific patient demographics are presented in Table 1. All operations were successfully performed inside the graft–host wound and all incisions were located intrastromally (Figures 1A and 1B). No epithelial or endothelial breakage was noted either intraoperatively or postoperatively.

Corrected distance visual acuity (CDVA) improved by 0.18 ± 0.26 logMAR (P = .016). Refractive cylinder decreased by 3.1 ± 2.1 D (P = .001). The topographic anterior cylinder decreased by 5.1 ± 4.7 D (P = .001) and posterior cylinder by 0.7 ± 0.6 D (P = .002) (Table 2). There was a significant correlation between the magnitude of preoperative values and amount of improvement in CDVA and refractive and topographic cylinders. The worse the preoperative CDVA was and the higher the preoperative values for refractive and topographic cylinders were, the higher the surgically induced changes were (P < .001) (Figures 2A-2C).

CDVA and refractive cylinder continued to improve up to 3 months. The average topographic cylinder reached a stable level at 1 month postoperatively (Figure 3). The coupling ratio was 0.57 ± 2.65 at 3 months. The arithmetic mean of the surgically induced astigmatism was 7.7 ± 5.1 D and the mean vector was 1.1 D in axis of 26°.

Nine eyes were operated on with an anterior side cut angle of 90° and 7 eyes with 120°. Both groups had statistically similar preoperative values. The 90° cut angle

<table>
<thead>
<tr>
<th>Variable</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients/eyes</td>
<td>16/16</td>
</tr>
<tr>
<td>Age, mean ± SD (y)</td>
<td>50 ± 18 (range: 21 to 81)</td>
</tr>
<tr>
<td>Sex</td>
<td>6 females, 10 males</td>
</tr>
<tr>
<td>Reason for PKP</td>
<td></td>
</tr>
<tr>
<td>Keratoconus</td>
<td>11 eyes</td>
</tr>
<tr>
<td>Fuchs’ dystrophy</td>
<td>3 eyes</td>
</tr>
<tr>
<td>Lattice dystrophy</td>
<td>2 eyes</td>
</tr>
<tr>
<td>Other ocular pathologies</td>
<td></td>
</tr>
<tr>
<td>Earlier corneal surgery (stabilized)</td>
<td>1 eye</td>
</tr>
<tr>
<td>Re-graft</td>
<td>1 eye</td>
</tr>
<tr>
<td>Conventional AK</td>
<td>2 eyes</td>
</tr>
<tr>
<td>Senile cataract (untreated)</td>
<td>1 eye</td>
</tr>
<tr>
<td>IOL</td>
<td>4 eyes</td>
</tr>
</tbody>
</table>

SD = standard deviation; PKP = penetrating keratoplasty; AK = arcuate keratotomy; IOL = intraocular lens

### Table 1

**Patient Demographics**

### Results

- Corrected distance visual acuity (CDVA) improved by 0.18 ± 0.26 logMAR (P = .016).
- Refractive cylinder decreased by 3.1 ± 2.1 D (P = .001).
- Topographic anterior cylinder decreased by 5.1 ± 4.7 D (P = .001).
- Posterior cylinder by 0.7 ± 0.6 D (P = .002). (Table 2).

### Figures

1A and 1B: No epithelial or endothelial breakage was noted either intraoperatively or postoperatively.
2A-2C: Significant correlation between the magnitude of preoperative values and amount of improvement in CDVA and refractive and topographic cylinders.
3: Coupling ratio was 0.57 ± 2.65 at 3 months.
produced a reduction of $3.6 \pm 1.9 \text{ D}$ and the $120^\circ$ cut angle a reduction of $2.5 \pm 2.3 \text{ D}$ in refractive cylinder ($P = .425$ for comparison between cut angles). Topographic anterior cylinder reduced by $5.2 \pm 4.8 \text{ D}$ with $90^\circ$ and by $4.9 \pm 5.0 \text{ D}$ with the $120^\circ$ cut angle ($P = .711$).

No correlation was found between the anterior diameter of incisions and change in topographic cylinder ($r = .001$).

One patient developed a bulge in the temporal incision 2 weeks after the operation and was treated using compression sutures. After suture removal and stabilization, the final topographic anterior cylinder was $3.8 \text{ D}$ compared to $18.1 \text{ D}$ before laser and CDVA was 0.3 (Snellen 20/40) compared to 0.7 before laser. No other adverse effects were recorded.

In two eyes, topographic anterior cylinder improvement was less than 1 D and was considered undercorrected. Overcorrection, defined as topographic cylinder axis change over $45^\circ$, presented in three eyes. In these three eyes, refractive and topographic anterior cylinders changed from $6.0 \pm 2.0 \text{ D}$ to $4.0 \pm 1.3 \text{ D}$ and from $8.4 \pm 4.6 \text{ D}$ to $4.6 \pm 2.6 \text{ D}$, respectively ($P > .05$).

**DISCUSSION**

Significant improvements were found in all main parameters after femtosecond laser-assisted arcuate keratotomy: CDVA, refractive cylinder, and topographic cylinder. Because both anterior and posterior topographic cylinders had a significant reduction in astigmatism, this indicated that the effect of intrastromal

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**TABLE 2**

**Main Outcome Measures Compared to Preoperative Values at 3 Months (N = 16)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Preoperative</th>
<th>3 Months</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDVA (logMAR)</td>
<td>0.50 ± 0.29</td>
<td>0.32 ± 0.23</td>
<td>.016</td>
</tr>
<tr>
<td>CDVA (Snellen)</td>
<td>20/63</td>
<td>20/40</td>
<td></td>
</tr>
<tr>
<td>Refractive cylinder (D)</td>
<td>6.78 ± 2.20</td>
<td>3.67 ± 1.66</td>
<td>.001</td>
</tr>
<tr>
<td>Topographic cylinder (D)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior</td>
<td>9.49 ± 4.78</td>
<td>4.41 ± 2.14</td>
<td>.001</td>
</tr>
<tr>
<td>Posterior</td>
<td>1.38 ± 0.78</td>
<td>0.71 ± 0.64</td>
<td>.002</td>
</tr>
<tr>
<td>Intraocular pressure (mm Hg)</td>
<td>12.4 ± 3.39</td>
<td>13.9 ± 3.45</td>
<td>.076</td>
</tr>
<tr>
<td>Corneal thickness (µm)(^c)</td>
<td>522 ± 75.3</td>
<td>511 ± 65.7</td>
<td>.187</td>
</tr>
<tr>
<td>Spherical equivalent (D)</td>
<td>-3.58 ± 3.75</td>
<td>-4.07 ± 3.78</td>
<td>.605</td>
</tr>
<tr>
<td>Average K (D)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior</td>
<td>47.8 ± 5.44</td>
<td>48.2 ± 4.50</td>
<td>.083</td>
</tr>
<tr>
<td>Posterior</td>
<td>-6.87 ± 0.45</td>
<td>-6.83 ± 0.42</td>
<td>.458</td>
</tr>
</tbody>
</table>

CDVA = corrected distance visual acuity; D = diopters; K = keratometry
\(^c\)Mean ± standard deviation.
\(^{P} > .05\) was significant, Wilcoxon signed-rank test.
\(^\text{Thinnest corneal thickness value from optical coherence tomography.}\)
incisions extended throughout the whole cornea. Similarly, the coupling ratio was close to one indicating both flattening of the steep meridian and steepening of the flat meridian, with steepening being only slightly greater than flattening. The correlations between preoperative values and change after the operation suggested that intrastromal relaxing incisions were also effective when treating high astigmatism.

Comparing the effect of intrastromal relaxing incisions to epithelium breaking methods, the decrease in refractive cylinder seemed to be similar. Using femtosecond laser-assisted epithelium breaking techniques, the reduction was 40% to 66% in refractive cylinder\cite{15,17} and 36% to 40% in keratometric cylinder.\cite{15,20} Using non-laser mechanical techniques, the reduction was 30% to 54% in refractive cylinder\cite{4,10-12,15} and 35% in keratometric cylinder.\cite{15}
Topographic cylinder seemed to stabilize roughly 1 month postoperatively. On the other hand, CDVA and refractive cylinder slightly improved toward the 3-month follow-up. This may indicate that although the cornea was stabilized, some adaptive processes may have taken place, causing change in refraction values.

Two different anterior side cut angles and three different anterior diameters of incisions were evaluated. Anterior side cut angles 90° and 120° produced statistically similar changes in all key parameters. Neither 90° nor 120° cut angles created different outcomes with regard to undercorrection or overcorrection. The absence of correlation between diameter of incisions and topographic cylinder change suggested that all incisions close to the graft–host wound would release astigmatism-inducing forces.

In October 2011, we received a letter of caution from the IntraLase Corporation concerning a possible risk of perforation when performing non-penetrating deeper corneal incisions and recommendations to program at least 125 μm of intact posterior cornea. This study was done by setting the posterior depth to 90% of measured corneal thickness. Further studies may enlighten the effect of these new guidelines.

The theoretical advantage of intrastromal relaxing incisions for treating astigmatism is its relative simplicity, less risk of postoperative infections, and reduced discomfort to the patient. In this patient material, no infections were recorded and patients did not report pain or unpleasant effects due to incisions. However, it is not possible to differentiate between intrastromal incisions and epithelium-penetrating femtosecond laser incisions or manual arcuate keratotomy based on this population, because the other methods also have a low rate of complications.

Intrastromal relaxing incisions seem to be a good alternative to more penetrating methods of treating postoperative keratoplastic astigmatism. Based on this study, the effect was good and the rate of adverse effects or complications was low.

**AUTHOR CONTRIBUTIONS**

Study concept and design (OW, KK); data collection (OW, KK); analysis and interpretation of data (OW, JMH, KK); drafting of the manuscript (OW, KK); critical revision of the manuscript (JMH, KK); statistical expertise (JMH); obtained funding (KK); administrative, technical, or material support (KK); supervision (KK)

**REFERENCES**