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Original article

Femtosecond astigmatic keratotomy for postkeratoplasty astigmatism

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Abstract

Purpose: To evaluate the initial outcomes of femtosecond laser arcuate keratotomies (AK) to correct high astigmatism after keratoplasty.
Methods: This retrospective non-comparative interventional study included 52 consecutive patients (52 eyes) who underwent Intralase-enabled arcuate keratotomies. Changes in uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BCVA), mean refractive and keratometric astigmatism, preoperative and postoperative manifest refraction and complications were the main outcome measures.
Results: The mean follow-up period was 13.77 ± 4.17 months. Mean BCVA and UCVA improved statistically significantly from 0.30 ± 0.18 LogMAR and 0.90 ± 0.43 LogMAR preoperatively to 0.20 ± 0.14 and 0.60 ± 0.39 postoperatively respectively ($P < 0.05$, all comparisons). Mean subjective cylinder decreased statistically significantly from 7.15 ± 1.32 D preoperatively to 5.19 ± 2.25 D at the last postoperative visit ($P = 0.0002$). Two eyes (4%) lost one line or more of BCVA. Three patients (5.8%) had corneal perforation and only one eye required resuturing of the AK wound. Twelve patients (23%) were overcorrected.
Conclusions: AK performed with the femtosecond laser was relatively easy to perform, safe, and effective for treating post-keratoplasty astigmatism. There was a significant improvement in UCVA and BCVA with a very low rate of complications. A larger series is required to refine the nomogram to achieve a greater reduction in cylinder.

Keywords: Astigmatic keratotomy, Astigmatism, Femtosecond

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Introduction

High astigmatism after penetrating keratoplasty can limit visual rehabilitation. Numerous surgical procedures have been used to treat astigmatism including, relaxing procedures, wedge resections, and photorefractive procedures.[1–9] The most commonly used method for reducing post-keratoplasty astigmatism is arcuate keratotomy (AK).[10–16] However, manual AK is often associated with unpredictable outcomes and complications including epithelial ingrowth, infection, scarring, and, rarely, corneal perforation.[17,18]

Recently astigmatic keratotomies have been created with a femtosecond laser.[19–23] The major advantages of the femtosecond laser include greater reproducibility and accuracy of the depth of the incision.[23] The purpose of this study was to report our initial experience with the use of femtosecond laser AK for post-keratoplasty astigmatism.

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Materials and methods

Study design

This study was approved by the King Khaled Eye Specialist Hospital review board. A chart review was performed for patients who underwent femtosecond laser astigmatic keratotomy (FSAK) between January 2010 and December 2012. Data were collected on 52 eyes of 52 consecutive patients (34 males, 18 females) with mean age 31.9 ± 8.88 years (range, 17–66 years). Patients with irregular astigmatism were excluded.

The minimum follow-up period for the patients included in this study was 24 weeks. All the AK procedures were performed on the donor side of the cornea. In all patients, the graft sutures had been removed at least 12 weeks prior to AK.

Outcome measures included uncorrected Snellen visual acuity (UCVA), best corrected Snellen visual acuity (BCVA), manifest and cycloplegic (if available) refractions, corneal topography (Orbscan 2; Bausch and Lomb Inc., Rochester, NY, USA) to assess the amount and axis of the corneal cylinder. Postoperative visits were performed at 1 day, 2–3 weeks, 3 months, 6 months, and 12 months. At each visit pre- and post-operatively, slit-lamp examination and tonometry were performed and outcome measures were recorded. For outcome measurement analysis, both interval and last visit data were used. The efficacy index was calculated as the ratio of the mean postoperative UCVA to the mean preoperative BCVA. The safety index was calculated as the ratio of mean postoperative BCVA to the mean preoperative BCVA.

Surgical technique

Two drops of topical anesthetic proparacaine hydrochloride 0.5% (ALCAINE) were instilled in the eye. The eyelids were cleansed with Betadine sponges. The graft–host junction was marked in the steep and flat axis with a sterile marking pen (Surgical Markers from Accu-line Products Inc., Hyannis, MA, USA). Marking allowed better centration of the graft incisions. Corneal thickness at the incision wound was measured with ultrasonic pachymetry (Corneo-Gage; Sonogage Inc., Cleveland, Ohio, USA). The size of the optical zone was calculated based on the original graft size. Each incision was made 0.5–0.7 mm within the graft–host junction, such that the diameter was set at 1–1.4 mm less than the graft diameter measured by calipers at the time of surgery. Using the keratoplasty software, 2 anterior arcuate incisions were created at 75–85% depth of the thinnest measurement of the graft at the desired optical zone with the femtosecond laser (60 kHz IntraLase. AMO Inc., Chicago, Ill., USA). If the axis of the manifest refraction and the topography differed, we used the topographic axis. The amount of topographic cylinder rather than the manifest cylinder was used to determine the length (degrees) of the keratotomy. The Nordan nomogram was used by most surgeons to create paired symmetric (same length) incisions centered on the steep axis as follows: 1.75–2.5 diopters (D) of cylinder with 50° arc length, 2.75–3.3 D of cylinder with 57° arc length, 3.75–4.5 D of cylinder with 60° arc length, and more than 5 D of astigmatism with 70° arc length.

The laser settings were anterior side-cut energy 2.20 microjoules, anterior side-cut spot separation was set at 3 and anterior side-cut layer separation was set at 3. The IntraLase limbal suction ring was then applied, and the cone was positioned. Applanation was judged as adequate if the fluid meniscus was at least beyond the graft–host junction. There were no suction breaks during treatment in any case. Once complete, suction was released, and the ring was removed. Both incisions were opened with a Sinskey hook immediately after creation and the effect of the incisions was checked with a Placido disc (Maloney handheld keratometer) during surgery. After surgery, antibiotic and steroid eye drops were prescribed four times daily for 4 weeks. The patients were instructed to avoid rubbing their eyes and to use preservative-free artificial tears frequently.

Statistical analysis

The Wilcoxon rank sum test was used to assess the difference between preoperative and postoperative values. Statistical analysis was performed with the Statistical Package for the Social Sciences 20.0 for Windows (IBM Corp., New York, NY, USA). Data were expressed as mean ± standard deviation, and a P value less than 0.05 was considered statistically significant.

Results

Preoperative data and clinical characteristics are presented in Table 1. Fifty-two eyes of 52 patients (34 males and 18 Females) were included in this study. Indications for keratoplasty in this study were keratoconus, corneal scar

Table 1. Demographic and preoperative data for patients who underwent femtosecond laser arcuate keratotomies after keratoplasty.

Variable	
Eye (n)	
Right	21 (40.4%)
Left	31 (59.6%)
Total	52 (100%)
Age at surgery (y)	
Range	17–66
Mean ± SD	31.9 ± 8.88
Median	32
Gender (n)	
Male	34 (65.4%)
Female	18 (34.6%)
Preoperative UCVA	
⩾20/40	2 (3.84%)
⩾20/100	17 (32.69%)
⩾20/400	43 (82.69%)
Preoperative BCVA	
⩾20/20	3 (5.79%)
⩾20/40	36 (69.23%)
⩾20/125	52 (100%)
Follow-up (months)	
Range	6–22
Mean ± SD	13.77 ± 4.17
Type of graft	
PKP	36 (69.2%)
LKP	14 (26.90%)
Unknown	2 (3.80%)

UCVA = uncorrected visual acuity. BCVA = best corrected visual acuity. PKP = penetrating keratoplasty. LKP = lamellar keratoplasty.

and pseudophakic bullous keratopathy. The mean follow-up was 13.77 ± 4.17 months (range, 6–22 months). The mean incision length was 58° (range 45–90°).

Refractive outcome

There was a statistically significant increase in mean UCVA from 20/160 preoperatively to 20/80 postoperatively ($P = 0.001$). There was a statistically significant increase in mean BCVA from 20/40 preoperatively to 20/30 postoperatively ($P = 0.014$) (Table 2). The mean spherical equivalent was −3.76 ± 4.65 D preoperatively and −3.99 ± 4.44 D at the last postoperative visit ($P = 0.732$) (Table 3).

There was a statistically significant decrease in mean refractive astigmatism from 7.15 ± 1.32 D (range, 5.00–10.0 D), to 4.53 ± 2.19 D (range 1.00–8.75 D) 1 month postoperatively ($P = 0.004$). The refractive astigmatism remained stable up to the last postoperative visit ($P > 0.05$ at each postoperative interval) Fig. 1. This represents an empirical reduction in the mean cylinder of 2 D (28%).

There was a statistically significant change in mean keratometric cylinder of −2.38 ± 3.71 D ($P = 0.002$). At the last postoperative visit, 75.5% of eyes gained 1 or more lines of UCVA (23.8% gained 2 lines or more) and UCVA remained stable in 11.5% of eyes and 13% lost 1 or more lines of UCVA (Fig. 2).

At the last postoperative visit, 61.5% of eyes gained 1 or more lines of BCVA (17.3% gained 2 lines or more), and BCVA remained stable in 34.5% of eyes and 4% eyes lost 1 or more lines of BCVA (Fig. 3).

Preoperative best spectacle-corrected acuity versus postoperative uncorrected visual acuity:

The last postoperative UCVA was compared to preoperative BSCVA. Comparing the proportion of eyes with 20/20 or better acuity, only 5.76% of eyes had this level of BSCVA preoperatively, compared to 2% of eyes with this level of UCVA at the last postoperative visit. Similarly, at the last postoperative visit 13.46% of eyes had 20/40 or better UCVA, compared with 65.4% of eyes with 20/40 BCVA at baseline (Fig. 4). The efficacy index was 2 and the safety index was 0.66.

Complications

Table 4 presents the postoperative complication rates. Three patients (5.8%) had corneal perforation and only one required resuturing of the AK. The other two cases were self-sealing and anterior chamber depth was maintained yet

Table 2. Visual acuity in patients who underwent femtosecond laser arcuate keratotomies after keratoplasty.

Variable	Visual acuity		*P*-value
UCVA	Snellen	LogMar	0.001
Preoperative (mean)	20/160	0.90 ± 0.43	
Final examination (mean)	20/80	0.60 ± 0.39	
BCVA			0.014
Preoperative examination (mean)	20/40	0.30 ± 0.18	
Final examination (mean)	20/30	0.20 ± 0.14	

UCVA = uncorrected visual acuity. BCVA = best corrected visual acuity. *P* value = statistical significance (Wilcoxon rank-sum test). $P < 0.05$ is statistically significant.

Table 3. Refraction in patients who underwent femtosecond laser arcuate keratotomies after keratoplasty.

Variable		*P*-value
Refractive cylinder (D)		0.0002
Preoperative examination	7.15 ± 1.32	
Final examination	5.19 ± 2.25	
Mean difference	−2.19 ± 2.35	
Keratometric cylinder (D)		0.002
Preoperative examination	6.73 ± 2.49	
Final examination	4.35 ± 3.83	
Mean difference	−2.38 ± 3.71	
Spherical equivalent (D)		0.732
Preoperative examination	−3.76 ± 4.65	
Final examination	−3.99 ± 4.44	
Ocular residual astigmatism		
Mean ± SD (D)	5.40 ± 2.34	
Range (D)	0.50–9.00	

P value = statistical significance (Wilcoxon rank-sum test). $P < 0.05$ is statistically significant. SD = standard deviation.

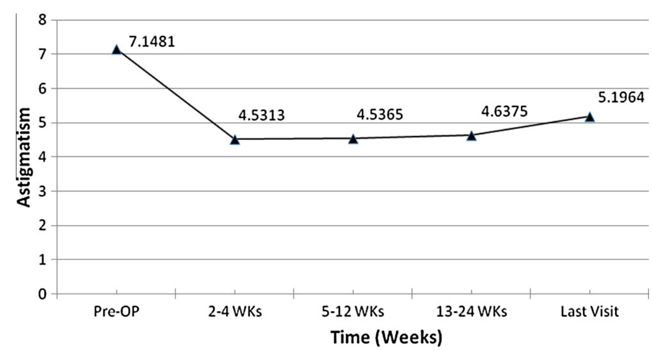

Figure 1. Changes of mean subjective astigmatism (expressed in diopters) at different time points after femtosecond laser (FSL) arcuate keratotomy (AKs).

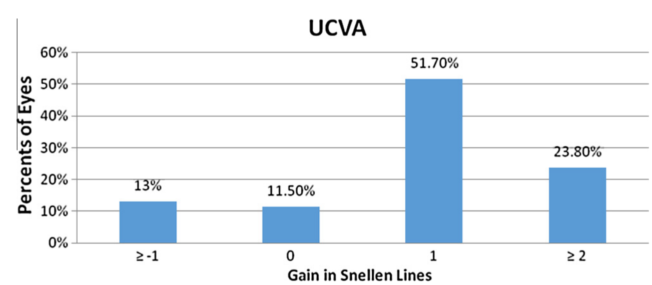

Figure 2. Gain and loss in uncorrected visual acuity after femtosecond laser arcuate keratotomy.

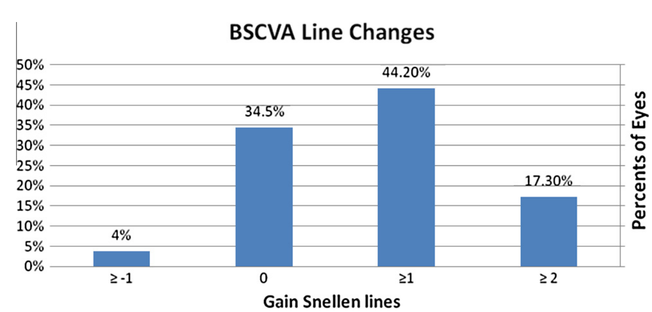

Figure 3. Gain and loss of best corrected visual acuity after femtosecond laser arcuate keratotomy.

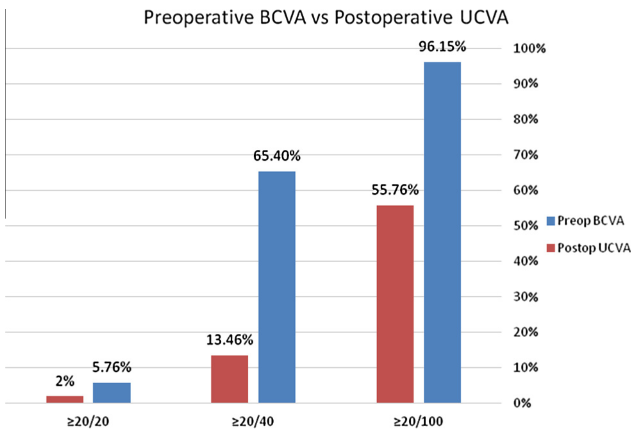

Figure 4. Preoperative best corrected acuity (BCVA) (blue column) versus postoperative uncorrected visual acuity (UCVA) (red column) after femtosecond laser arcuate keratotomy.

Table 4. The complication rates after femtosecond astigmatic keratectomy.

Complications	*N* (%)
Perforation	3 (5.8%)
Overcorrection	12 (23%)
Regression	1 (1.92%)
Infectious keratitis	0 (0.0%)
Rejection episode	0 (0.0%)

they was a slight intraoperative leak but required no specific action other than application of a bandage contact lens. Overcorrection occurred in twelve patients (23%). There were no cases of immunologic rejection or infectious keratitis during the follow-up period. Postoperative healing and clinical outcomes were uneventful in all cases.

Discussion

In the present study, femtosecond technology was used to perform non-mechanized AK to correct post-keratoplasty astigmatism. AK flattens the steepest corneal meridian to treat post-keratoplasty astigmatism that cannot be corrected with spectacles or contact lenses. Femtosecond laser is the most current method to create arcuate AK, and has the ability to create very precise arc, depth and length in the cornea that are difficult to perform with manual AK.[19–24]

Visual acuity

The data in Table 2 illustrate that there was a statistically significant increases in mean UCVA and BCVA postoperatively ($p < 0.05$ both cases). BCVA increased from 0.30 ± 0.18 LogMar preoperatively to 0.20 ± 0.14 LogMar postoperatively. The BCVA increased by 1 or more lines in 61.5% of eyes after femtosecond laser AK while the UCVA increased by 1 or more lines in 75.5% of eyes. Two eyes (4%) lost ⩾1 line of BCVA because of the development of posterior subcapsular cataract during follow-up. These visual results are similar to those published in a recent report in which a femtosecond laser was used to perform AK in patients with high post-keratoplasty astigmatism[22,23] and those described for other AK techniques.[13,14,16,17,22,24–26]

Reduction in mean cylinder

In the present study there was a statistically significant reduction of preoperative refractive cylinder with an average of 2 D (28%) reduction in mean refractive cylinder ($P = 0.004$). The reduction in cylinder correlated strongly with the amount of pre-existing cylinder. Our results are comparable to those achieved with previous AK studies.[19–23]

Hoffart and associates22 found that refractive cylinder decreased by 55.4% in the femtosecond group and by 29.7% in patients who underwent manual AK. Nubile and associates23 also found mean reduction of 4.7 D (66%). The greater effect noted by Nubile and associates23 may be due to the variable length of the relaxing arcuate incisions that was determined by the borders of the steep semi-meridians based on the topographic identification of these semi-meridians regardless of the magnitude of the preoperative astigmatism and also the strict adherence to staying 1.00 mm inside the graft edge and 90% depth of incisions.[23] Bahar and associates21 recently reported a mean cylinder reduction of 4.26 D. Bahar and associates21 based the incision length on the location and extent of the steepest meridian on the topographic map in the first 10 eyes and they found these eyes were overcorrected. In the following 10 eyes, they changed the protocol and treated astigmatism up to 6 D with 60° arc length and 6–10 D astigmatism with 75° arc length and more than 10 D with 90° arc length. 21 Following the topographic map to determine the length of arcuate incision could explain the higher reduction in cylinder femtosecond laser AK compared to our study with mean incision length of 58° based on the magnitude of preoperative astigmatism. In addition, Kumar and associates27 reported a mean reduction of 64% and they determined the length (degree) of arcuate incision based on the topographic map rather than the refractive cylinder.

Residual refractive astigmatism (5.19 ± 2.25 D) found in the present study was higher than reported in other femtosecond AK studies. Hoffart and associates22 evaluated 10 eyes that underwent femtosecond laser AK and reported a mean preoperative and postoperative astigmatism of 8.64 and 3.85 D, respectively. Bahar and associates21 reported the results of 20 eyes with a mean preoperative and postoperative astigmatism of 7.84 and 3.58 D, respectively.

On average, AK had a minimal effect on spherical equivalent refraction.[28] The spherical equivalent change in our study was not statistically significant due to the coupling effect. Studies in both human and cadaver eyes have demonstrated that AK not only flattens the incised meridian but also induces steepening of the opposite meridian 90° away.[29] The ratio of the amount of flattening of the incised meridian to the amount of steepening of the opposite meridian is defined as the coupling ratio.[30] The coupling ratio is useful in planning a refractive procedure because it predicts the effect of AK on spherical equivalent refraction. If the coupling ratio is 1, the flattening of the incised meridian will equal the steepening of the opposite meridian, and the spherical equivalent will not change after astigmatic keratotomy. A coupling ratio greater than 1 indicates that the flattening of the incised meridian will be greater than the steepening of the opposite meridian, there will be overall corneal flattening, and the spherical equivalent will shift toward hyperopia. Conversely, a coupling ratio less than 1 means that the steepening of the incised meridian will be greater than the flattening of the opposite meridian and the spherical equivalent will shift toward myopia.

Complications

An important factor in determining the outcomes of an astigmatism correction technique post-keratoplasty is the rate of complications. In our study, three eyes (5.8%) had a perforation. Two of these eyes were self-sealing and did not require the use of sutures to control the leak. The rate of perforation in the present study is well within the range of 0.0–17% reported in previous studies.[21,23,27]

The overcorrection rate (23%) was similar to Bahar and associates21 and Kumar and associates27 who reported rates of 25% and 24%, respectively. The outcomes of AK are influenced by several variables in eyes with astigmatism including the number of incisions, arc length, incision depth, and arc radius.[21,27] In analyzing our overcorrected cases, we noted that the mean arc length was 68° and 6.72 mm mean arc radius with different incision depth. Due to the retrospective nature of this study, with variable parameters between surgeons, we could not use this data to refine our approach. This will be investigated in the future study.

The loss of one line or more of BCVA was noted in two eyes (4%), which was related to steroid induced posterior subcapsular cataract. This loss of BCVA is comparable to other studies, which range from 0.00% to 20%.[21,27] To conclude, we found AK was performed with the femtosecond laser was relatively easy, safe, and effective means of treating post-keratoplasty astigmatism. Our results showed a significant improvement in UCVA and BCVA with a very low rate of complication. A larger series is required to evaluate and refine a nomogram to achieve greater reduction of cylinder.

What was known

Femtosecond may have advantages compared to manual keratotomy for treating astigmatism after keratoplasty.

What this paper adds

Femtosecond astigmatic keratotomy for postkeratoplasty astigmatism resulted in a better visual acuity compared to preoperatively with a very low rate of complications.

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Conflict of interest

The authors declared that there is no conflict of interest.

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