

Original Article

Comparison of manual and femtosecond laser arcuate keratotomy procedures for the correction of post-keratoplasty astigmatism



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Abstract

Purpose: To compare the effectiveness of femtosecond laser (FSL) assisted and manual arcuate keratotomy (AK) procedures for the correction of postkeratoplasty astigmatism.

Methods: Fifty-two eyes (52 patients) were treated with FSL assisted AK and 53 eyes (51 patients) with manual AK for post-keratoplasty astigmatism. The main outcome measures included preoperative and postoperative manifest refraction, uncorrected and corrected distance visual acuity (UDVA, CDVA), corneal topography and complications.

Results: In FSL group, UDVA changed significantly from 0.90 ± 0.43 preoperatively to 0.60 ± 0.39 at last follow-up ($p = 0.001$). In manual group, preop- (0.87 ± 0.35) and post-operative UDVA (0.93 ± 0.42) were comparable ($p = 0.535$). CDVA improved from 0.30 ± 0.18 preoperatively to 0.20 ± 0.14 at last follow-up visit in FSL group (0.014) and 0.28 ± 0.15 preoperative to 0.23 ± 0.19 at last postoperative visit (0.074) in manual group. Postoperative UDVA and CDVA were comparable between both the groups ($p > 0.05$). The mean preoperative refractive cylinder was 6.38 ± 3.73 and 7.15 ± 1.32 , decreasing significantly to 5.06 ± 2.06 and 5.19 ± 2.25 after manual and FSL assisted AK procedures respectively. Mean change in the refractive cylinder was -1.10 ± 4.11 in manual AK group and -2.19 ± 2.35 in FSL group ($p = 0.134$). Perforation, overcorrection and regression occurred in respectively 3 eyes (5.8%), 12 eyes (23.07%) and 1 eye (1.92%) in FSL group and 1 eye (1.9%; macro-perforation), 7 eyes (13.21%) and 8 eyes (15.09%) in manual group. Additionally, in the manual group, severe ectasia occurred in 1 eye (1.9%).

Conclusion: FSL assisted AK procedure is comparable or to a certain extent better regarding safety and efficacy than manual AK procedure. Postoperatively, FSL resulted in better outcomes of UCVA, BCVA, refractive cylinder and keratometric astigmatism compared to the manual AK procedures; although, the difference between the groups was not statistically significant.

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Introduction

Penetrating (PKP) and lamellar (LKP) keratoplasty procedures remain the mainstay for the treatment of advanced cor-

neal diseases. Improvements in surgical technique and postoperative management have reduced the rate of complications and graft failures. However, the persistence of high astigmatism is a significant limiting factor in visual recovery

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and patient satisfaction following keratoplasty.^{1–4} Mild astigmatism successfully treated with spectacles or contact lenses, but the surgical correction required in cases with excessive astigmatism. Previously, surgical procedures to address this problem were limited to continuous suture adjustment and selective suture removal, relaxing incisions with or without compression sutures,⁵ manual astigmatic keratotomy⁶ and wedge resection.⁷ Suture manipulation can be helpful only in early postoperative period^{3,8} and most of the incisional keratotomy procedures are associated with unpredictable outcomes.^{1,9} In the past several years, excimer laser photoablation techniques have been reported to provide stable and predictable results after PKP^{10,11}; however, their efficacy to reduce higher degrees of astigmatism is limited.^{12,13}

Arcuate keratotomy (AK) is a well established surgical procedure for minimizing excessive post-keratoplasty astigmatism.^{4,14,15} Incisions are performed by freehand technique,^{2,14} but mechanized devices such as Hanna arcitome could also be used¹⁵. However, manual AK often associated with poor predictability and reliability and complications including wound gape, perforation, infection and irregular astigmatism.^{1,4,15,16} The advent of the femtosecond laser in the field of corneal microsurgery has improved the safety, predictability and reproducibility of AK procedures. Recently, several authors have reported encouraging outcomes with the use of femtosecond laser technology to create arcuate keratotomy incisions for the management of high post-keratoplasty astigmatism.^{3,8,17}

The purpose of this study is to compare the outcomes of femtosecond laser-assisted and manual AK procedures for post-keratoplasty astigmatism.

Patients and methods

The consecutive medical charts of the patients with high post-keratoplasty astigmatism who underwent manual AK procedures from January 2005 to December 2012 and femtosecond laser-assisted AK procedures from February 2010 to May 2012 were retrospectively analyzed. All surgeries had been performed at King Khaled Eye Specialist Hospital, Riyadh, Saudi Arabia by experienced surgeons. The study protocol was approved by the King Khaled Eye Specialist Hospital Review Board committee. Informed consent for the surgery obtained from all patients after explaining the pros and cons of the surgical procedure.

The underlying conditions leading to PKP or LKP included keratoconus, post LASIK ectasia, pseudophakic bullous keratopathy and microbial keratitis scar. Eyes with stable refractive error were included in this study. The minimum follow up period for the patients included in this study was 6 months. In all eyes, the graft sutures had been removed at least 12 weeks prior to performing AK procedures.

Manual AK surgical procedure

Arcuate keratomies were created using diamond micrometer blade (diamond A/K knife, Katena). In each case, paired arcuate incisions were placed at the steep corneal meridian. The arc length of paired incisions was planned on the basis of surgeons' experience. The lengths of arcuate incisions ranged from 30° to 120° and the incisions were centered at 0.5–1.0 mm within the graft-host junction such that the diameter was set at 1–2 mm

less than the graft diameter measured by calipers at the time of surgery. Incisions were created at 80–90% depth of the thinnest measurement of the graft at the desired optical zone. After administering topical anesthesia (Proparacaine hydrochloride 0.5%; Alcaine; Alcon Laboratories, Fort Worth, TX), the center of the pupil was marked with a sterile marking pen (Surgical Markers from Accu-line Products Inc., Hyannis, MA, USA). The positioning of the keratomies was guided by pre-operative refraction and topography. Pachymetry was performed at the area of the planned incision with ultrasonic pachymeter (Corneo-Gage Plus; Sonogage Inc., Cleveland, OH). The diamond blade calibrated to the desired depth (80–90%) at the thinnest measurement of the graft. Both incisions were made as a single forward sweep with no suction and later irrigated with a balanced salt solution. The effect of the surgery was confirmed using keratoscopy and if needed, the incision length was altered. The wounds were checked and a drop of maxitrol (Alcon Laboratories, Fort Worth, TX) was instilled.

Femtosecond laser enabled AK surgical procedure

Surgeries were performed using 60 kHz IntraLase (IntraLase; AMO Inc., Chicago, IL) under topical anesthesia (proparacaine hydrochloride 0.5%). The eyelids were prepared using Betadine sponges. The graft-host junction was marked in the steep and flat axis with a sterile marking pen; this marking allowed better centration of the graft incisions. The Corneal thickness at the incision wound was measured with ultrasonic pachymetry (Corneo-Gage; Sonogage Inc., Cleveland, Ohio, USA).

The laser's limbal suction ring then was applied and the docking cone was positioned. The adequacy of applanation was judged if the fluid meniscus was at least beyond the graft-host junction.

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.

The topographic cylinder rather than the manifest cylinder was used to determine the length and axis of the arcuate incisions. 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. 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. The anterior side-cut energy of the femtosecond laser was set at 2.2 mJ, anterior side-cut spot separation was set at 3 and anterior side-cut layer separation was set at 3. Once complete, suction was then released and the ring was removed. Both incisions were opened with a Sinsky hook immediately. The effect of the incisions was checked with a Placido disc (Maloney hand-held keratometer; Storz Ophthalmics Inc., St Louis, MO) during surgery.

Post-operative medications

After surgery, antibiotic Ofloxacin 0.3% eye drops (Ocuflox; Allergan Pharmaceuticals, Irvine, CA) were prescribed

4 times a day for 1 week. Patients have prescribed steroid eye drops of prednisolone acetate 1% (Pred Forte; Allergan Pharmaceuticals, Irvine, CA) with different regimens, either with the tapering of the dose (QID, TID, BID and QD) each week or 4 times daily for a period of 1–2 weeks. The patients were instructed to use preservative-free artificial tears (Tears Naturale Free; Alcon Laboratories, Fort Worth, TX) frequently.

Pre and post-operative examination variables included, manifest sphere, cylinder, axis, and manifest refraction spherical equivalent (MRSE), uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), and keratometry. UDVA and CDVA were tested using Snellens' visual acuity (VA) chart under standard lighting conditions. Corneal topography was recorded with the help of Orbscan 2 (Bausch and Lomb Inc., Rochester, NY).

Statistical analysis

Statistical analysis of the data was carried out with SPSS software (version 17.0; SPSS Inc., Chicago, IL). The Shapiro Wilk test and Q-Q plots were used to check the normality of the data. Paired t-test was used to evaluate the difference between pre- and postoperative values within the same group for normally distributed data; otherwise, corresponding nonparametric test (i.e., Wilcoxon rank sum test) was used. The independent t-test was used to compare the outcomes between the two groups. If the data was not normally distributed, the corresponding nonparametric test (i.e., Mann–Whitney U-test) was used. The differences were considered statistically significant when the p-value was ≤ 0.05 . Surgically induced change in astigmatism was compared both as a scalar value, by comparing the changes in absolute cylinder value, and as vectors by calculating the computing the preoperative and postoperative cardinal and orthogonal components, using Alpins method.

Results

The preoperative patient demographic information for both manual and femtosecond laser-assisted AK groups are summarized in Table 1. Both groups were comparable concerning preoperative mean visual acuity (CDVA and UDVA), refractive cylinder and keratometric cylinder ($p > 0.05$). Pre-

Table 2. Comparison of Femtosecond laser and manual arcuate keratotomy for post-keratoplasty astigmatism correction.

Parameters	FSL AK group Mean \pm SD	Manual AK Group Mean \pm SD	P values [#]
UDVA			
Preoperative	0.90 \pm 0.43	0.87 \pm 0.35	0.20
Postoperative	0.60 \pm 0.39	0.93 \pm 0.42	0.19
P values [*]	0.001	0.535	
CDVA			
Preoperative	0.30 \pm 0.18	0.28 \pm 0.15	0.42
Postoperative	0.20 \pm 0.14	0.23 \pm 0.19	0.87
P values [*]	0.014	0.074	
Spherical equivalent			
Preoperative	-3.76 \pm 4.65	-5.24 \pm 3.53	0.043
Postoperative	-3.99 \pm 4.44	-6.42 \pm 3.60	0.014
P values [*]	0.73	0.004	
Refractive cylinder			
Preoperative	7.15 \pm 1.32	6.38 \pm 3.73	0.167
Postoperative	5.19 \pm 2.25	5.06 \pm 2.06	0.799
Mean difference	-2.19 \pm 2.35	-1.10 \pm 4.11	0.134
P values [*]	<0.001	<0.001	
Keratometric astigmatism			
Preoperative	6.73 \pm 2.49	7.32 \pm 2.62	0.125
Postoperative	4.35 \pm 3.83	5.55 \pm 3.83	0.648
Mean difference	-2.38 \pm 3.71	1.92 \pm 4.48	0.875
P values [*]	0.002	0.006	
Surgically induced astigmatism	6.08 \pm 3.76	6.07 \pm 3.83	0.984

UDVA: Uncorrected Distance Visual Acuity, CDVA: Corrected Distance Visual Acuity, ^{*}Paired t-test/Wilcoxon Signed Ranks Test, [#]Independent T-test/Mann-Whitney U Test, FSL: Femtosecond Laser, AK: Arcuate Keratotomy.

operative MRSE was significantly lower in femtosecond laser group ($p = 0.043$) (Table 2).

UDVA and CDVA improved significantly from preoperative to postoperative level in femtosecond laser group (p values; UDVA = 0.001, CDVA = 0.014); however, in the manual group preoperative and postoperative UDVA and CDVA were comparable (p values; UDVA = 0.535, CDVA = 0.074). Mean postoperative UDVA ($p = 0.19$) and CDVA ($p = 0.87$) were comparable between the two groups (Table 2). In the manual AK group, preoperative CDVA of $\geq 20/40$ was observed in 38.9% eyes and the same level of UDVA was exhibited by 2.8% of eyes at the last postoperative visit (Fig. 1). In the femtosecond laser AK group, preoperatively, the CDVA of $\geq 20/40$ was observed in 13.46% eyes. At the last postoperative visit, 65.4% of eyes had UDVA of 20/40

Table 1. Patient demographics of the two groups.

Variables	Manual AK group	FSL AK group	p-value
Total number of patients (eyes)	51(53)	52(52)	
OD (right)	24	21	
OS (left)	29	31	
PKP	43	36	
LKP	10	14	
Unknown	0	2	
Males	41	34	0.087
Females	10	18	
Age (Mean \pm SD) (y)	31.11 \pm 8.88	31.90 \pm 8.88	0.649
Follow up (Mean \pm SD) (mo)	35.98 \pm 29.74	13.77 \pm 4.17	0.000

AK: arcuate keratotomy, FSL: femtosecond Laser, PKP: penetrating keratoplasty; LKP: lamellar keratoplasty, y: years; mo: months.

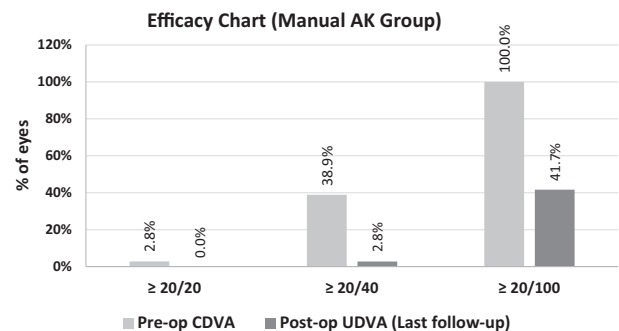


Fig. 1. Preoperative corrected distance visual acuity (CDVA) versus postoperative uncorrected distance visual acuity (UCVA) after manual arcuate keratotomy.

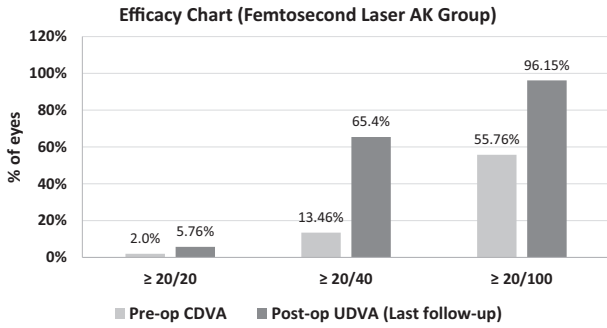


Fig. 2. Preoperative corrected distance visual acuity (CDVA) versus postoperative uncorrected distance visual acuity (UCVA) after femtosecond laser arcuate keratotomy.

or better (Fig. 2). Regarding safety, at the last postoperative visit, 4% and 23.50% eyes lost 1 or more lines of CDVA femtosecond laser and manual group respectively. The gain of 1 or more lines of CDVA was found in 61.50% of eyes in femtosecond laser group (17.30% gained ≥2 lines) and 49.73% eyes in the manual group (27.70% eyes gained 2 lines or more). CDVA remained stable at 34.50% and 37.29% eyes in femtosecond laser and manual groups respectively (Fig. 3). Further, regarding UDVA, in the femtosecond laser group, 13% eyes lost ≥1 line, 75.50% eyes gained ≥1 lines and UDVA remained stable in 11.50% eyes. In manual AK group, 52.80% eyes lost ≥1line, 47.03% eyes gained ≥1 lines and UDVA remained stable in 37.29% eyes (Fig. 4).

The mean MRSE was -3.76 ± 4.65 D preoperatively and -3.99 ± 4.44 D at the last postoperative visit ($P = 0.732$) in the femtosecond-laser group. In the manual group, the preoperative MRSE was -5.24 ± 3.53 D and postoperative MRSE was -6.42 ± 3.60 D ($p = 0.004$). (Table 2).

A statistically significant improvement in refractive astigmatism was observed in both manual and femtosecond laser groups (p values; Femtosecond laser group and manual group: < 0.001). Between the groups comparison of the postoperative refractive cylinder, no statistically significant difference was found ($p = 0.799$) (Table 2). Fig. 5 represents a comparative analysis of femtosecond laser and manual groups' preoperative to postoperative (different time points) transition in the refractive cylinder. Keratometric cylinder also improved significantly from preoperative-to-postoperative level in both groups (p values; Femtosecond laser group = 0.002, manual group = 0.006). Again, there was no significant difference between both the treatment groups

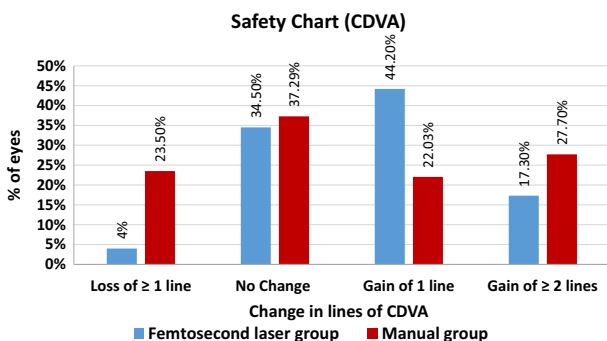


Fig. 3. Gain and loss of corrected distance visual acuity (CDVA) after femtosecond laser (Blue) versus manual (Red) arcuate keratotomy.

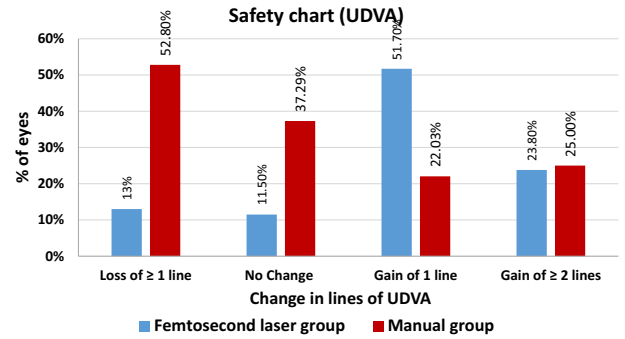


Fig. 4. Gain and loss of uncorrected distance visual acuity (UDVA) after femtosecond laser (Blue) versus manual (Red) arcuate keratotomy.

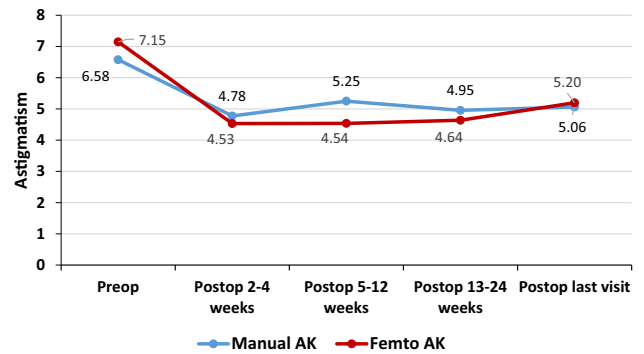


Fig. 5. Preoperative to postoperative (different time points) transition in refractive astigmatism after manual versus femtosecond laser arcuate keratotomy.

for postoperative keratometric cylinder ($P = 0.648$) (Table 2). Mean SIA was also found to be comparable between the two groups (Table 2).

Complications

In the femtosecond laser group, 3 eyes (5.8%) had a perforation. The overcorrection was observed in 12 eyes (23.07%) and regression occurred in 1 eye (1.92%).

In the manual group, there was one case of macroperforation (1.9%), overcorrection occurred in 7 eyes (13.21%) and regression occurred in 8 eyes (15.09%). In one eye (1.9%), severe ectasia was observed.

Other complications such as Infectious keratitis, endophthalmitis and rejection episode were not observed in any eye in both femtosecond laser and manual AK groups.

Discussion

Arcuate keratotomy is a frequently performed procedure to correct high residual astigmatism after keratoplasty. The use of femtosecond laser for AK is gaining popularity because it offers several potential advantages over manual incision including increased precision, fully customizable and reproducible incision parameters, as well as increased efficacy and safety.^{3,9} While several studies have reported favorable outcomes of this procedure in the management of high post-PKP astigmatism,^{3,8,9,18-20} there is a lack of literature regarding the comparison of manual and laser-assisted

arcuate keratotomy procedures in post-keratoplasty eyes. To the best of our knowledge, two such comparative studies by Bahar et al.²¹ and Hoffart et al.²² have been published until now. While Bahar et al.²¹ have reported comparable outcomes of 10 eyes in each group, Hoffart et al.²² have reported the outcomes of 20 eyes in each group.

In the current study, we have included a relatively higher number of eyes: 52 in femtosecond laser group and 53 eyes in manual groups. The outcomes of femtosecond laser and manual AK procedures were found to be statistically comparable in the current study; however, there is a trend towards better outcomes in the femtosecond laser group. The average reduction in the refractive cylinder was 2.19 ± 2.35 D (29%) in the femtosecond laser group and 1.10 ± 4.11 D (25%) manual group. Previous non-comparative studies in post-keratoplasty eyes have reported the range of refractive astigmatism reduction after AK as 2.8–5.7 D^{14–16} and 3.1–6.0 D^{1,3,17,23,24} in manual and femtosecond laser respectively. In a comparative study carried out by Bahar et al.,²¹ the mean reduction in the refractive cylinder was found to be 4.26 D after femtosecond laser and 3.23 D after manual AK procedures. One more study carried out by Hoffart et al.²² reported 4.79 D and 2.00 D of reduction in the refractive cylinder after femtosecond laser and manual AK procedures respectively. Apparently, similar to these studies, in the current study also, the postoperative refractive astigmatism outcomes were better in the femtosecond laser group compared to the manual group.

The outcomes of AK are influenced by several variables such as the number of incisions, arc length, incision depth, and arc radius.²¹ The incision dimensions in the current study differ from those reported previously in similar comparative studies.^{21,22} Paired AK were performed in the current study with arc lengths ranging between 40 and 120 degrees in femtosecond group and 30–120 degrees in manual group. On the contrary, Bahar et al.²¹ performed arcuate keratotomies with a maximum of 90-degree arc length in both manual and Femto assisted procedures. In the current study, the incision depth was 75–85% in the femtosecond laser AK group and 65–90% in the manual group. The corresponding values reported by Bahar et al. are 90% in Femtosecond laser group and 500 μ m in the manual group. Additionally, in the current study, the arc length was determined on the basis of the topographic cylinder in both femtosecond laser and manual groups. In contrast, Hoffart et al.²² planned the arcuate keratotomies on the basis of refractive data instead of topography data in both manual and Femtosecond laser groups. Collectively, the variability in the factors mentioned above may be the reason for the difference in refractive astigmatism outcomes found in the current study and the previous literature.

A trend of better visual outcomes has been observed in femtosecond laser-assisted AK eyes compared to manual AK (Table 1). However, the difference was not statistically significant. Two previously published comparative studies have also reported a similar trend showing comparable visual acuity outcomes between manual and femtosecond laser AK groups.^{21,22} Additionally, in femtosecond laser group, statistically significant improvement in both UDVA and CDVA was observed at last follow-up as compared to the preoperative level; however, in the manual group no significant differences were obtained. Our result for both groups was comparable to the previously reported publications.^{21,22} In femtosecond

laser AK group, 13% eyes lost ≥ 1 line compared to 52.80% eyes in the manual group. The gain of ≥ 1 lines of UDVA was observed in 75.50% eyes after femtosecond laser-assisted AK procedure compared to 47.03% in the manual AK group (Fig. 4). Further, improvement of one or more CDVA lines was observed in 61.50% eyes in femtosecond laser AK group and 49.73% of the eyes in the manual group (Fig. 3). Loss of one or more CDVA lines was observed in only 4% of the eyes in femtosecond laser-assisted AK group as compared to the 23.50% eyes in manual group. Thus overall, the outcomes of visual acuity were better in the femtosecond laser group.

Regarding the complication rate, one eye (1.92%) in the manual group and 3 eyes (5.8%) in the femtosecond laser group had a corneal perforation. Two of these eyes were self-sealing and the suturing was not required to control the leak. The micro-perforation rates found in the current study are well within the literature-reported range of 3.2–33.3%^{17,19} after laser-assisted AK and 0–15%^{2,4,14–16,21,22,25} after manual AK.

In the current study, the overcorrection rate was found to be higher after Femtosecond laser AK. On the other hand, after manual AK, regression rate was found to be higher. However, the overcorrection rate (23%) found in the current study after femtosecond assisted AK is consistent with previously reported rates of 24% and 25% by Kumar et al.⁸ and Bahar et al.²¹ respectively. In the manual group, overcorrection occurred in 13.21% eyes. In the literature, massive overcorrection has been reported in one case (1/11eyes; 9.09%) after manual AK procedure.¹⁴ The regression rate in the current study has been found to be 1.92% and 15.09% eyes in femtosecond laser and manual AK groups respectively. These results are also consistent with a previous publication which has reported a regression in 1 out of 6 eyes (16.67%) after beveled femtosecond laser-assisted AK for post PKP astigmatism correction.¹ Additionally, one eye developed severe ectasia in manual AK group. Overall, the femtosecond laser-assisted AK procedures seemed to be safer and more predictable than manual AK procedures.

Femtosecond-laser assisted arcuate keratotomy exhibited either comparable or better refractive and keratometric results with lower complication rate than manual arcuate keratotomy; although, the difference between the groups was not statistically significant. Being safer and more effective than manual arcuate keratotomy, femtosecond-laser assisted arcuate keratotomy seems to be a good alternative than the manual method in treating post-keratoplasty astigmatism.

Conflict of interest

The authors declared that there is no conflict of interest.

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