Original Article

Correction of preexisting astigmatism by penetrating arcuate keratotomy in femtosecond laser-assisted cataract surgery

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Purpose: To evaluate the astigmatism correcting effect of penetrating arcuate keratotomy (AK) done during femtosecond laser-assisted cataract surgery (FLACS). **Methods:** In this nonrandomized prospective study, 80 eyes of 70 patients were studied. The study included patients who underwent combined FLACS and AK, with corneal astigmatism ranging from 0.4 to 1.5 diopters (D). Femtosecond laser-assisted penetrating arcuate keratotomies were created at 8 mm optical zone at 80% depth and were centered at the limbus. Keratometric astigmatism was measured prior to and 3 months post-surgery. Vector analysis was performed using Power vector analysis method. **Results:** The mean preoperative keratometric astigmatism without accounting for axis was 0.85 ± 0.27 D, which reduced significantly to 0.47 ± 0.27 D at 3-month follow-up. The mean astigmatism correction attained without accounting for axis was 0.38 ± 0.32 D. The vector corrected mean preoperative astigmatism was 0.85 ± 0.27 D which reduced significantly to 0.50 ± 0.31 D postoperatively ($P < 0.001$, 95% CI). Vector corrected mean astigmatism correction attained was 0.35 ± 0.38 D. There were no significant intraoperative or postoperative complications. **Conclusion:** Preexisting astigmatism can be tackled effectively with penetrating AK during FLACS although under correction is observed with present nomograms. Further refinements may achieve better correction.

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An increasingly important goal of modern cataract surgery is to obtain the most desirable refractive outcomes for patients and decreasing their dependence on spectacles. Control of surgically induced astigmatism and reduction of preexisting astigmatism are now an integral part of cataract surgery. The blur of astigmatism, apart from the visual impairment, may also cause asthenopic symptoms such as headache, tiredness, and difficulty concentrating. A number of studies have evaluated the outcomes of the use of limbal/corneal relaxing incision (LRI/CRI), opposite clear corneal incision (OCCI), intraocular toric lens, and excimer laser for the correction of preexisting astigmatism at the time of cataract surgery.[1-4] There are studies which have evaluated the correction of preexisting astigmatism by penetrating arcuate keratotomy (AK) during FLACS, but none of them is carried out on Indian eyes.[5-11] In our study, we aim to evaluate the efficacy of penetrating AK in correcting preexisting astigmatism on Indian eyes when performed during FLACS.

Methods

This prospective, experimental cohort study was performed after approval from Institutional Ethics Committee in cataract patients having preoperative corneal astigmatism ranging from 0.4 to 1.5 diopters (D), who underwent FLACS between January 2017 and August 2018. Informed consent was obtained from all patients. Patients with irregular astigmatism, lenticular astigmatism, astigmatism without cataract, severe dry eye, keratoconus, active corneal disease, significant corneal pathology, multifocal and toric IOL, previous uveitis, retinal detachment, other preexisting retinal disease, previous refractive surgery, and previous intraocular surgery were excluded from the study. Preoperative uncorrected visual acuity, refraction, best-corrected visual acuity, tonometry, dilated fundoscopy, biomicroscopy, keratometry, and biometry (by Lenstar LS 900®, Haag Streit U.S.A.) were performed in all patients.

Catalys-I® Precision Laser System (Optimedica, Johnson & Johnson vision U.S.A.) femtosecond laser platform was used in our study to perform AK. Settings for main port, side port incision, capsulorrhexis, nuclear fragmentation, and softening were made using the femtosecond laser unit. Anterior penetrating arcuate keratotomies were given at 80% corneal depth with 90° side cut angle. Horizontal and vertical spot spacing were 5 μm and 10 μm, respectively, pulse energy used was 5 μJ. Arc diameter for these arcuate keratotomies was kept 8 mm and they were centered around limbus. Angular arc length of incision and number of incisions were decided according to the magnitude of preoperative keratometric astigmatism by using a nomogram modified from the Donnenfeld Limbal Relaxing Incision Nomogram (reducing arc length by 33%

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and optical zone to 8 mm).[12] Based on this nomogram, limbal relaxing incision (LRI) calculator is available online (on www.lricalculator.com), which calculates angular arc length of incision, number of incisions, and axis of placement of incision after considering both surgically induced astigmatism (SIA) and preexisting keratometric astigmatism. In eyes where arcuate keratotomies coincided with the temporal corneal incision, in them, instead of two arcuate incisions, we gave single arcuate incision of double arc length. For example, if two arcuate incisions of 30° length are required at 180° and 90° with temporal corneal incision at 180°, then instead of two arcuate incisions, we had given only one arcuate incision at 90° of 60° length. Markings were made at limbus with surgical marker in sitting position at 90° and 180° on the slit lamp under topical anesthesia. In supine position (on femtosecond platform), markings of suction cone were aligned with the limbal markings at 90° and 180° during docking. Hence, arcuate incisions were given according to the axis of astigmatism that is obtained during biometry in sitting position. Cone was filled with balanced salt solution (BSS), disposable lens attached and assembled with cone. After docking, anterior segment optical coherence tomography (OCT) was captured, following which laser was applied to create anterior capsulotomy, lens fragmentation, corneal incision, and astigmatic keratotomy; in this sequence. Vacuum was released; the patient was shifted to phacoemulsification operation theater. In all patients, arcuate keratotomies were opened using femtosecond spatula under topical anesthesia with strict aseptic precautions and then phacoemulsification was completed. Patients were followed on day 1, 2-week, and 3-month after the procedure. The effect of FSL-AK was seen to its maximum effect by 1.5 months after the procedure and stabilized by 3 months.[13] There was no statistically significant difference between postoperative corneal astigmatism over 2 years in a study conducted by Chan *et al*.[14] Hence, a 3-month follow-up period was adequate. Postoperative evaluation was done with keratometry (by Lenstar LS 900® Haag Streit U.S.A.) at 2-week and 3-month follow-up. Calculation of SIA for main port incision was done using Doctor Hill`s SIA calculator (available at https://sia-calculator.com) with the data of 20 patients in whom AK was not performed during FLACS. Mean SIA obtained in our study is 0.29 D at 180° in right eye and 0° in left eye.

Vector analysis

Vector analysis was done by using power vector analysis method. We converted the corneal astigmatism from cylindrical notation to power vector notation by applying a Fourier transformation using the following equations[15]:

$J_0 = -C/2 \times \cos 2\alpha$

$J_{45} = -C/2 \times \sin 2\alpha$

Where C is negative cylindrical power and α is cylindrical axis. J_0 refers to cylindrical power set at orthogonally 90° and 180° meridians, representing Cartesian astigmatism. Positive values of J_0 indicate with the rule astigmatism, and negative values of J_0 indicate against the rule astigmatism. J_{45} refers to a cross-cylinder set at 45° and 135°, representing oblique astigmatism.[15] For interpreting astigmatism using power vector values, cylindrical power is defined as two times the square root of sum of J_0^2 and J_{45}^2.[15] Vector corrected astigmatism = $2\sqrt{J_0^2 + J_{45}^2}$.

Calculation of coupling ratio, coupling constant, and total spherical shift

The coupling ratio, coupling constant, and total spherical shift were calculated according to Alpins *et al*., using ASSORT Coupling Calculator (available at: http://www.assort.com). By determining coupling, the spherical effect of astigmatic treatment can be anticipated.[16]

Coupling ratio (CR) = $-\Delta KO/\Delta KT$

Where, ΔKO is the change in corneal power at the opposite meridian and ΔKT is the change in corneal power at the treatment meridian. CR of 1.0 shows that the changes in corneal power at the treatment meridian and the opposite meridian are equal in magnitude (100% coupling) and opposite in sign.[16]

Coupling constant (CC) = ΔK Mean/($\Delta KT - \Delta KO$)

Where, Δ K Mean is the change in the mean corneal power and Δ KT - Δ KO is the difference between the change in corneal power at the treatment meridian and change in corneal power at opposite meridian. The CC of zero means that the treatment of corneal astigmatism has no effect on the spherical equivalent.[16]

Statistical methods

The primary objective of the study is to evaluate astigmatism correcting effect of penetrating arcuate keratotomy given during femtosecond laser-assisted cataract surgery. For the purpose of sample size calculation, we expected the success rate (P) =70%, with precision error of estimation (d) = 0.10, and alpha = 0.05, a sample size of 80 cases is needed.

Formula used:

$$n = \frac{Z^2_{\frac{\alpha}{2}} pq}{d^2}$$

n = 0.000166 (70) (69)/0.01

n = 80

Where

p is the expected success rate

$q = 1 - p$

d is the margin of error

$Z_{\alpha/2}$ is the ordinate of standard normal distribution at α% level of significance.

Statistical analysis was carried out using SPSS version 17.0 software. Categorical variables were presented as frequencies and percentages. Continuous variables were presented as mean ± SD. Paired T-test for statistical analysis was used to determine the association between two continuous variables. Level of statistical significance was set at P value <0.05 at 95% confidence interval (CI). For the purpose of sample size calculation, we expected the success rate (P) = 70%, with precision error of estimation (d) = 0.10, and alpha = 0.05, a sample size of 80 cases was needed.

Results

Mean age of patients studied was 63 ± 9.1 years, 40% females and 60% males. Mean preoperative and postoperative keratometric astigmatism at 3-month without accounting for axis was 0.85 ± 0.27 D and 0.47 ± 0.25 D, respectively, P value < 0.001 at 95% CI. Mean astigmatism correction without accounting for axis was 0.38 ± 0.32 D. Preoperatively, 67.5% patients were having astigmatism between 0.50 and 1.00 D, whereas postoperatively, 68.75% patients were having astigmatism of < 0.50 D [Table 1]. Vector corrected mean preoperative and postoperative astigmatism was 0.85 ± 0.27 D and 0.50 ± 0.31 D, respectively, (P < 0.001, 95% CI). Vector corrected mean astigmatism correction obtained was 0.35 ± 0.38 D [Fig. 1]. Fig. 2 shows the astigmatic component of the power vector, as represented by the 2-dimentionl vector (J_0, J_{45}). Preoperatively, the cluster of points was away from the origin, whereas postoperatively, the cluster of points collapse around the origin, indicating a reduction in astigmatism in the postoperative values. The median coupling ratio was 0.91, indicating that the change in corneal power at the opposite meridian was 91% of the treatment meridian. The mean coupling constant was 0.2, indicating that each diopter change in astigmatism produced a 0.2 D change in spherical equivalent. The median total spherical shift was -0.005 D.

Discussion

The prevalence of astigmatism increases with age. Around 70% of patients undergoing cataract surgery have about 1 D of astigmatism, and 33% of these patients are eligible for the treatment of preexisting astigmatism.[17,18] Astigmatism remains a major hindrance in attaining emmetropia; it can produce glare, monocular diplopia, asthenopia, and visual distortions. Therefore, correction of preexisting astigmatism in patients undergoing cataract surgery is important. Femtosecond laser arcuate keratotomies have many advantages over the manual ones: the corneal incisions are produced with great precision, and these are easy to plan and are rapidly created during femtosecond laser-assisted cataract surgery without adding any further cost to the procedure. Correction of astigmatism may be carried out by penetrating arcuate AK or intrastromal AK. Most studies have shown good correction with penetrating arcuate keratotomy.[5-7] We performed penetrating AK and all keratotomies were opened on table in order to achieve better outcome,[6] while some other authors prefer to open them later.[5,7] AK were placed at 80% corneal depth at the axis determined by the LRI calculator and the mainport at 0° or 180° meridian. The greater the depth of arcuate incisions, more is the astigmatic correcting effect of these incisions. The maximum permissible depth of AK in the femtosecond laser machine used in the study was 80%. Depth of keratotomy used in various studies varied from 80% to 85%.[7,6] Chan *et al*. had taken 450 μm depth in all eyes irrespective of the corneal thickness.[5] Some surgeons choose to create the mainport incision at steep axis,[7,6] whereas some at 180°.[5] The creation of main incision on steep meridian entails difficulty to the surgeon, necessitating a change in position.

SIA was taken into account while calculating the arc length and axis of AK in the study. SIA was not considered in a previous study;[19] hence, astigmatic correction obtained was due to combined effect of both SIA and AK, and actual correction was less than what had been obtained.[19] Vector analysis was done by power vector analysis method, which is entirely based on the mathematical formulas, requiring no specific software. Statistical formulas can be easily applied on the values obtained by power vector analysis. Vector analysis has been done using Alpins method in some studies which require ASSORT software.[5-7,19] A statistically significant reduction was observed in the keratometric astigmatism after femtosecond laser arcuate keratotomy (FSL-AK) in the present study. Mean astigmatism correction achieved was 0.35 ± 0.38 D, whereas Wang *et al*. and Ruckl *et al*. had observed astigmatism correction of 0.72 D and 0.87 D, respectively.[6,10] In some studies, correction achieved was around 0.45 D.[5,8,19] Coupling ratio and coupling constant for penetrating arcuate keratotomy were found to be 0.91 and 0.2, respectively, with a total spherical shift of -0.005 D. According to Alpins *et al*., the coupling ratio and coupling constant for LRI were approximately 1.0 and 0, respectively.[16] CR and CC were found to be 0.56 and -0.01, respectively, in another study for intrastromal arcuate keratotomy with a total spherical shift of 0.00 D.[19]

A possible reason for under correction observed in our study could be the greater reduction in the length of arcuate keratotomy. In our study, AK was given at 8 mm optical zone with 33% reduction in the length of incision from what had been advised by LRI calculator. In a study with AK at 9 mm optical zone, only 18% reduction in length was done.[6] In another study,

Table 1: Preoperative and postoperative keratometric astigmatism by group

Keratometric astigmatism in diopters (D)	≤0.50 D	0.51-1.00 D	>1.00 D
Preoperative	3.75%	67.5%	28.75%
Postoperative	68.75%	26.25%	5%

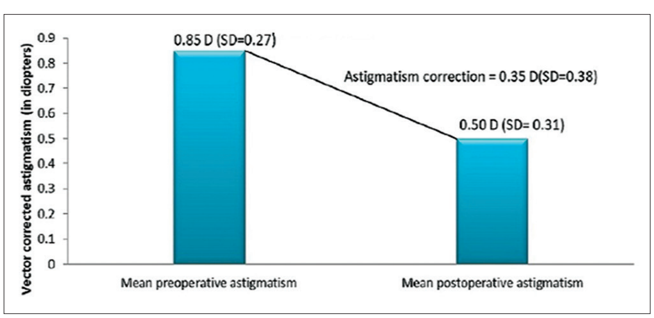

Figure 1: Vector corrected values of mean preoperative astigmatism, mean postoperative astigmatism, and astigmatism correction

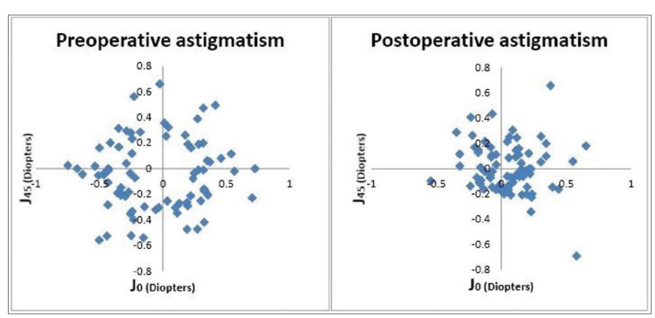

Figure 2: Astigmatic component of the power vector, as represented by the 2-dimentionl vector (J_0, J_{45}). Preoperatively, the cluster of points was away from the origin, whereas postoperatively, the cluster of points collapses around the origin, indicating reduction in astigmatism in the postoperative values

the percentage of length according to Donnenfeld nomogram used was 100% for against the rule (ATR) astigmatism, 70% for with the rule (WTR) astigmatism, and 80% for oblique (OBL) astigmatism.[7] The maximum astigmatic correction was observed in ATR astigmatism group.[7] A known factor for reduced correction is misalignment of axis of placement of arcuate keratotomy. Loss of flattening effect of AK is 1.5% when the incision is misaligned by 5°, 13.4% when 15°, and 50% when 30°. The effect is totally lost when the misalignment is by 45°.[20] Incision location may change due to eyeball rotation in supine position. Preoperative marking reduces the chances of misalignment, but there can be errors due to thick marks, oblique marks, or faint marks. Manual marking errors could be tackled with the use of cataract surgery navigation system, but presently, there is no fool-proof method by which misalignment can be avoided totally. Three months after the procedure, 56.25% of eyes in our study were within 15°, 88.75% were within 30°, and 97.5% of eyes were within 45° of the preoperative meridian of astigmatism. The proportion of eyes achieving within 15° and 45° of the preoperative meridian of astigmatism in a study by Chan *et al*. were 59.3% and 87%, respectively.[5] In another study by Venter *et al*., 50% of the eyes were within 15° and 76% of eyes were within 45° of the preoperative meridian of astigmatism.[21] In one patient, a small corneal perforation occurred while performing FSL-AK which did not result in any sequelae. There were no other intraoperative or postoperative complications encountered in our study.

Conclusion

This study shows the effectiveness of femtosecond laser arcuate keratotomy in reducing preexisting astigmatism in patients undergoing femtosecond laser-assisted cataract surgery. Although the study shows less correction of astigmatism, better nomograms can further improve astigmatic correction.

A limitation of the study was a relatively small number of subjects. The cases selected for the study were only in the range of 0.4 to 1.5 D and did not include cases of astigmatism higher than 1.5 D.

What is already known

FSL-AK is an effective method of reducing preexisting astigmatism in patients undergoing FLACS.

What our study adds

This study adds valuable data on the subject of correction of astigmatism by penetrating femtosecond laser arcuate keratotomy, with currently available nomograms. The study also adds data from the Indian population which has not been studied earlier.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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