Visual and Refractive Outcomes of Femtosecond Laser-Assisted LASIK for Mixed Astigmatism: A Retrospective Study

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Abstract—**Purpose: To evaluate the long-term efficacy, refractive predictability, visual stability, safety, and higher-order aberration (HOA) outcomes of femtosecond laser-assisted in situ keratomileusis (FS-LASIK) for correcting mixed astigmatism over five years.**

Methods: This retrospective longitudinal study included 92 eyes of 63 patients with mixed astigmatism who underwent FS-LASIK between January 2017 and December 2021 at a tertiary refractive surgery center. Patients completed a mean follow-up of 4.96 ± 0.88 years. Clinical evaluations included uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), manifest refraction spherical equivalent (MRSE), keratometric values, corneal pachymetry, and wavefront aberrations. Assessments were performed preoperatively and at 1-, 3-, and 5-year postoperative intervals.

Results:Mean UDVA improved significantly from 0.71 ± 0.29 logMAR preoperatively to 0.02 ± 0.04 logMAR at final follow-up ($p < 0.001$). CDVA improved from 0.09 ± 0.08 to 0.00 ± 0.02 logMAR ($p < 0.001$). Mean spherical and cylindrical refractive errors significantly decreased to +0.14 ± 0.28 D and −0.36 ± 0.29 D, respectively. At five years, 93.5% of eyes achieved UDVA of 20/25 or better, while 91.3% were within ±0.50 D of intended correction. Significant reductions in central HOAs were observed without major complications.

Conclusion: FS-LASIK is a safe and effective long-term treatment for mixed astigmatism, providing excellent visual outcomes, refractive stability, and high predictability over five years. Precise femtosecond flap creation and wavefront-optimized ablation contribute to improved visual quality, reduced higher-order aberrations, and high patient satisfaction.

Index Terms—**FS-LASIK; mixed astigmatism; femtosecond laser; refractive surgery; higher-order aberrations; long-term outcomes, visual acuity**

I. INTRODUCTION

Mixed astigmatism is a complex refractive condition in which one principal meridian exhibits myopia while the perpendicular meridian exhibits hyperopia, resulting in two focal lines positioned anterior and posterior to the retina [1]. This configuration leads to significant visual distortion, asthenopia, headaches, and reduced quality of life, often prompting patients to seek permanent surgical correction for spectacle independence [10].

Laser-assisted in situ keratomileusis (LASIK) has revolutionized refractive surgery since its introduction, offering rapid visual recovery and high predictability [1]. The advent of femtosecond laser-assisted LASIK (FS-LASIK) has further improved outcomes by providing superior flap precision, smoother stromal beds, reduced biomechanical impact, and lower complication rates compared to mechanical microkeratomes [7].

Technological advancements, including wavefront-optimized and wavefront-guided ablation, iris registration, and cyclotorsion compensation, have markedly enhanced the accuracy of astigmatic correction, particularly in complex cases such as mixed astigmatism [13, 19]. Although favorable outcomes have been reported for myopic and

hyperopic astigmatism [6, 8, 11], long-term data exceeding three years specifically addressing mixed astigmatism remain limited [11, 19].

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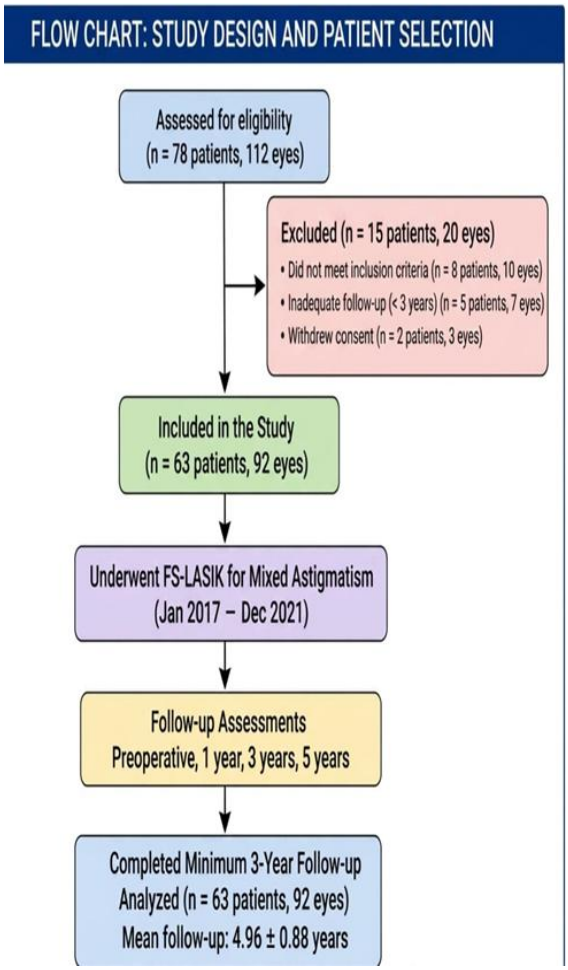


The present study aims to provide a comprehensive evaluation of five-year visual and refractive outcomes following FS-LASIK in 92 eyes with mixed astigmatism, with particular emphasis on efficacy, predictability, stability, safety, and changes in higher-order aberrations.

II. MATERIALS AND METHODS

Study Design This retrospective longitudinal observational study was conducted at the high-volume Chaudhary Eye Centre, New Delhi. The study protocol received approval from the Institutional Ethics Committee and was carried out in accordance with the principles outlined in the Declaration of Helsinki.

Patient Selection Inclusion criteria were: age ≥18 years, stable refraction (change ≤0.50 D) for at least one-year, mixed astigmatism with cylinder power ranging from −1.00 D to −6.50 D, central corneal thickness >500 µm, normal corneal topography and tomography, and minimum postoperative follow-up of three years [12].

Exclusion criteria included previous ocular surgery, keratoconus or forme fruste keratoconus, severe dry eye disease, autoimmune disorders, cataract, retinal pathology, and pregnancy or lactation.

Preoperative Evaluation All patients underwent a comprehensive ophthalmologic assessment including UDVA, CDVA, manifest and cycloplegic refraction, slit-lamp biomicroscopy, Goldmann applanation tonometry, dilated fundus examination, Scheimpflug-based corneal tomography (Pentacam), pachymetry, and wavefront aberrometry.

Table 1. Preoperative Base Line Characteristics (n=92Eyes)

Parameter	Mean ± SD (Range)
Age (years)	30.87 ± 6.34 (19 – 46)
Male : Female (patients)	38 (60.3%) : 25 (39.7%)
Sphere (D)	+1.82 ± 1.36 (-1.50 to +5.25)
Cylinder (D)	-4.01 ± 1.17 (-1.00 to -6.50)
Spherical Equivalent (D)	-0.19 ± 1.52 (-3.50 to +2.75)
Keratometry – K1 (D)	43.21 ± 1.37 (40.10 – 46.80)
Keratometry – K2 (D)	46.33 ± 1.45 (43.10 – 49.80)
Central Corneal Thickness (µm)	542.61 ± 31.46 (501 – 612)
Pupil Diameter (mm)	6.21 ± 0.69 (4.8 – 7.8)

Surgical Technique Procedures were performed by experienced refractive surgeons. Corneal flaps were created using a femtosecond laser platform (VisuMax or IntraLase) with intended thickness of 100–110 µm and diameter of 8.5–9.0 mm. Stromal ablation was performed using a wavefront-optimized excimer laser (WaveLight EX500 or MEL 90) with optical zones of 6.0–6.5 mm. Intraoperative cyclotorsion control and

iris registration were routinely employed to enhance astigmatic correction accuracy [13].

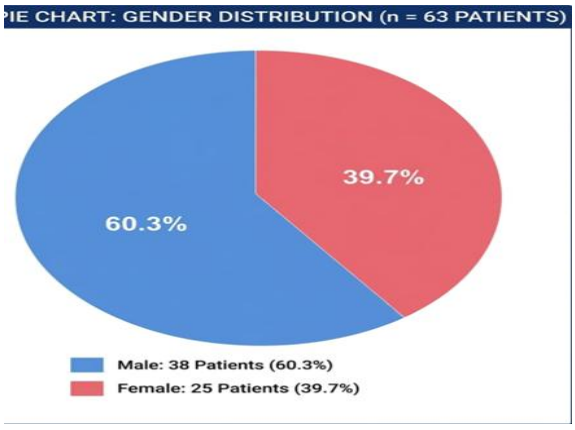
Postoperative medication regimen included topical moxifloxacin 0.5% four times daily for one week, prednisolone acetate 1% tapered over four weeks, and preservative-free lubricants for at least three months.

Outcome Measures and Follow-up Patients were examined at 1 day, 1 week, 1 month, 3 months, 1 year, 3 years, and 5 years postoperatively. Primary outcome measures included UDVA, CDVA, refractive predictability, and stability. Secondary measures included higher-order aberrations (4-mm and 6-mm zones), corneal topography, complications, and patient satisfaction.

Statistical Analysis Data were analyzed using SPSS version 26.0. Continuous variables are expressed as mean ± standard deviation. Repeated-measures ANOVA with Bonferroni correction and paired t-tests were used for comparisons. A p-value < 0.05 was considered statistically significant. Efficacy and safety indices were calculated.

III. RESULTS

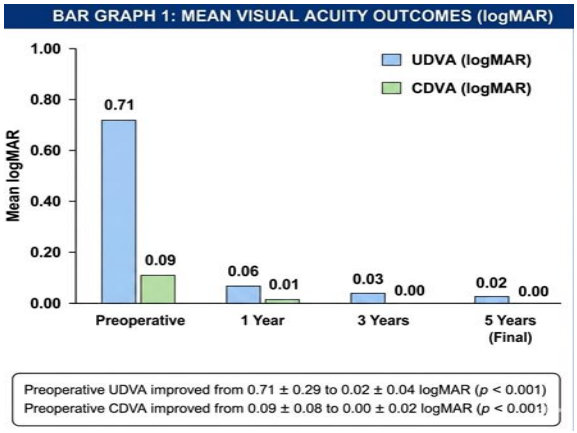
Demographic Characteristics The study included 92 eyes of 63 patients (38 males and 25 females). Mean age was 30.87 ± 6.34 years (range 19–46 years). Mean follow-up duration was 4.96 ± 0.88 years. Preoperative mean cylindrical refraction was −4.01 ± 1.17 D (range −1.50 to −6.25 D)



Visual Acuity Outcomes Mean UDVA improved significantly from 0.71 ± 0.29 logMAR preoperatively to 0.02 ± 0.04 logMAR at final follow-up (p < 0.001). Mean CDVA improved from 0.09 ± 0.08 logMAR to 0.00 ± 0.02 logMAR (p < 0.001).

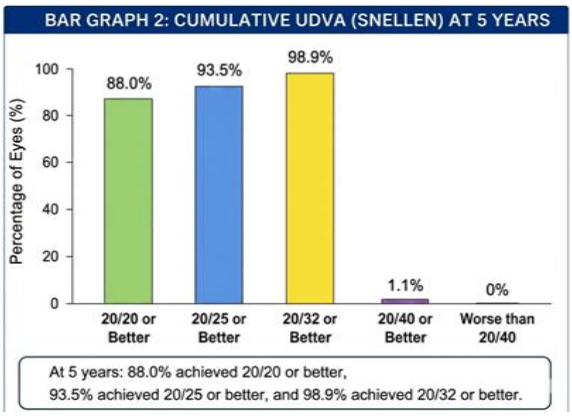
At the five-year visit:

- 93.5% of eyes achieved UDVA ≥20/25
- 88.0% achieved UDVA of 20/20 or better
- 17.4% gained one or more lines of CDVA
- No eye lost more than one line of CDVA



Efficacy index ranged between 1.05–1.10 and safety index between 1.08–1.12 across follow-up periods. These outcomes are consistent with previous reports on FS-LASIK for mixed astigmatism [8, 11, 19].

Refractive Outcomes Mean spherical refraction decreased from +1.82 ± 1.36 D to +0.14 ± 0.28 D (p < 0.001). Mean cylindrical refraction improved from −4.01 ± 1.17 D to −0.36 ± 0.29 D (p < 0.001). MRSE showed excellent stability with minimal regression (<0.25 D) between 1 and 5 years postoperatively.



Refractive predictability was high, with 91.3% of eyes within ±0.50 D and 97.1% within ±1.00 D of the intended correction at the final visit. These results

align with earlier studies on bitoric ablation and optimized excimer platforms [12, 14, 19, 22].

Table 2: Refractive Outcomes At 5 Years (Final Follow-Up)

Outcome Measure	Result (Mean ± SD)	Eyes within Range (%)
Sphere (D)	0.14 ± 0.28	94.6% within ±0.50 D; 99.0% within ±1.00 D
Cylinder (D)	-0.36 ± 0.29	91.3% within ±0.50 D; 97.1% within ±1.00 D
Spherical Equivalent (D)	-0.04 ± 0.32	91.3% within ±0.50 D; 97.1% within ±1.00 D
Efficacy Index (UDVA)	1.03 ± 0.09	—
Safety Index (CDVA)	1.07 ± 0.11	—
Note: 91.3% of eyes were within ±0.50 D of intended correction at 5 years.		

Higher-Order Aberration Analysis Wavefront analysis revealed a significant reduction in central coma and trefoil aberrations within the 4-mm optical zone ($p < 0.001$). Total HOA RMS showed a mild increase in the 6-mm zone under mesopic conditions, primarily related to minor spherical aberration changes. Overall, these changes contributed to improved subjective optical quality and contrast sensitivity [18, 23].

Safety and Complications No intraoperative complications were recorded. Postoperative complications were mild and transient: dry eye symptoms in 19.5% (resolved by 6–12 months), night glare/halos in 8.6%, and temporary photophobia in 5.4%. There were zero cases of corneal ectasia, infectious keratitis, significant flap complications, or severe diffuse lamellar keratitis [7].

IV. DISCUSSION

This five-year retrospective analysis demonstrates that FS-LASIK provides excellent and stable visual and refractive outcomes in patients with mixed astigmatism. The significant improvements in UDVA, CDVA, and refractive accuracy were well-maintained throughout the follow-up period, confirming the long-term efficacy of the procedure [11, 19].

The superior performance of femtosecond lasers in flap creation contributes to better biomechanical stability and lower induction of higher-order aberrations compared to mechanical microkeratomes [7]. The incorporation of cyclotorsion compensation proved especially valuable given the relatively high preoperative cylinder values in this cohort [13].

Refractive stability observed in this study is particularly noteworthy. Mixed astigmatism corrections have historically been associated with higher regression risk due to opposing forces in the two meridians [1, 12]. Modern ablation algorithms and adequate optical zones appear to effectively mitigate this issue [6, 13].

The HOA profile showed favorable central zone improvement with clinically acceptable peripheral changes, consistent with previous wavefront studies [18, 23]. These optical quality enhancements likely contributed to high patient satisfaction rates.

Limitations As a retrospective single-center study, limitations include potential selection bias and lack of a comparative control group (e.g., SMILE or toric ICL). Future prospective, multicenter randomized trials with larger sample sizes and standardized patient-reported outcome measures are recommended.

Comparison with Alternatives While emerging techniques such as SMILE and phakic intraocular lenses show promising results [25–27], FS-LASIK continues to offer advantages in terms of rapid visual recovery, broad treatable range, and extensive long-term safety data, making it a preferred option for suitable candidates.

V. CONCLUSION

FS-LASIK using contemporary femtosecond and excimer laser platforms delivers excellent long-term visual and refractive outcomes in the treatment of mixed astigmatism. The procedure demonstrates high efficacy, predictability, stability, and safety over five years, significantly improving quality of life for patients.

ACKNOWLEDGEMENTS

Authors would like to thanks all Research management of Eye 7 Chaudhary Eye Centre, New Delhi, India for providing all possible support for the smooth conduction of this research. They would like to extend their regards to HOD and faculty, for their support and timely help throughout the study.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee

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