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Three-month clinical and anterior corneal aberration outcomes of ray-tracing-guided versus topography-guided femtosecond LASIK for myopic astigmatism: a retrospective comparative study

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Abstract

Background

Accurate astigmatic correction and favorable optical outcomes are important goals of customized laser in situ keratomileusis (LASIK). We compared three-month clinical outcomes and anterior corneal higher-order aberrations (HOAs) after ray-tracing-guided LASIK (RTG-LASIK) and topography-guided femtosecond LASIK (TG-FS-LASIK) for myopic astigmatism.

Methods

This retrospective comparative study included 156 eyes of 104 patients with preoperative cylinder magnitude ≥ 1.50 D: 79 eyes of 58 patients underwent RTG-LASIK and 77 eyes of 46 patients underwent TG-FS-LASIK. Preoperative and three-month postoperative uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), and manifest refraction were assessed. Anterior corneal HOAs were evaluated at three months over a 4-mm analysis diameter. Astigmatic outcomes were evaluated using Alpins vector analysis. Generalized estimating equations accounted for within-patient correlation between fellow eyes.

Results

At three months, UDVA and CDVA were better after RTG-LASIK than after TG-FS-LASIK (both $P < 0.001$). Residual cylinder magnitude was lower after RTG-LASIK (0.20 ± 0.19 vs 0.47 ± 0.25 D; between-group difference, − 0.278 D; 95% confidence interval, − 0.346 to − 0.209 D; $P < 0.001$). The difference vector was smaller (0.196 ± 0.186 vs 0.475 ± 0.252 D), as was the absolute angle of error (1.54 ± 1.96° vs 4.76 ± 3.72°; both $P < 0.001$). Postoperative total HOA root mean square (RMS) was lower after RTG-LASIK (0.132 ± 0.044 vs 0.156 ± 0.059 μm; $P = 0.007$), as was third-order trefoil RMS (0.060 ± 0.033 vs 0.088 ± 0.058 μm; $P < 0.001$). No statistically significant between-group differences were detected in manifest refraction spherical equivalent, correction index, coma, or spherical aberration.

Conclusions

In eyes with myopic cylinder magnitude ≥ 1.50 D, RTG-LASIK was associated with better three-month visual acuity, less residual astigmatism, and lower postoperative anterior corneal total HOA and trefoil RMS than TG-FS-LASIK. Nonrandomized treatment allocation and differences in treatment planning limit causal interpretation.

Background

Correction of myopia with astigmatism requires treatment of both spherical refractive error and the magnitude and axis of astigmatism. Uncorrected astigmatism can impair distance and near vision and visual performance under low-contrast conditions; its effects depend on cylinder magnitude and axis [1]. Although corneal refractive surgery effectively treats myopic astigmatism, undercorrection, axis misalignment, and residual astigmatism remain possible, particularly when astigmatism is more pronounced [2]. Improving astigmatic accuracy while limiting surgically induced HOAs is therefore an important goal of customized corneal refractive surgery.

Topography-guided femtosecond laser-assisted laser in situ keratomileusis (TG-FS-LASIK) uses corneal surface measurements to plan individualized ablation with the aim of correcting refractive error and improving corneal optical regularity. Previous studies have reported favorable visual and refractive outcomes and, in some settings, better control of corneal HOAs; however, improved aberration profiles do not necessarily translate into more accurate astigmatic correction [3]. Differences between corneal and manifest astigmatism, and the way these measurements are integrated during treatment planning, may also influence residual astigmatism [4].

Ray-tracing-guided LASIK (RTG-LASIK) integrates corneal tomography, whole-eye wavefront aberrations, and ocular biometry to construct an individualized optical model. Simulated propagation of light through the eye is then used to calculate a customized ablation profile [5]. A multicenter study has reported its safety and efficacy for myopia and myopic astigmatism [6]. However, a contralateral-eye comparison of RTG-LASIK and Q-value-adjusted LASIK found that a more favorable corneal aberration profile did not consistently yield a smaller residual refractive error, indicating that refractive accuracy and optical quality should be assessed separately [7].

RTG-LASIK and topography-guided LASIK have been compared directly. Cao et al. reported an advantage of RTG-LASIK for selected postoperative visual acuity outcomes [8], whereas Ao et al. found similar central visual acuity but differences in spherical aberration and peripheral refractive distribution [9]. These findings suggest that the two customized ablation strategies may have different optical profiles. Postoperative UDVA or spherical equivalent alone may therefore be insufficient to characterize their outcomes. In patients with greater astigmatism, combining vector analysis with HOA assessment may provide a more comprehensive evaluation of correction accuracy and optical quality.

Luo et al. compared RTG-LASIK with Q-value-adjusted LASIK for astigmatism of at least 2.00 D at three months [10]. Their comparator was not TG-FS-LASIK, and HOAs were not evaluated. We therefore studied patients with preoperative cylinder magnitude of at least 1.50 D. Using Alpins vector analysis [11], we compared three-month visual acuity, refraction, astigmatic vector outcomes, and anterior corneal HOAs after RTG-LASIK and TG-FS-LASIK to inform selection between these treatment strategies.

Methods

Study design and participants

This single-center retrospective comparative study included 156 eyes of 104 adults with myopic cylinder magnitude ≥ 1.50 D who underwent laser refractive surgery at the Refractive Surgery Center of Liaoning Aier Eye Hospital between September 2025 and May 2026. The RTG-LASIK group comprised 79 eyes of 58 patients, and the TG-FS-LASIK group comprised 77 eyes of 46 patients. All included patients completed the three-month follow-up. The study adhered to the Declaration of Helsinki and was approved by the Medical Ethics Committee of Liaoning Aier Eye Hospital (approval No. 2026-003-01). Written informed consent to participate was obtained from all participants.

Inclusion criteria were: (1) age at least 18 years at surgery; (2) preoperative sphere between − 10.00 and − 1.00 D and myopic cylinder magnitude of at least 1.50 D; (3) stable refraction, with a change of no more than 0.50 D during the preceding year; (4) eligibility for corneal laser refractive surgery based on preoperative corneal morphology, thickness, and other clinical assessments; and (5) discontinuation of soft contact lens wear for more than one week or orthokeratology lens wear for more than three months.

Exclusion criteria were: (1) previous corneal refractive surgery, corneal transplantation, or other ocular surgery potentially affecting study outcomes; (2) keratoconus or suspected keratoconus, corneal ectasia, or substantial corneal scarring; (3) active ocular inflammation, severe dry eye that could affect measurements, or another ocular condition affecting visual function; (4) uncontrolled systemic disease or medication likely to impair corneal healing; and (5) pregnancy or breastfeeding at the time of surgery.

Preoperative assessment

All patients underwent comprehensive preoperative assessment, including UDVA, CDVA, manifest and cycloplegic refraction, intraocular pressure measurement, slit-lamp examination, and dilated fundus examination. Corneal thickness was measured using RTVue XR-100 optical coherence tomography, and corneal tomography and pupil measurements were obtained using Sirius. In the RTG-LASIK group, InnovEyes Sightmap was additionally used to obtain corneal tomography, whole-eye wavefront, and biometric data for individualized optical modeling and ray-tracing-guided ablation planning. In the TG-FS-LASIK group, WaveLight Topolyzer VARIO was used to obtain topographic data for ablation planning. Patients received a total of 12 instillations of 0.5% levofloxacin eye drops during the one to three days before surgery.

Surgical procedures

All procedures were performed by the same refractive surgeon (Xuejun Fang), with emmetropia as the refractive target. Iris registration was successfully completed in all eyes. In both groups, a corneal flap 100–110 μm thick with a 105° side-cut angle was created using the WaveLight FS200 femtosecond laser system (Alcon). After the flap was lifted, stromal ablation was performed using the WaveLight EX500 excimer laser system (Alcon). The optical zone diameter was 6.0–6.5 mm, with a 1.25-mm transition zone.

In the RTG-LASIK group, InnovEyes Sightmap data were used to construct an individualized ocular optical model and generate a ray-tracing-guided ablation profile, which was transferred to the excimer laser system. When the absolute difference between the Sightmap-derived spherical equivalent and manifest refraction spherical equivalent (MRSE) was ≤ 0.75 D, the treatment recommended by the InnovEyes software was used. When the difference exceeded 0.75 D, the treatment plan was finalized after nomogram adjustment.

In the TG-FS-LASIK group, topographic data from the WaveLight Topolyzer VARIO were used to generate a customized ablation plan with Contoura Vision topography-guided treatment software. Treatment sphere, cylinder, and astigmatic axis were based on manifest refraction, without additional nomogram adjustment.

Postoperative medication and follow-up

Postoperative medication consisted of 0.5% levofloxacin four times daily for one week; 0.1% fluorometholone four times daily initially, with the dosing frequency reduced by one instillation per day every ten days over a 40-day course; and artificial tears four times daily. UDVA, CDVA, manifest refraction, intraocular pressure, and slit-lamp findings were assessed at postoperative day 1, week 1, month 1, and month 3.

Data collection and statistical analysis

Age, sex, laterality, and preoperative and three-month postoperative UDVA, CDVA, manifest sphere, cylinder, and astigmatic axis were recorded. MRSE was calculated as sphere plus half the cylinder. Visual acuity was converted to logarithm of the minimum angle of resolution (logMAR) units for analysis. The efficacy index was calculated as postoperative UDVA divided by preoperative CDVA, and the safety index as postoperative CDVA divided by preoperative CDVA, using decimal visual acuity. Astigmatism was analyzed using the Alpins method, with refraction converted to the corneal plane using a 12-mm vertex distance. The difference vector (DV) represents the magnitude and direction of the additional astigmatic correction required to reach the intended target; a smaller magnitude indicates a smaller residual correction error. The correction index was calculated as surgically induced astigmatism divided by target-induced astigmatism, and the index of success as DV divided by target-induced astigmatism. Anterior corneal HOAs at three months were assessed over a 4-mm analysis diameter. Analyses were performed using SPSS version 27.0. Continuous variables are presented as mean ± standard deviation (SD), and categorical variables as numbers and percentages of patients or eyes, as appropriate. Between-group differences in age were assessed using Welch's independent-samples t test, and sex distributions were compared using Fisher's exact test. Eye-level between-group comparisons used generalized estimating equations (GEE) to account for within-patient correlation between fellow eyes. All tests were two-sided, and $P < 0.05$ was considered statistically significant.

Results

Participant characteristics and preoperative findings

The analysis included 156 eyes of 104 patients: 79 eyes of 58 patients in the RTG-LASIK group and 77 eyes of 46 patients in the TG-FS-LASIK group. Mean age was 20.81 ± 3.90 years in the RTG-LASIK group and 21.89 ± 5.14 years in the TG-FS-LASIK group (P = 0.241). Men accounted for 72.4% and 69.6% of patients, respectively (P = 0.829). Preoperative cylinder magnitude ranged from 1.50 to 3.75 D in the RTG-LASIK group and from 1.50 to 4.50 D in the TG-FS-LASIK group.

Preoperative sphere, cylinder, MRSE, UDVA, and CDVA did not differ significantly between groups (all P > 0.05; Table 1).

Table 1
Patient characteristics and preoperative ocular parameters

Parameter	**RTG-LASIK** **58 patients, 79 eyes**	**TG-FS-LASIK** **46 patients, 77 eyes**	**P**
Age (years)	20.81 ± 3.90	21.89 ± 5.14	0.241
Male patients, n (%)	42 (72.4)	32 (69.6)	0.829
SPH (D)	−4.18 ± 1.55	−4.39 ± 1.74	0.476
CYL (D)	−2.19 ± 0.47	−2.25 ± 0.83	0.863
MRSE (D)	−5.28 ± 1.56	−5.52 ± 1.72	0.445
UDVA (logMAR)	1.318 ± 0.302	1.383 ± 0.311	0.287
CDVA (logMAR)	−0.001 ± 0.009	0.000 ± 0.028	0.677

Values are mean ± SD or n (%). Age and sex were analyzed per patient; ocular parameters were analyzed per eye. Age was compared using Welch's t test and sex using Fisher's exact test. Ocular parameters were compared using generalized estimating equations accounting for intereye correlation within patients. SPH, sphere; CYL, cylinder; MRSE, manifest refraction spherical equivalent; UDVA, uncorrected distance visual acuity; CDVA, corrected distance visual acuity; D, diopters; logMAR, logarithm of the minimum angle of resolution.

Postoperative visual acuity and refraction

Postoperative outcomes are presented in Table 2. At three months, UDVA was better in the RTG-LASIK group than in the TG-FS-LASIK group (− 0.070 ± 0.051 vs − 0.026 ± 0.037 logMAR). CDVA was also better (− 0.075 ± 0.046 vs − 0.026 ± 0.037 logMAR; both P < 0.001).

UDVA of at least 1.2 (decimal scale) was achieved in 81.0% of RTG-LASIK eyes and 32.5% of TG-FS-LASIK eyes (P < 0.001; Fig. 1A). The corresponding proportions achieving UDVA of at least 1.0 were 97.5% and 100.0% (P = 0.310). Postoperative UDVA was at least as good as preoperative CDVA in 97.5% and 93.5% of eyes, respectively (P = 0.380; Fig. 1B). No RTG-LASIK eyes and five TG-FS-LASIK eyes (6.5%) lost any CDVA (P = 0.085); no eye in either group lost 0.1 logMAR or more (Fig. 1C). Efficacy and safety indices are shown in Table 2.

Mean postoperative MRSE was + 0.03 ± 0.30 D after RTG-LASIK and + 0.13 ± 0.51 D after TG-FS-LASIK (P = 0.163). MRSE was within ± 0.50 D of the target in 94.9% and 64.9% of eyes, respectively (P < 0.001), and within ± 1.00 D in 100.0% and 94.8% (Fig. 1D, E). Postoperative sphere was + 0.12 ± 0.29 D and + 0.37 ± 0.52 D, respectively (P = 0.001).

Residual cylinder magnitude was lower after RTG-LASIK than after TG-FS-LASIK (0.20 ± 0.19 vs 0.47 ± 0.25 D; P < 0.001). Residual cylinder was no more than 0.25 D in 81.0% versus 44.2% of eyes and no more than 0.50 D in 100.0% versus 66.2% (both P < 0.001). All eyes in both groups had residual cylinder of no more than 1.00 D (Fig. 1F). Detailed outcomes and proportions are shown in Table 2 and Table S1 in Additional file 1.

Table 2
Visual acuity and refractive outcomes at three months

Parameter	**RTG-LASIK (n = 79 eyes)**	**TG-FS-LASIK (n = 77 eyes)**	**P**
UDVA (logMAR)	−0.070 ± 0.051	−0.026 ± 0.037	< 0.001
CDVA (logMAR)	−0.075 ± 0.046	−0.026 ± 0.037	< 0.001
SPH (D)	0.12 ± 0.29	0.37 ± 0.52	0.001
Residual cylinder magnitude (D)	0.20 ± 0.19	0.47 ± 0.25	< 0.001
MRSE (D)	0.03 ± 0.30	0.13 ± 0.51	0.163
Efficacy index	1.18 ± 0.13	1.07 ± 0.13	< 0.001
Safety index	1.19 ± 0.12	1.07 ± 0.13	< 0.001

Values are mean ± SD. Eye-level P values were obtained using generalized estimating equations (GEE) accounting for intereye correlation within patients. Refraction was measured by manifest refraction. For each eye, the efficacy index was calculated as postoperative UDVA/preoperative CDVA, and the safety index as postoperative CDVA/preoperative CDVA, using decimal visual acuity; the table reports the mean ± SD of these individual-eye ratios. The between-group difference in residual cylinder magnitude (RTG − TG) was − 0.278 D (95% CI, − 0.346 to − 0.209 D). SPH, sphere; MRSE, manifest refraction spherical equivalent; UDVA, uncorrected distance visual acuity; CDVA, corrected distance visual acuity.

Astigmatic vector analysis at three months

Alpins vector analysis showed lower DV, absolute angle of error (|AE|), and index of success (IOS) after RTG-LASIK than after TG-FS-LASIK (all P < 0.001), indicating smaller astigmatic correction errors. An |AE| of no more than 5° was observed in 94.9% versus 61.0% of eyes (P < 0.001; Fig. 1H).

Target-induced astigmatism (TIA), surgically induced astigmatism (SIA), and correction index (CI) did not differ significantly between groups (all P > 0.05). Principal vector results are shown in Table 3 and Figs. 1G and 2. Magnitude of error (ME) and signed AE are presented in Table S3 in Additional file 1; the between-group difference in signed AE was statistically significant (P = 0.013).

Table 3
Astigmatic vector analysis at 3 months postoperatively

Parameter	RTG-LASIK (n = 79 eyes)	TG-FS-LASIK (n = 77 eyes)	P
TIA (D)	1.940 ± 0.410	1.977 ± 0.723	0.930
SIA (D)	1.972 ± 0.474	2.049 ± 0.811	0.739
DV (D)	0.196 ± 0.186	0.475 ± 0.252	< 0.001
CI	1.015 ± 0.119	1.045 ± 0.214	0.375
|AE| (°)	1.54 ± 1.96	4.76 ± 3.72	< 0.001
IOS	0.105 ± 0.102	0.259 ± 0.157	< 0.001

Values are mean ± SD. Refraction was converted to the corneal plane using a 12-mm vertex distance. TIA, target induced astigmatism; SIA, surgically induced astigmatism; DV, difference vector, representing the residual astigmatic correction required to reach the target; CI, correction index; |AE|, absolute angle of error; IOS, index of success. TIA, SIA, and DV are summarized as arithmetic means of individual vector magnitudes, distinct from the vector means plotted in Fig. 2. CI = SIA/TIA (ideal value, 1); IOS = DV/TIA (ideal value, 0). P values were obtained using generalized estimating equations accounting for intereye correlation within patients. The between-group difference in DV magnitude (RTG − TG) was − 0.279 D (95% CI, − 0.348 to − 0.211 D). ME and signed AE are reported in Table S3 in Additional file 1.

Anterior corneal higher-order aberrations at three months

At three months, over a 4-mm analysis diameter, anterior corneal total HOA RMS was lower after RTG-LASIK than after TG-FS-LASIK (0.132 ± 0.044 vs 0.156 ± 0.059 μm; P = 0.007). Third-order trefoil RMS was also lower (0.060 ± 0.033 vs 0.088 ± 0.058 μm; P < 0.001; Table 4 and Fig. 3).

Third-order coma RMS was 0.088 ± 0.050 μm after RTG-LASIK and 0.091 ± 0.046 μm after TG-FS-LASIK (P = 0.769). Spherical aberration Z(4,0) was 0.015 ± 0.040 μm and 0.014 ± 0.039 μm, respectively (P =

0.698).

Individual third-order Zernike coefficients are reported in Table S2 in Additional file 1. These results represent between-group differences in postoperative aberration levels only.

Table 4
Anterior corneal higher-order aberrations over a 4-mm diameter at three months

Parameter	RTG-LASIK (n = 79 eyes)	TG-FS-LASIK (n = 77 eyes)	P
Total HOA RMS	0.132 ± 0.044	0.156 ± 0.059	0.007
Third-order coma RMS	0.088 ± 0.050	0.091 ± 0.046	0.769
Third-order trefoil RMS	0.060 ± 0.033	0.088 ± 0.058	< 0.001
Spherical aberration Z(4,0)	0.015 ± 0.040	0.014 ± 0.039	0.698

Values are mean ± SD in μm. RMS, root mean square; HOA, higher-order aberration. Spherical aberration Z(4,0) retains its sign. P values were obtained using generalized estimating equations (GEE) accounting for intereye correlation within patients. The between-group difference in total HOA RMS (RTG − TG) was − 0.024 μm (95% CI, − 0.042 to − 0.007 μm). Individual third-order Zernike coefficients are presented in Table S2 in Additional file 1.

Discussion

We compared three-month outcomes after RTG-LASIK and TG-FS-LASIK in eyes with preoperative cylinder magnitude ≥ 1.50 D. RTG-LASIK was associated with better UDVA and CDVA, less residual astigmatism, smaller astigmatic correction errors, a greater proportion of eyes within ± 0.50 D of the MRSE target, and lower postoperative anterior corneal total HOA and trefoil RMS. The visual acuity findings are consistent with aspects of the studies by Schumacher et al., Cummings et al., and Cao et al. [8, 12, 13]. In contrast, Khoramnia et al. found no significant differences in most visual acuity measures when comparing RTG-LASIK with wavefront-optimized LASIK [14], and Ao et al. reported similar central visual acuity after RTG-LASIK and TG-FS-LASIK [9]. Studies by Saleh et al. and Lu et al. also support favorable outcomes with topography-guided LASIK [15, 16]. Luo et al. found that selected visual and astigmatic error measures favored RTG-LASIK over Q-value-adjusted LASIK [10], although their comparator and astigmatism eligibility threshold differed from ours. Differences in patient characteristics, treatment planning, and outcome definitions should therefore be considered when comparing these studies.

The principal finding was less residual astigmatism and smaller astigmatic correction errors after RTG-LASIK. Residual cylinder magnitude, DV, and |AE| were 0.20 ± 0.19 D, 0.196 ± 0.186 D, and 1.54 ± 1.96°, respectively, after RTG-LASIK, compared with 0.47 ± 0.25 D, 0.475 ± 0.252 D, and 4.76 ± 3.72° after TG-FS-

LASIK (all P < 0.001). Accurate astigmatic correction depends on both magnitude and axis, and vector analysis provides a more complete assessment of these components [11, 17–19]. Mean CI was close to 1 in both groups, with no statistically significant between-group difference. Lower |AE|, DV, and IOS in the RTG-LASIK group indicated closer alignment with the intended correction and less residual astigmatism. Differences in measurement integration and treatment parameter selection may partly explain these findings. RTG-LASIK integrates corneal tomography, whole-eye wavefront data, and ocular biometry into an individualized optical model [5]. TG-FS-LASIK planning combines topography with manifest refraction, and discrepancies between these measurements may affect outcomes [20, 21]. Previous studies have also examined the influence of planning algorithms and astigmatism magnitude [22, 23]. Importantly, nomogram adjustment was permitted in the RTG-LASIK group but was not used in the TG-FS-LASIK group. The observed differences therefore reflect the treatment strategies as implemented and cannot be attributed solely to the ablation algorithms.

Lower residual astigmatism may partly explain the better postoperative UDVA after RTG-LASIK, because uncorrected astigmatism can impair visual performance [1]. However, residual refractive cylinder alone does not adequately explain the difference in CDVA, which is measured with refractive correction. Differences in optical quality or measurement conditions may have contributed, but the present data do not establish the mechanism. The mean between-group differences in UDVA and CDVA were 0.044 and 0.049 logMAR, respectively, both smaller than 0.1 logMAR. Their clinical importance should therefore be considered alongside the statistical significance. Although mean MRSE did not differ significantly between groups, 94.9% of RTG-LASIK eyes were within ± 0.50 D of the target compared with 64.9% of TG-FS-LASIK eyes. Positive and negative refractive errors can offset one another in a mean, so similar mean values do not imply similar distributions of individual outcomes. The greater proportion within the target range indicates better observed refractive accuracy in this cohort, although differences in treatment planning may have contributed.

Postoperative anterior corneal total HOA and third-order trefoil RMS over a 4-mm analysis diameter were lower after RTG-LASIK, whereas no statistically significant differences were detected in coma or spherical aberration. Different ablation designs may contribute to these findings, because ray-tracing treatment planning considers both lower-order refractive error and higher-order optical features [5]. Previous HOA findings have varied. Luo et al. and Thananjeyan et al. reported increases in postoperative whole-eye HOAs [24, 25]; Xu et al. observed reduced trefoil but no significant change in total HOAs, spherical aberration, or coma [26]; and Zhang et al. reported favorable corneal optical quality after topography-guided ablation [27]. The relationship between aberrations and visual acuity depends on the aberration modes and their magnitudes [28]. Furthermore, anterior corneal aberrations do not directly represent whole-eye aberrations, because internal ocular optics can partly compensate for corneal aberrations [29]. The approximately 0.024-μm between-group difference in total HOA RMS cannot, by itself, establish a perceptible visual benefit. Assessment of whole-eye aberrations, contrast sensitivity, and patient-reported visual quality would be needed to evaluate its functional relevance. Without preoperative HOA data, this study establishes only a difference in postoperative aberration levels and cannot determine which treatment induced fewer aberrations.

This study has several limitations. Its single-center retrospective design and relatively small sample limit generalizability, and nonrandomized treatment allocation creates a risk of selection bias and confounding. Differences in nomogram adjustment and other treatment parameters may have affected the results. Although GEE accounted for intereye correlation, accounting for this correlation does not itself remove confounding. The assessment of multiple outcomes also warrants cautious interpretation of individual P values. Preoperative HOA data were unavailable, preventing comparison of baseline aberrations or surgically induced changes. In addition, the 4-mm analysis diameter limits extrapolation to larger pupils and low-light visual performance. Follow-up ended at three months, precluding assessment of long-term refractive stability and safety. Astigmatic vector outcomes can vary over time [30], and epithelial remodeling may influence refractive and optical outcomes [31, 32]. Other studies have followed RTG-LASIK outcomes for up to two years [33]. Larger prospective comparative studies with standardized treatment planning, longer follow-up, and additional measures of visual quality are needed to confirm these findings and establish their clinical importance.

Conclusions

In this cohort of eyes with myopic cylinder magnitude ≥ 1.50 D, RTG-LASIK was associated with better three-month UDVA and CDVA, less residual astigmatism, smaller astigmatic correction errors, and lower postoperative anterior corneal total HOA and trefoil RMS than TG-FS-LASIK. No statistically significant between-group differences were detected in mean MRSE, correction index, coma, or spherical aberration. Nonrandomized treatment allocation, differences in treatment planning, and the absence of preoperative HOA data limit interpretation of these short-term findings.

Abbreviations

AE
angle of error
CDVA
corrected distance visual acuity
CI
correction index (or confidence interval when used with 95%)
CYL
cylinder
D
diopter
DV
difference vector
GEE
generalized estimating equations
HOA
higher-order aberration

IOS
index of success
IQR
interquartile range
LASIK
laser in situ keratomileusis
logMAR
logarithm of the minimum angle of resolution
ME
magnitude of error
MRSE
manifest refraction spherical equivalent
RMS
root mean square
RTG-LASIK
ray-tracing-guided LASIK
SD
standard deviation
SIA
surgically induced astigmatism
SPH
sphere
TG-FS-LASIK
topography-guided femtosecond LASIK
TIA
target-induced astigmatism
UDVA
uncorrected distance visual acuity.

Declarations

Ethics approval and consent to participate

This study was approved by the Medical Ethics Committee of Liaoning Aier Eye Hospital (approval No. 2026-003-01) and was conducted in accordance with the Declaration of Helsinki. Written informed consent to participate was obtained from all participants.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Supplementary information

Table S1 presents visual acuity and refractive outcome proportions; Table S2 presents individual third-order anterior corneal Zernike coefficients; and Table S3 presents additional astigmatic vector parameters.

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Author Contribution

Guosheng Cheng and Xianhao Zhao contributed to the study design, data analysis, and manuscript drafting. Yue Wang, Jiayu pan and Jifan Wang contributed to data collection and interpretation. Xuejun Fang supervised the study and critically revised the manuscript. All authors read and approved the final manuscript.

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Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

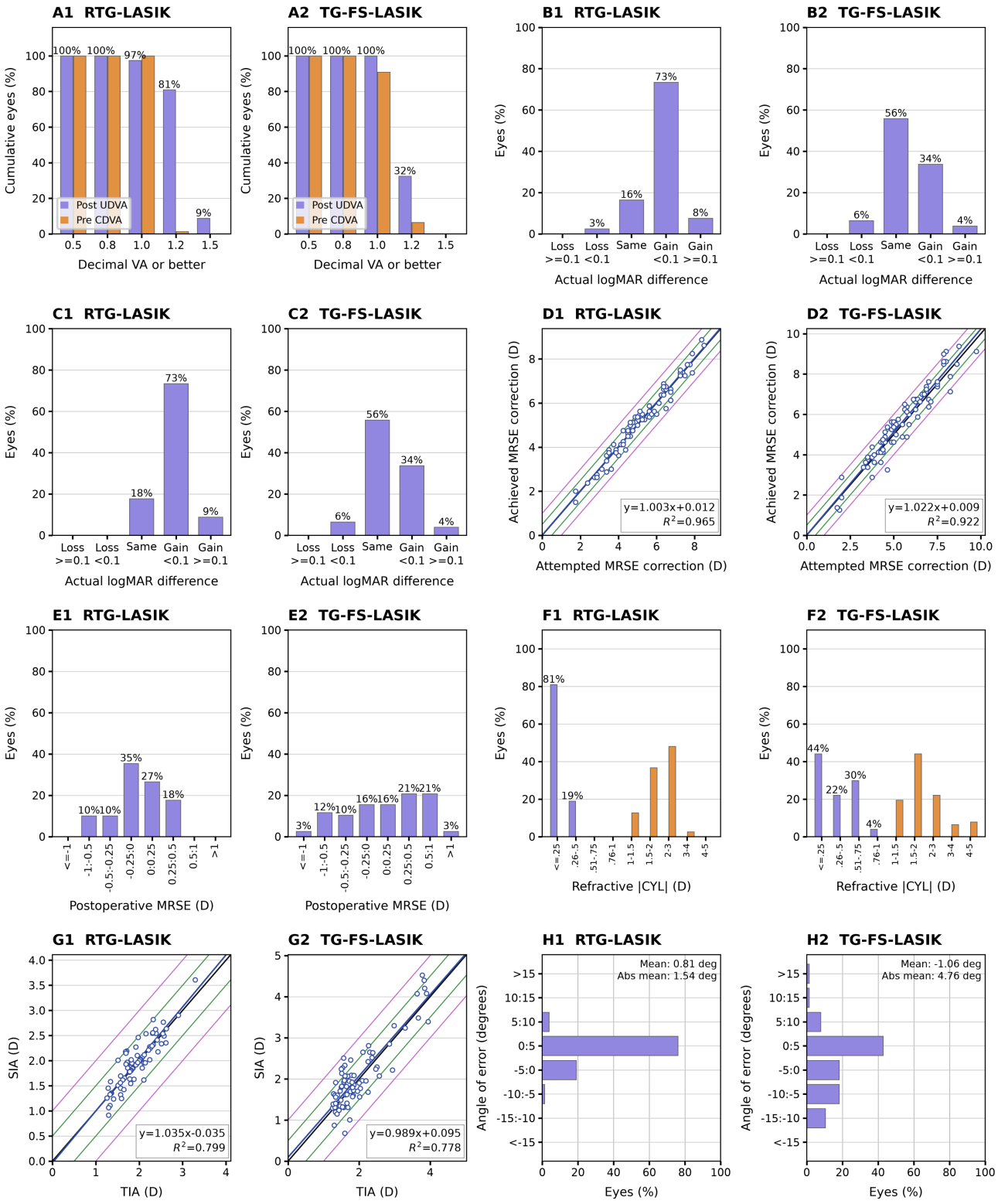

Figure 1

Visual, refractive, and astigmatic outcomes at 3 months. Suffixes 1 and 2 denote RTG-LASIK (79 eyes) and TG-FS-LASIK (77 eyes), respectively. (A) Cumulative visual acuity; (B) postoperative UDVA versus preoperative CDVA; (C) change in CDVA; (D) attempted versus achieved MRSE correction; (E) postoperative MRSE; (F) preoperative and postoperative cylinder magnitude; (G) TIA versus SIA; (H) angle of error. In D and G, black lines indicate equality, green and magenta lines indicate ±0.50 D and

±1.00 D, respectively, and blue lines show descriptive linear fits. Purple and orange bars indicate postoperative and preoperative values, respectively. UDVA, uncorrected distance visual acuity; CDVA, corrected distance visual acuity; MRSE, manifest refraction spherical equivalent; TIA, target induced astigmatism; SIA, surgically induced astigmatism.

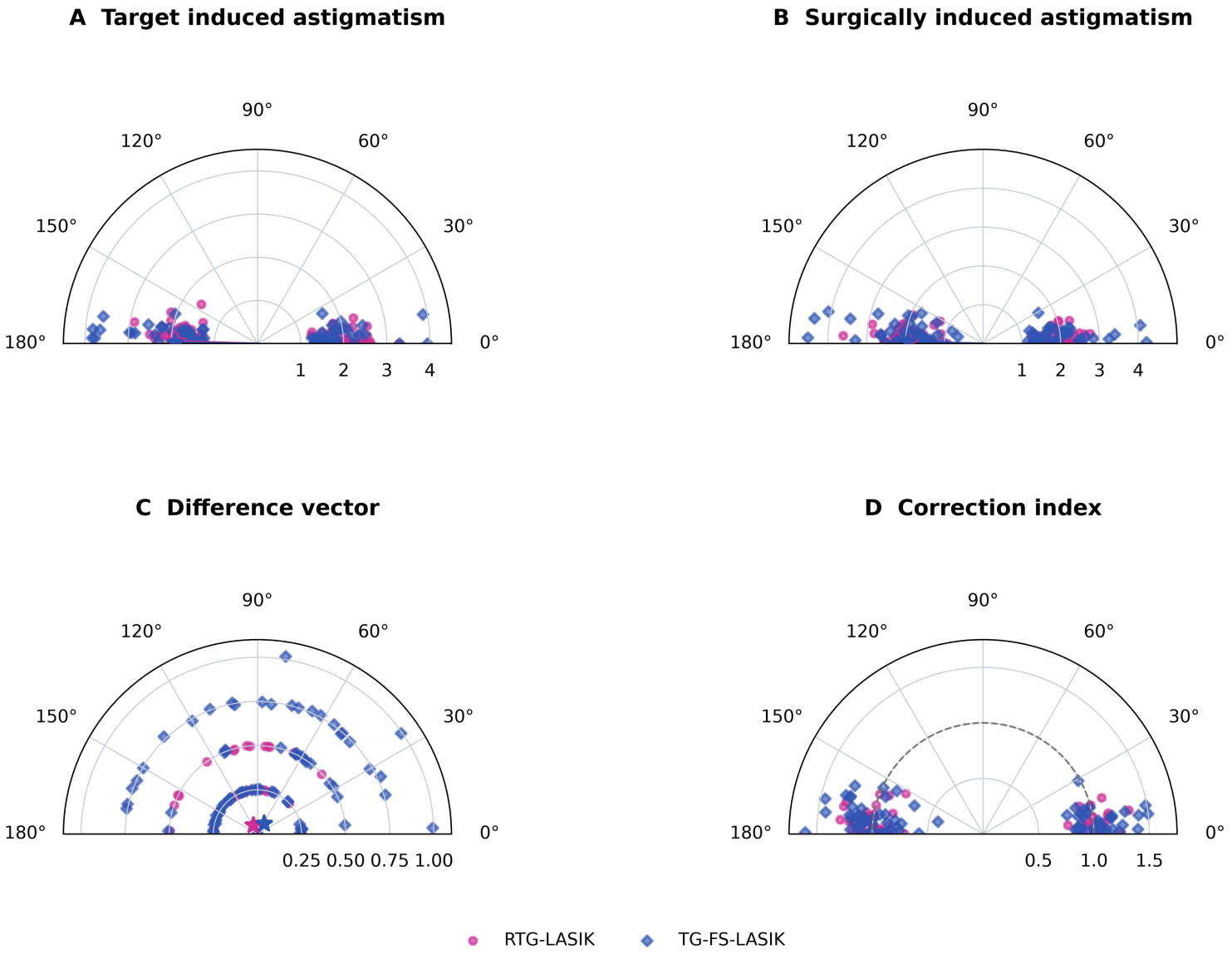

Figure 2

Single-angle polar plots of astigmatic vectors at 3 months. (A) Target induced astigmatism (TIA); (B) surgically induced astigmatism (SIA); (C) difference vector (DV), representing the residual astigmatic correction required to reach the target; (D) correction index (CI). Pink circles and blue diamonds denote RTG-LASIK and TG-FS-LASIK, respectively. In A–C, stars and radial lines indicate vector means calculated from double-angle components; radial units are diopters. In D, CI is plotted at the SIA axis; the dashed arc indicates the ideal value of 1.

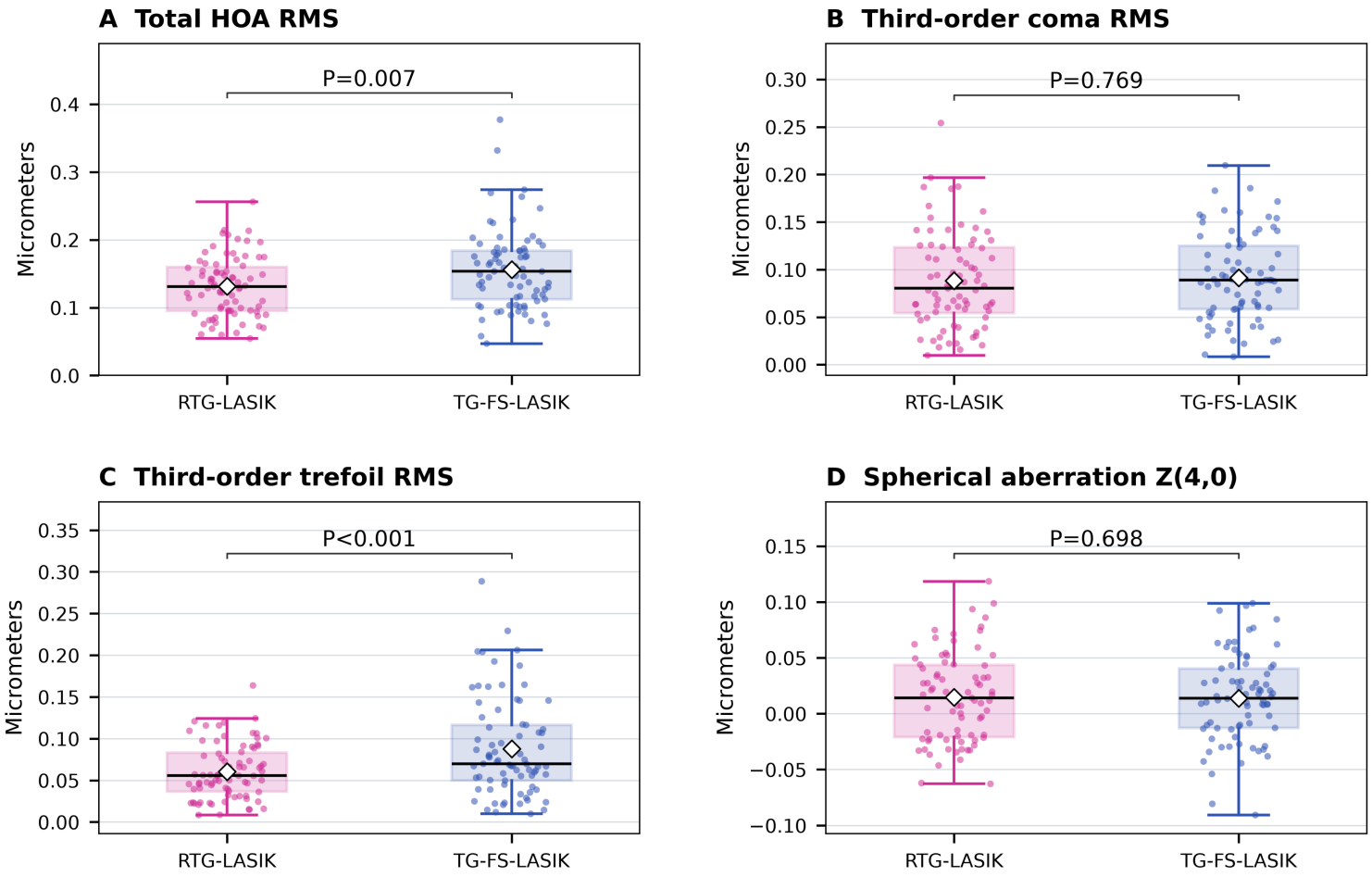

Figure 3

Anterior corneal aberrations over a 4-mm diameter at 3 months. (A) Total higher-order aberration (HOA) RMS; (B) third-order coma RMS; (C) third-order trefoil RMS; (D) spherical aberration Z(4,0). Each dot represents one eye. Boxes indicate the interquartile range (IQR), center lines the median, whiskers the most extreme values within 1.5 × IQR, and open diamonds the mean. P values were obtained using generalized estimating equations. RMS, root mean square.

Supplementary Files

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- TableS1toS3.docx