Comparison of Visual Outcomes for Myopia after Refractive Surgery using Femtosecond Laser-Assisted and Flap-off Epi-LASIK

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Abstract
Background This study clinically evaluated the visual outcomes after refractive surgery for myopia using femtosecond laser-assisted in situ keratomileusis (femto-LASIK) and epi-LASIK (flap-off).

Methods In this prospective cohort study, 40 eyes of 27 patients were divided into two groups depending on the technique used for refractive surgery. Femto-LASIK flaps and epi-LASIK flaps (flap-off) were created using femtosecond laser and Epi-K TM epikeratome, respectively. Uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), manifest refraction (MR), corneal asphericity (Q-value), and corneal higher-order aberrations (HOAs) were assessed pre- and postoperatively.

Results The improvement in LogMAR UDVA after refractive surgery was statistically significant for both groups (P < 0.001 for all groups); it was significantly improved in the femto-LASIK group, 1 day and 1 week postoperatively (P < 0.001, P = 0.019, respectively). With regard to the front and total corneal HOAs, there were significant differences in spherical aberrations (Z 4.0) between the femto-LASIK and flap-off epi-LASIK groups (P = 0.016 and P = 0.017, respectively). With regard to the back corneal HOAs, there were significant differences in vertical coma (Z 3,-1) aberration, 0.027 ± 0.027 μm (femto-LASIK) and 0.001 ± 0.034 μm (flap-off epipolis LASIK); horizontal secondary astigmatism (Z 4,2) aberration, -0.008 ± 0.012 μm (femto-LASIK) and 0.007 ± 0.018 μm (flap-off epipolis LASIK); oblique tetrafoil (Z 4,-4) aberration, -0.008 ± 0.029 μm (femto-LASIK) and 0.015 ± 0.026 μm (flap-off epi-LASIK), respectively (P = 0.018, P = 0.007, and P = 0.022, respectively). However, the back corneal HOA changes did not have a significant effect on the total corneal HOA changes.

Conclusion Femto-LASIK yielded better early visual outcomes than did flap-off epi-LASIK, but there was no significant difference between the outcomes of the two procedures, 1 week postoperatively.

Background
For myopia, the refractive error commonly corrected by eyeglasses, contact lens, implantable contact lens [1], and corneal refractive surgery [2]. In the early 1990s, photorefractive keratectomy (PRK) was first introduced for the surgical correction of myopia [3]; laser ablation refractive surgery was widely applied for anterior segment operation. With advances in the techniques used for epithelium removal,
femtosecond laser-assisted LASIK (femto-LASIK) and epi-LASIK have emerged as new approaches in the field of refractive surgery. Depending on whether it was performed with or without creating a flap, epi-LASIK technique is divided into types: flap-on technique and flap-off technique. Ang RE et al. [4] and Zhang Y et al. [5] reported that flap-off epi-LASIK with mitomycin C (MMC) results in less pain and corneal haze, and faster visual recovery, while visual results, refractive outcomes, contrast sensitivity (CS), and higher-order aberrations (HOAs) were comparable with those in flap-on epi-LASIK. Numerous studies have compared the visual outcomes of femto-LASIK and flap-on epi-LASIK (flap creation using a microkeratome); reportedly, greater corneal backscattering [6], faster recovery of corneal sensation, lesser degree of spherical aberration, some CS values [7], and superior outcomes of visual acuity were observed in an early stage [8] after femto-LASIK than after flap-on epi-LASIK. However, Kezirian et al. [9] reported that femto-LASIK and flap-on epi-LASIK are associated with equivalent visual outcomes during the first 3 months postoperatively.Wen D et al. [2] performed a network meta-analysis to compare visual outcomes and quality between these two techniques and found that there were no statistically significant difference in either visual outcomes (efficacy and safety) or visual quality (HOAs and CS); however, they reported that the outcome of femto-LASIK was more predictable than any other type of surgery. Moreover, current study, the outcomes were evaluated by Pentacam which is using scheimpflug camera to determinate corneal tomography and topography to provide more detailed corneal biomechanical information [10-12]. The aim of the present study was to compare the visual outcomes and corneal biomechanical properties changes between femto-LASIK and flap-off epi-LASIK.

Methods

Patients

40 eyes of 27 patients, who underwent LASIK surgery between April 2014 and February 2016 in the Department of Ophthalmology, Catholic University, St. Mary’s Hospital, Seoul, South Korea, were enrolled in this prospective cohort study. This study protocol followed the guidelines of the Declaration of Helsinki and was approved by the Institutional Review Board of St. Mary’s Hospital,
Seoul, South Korea. Written informed consent was obtained from all patients before commencement of the study.

Patients included in the study underwent refractive surgery for the correction of myopia, and had normal preoperative topography. All patients demonstrated at least 1 year of stable refraction before undergoing refractive surgery, and were followed-up for at least 2 years postoperatively. Exclusion criteria included the presence of ocular pathology; retinal disorders; previous ocular surgery; co-morbidities, such as diabetes, autoimmune pathologies, and endocrine pathologies; dry eye symptoms; and insufficient follow-up. We also excluded patients with corneal instability, haze or other complications, and those undergoing retreatment. The included patients were required to discontinue the use of soft contact lenses for at least 2 weeks and the use of rigid gas permeable (RGP) lenses for at least 4 weeks prior to surgery.

**Preoperative assessment**

All patients underwent a standard ophthalmologic examination preoperatively. The investigations included manifest refraction (MR), cycloplegic refraction, slit-lamp examination, ultrasound pachymetry, dilated funduscopy, and intraocular pressure (IOP) measurement using a Goldmann applanation tonometer. Uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA) were assessed using Snellen charts. The CDVA was always assessed using trial frames rather than contact lenses.

Corneal asphericity (Q-value), corneal HOAs and keratometry were evaluated using a Pentacam (OCULUS Optikgerate GmbH, Wetzlar, Germany). Corneal topography and HOAs were measured using videokeratoscopy (Keratron Scout topographer, Optikon 2000 SpA, Rome, Italy) under photopic conditions (270 lux), which were similar to those used for deciding a surgery plan under an operating microscope.

**Postoperative evaluation**

Patients were reviewed at 1 day, 1 week, 1, 3, and 6 months, and 1 and 2 years postoperatively. All
postoperative follow-up visits included the assessment of UDVA, CDVA, MR, and the recording of manual keratometry readings. Pentacam was used to evaluate keratometry, central corneal thickness (CCT), corneal asphericity (Q-value), and corneal HOAs.

**Surgical procedure**

All surgeries were targeted toward achieving emmetropia, and the treatment plan followed the Custom Ablation Manager protocol. Ablations were performed using the AMARIS 750S excimer laser (SCHWIND Eye-Tech Solutions, Kleinostheim, Germany). The aberration-free mode was used, in which ablation was performed with an optimized aspheric profile [13]. All surgeries were performed by a single experienced surgeon (CKJ). Topical anesthetic eye drops containing proparacaine (Alcaine, Alcon-Couvreur, Puur, Belgium) were administered. Femtosecond laser-assisted LASIK flaps were cut using the iFS Advanced Femtosecond Laser (Abbott Medical Optics, Inc., Irvine, CA, USA) with superior hinges, 100-μm flap thickness, and 8.4- or 8.5-mm flap diameters. Flap-off epi-LASIK was performed using the Epi-K™ epikeratome (Moria SA, Antony, France). After lifting the flap, ablation was performed on a 6.5-mm-diameter optical zone. The planned refractive correction (6.7-9.0 mm) of the ablation zone was carried out automatically in a variable transition zone size. MMC (0.02%) was placed on the residual bed for 5 seconds per diopter, after which the stromal surface was irrigated with a balanced salt solution, and a bandage contact lens (Senofilcon A, Acuvue Oasys; Johnson & Johnson, Jacksonville, FL, USA) was placed over the surgical site.

The patients were administered topical antibiotic eye drops 4 times/week, topical corticosteroid eye drops 4 times/day (tapered off over 1 week), and topical lubricants.

**Statistical analysis**

Data were entered into an Excel spreadsheet database (Microsoft, Redmond, WA, USA) and statistical analysis was performed using SPSS for Windows, version 18.0 (SPSS, Inc., Chicago, IL, USA). Normality of data distribution was tested using the Shapiro-Wilk test. The Wilcoxon rank-sum test and Mann-Whitney U test were used for nonparametric analysis. $P$-values of $<0.05$ were considered
significant.

Results

40 eyes of 27 patients were divided into two groups based on whether a flap was created by femtosecond laser during surgery (20 eyes in femto-LASIK) or not (20 eyes in flap-off epi-LASIK). The aberration-free treatment mode of the laser procedure was used for all patients. The characteristics of the two groups are summarized in Table 1. There were no significant differences between the baseline ophthalmic characteristics of the two groups.

Table 2 shows the comparative evaluation of the pre- and postoperative changes between the 2 groups. Keratometry was performed using a manual keratometer. There were no significant differences between the two groups with regard to the flattest keratometry reading (K₁), steepest keratometry reading (K₂), CCT, or Q-value (Ant. and Post.). Differences between pre- and postoperative K₁, K₂, CCT, and Q-value (Ant.) were significant for both the groups (all P < 0.05, in femto-LASIK; all P < 0.001, in flap-off epi-LASIK).

Changes in the corneal thickness spatial profile (CTSP) are shown in Table 3. There were no statistically significant differences in preoperative and postoperative CTSP values between the two groups at corneal ring diameters of 0-mm, 2-mm, 4-mm and 8-mm (all P > 0.05), but it was significantly thinner after flap-off epi-LASIK than after femto-LASIK at a ring diameter of 6-mm (P = 0.039). Further details can be found in Table 3.

The changes in UDVA and CDVA are shown in Figure 1. The mean changes in LogMAR UDVA (improvement) were significant in both the groups postoperatively (all P < 0.001). The improvement was more significant for femto-LASIK at 1 day and 1 week postoperatively (P < 0.001 and P = 0.019, respectively). There were statistically significant differences in CDVA at 1 day and 1 week postoperatively between the femto-LASIK and flap-off epi-LASIK groups (P = 0.026 and P = 0.009, respectively).

The mean preoperative manifest refraction spherical equivalent values were -5.94 ± 2.23 D and -5.94 ± 1.62 D for the femto-LASIK and flap-off epi-LASIK groups, respectively (P = 0.904). The postoperative refraction showed significantly greater myopic refraction errors after 1 day and 1 week.
in the flap-off epi-LASIK group than in the femto-LASIK group ($P < 0.001$ and $P = 0.009$, respectively), and there were statistically significant improvements in refraction errors in both groups from 1 day after refractive surgery (all $P < 0.001$) (Figure 2). Table 4 and Table 5 show the changes in HOAs of the front, back, and total cornea in the femto-LASIK and flap-off epi-LASIK groups. There was a significant reduction in the vertical coma ($Z_{3,-1}$) aberration, from -0.086 ± 0.251 μm to -0.393 ± 0.335 μm; the horizontal secondary astigmatism ($Z_{4,2}$) aberration, from 0.013 ± 0.051 μm to -0.113 ± 0.113 μm; and induction of spherical aberration (SA) ($Z_{4,0}$), from 0.271 ± 0.132 μm to 0.479 ± 0.139 μm, in the front corneal HOAs after femto-LASIK ($P = 0.021$, $P = 0.001$, and $P = 0.001$, respectively). In terms of total corneal HOAs changes, there was a significant reduction in the vertical coma ($Z_{3,-1}$) aberration, from -0.128 ± 0.215 μm to -0.368 ± 0.328 μm; horizontal secondary astigmatism ($Z_{4,2}$) aberration, from -0.007 ± 0.055 μm to -0.122 ± 0.117 μm; and induction of SA ($Z_{4,0}$), from 0.168 ± 0.061 μm to 0.430 ± 0.137 μm, after femto-LASIK ($P = 0.007$, $P = 0.004$, and $P < 0.001$, respectively). However, in terms of back corneal HOAs changes, there was a significant induction of vertical coma ($Z_{3,-1}$) aberration, from 0.013 ± 0.025 μm to 0.027 ± 0.027 μm; reduction of oblique trefoil ($Z_{3,-3}$) aberration, from -0.026 ± 0.042 μm to -0.055 ± 0.037 μm; and oblique tetrafoil ($Z_{4,-4}$) aberration, from 0.006 ± 0.030 μm to -0.008 ± 0.029 μm ($P = 0.015$, $P = 0.046$, and $P = 0.049$, respectively). In the flap-off epi-LASIK group, there was only significant induction of SA from 0.250 ± 0.128 μm to 0.626 ± 0.232 μm and from -0.156 ± 0.033 μm to 0.556 ± 0.227 μm in the front and total corneal HOAs after surgery (all $P < 0.001$). In the back corneal HOAs, there was a significant induction of horizontal secondary astigmatism ($Z_{4,2}$) aberration, from -0.001 ± 0.016 μm to 0.007 ± 0.018 μm; reduction of SA ($Z_{4,0}$), from -0.156 ± 0.033 μm to -0.163 ± 0.037 μm ($P = 0.027$ and $P = 0.011$, respectively).

When we compared the corneal HOA changes between the two groups after surgery, the increment in SA ($Z_{4,0}$) was greater in the flap-off epi-LASIK group than in the femto-LASIK group: 0.626 ± 0.232 μm and 0.479 ± 0.139 μm in the front cornea, and 0.556 ± 0.227 μm and 0.430 ± 0.137 μm in the total
cornea, respectively ($P = 0.016$ and $P = 0.017$, respectively). With regard to the back corneal HOAs, there were significant differences in vertical coma ($Z_{3,1}$) aberration: $0.027 \pm 0.027 \, \mu m$ (femto-LASIK) and $0.001 \pm 0.034 \, \mu m$ (flap-off epi-LASIK); horizontal secondary astigmatism ($Z_{4,2}$) aberration: $-0.008 \pm 0.012 \, \mu m$ (femto-LASIK) and $0.007 \pm 0.018 \, \mu m$ (flap-off epi-LASIK); oblique tetrafoil ($Z_{4,-4}$) aberration: $-0.008 \pm 0.029 \, \mu m$ (femto-LASIK) and $0.015 \pm 0.026 \, \mu m$ (flap-off epi-LASIK), respectively ($P = 0.018$, $P = 0.007$, and $P = 0.022$, respectively) (Figure 3).

Discussion

Many studies have investigated whether flap creation using a femtosecond laser (femto-LASIK) is more effective than that using a microkeratome (flap-on epi-LASIK) [6-9]. However, in the present study, we compared the outcomes between femto-LASIK and flap-off epi-LASIK. In previous studies, Kalyvianaki MI et al. [14] reported that flap-on epi-LASIK and flap-off epi-LASIK produced equivalent visual and refractive results for the treatment of low and moderate myopia. Furthermore, Na KS et al. [15] found that flap-off epi-LASIK yielded superior visual recovery and corneal re-epithelialization than flap-on epi-LASIK surgery in the early postoperative period.

Corneal haze with decreased corneal transparency is typically determined by corneal backward light scattering. It has been reported that the ablation volume may increase the degree of backscattering [16], and cases of severe myopia that require more ablation may require a higher dose of MMC during the refractive procedure [17,18]. Sia RK et al. [19] and Chen J et al. [20] reported that MMC was beneficial for reduction of corneal haze, without delaying epithelialization. The present study demonstrated little difference between the two techniques. Significantly better visual and refractive outcomes were associated with femto-LASIK than with the flap-off epi-LASIK at 1 day and 1 week postoperatively, with no additional significant differences during the remaining follow-up.

Myopic or hyperopic refractive surgery aims to correct the corneal shape by changing the keratometric power [4,21]. Huang J et al. [22] and Jain R et al. [23] confirmed obtaining highly repeatable results after LASIK using a Scheimpflug camera, with no significant difference between the automatic and manual keratometric readings [24]. In this study, we used the Scheimpflug camera to evaluate the outcomes after refractive surgery. We found that both procedures showed a statistically
significant decrease in CCT, keratometry readings, and ACD values after surgery. Dai ML and associates [25] reported that the anterior chamber depth was shallower in LASIK than in non-operated myopic eyes.

However, the surface ablation technique can help avoid numerous surgical complications arising from the creation of a lamellar corneal flap required in LASIK and can theoretically provide more stable corneal biomechanics. Shih PJ et al. [26] demonstrated that the corneal biomechanical simulation of stress concentration after refractive surgery, and they proposed that both surface and stromal ablation techniques caused stress in an obliquely downwards direction after surgery.

The concept of CTSP was first introduced by Ambrosio R Jr et al. [27]. Moreover, Buhren J et al. [28] found that the posterior aberrations and thickness spatial profile data did not markedly improve discriminative ability over that of anterior wavefront data alone. In our study, we used CTSP to evaluate changes in corneal thickness at different corneal diameters, and found that CTSP changes were significantly smaller in the flap-off epi-LASIK group than the femto-LASIK group at a corneal ring diameter of 6-mm; the CTSP changes in the central region were greater than at the mid-periphery. In addition, the corneal HOAs at the 6.5-mm diameter were significantly different in the front and total HOAs of SA, while few significant differences were found in posterior HOAs of vertical coma aberration, oblique trefoil aberration, and oblique tetrafoil aberration. We postulated that these changes in the CTSP may influence the changes in corneal HOAs and may also affect the Q-value (8 mm) changes after LASIK, in a manner dependent on the size of the optical zone being treated.

The effect of SA on the depth of focus has been investigated using adaptive optics systems [29]. The depth of focus, by definition, is relatively insensitive to focal length and subject distance for a fixed f-number. Typically, myopia is a condition in which light is focused in front of the retina rather than on it. However, corneal refractive surgery is the kind of refractive surgery that ablates the corneal tissue to change the accommodation power. Wallace HB et al. [30] found that ACD was significant reduced by 0.10 mm with accommodation, and statistically significant change in corneal curvatures were seen in all participants with accommodation.

The principle of refractive surgery is to induce positive SA shifts for the correction of myopia, and
negative shifts for hyperopic correction [31,32]. Moreover, the concept of the SCHWIND Amaris 750S excimer laser involves using the optimized aspheric profile [13] to prevent the surgically induced HOAs, especially SA and coma aberration. Although the amount of corneal SA and asphericity are intrinsically related, they provide a 2:1 correspondence between corneal and ocular SA [33]. However, in the present study, there were significant and slight inductions of SA before and after LASIK surgery in patients with low and moderate myopia (0.123 ± 0.217 μm in femto-LASIK and 0.124 ± 0.218 μm in epi-LASIK, respectively; data not shown), and much more significant induction of SA in patients with high myopia (0.305 ± 0.131 μm in femto-LASIK and 0.459 ± 0.149 μm in epi-LASIK, respectively; data not shown).

Total corneal refractive power involves compensation for negative posterior refractive power by positive anterior refractive power. Steepening of the anterior corneal surface increases the positive refractive power; when both surfaces bulge similarly, the anterior surface induces far greater absolute refractive changes than the posterior surface. According to our results, there were no statistically significant differences in SA between the two groups in patients with low and moderate myopia (femto-LASIK, 0.417 ± 0.140 μm; epi-LASIK, 0.419 ± 0.137 μm; P = 0.504, data not shown); however, there were statistically significant differences in patients with high myopia, and the postoperative SA was markedly higher in the flap-off epi-LASIK group (femto-LASIK, 0.550 ± 0.106 μm; flap-off epi-LASIK, 0.661 ± 0.158 μm; P = 0.013, data not shown).

The induced changes in corneal asphericity (Q) and SA after laser ablation are key factors associated with the selection of candidates for refractive surgery. Scheimpflug imaging provided reliable measurements, consistent with those reported in the literature; there was a positive change in the Q value of the anterior surface after myopic ablation and a negative change after hyperopic ablation [34].

Corneal aberrations are usually positive; aberrations of the lens are usually negative, and the total SA changed more than other HOAs with accommodation. Moreover, ocular wavefront aberrations are primarily created in the cornea and lens and are strongly affected by various factors, including the accommodative state [35], pupil diameter [36], tear film [37], age [38], and pupil entrance
decentration [39]. We found a statistically significant difference in postoperative SA between the two different surgical techniques, but found no clinically significant difference for 2 years postoperatively; femto-LASIK produced superior visual outcomes to flap-off epi-LASIK in the early postoperative stage. A meta-analysis shows that there were no statistically significant differences in either visual outcomes or visual quality between different corneal refractive surgery techniques and that femto-LASIK shows a better predictability than any other type of surgery. However, this study was limited by the small sample size; therefore, studies involving a larger population of patients are necessary to ensure more dependable results [40].

Conclusion
Refractive surgery has been regarded as an excellent surgical option, negating the need for contact lenses or glasses. Our study results indicated that both femto-LASIK and flap-off epi-LASIK was safe, effective, and predictable refractive surgeries. Femto-LASIK would be a better surgical option that provides less postoperative SA after surgery, and superior visual outcomes in the early postoperative stage. Preoperative corneal thickness should be considered when choosing corneal refractive surgery in clinical practice.

Abbreviations
Femto-LASIK = femtosecond laser-assisted in situ keratomileusis, Epi-LASIK = epipolis laser-assisted in situ keratomileusis, UDVA = uncorrected distance visual acuity, CDVA = corrected distance visual acuity, MR = manifest refraction, CS = contrast sensitivity, HOAs = higher-order aberrations, \( K_1 \) = flattest keratometry reading, \( K_2 \) = steepest keratometry reading, CCT = central corneal thickness, Q-value = corneal asphericity, AD = ablation depth, ACD = anterior chamber depth, RBT = preoperative predict residual bed thickness.

Declarations
-Ethics approval and consent to participate: This study was approved by the Ethics Committee of the Seoul St. Mary’s Hospital (Korea) and requirement for individual consent was waived (IRB Registry Number KC14RISI0570).

-Consent for publication: Not applicable
Availability of data and materials: The datasets obtained and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Authors’ contributions:
Conceived and designed the experiments: W-JW C-KJ.
Performed the experiments: C-KJ.
Analyzed the data: JP W-JW.
Contributed regents/materials/analysis tools: JP C-KJ.
Wrote the paper: JP.
All authors have read and approved the manuscript.

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Tables

Table 1. Preoperative Parameters between the two groups

| Parameter       | Femto-LASIK | Flap-off epi-LASIK | P-value |
|-----------------|-------------|--------------------|---------|
| SE (D)          | -5.94 ± 2.23| -5.94 ± 1.92       | 0.783   |
| K₁ (D)          | 42.35 ± 2.06| 42.50 ± 2.13       | 0.829   |
| K₂ (D)          | 43.53 ± 1.31| 43.79 ± 2.20       | 0.989   |
| AD (µm)         | 100.15 ± 34.13| 90.31 ± 27.57     | 0.813   |
| ACD (mm)        | 3.12 ± 0.26 | 3.25 ± 0.30        | 0.331   |
| RBT (µm)        | 365.00 ± 43.28| 331.95 ± 40.03    | 0.777   |
| CCT (µm)        | 597.15 ± 27.69| 552.15 ± 28.76    | 0.597   |

Femto-LASIK = femtosecond laser-assisted in situ keratomileusis; epi-LASIK = epipolis laser-assisted in situ keratomileusis; SE = spherical equivalent; K₁ = flat keratometry; K₂ = steep keratometry; AD = ablation depth; ACD = anterior chamber depth; RBT = preoperative predict residual bed thickness; CCT = central corneal thickness.

Table 2. Comparison of preoperative and postoperative changes in corneal biometric parameters between the two groups

| Parameter       | Femto-LASIK | Flap-off epi-LASIK | P-value |
|-----------------|-------------|--------------------|---------|
| K₁ (D)          |             |                    |         |
| Pre-op          | 42.65 ± 1.25| 42.81 ± 2.09       | 0.828   |
| Post-op         | 37.95 ± 2.52| 38.04 ± 2.33       | 0.692   |
| P-value*        | 0.001       | <0.001             |         |
| K₂ (D)          |             |                    |         |
| Pre-op          | 43.79 ± 1.47| 43.84 ± 2.11       | 0.766   |
| Post-op         | 38.74 ± 2.73| 38.61 ± 2.40       | 0.942   |
| P-value*        | 0.003       | <0.001             |         |
| CCT (µm)        |             |                    |         |
| Pre-op          | 597.15 ± 27.69| 552.15 ± 28.76   | 0.597   |
| Post-op         | 475.27 ± 28.89| 454.89 ± 43.54   | 0.086   |
| P-value*        | <0.001      | <0.001             |         |
| ACD (mm)        |             |                    |         |
| Pre-op          | 3.06 ± 0.24 | 3.28 ± 0.30        | 0.056   |
| Post-op         | 2.98 ± 0.22 | 3.19 ± 0.28        | 0.066   |
| P-value*        | 0.001       | <0.001             |         |
| Q-value (Ant.)  |             |                    |         |
| Pre-op          | -0.41 ± 0.13| -0.39 ± 0.18       | 0.732   |
| Post-op         | 0.88 ± 0.65 | 0.73 ± 0.33        | 0.732   |
| P-value*        | 0.001       | <0.001             |         |
| Q-value (Post.) |             |                    |         |
| Pre-op          | -0.30 ± 0.11| -0.30 ± 0.08       | 0.304   |
| Post-op         | -0.28 ± 0.10| -0.28 ± 0.09       | 0.231   |
| P-value*        | 0.068       | 0.337              |         |

K₁ = flattest keratometry reading; K₂ = steepest keratometry reading; CCT = central corneal thickness; Pre-op = preoperative; Post-op = postoperative; ACD = anterior chamber depth (between endothelium to anterior lens surface); Ant. = anterior corneal surface; Post. = posterior corneal surface; Q-value = corneal asphericity.
Table 3. Comparison of preoperative and postoperative changes in CTSP between the two groups

| Parameter       | Mean ± Standard Deviation | P-value |
|-----------------|---------------------------|---------|
|                 | Femto-LASIK | Flap-off epi-LASIK |         |
| 0 mm            |             |                   |         |
| Pre-op          | 574.45 ± 28.45 | 547.45 ± 28.34   | 0.381   |
| Post-op         | 473.53 ± 28.38 | 452.47 ± 43.15   | 0.074   |
| P-value         | <0.001      | <0.001            |         |
| 2 mm            |             |                   |         |
| Pre-op          | 584.30 ± 28.15 | 557.20 ± 27.87   | 0.418   |
| Post-op         | 490.67 ± 26.29 | 469.95 ± 42.37   | 0.068   |
| P-value         | <0.001      | <0.001            |         |
| 4 mm            |             |                   |         |
| Pre-op          | 614.90 ± 28.67 | 552.15 ± 28.76   | 0.431   |
| Post-op         | 546.53 ± 20.97 | 454.89 ± 43.54   | 0.066   |
| P-value         | <0.001      | <0.001            |         |
| 6 mm            |             |                   |         |
| Pre-op          | 668.95 ± 30.15 | 639.90 ± 27.30   | 0.531   |
| Post-op         | 634.93 ± 20.40 | 605.47 ± 49.14   | 0.039   |
| P-value         | <0.001      | <0.001            |         |
| 8 mm            |             |                   |         |
| Pre-op          | 752.40 ± 31.73 | 722.95 ± 31.84   | 0.889   |
| Post-op         | 731.20 ± 27.52 | 709.42 ± 41.02   | 0.074   |
| P-value         | 0.007       | 0.001             |         |

CTSP = corneal thickness spatial profile; Pre-op = preoperative; Post-op = postoperative.

Table 4. Comparison of preoperative and postoperative changes in corneal HOAs in femto-LASIK

| Parameter       | Preoperative | Postoperative | P-value |
|-----------------|--------------|---------------|---------|
| Front corneal HOAs |              |               |         |
| Z_{3,3}         | 0.006 ± 0.076 | -0.017 ± 0.149 | 0.644   |
| Z_{3,1}         | 0.007 ± 0.139 | -0.019 ± 0.471 | 0.845   |
| Z_{3,-1}        | -0.086 ± 0.251 | -0.393 ± 0.335 | 0.021   |
| Z_{3,-3}        | -0.056 ± 0.120 | 0.026 ± 0.176  | 0.206   |
| Z_{4,4}         | -0.024 ± 0.090 | -0.069 ± 0.073 | 0.233   |
| Z_{4,2}         | 0.013 ± 0.051 | -0.113 ± 0.113 | 0.001   |
| Z_{4,0}         | 0.271 ± 0.132 | 0.479 ± 0.139  | 0.001   |
| Z_{4,-2}        | -0.016 ± 0.047 | 0.005 ± 0.089  | 0.479   |
| Z_{4,-4}        | 0.007 ± 0.076 | 0.034 ± 0.126  | 0.496   |
| Back corneal HOAs |              |               |         |
| Z_{3,3}         | 0.008 ± 0.048 | 0.009 ± 0.052  | 0.971   |
| Z_{3,1}         | -0.001 ± 0.025 | 0.004 ± 0.035  | 0.463   |
| Z_{3,-1}        | 0.013 ± 0.025 | 0.027 ± 0.027  | 0.015   |
| Z_{3,-3}        | -0.026 ± 0.042 | -0.055 ± 0.037 | 0.046   |
| Z_{4,4}         | -0.038 ± 0.035 | -0.041 ± 0.038 | 0.695   |
| Z_{4,2}         | -0.009 ± 0.014 | -0.008 ± 0.012 | 0.695   |
| Z_{4,0}         | -0.143 ± 0.017 | -0.140 ± 0.024 | 0.277   |
| Z_{4,-2}        | 0.003 ± 0.013 | -0.001 ± 0.016 | 0.339   |
| Z_{4,-4}        | 0.006 ± 0.030 | -0.008 ± 0.029 | 0.049   |
| Total corneal HOAs |              |               |         |
| Z_{3,3}         | 0.042 ± 0.114 | -0.008 ± 0.157 | 0.339   |
| Z_{3,1}         | -0.001 ± 0.131 | -0.015 ± 0.450 | 0.878   |
| Z_{3,-1}        | -0.128 ± 0.215 | -0.368 ± 0.328 | 0.007   |
| Z_{3,-3}        | -0.031 ± 0.122 | -0.023 ± 0.173 | 0.883   |
| Z_{4,4}         | -0.096 ± 0.091 | -0.108 ± 0.064 | 0.659   |
| Z_{4,2}         | -0.007 ± 0.055 | -0.122 ± 0.055 | 0.004   |
| Z_{4,0}         | 0.168 ± 0.061 | -0.430 ± 0.137 | <0.001  |
| Z_{4,-2}        | -0.016 ± 0.047 | 0.004 ± 0.098  | 0.538   |
| Z_{4,-4}        | 0.002 ± 0.089 | 0.033 ± 0.133  | 0.423   |

HOAs = higher-order aberrations; femto-LASIK = femtosecond laser-assisted in situ keratomileusis.
Table 5. Comparison of preoperative and postoperative changes in corneal HOAs in flap-off epi-LASIK

| Parameter                  | Mean ± Standard Deviation | P-value |
|----------------------------|---------------------------|---------|
|                            | Preoperative | Postoperative |         |
| **Front corneal HOAs**     |              |              |         |
| Z₃,₃                      | 0.020 ± 0.076 | 0.033 ± 0.157 | 0.702   |
| Z₃,₁                      | 0.022 ± 0.151 | -0.019 ± 0.476 | 0.666   |
| Z₃,-₁                     | -0.082 ± 0.229 | -0.191 ± 0.303 | 0.128   |
| Z₃,-₃                     | -0.059 ± 0.104 | -0.004 ± 0.204 | 0.217   |
| Z₄,₄                      | -0.020 ± 0.084 | -0.021 ± 0.091 | 0.975   |
| Z₄,₂                      | 0.000 ± 0.051 | -0.060 ± 0.173 | 0.141   |
| Z₄,₀                      | 0.250 ± 0.128 | 0.626 ± 0.232 | <0.001  |
| Z₄,-₂                     | -0.015 ± 0.044 | -0.014 ± 0.088 | 0.947   |
| Z₄,-₄                     | 0.007 ± 0.070 | 0.006 ± 0.146 | 0.975   |
| **Back corneal HOAs**      |              |              |         |
| Z₃,₃                      | 0.001 ± 0.063 | 0.000 ± 0.063 | 0.968   |
| Z₃,₁                      | -0.006 ± 0.026 | -0.006 ± 0.039 | 0.913   |
| Z₃,-₁                     | -0.002 ± 0.035 | 0.001 ± 0.034 | 0.464   |
| Z₃,-₃                     | -0.028 ± 0.041 | -0.023 ± 0.054 | 0.639   |
| Z₄,₄                      | -0.035 ± 0.027 | -0.041 ± 0.028 | 0.147   |
| Z₄,₂                      | -0.001 ± 0.016 | 0.007 ± 0.018 | 0.027   |
| Z₄,₀                      | -0.156 ± 0.033 | -0.163 ± 0.037 | 0.011   |
| Z₄,-₂                     | -0.004 ± 0.011 | -0.005 ± 0.014 | 0.796   |
| Z₄,-₄                     | 0.013 ± 0.025 | 0.015 ± 0.026 | 0.713   |
| **Total corneal HOAs**     |              |              |         |
| Z₃,₃                      | 0.020 ± 0.063 | 0.035 ± 0.180 | 0.692   |
| Z₃,₁                      | 0.015 ± 0.026 | -0.026 ± 0.456 | 0.653   |
| Z₃,-₁                     | -0.077 ± 0.035 | -0.185 ± 0.302 | 0.179   |
| Z₃,-₃                     | -0.084 ± 0.041 | -0.024 ± 0.216 | 0.211   |
| Z₄,₄                      | -0.053 ± 0.027 | -0.059 ± 0.091 | 0.815   |
| Z₄,₂                      | -0.004 ± 0.016 | -0.056 ± 0.171 | 0.201   |
| Z₄,₀                      | 0.194 ± 0.033 | 0.556 ± 0.227 | <0.001  |
| Z₄,-₂                     | -0.019 ± 0.011 | -0.018 ± 0.095 | 0.959   |
| Z₄,-₄                     | 0.019 ± 0.025 | 0.021 ± 0.137 | 0.955   |

HOAs = higher-order aberrations; epi-LASIK = epipolis laser-assisted in situ keratomileusis.

Figures
Figure 1

UDVA and CDVA before and after femto-LASIK and flap-off epi-LASIK treatments (UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; femto-LASIK = femtosecond laser-assisted in situ keratomileusis; epi-LASIK = epipolis laser-assisted in situ keratomileusis).
Spherical equivalent refraction measured preoperatively (Pre-op) and at 1 day (d), 1 week (w), 1, 3, 6 months (M), 1 and 2 years (Y) after femto-LASIK and flap-off epi-LASIK (D = diopters) (femto-LASIK = femtosecond laser-assisted in situ keratomileusis; epi-LASIK = epipolis laser-assisted in situ keratomileusis).
Comparison of changes in the corneal higher-order aberrations (HOAs) between femto-LASIK and flap-off epi-LASIK (A. The differences in postoperative corneal HOAs between femto-LASIK and flap-off epi-LASIK in the front cornea; B. The differences in postoperative corneal HOAs between femto-LASIK and flap-off epi-LASIK in the back cornea; C. The differences in postoperative corneal HOAs between femto-LASIK and flap-off epi-LASIK in the total cornea) (femto-LASIK = femtosecond laser-assisted in situ keratomileusis; epi-LASIK = epipolis laser-assisted in situ keratomileusis).