

Comparison of Visual Outcomes for Myopia after Refractive Surgery using Femtosecond Laser-assisted and Epipolis LASIK

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Abstract

Background This prospective cohort study clinically evaluated the visual outcomes after refractive surgery for myopia using femtosecond laser-assisted in situ keratomileusis (femto-LASIK) and epipolis LASIK (flap-off epi-LASIK). **Methods** Forty eyes of 27 patients were divided into 2 groups in this prospective cohort study. Femto-LASIK flaps were created using a femtosecond laser; epi-LASIK flaps (flap-off) were made using and Epi-K TM epikeratome. 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 for femto-LASIK at 1 day and 1 week postoperatively ($P < 0.001$, $P = 0.019$, respectively). In analysis of 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). In analysis of the back corneal HOAs, there were significant differences in vertical coma (Z 3,-1) aberration 0.027 ± 0.027 (femto-LASIK) and 0.001 ± 0.034 (flap-off epi-LASIK); horizontal secondary astigmatism (Z 4,2) aberration -0.008 ± 0.012 (femto-LASIK) and 0.007 ± 0.018 (flap-off epi-LASIK); oblique tetrafoil (Z 4,-4) aberration -0.008 ± 0.029 (femto-LASIK) and 0.015 ± 0.026 (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 that by flap-off epi-LASIK, but there was no significant difference between the outcomes of the 2 procedures 1 week postoperatively.

Precis

We compared the outcomes after LASIK surgery for correction of myopia or myopic astigmatism using a six-dimensional Amaris excimer laser, and found that both femto-LASIK and flap-off epi-LASIK are safe, effective, and predictable.

Background

The refractive power of the eye changes during growth and maturation. Myopia, a condition in which the cornea focuses light in front of the retina rather than directly on it, has become the most common medical condition in younger patients. Conventionally, orthokeratology (ortho-k) has been used to correct corneal shape and to slow axial elongation of the eye during childhood [1,2]. However, refractive surgery may be more effective than ortho-k lens application for cases of moderate or severe myopia in patients older than 20 years [3].

In the early 1990s, photorefractive keratectomy (PRK) was first introduced for the surgical correction of myopia [4]; 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 epipolis LASIK (epi-LASIK) have emerged as new approaches in the field of refractive surgery.

Numerous studies have compared the visual outcomes of femto-LASIK and epi-LASIK (flap creation using a microkeratome) by comparing anterior corneal refraction errors [5-9]. Early after refractive surgery, there was slightly more forward straylight after the femto-LASIK procedure than after other refractive surgery techniques; and this was significantly increased throughout the follow-up period after epi-LASIK surgery (flap creation using a epikeratome) [10].

Depending on whether it was performed with or without a flap, epi-LASIK is divided into flap-on and flap-off epi-LASIK. Ang et al. [11] and Zhang et al. [12] reported that flap-off epi-LASIK with mitomycin C (MMC) results in less pain, corneal haze, and faster visual recovery, while visual results, refractive outcomes, contrast sensitivity (CS), and higher-order aberrations (HOAs) were comparable with that in flap-on epi-LASIK. Wen and associates [13] published a network meta-analysis to compare visual outcomes and quality; they showed that there were no statistically significant difference in either visual outcomes (efficacy and safety) or visual quality (HOAs and CS), but femto-LASIK was more predictable than any other type of surgery. Additionally, thinner corneas, higher intraocular pressure (IOP), and higher myopia requiring greater laser ablation are more predisposed to anterior shift of the cornea [14].

In principle, Pentacam is using scheimpflug camera to determinate corneal tomography and topography to provide more detailed corneal information [15-17]. The aim of the present study was to compare the visual outcomes and refractive error changes in the anterior and posterior surfaces and the effectiveness of 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 study. This prospective cohort 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 received refractive surgery to correct 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 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 retreatment cases. Patients had 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 investigation included a 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 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 (1500 lux), similar to those under an operating microscope for deciding a surgery plan.

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. The Pentacam was used to evaluate central corneal thickness (CCT), corneal asphericity (Q-value), and corneal HOAs.

Surgical procedure

All surgeries targeted 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 [18]. 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- μ m flap thickness, and 8.4- or 8.5-mm flap diameters. Flap-off epi-LASIK was performed using the Epi-KTM 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

Forty eyes of 27 patients were divided into 2 groups based on whether a flap was created by femtosecond laser during surgery (femto-LASIK) or not (flap-off epi-LASIK). The aberration-free treatment mode of the laser procedure was used for all patients. The characteristics of the 2 groups are summarized in Table 1. There were no significant differences between the baseline ophthalmic characteristics of the 2 groups.

Table 2 shows the comparative evaluation of the pre- and postoperative changes between the 2 groups. Keratometry measurement was performed using a manual keratometer. There were no significant differences between the 2 groups for the flattest keratometry reading (K_1), steepest keratometry reading (K_2), CCT, or Q-value (Ant. and Post.). The pre- and postoperative changes in K_1 , K_2 , 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).

The changes in the corneal thickness spatial profile (CTSP) are shown in Table 3. There were no statistically significant differences in preoperative and postoperative values between the 2 groups at the 0-mm, 2-mm, 4-mm and 8-mm rings of the cornea (all $P > 0.05$), but was statistically significant thinner after flap-off epi-LALSİK than after femto-LASİK at the 6-mm ring ($P = 0.039$). 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 for both groups postoperatively (all $P < 0.001$). The improvement was more significant for femto-LASİK at 1 day and at 1 week postoperatively ($P < 0.001$ and $P = 0.019$, respectively). There were statistically significant differences in CDVA at 1 day and at 1 week postoperatively between the femto-LASİK and flap-off epi-LASİK groups ($P = 0.026$ and $P = 0.009$, respectively).

The mean preoperative manifest refraction spherical equivalent (MRSE) was -5.94 ± 2.23 and -5.94 ± 1.62 D for the femto-LASIK and flap-off epi-LASIK groups, respectively ($P = 0.904$). The postoperative refraction showed statistically significantly greater myopic refraction errors after 1 day and 1 week in the flap-off epi-LASIK 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).

Figure 3 shows 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 to -0.393 ± 0.335 , and the horizontal secondary astigmatism ($Z_{4,2}$) aberration, from 0.013 ± 0.051 to -0.113 ± 0.113 , and induction of spherical aberration (SA) ($Z_{4,0}$), from 0.271 ± 0.132 to 0.479 ± 0.139 , 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 to -0.368 ± 0.328 , and in the horizontal secondary astigmatism ($Z_{4,2}$) aberration, from -0.007 ± 0.055 to -0.122 ± 0.117 , and induction of SA ($Z_{4,0}$) aberration, from 0.168 ± 0.061 to 0.430 ± 0.137 , 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 to 0.027 ± 0.027 , and reduction of oblique trefoil ($Z_{3,-3}$) aberration, from -0.026 ± 0.042 to -0.055 ± 0.037 , and oblique tetrafoil ($Z_{4,-4}$) aberration, from 0.006 ± 0.030 to -0.008 ± 0.029 ($P = 0.015$, $P = 0.046$, and $P = 0.049$, respectively). In flap-off epi-LASIK, there was only significant induction of SA from 0.250 ± 0.128 to 0.626 ± 0.232 and from -0.156 ± 0.033 to 0.556 ± 0.227 in the front and total corneal HOAs after surgery (all $P < 0.001$). In the back corneal HOAs, there was significant induction of horizontal secondary astigmatism ($Z_{4,2}$) aberration, from -0.001 ± 0.016 to 0.007 ± 0.018 , and reduction of SA ($Z_{4,0}$) aberration, from -0.156 ± 0.033 to -0.163 ± 0.037 ($P = 0.027$ and $P = 0.011$, respectively).

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

Discussion

Many studies have investigated whether flap creation using a femtosecond laser is more effective than flap creation using a microkeratome. However, in the present study, we compared the outcomes between

femto-LASIK and epi-LASIK (flap creation using a epikeratome which is more thinner flap creation than microkeratome). In addition, in previous studies, Kalyvianaki MI et al. [19] reported that epi-LASIK and off-flap epi-LASIK produced equal visual and refractive results for the treatment of low and moderate myopia. Another study by Na et al. [20] found that off-flap epi-LASIK yielded superior visual recovery and corneal re-epithelialization than epi-LASIK surgery in the early postoperative period. In addition, femto-LASIK surgery, despite allowing accurate, safe, and predictable in flap creation, occasionally involves either intraoperative or postoperative complications [21]. Hence, in the current study, we clinically compared the visual and refractive outcomes between femto-LASIK and flap-off epi-LASIK surgery in myopia or myopic astigmatism; however, we found no statistically significant differences in these outcomes for two years between the groups.

In generally, surface ablation techniques (such as photorefractive keratectomy [PRK], transepithelial photorefractive keratectomy [T-PRK], laser epithelial keratomileusis [LASEK], and epipolis laser in situ keratomileusis [epi-LASIK]) results in less painful and offer faster visual rehabilitation than stromal ablation methods (such as laser in situ keratomileusis with a flap created either mechanically with a microkeratome or with a femtosecond laser-based microkeratome [femto-LASIK]).

Meanwhile, 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 [22], and cases of severe myopia that require more ablation may require a higher dose of MMC during the refractive procedure [23,24]. Sia et al. [25] and Chen et al. [26] reported that MMC was beneficial for reduction of corneal haze, without delaying epithelialization. The present study demonstrated little difference. There was statistically significant improvement of visual acuity and refractive errors by 1 day and 1 week in the femto-LASIK group, as compared to the flap-off epi-LASIK group; however, similar outcomes were achieved between the 2 different surgical techniques during the remaining follow-up period.

The principle of refractive surgery is to induce positive SA shifts for correction of myopia, and negative shifts for hyperopic correction [27,28]. Moreover, the concept of the SCHWIND Amaris 750S excimer laser involves using the optimized aspheric profile [18] to prevent the surgically induced HOAs, especially SA and coma aberration. However, there were statistically significant and slight induction of SA between preoperative and postoperative LASIK surgery in low and moderate myopic patients (0.123 ± 0.217 in femto-LASIK and 0.124 ± 0.218 in epi-LASIK, respectively; data not shown), and much more significant induction of SA in high myopic patients (0.305 ± 0.131 in femto-LASIK and 0.459 ± 0.149 in epi-LASIK, respectively; data not shown).

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 focuses in front of the retina rather than on it. Myopic or hyperopic refractive surgery aims to correct the corneal shape by changing the keratometric power [11,30].

Huang et al. [31] and Jain et al. [32] confirmed obtaining highly repeatable results after LASIK using a Scheimpflug camera, with no significant difference in keratometry readings compared to those provided by manual keratometry [33]. In this study, we also used the Scheimpflug camera to evaluate the outcomes after refractive surgery. We found that both procedures showed a statistically significant decrease in CCT and reduced the keratometry readings. We also found changes of keratometry due to ablation of the keratometry axis. This ablation technique was achieved by balancing the negative and positive cylinder ablations to create a more aspherical optical zone [18].

The induced changes in corneal asphericity (Q) and SA after laser ablation are key factors when selecting 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].

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 2 groups in low and moderate myopic patients (0.417 ± 0.140 in femto-LASIK and 0.419 ± 0.137 in epi-LASIK, respectively; $P = 0.504$, data not shown); however, there were statistically significant differences in high myopic patients, and the postoperative SA was markedly higher in the flap-off epi-LASIK group (0.550 ± 0.106 in femto-LASIK and 0.661 ± 0.158 in epi-LASIK, respectively; $P = 0.013$, data not shown).

However, Shih et al. [35] demonstrated that Bowman's membrane and Descemet's membrane, as a pair of forces, provided approximately 20% of the rigidity against bending, despite their being very thin. After refractive surgery, the disruption of Bowman's or Descemet's layer had been associated with corneal ectasia. Moreover, corneal posterior surface elevation can be used to diagnose keratoconus and forme fruste keratoconus (FFKC). In addition, previous studies have focused on the biomechanical simulation of stress concentration after refractive surgery [35], and they proposed that both surface and stromal ablation techniques caused stress in an obliquely downwards direction after surgery. The present study revealed that the posterior surface underwent more oblate changes after surgery, and there were no accidents of keratectasia after refractive surgery. Dai and associates [36] reported that the anterior chamber depth was shallower in LASIK patients than in non-operated myopic eyes. However, in our study results, although there were significant changes in anterior chamber depth after surgery, and there were no statistically significant differences between 2 groups.

The cornea is an elastic and pellucid connective tissue. After refractive surgery, corneal curvature and opacity may influence the postoperative visual outcomes. The concept of CTSP was first introduced by Ambrosio et al. [37]. Bühren et al. [38] performed discriminant analysis in subclinical keratoconus and normal eyes by using corneal anterior and posterior surface aberrations and thickness spatial profiles. They 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 corneal thickness changes with different corneal diameters. We found that CTSP changes were significantly smaller in the flap-off epi-LASIK than the femto-LASIK group at the 6-mm ring of the cornea, and the CTSP changes in the central region were greater than at the mid-periphery. Zernike polynomial equation can be used for characterization of wavefront aberrations of the human eye and for complex corneal shapes. In this study, the corneal HOAs at the 6.5-mm diameter were statistically 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 principle of Scheimpflug imaging analysis systems involves examining slit images of light scattering of the anterior segment of the eyes light [39]; the different surgical techniques had different effects on corneal elasticity and backward light scattering after refractive surgery.

Aberrations include lower-order and higher-order components. Corneal aberrations are usually positive; aberrations of the lens are usually negative, and the total spherical aberration (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 [40], pupil diameter [41], tear film [42], age [43], and pupil entrance decentration [44]. We found a statistically significant difference in postoperative SA between the 2 different surgical techniques, but found no clinically significant difference for 2 years postoperatively, and femto-LASIK produced superior visual outcomes to flap-off epi-LASIK in the early postoperative stage.

Furthermore, the corneal epithelium comprises superficial, wing, and basal cells. Flap-off epi-LASIK involved separation using an Epi-KTM epikeratome, and the absence of the epithelium was a factor in corneal repairing. It has been verified that the epithelial flap acts as a barrier that protects the eye from inflammatory mediators and infectious bacteria, and stabilizes the tear film. It suggests that the epithelial layer played an important role in visual outcomes in case of myopia with low astigmatism. In addition, Zhou et al. [45] investigated the factors associated with optical and visual quality after epi-LASIK in high myopic patients, and found that designing a larger optical zone diameter was recommended to achieve better visual quality after surgery.

This study was limited by the small sample size; therefore, studies involving a larger population of patients are necessary to ensure more dependable results [46].

Conclusions

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. Moreover, we found that flap-off epi-LASIK was an effective surgical technique for patients, without accidents of corneal ectasia after refractive surgery. Femto-LASIK would

be a better surgical option that provides less postoperative SA after surgery, and superior visual outcomes in the early postoperative stage.

Abbreviations

Femto-LASIK = femtosecond laser-assisted in situ keratomileusis, Epi-LASIK = epipolis LASIK, 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

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 reagents/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 Femo-LASIK and Flap-off epi-LASIK | | | |
|--|-------------------------------|--------------------|---------|
| Parameter | Mean \pm Standard Deviation | | P-value |
| | Femto-LASIK | Flap-off epi-LASIK | |
| SE (D) | -5.94 \pm 2.23 | -5.94 \pm 1.92 | 0.783 |
| K ₁ (D) | 42.35 \pm 2.06 | 42.50 \pm 2.13 | 0.829 |
| K ₂ (D) | 43.53 \pm 1.31 | 43.79 \pm 2.20 | 0.989 |
| AD (μ m) | 100.15 \pm 34.13 | 90.31 \pm 27.57 | 0.813 |
| ACD (mm) | 3.12 \pm 0.26 | 3.25 \pm 0.30 | 0.331 |
| RBT (μ m) ^a | 365.00 \pm 43.28 | 331.95 \pm 40.03 | 0.777 |
| CCT (μ m) | 597.15 \pm 27.69 | 552.15 \pm 28.76 | 0.597 |

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.

| Parameter | Mean \pm Standard Deviation | | <i>P</i> -value |
|------------------|-------------------------------|--------------------|-----------------|
| | Femto-LASIK | Flap-off epi-LASIK | |
| K_1 (D) | | | |
| Pre-op | 42.65 \pm 1.25 | 42.81 \pm 2.09 | 0.828 |
| Post-op | 37.95 \pm 2.52 | 38.04 \pm 2.33 | 0.692 |
| <i>P</i> -value* | 0.001 | <0.001 | |
| K_2 (D) | | | |
| Pre-op | 43.79 \pm 1.47 | 43.84 \pm 2.11 | 0.766 |
| Post-op | 38.74 \pm 2.73 | 38.61 \pm 2.40 | 0.942 |
| <i>P</i> -value* | 0.003 | <0.001 | |
| CCT (μ m) | | | |
| Pre-op | 597.15 \pm 27.69 | 552.15 \pm 28.76 | 0.597 |
| Post-op | 475.27 \pm 28.89 | 454.89 \pm 43.54 | 0.086 |
| <i>P</i> -value* | <0.001 | <0.001 | |
| ACD (mm) | | | |
| Pre-op | 3.06 \pm 0.24 | 3.28 \pm 0.30 | 0.056 |
| Post-op | 2.98 \pm 0.22 | 3.19 \pm 0.28 | 0.066 |
| <i>P</i> -value* | 0.001 | <0.001 | |
| Q-value (Ant.) | | | |
| Pre-op | -0.41 \pm 0.13 | -0.39 \pm 0.18 | 0.732 |
| Post-op | 0.88 \pm 0.65 | 0.73 \pm 0.33 | 0.732 |
| <i>P</i> -value* | 0.001 | <0.001 | |
| Q-value (Post.) | | | |
| Pre-op | -0.30 \pm 0.11 | -0.30 \pm 0.08 | 0.304 |
| Post-op | -0.28 \pm 0.10 | -0.28 \pm 0.09 | 0.231 |
| <i>P</i> -value* | 0.068 | 0.337 | |

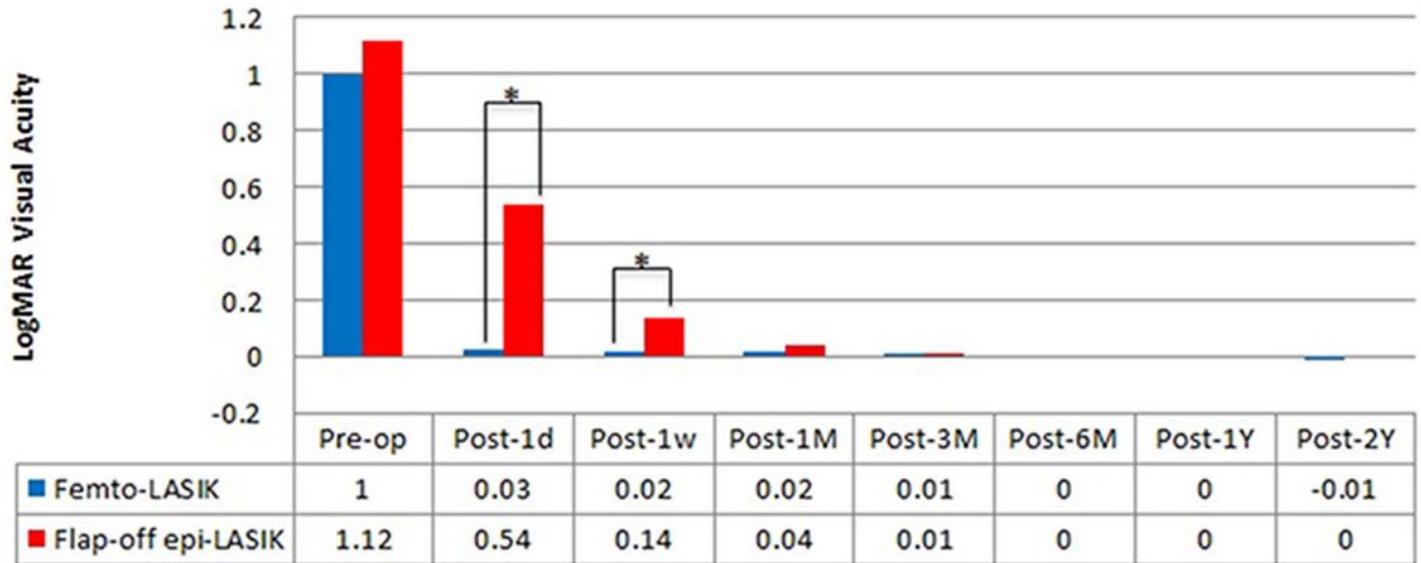
K_1 = flattest keratometry reading; K_2 = steepest keratometry reading; CCT = central corneal thickness; Pre-op = preoperative; Post-op = postoperative; ACD = anterior chamber depth (between endothelium to anterior lens surface); Ant. = anterior corneal surface; Post. = posterior corneal surface; Q-value = corneal asphericity.

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

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

Figures

UDVA



CDVA



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 LASIK).

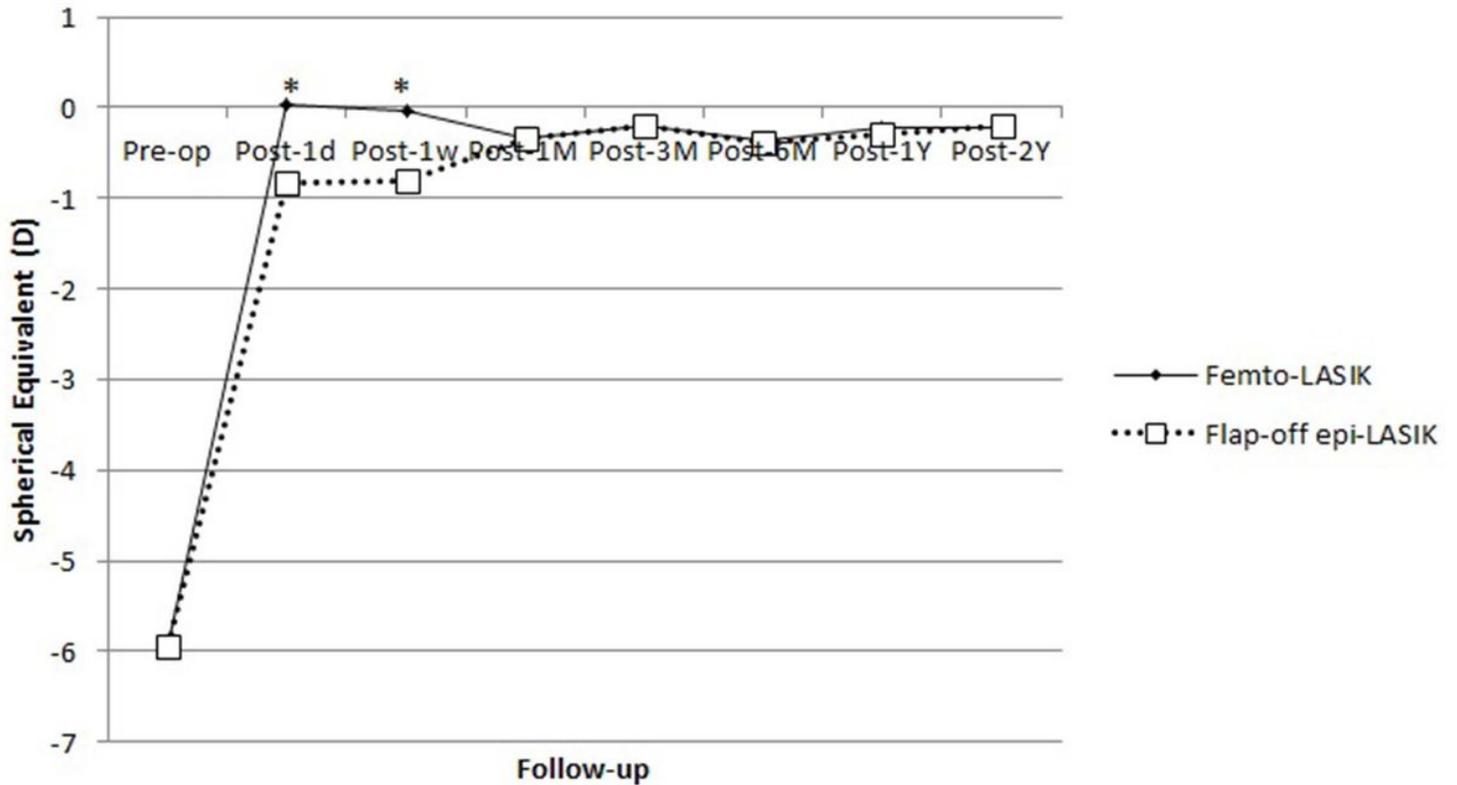


Figure 2

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).

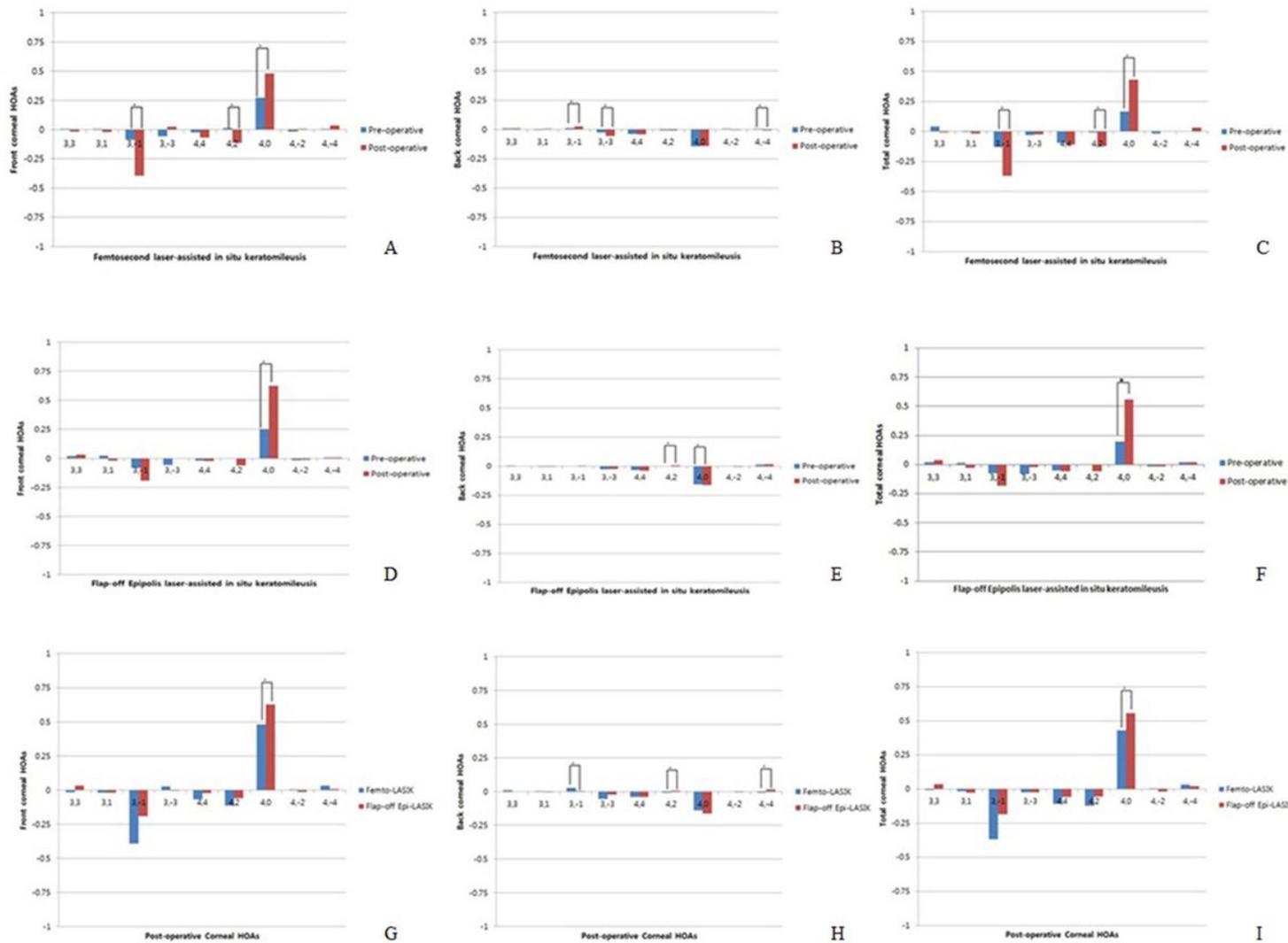


Figure 3

Comparison of the corneal higher-order aberrations (HOAs) changes between femto-LASIK and flap-off epi-LASIK (A. The front corneal HOAs changes between pre- and postoperative in femto-LASIK; B. The back corneal HOAs changes between pre- and postoperative in femto-LASIK; C. The total corneal HOAs changes between pre- and postoperative in femto-LASIK; D. The front corneal HOAs changes between pre- and postoperative in flap-off epi-LASIK; E. The back corneal HOAs changes between pre- and postoperative in flap-off epi-LASIK; F. The total corneal HOAs changes between pre- and postoperative in flap-off epi-LASIK; G. The differences in postoperative corneal HOAs between femto-LASIK and flap-off epi-LASIK in the front cornea; H. The differences in postoperative corneal HOAs between femto-LASIK and flap-off epi-LASIK in the back cornea; I. The differences in postoperative corneal HOAs between femto-LASIK and flap-off epi-LASIK in the total cornea).