Flap lift and photorefractive keratectomy enhancements after primary laser in situ keratomileusis using a wavefront-guided ablation profile: Refractive and visual outcomes

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PURPOSE: To analyze results of wavefront-guided laser vision correction retreatments performed either by lifting the original flap or by surface ablation over the flap.

SETTING: Optical Express, Glasgow, United Kingdom.

DESIGN: Retrospective case series.

METHODS: This retrospective study included patients grouped according to whether they had flap lift enhancement or photorefractive keratectomy (PRK) performed over the LASIK flap. All retreatment procedures were performed with the Visx Star S4 IR excimer laser with wavefront-guided ablation profile derived from the iDesign aberrometer. Visual acuities, refractive outcomes, vector analysis of refractive cylinder and complications were analyzed in this study. The results of the last available clinical visit are presented.

RESULTS: This retrospective study included 290 eyes of 202 patients divided into 2 groups: 119 eyes that had flap lift enhancement (Group A), and 171 eyes in which photorefractive keratectomy (PRK) was performed over the LASIK flap (Group B). The mean follow-up was 4.0 ± 1.9 months in Group A and 4.2 ± 1.6 in Group B. The mean postoperative manifest spherical equivalent was −0.01 ± 0.35 D and +0.06 ± 0.39 D in Groups A and B, respectively. The percentage of eyes with postenhancement UDVA 20/20 or better was 87.4% in Group A and 79.5 % in Group B ($P = .09$). In Group A, 22 eyes (18.5%) developed epithelial ingrowth, of which surgical intervention was required in 2 eyes (1.7%). Grade 1 or less haze was noted in 9 (5.3%) eyes in Group B, and resolved in all cases within the first 6 postoperative months.

CONCLUSION: Both retreatment techniques were considered to be effective, predictable, and safe.

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Although laser in situ keratomileusis (LASIK) is a well established technique for the surgical correction of refractive errors, undercorrection or overcorrection occurs in a small percentage of eyes, and, in some cases, retreatment may be necessary to improve unaided visual outcomes and patient satisfaction. The reported enhancement rate in the literature ranges between approximately 5% and 14%.[1–5] Various techniques have been proposed for the correction of residual refractive error after initial LASIK, such as lifting the original flap,[1,2,4,6–14] creating a new flap,[7,8] undersurface ablation of the flap stroma,[15,16] or surface ablation techniques.[17–23]

The use of wavefront technology in retreating eyes with previous excimer laser surgery has already been discussed.[9,24,25] The aim of the current study was to assess refractive predictability, visual acuity, and short-term postoperative complications in a large

cohort of patients undergoing wavefront-guided enhancement of previous wavefront-guided LASIK using 1 of 2 techniques (flap lift versus surface ablation on the existing flap).

SUBJECTS AND METHODS

A retrospective data review was performed to identify patients who had retreatment for residual refractive errors after primary LASIK between December 2013 and August 2014 by 1 of 2 techniques: lifting the original LASIK flap or surface ablation over the flap. The study was deemed exempt from full review by the Committee of Human Research at the University of California, San Francisco, because it used only retrospective, de-identified patient data. Informed consent to undergo primary and enhancement procedures was obtained from all patients.

Criteria for eye retreatment were residual refractive error with patient noting suboptimal uncorrected vision, a minimum of 1 line of improvement between uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA), and a stable manifest refraction of no more than a 0.50 D change in either sphere or cylinder documented over a minimum of 3 months. Only patients with a follow-up of 3 months or more postenhancement were included in this study. Exclusion criteria were active ophthalmic diseases, abnormal corneal shape, concurrent medications or medical conditions that could impair healing, and calculated residual stromal bed of less than 250 μm.

The ophthalmic examination before initial treatment and retreatment included manifest and cycloplegic refraction, monocular and binocular UDVA, CDVA using a calibrated projected eye chart, low-light pupil diameter, slitlamp biomicroscopy, dilated fundus examination, applanation tonometry, corneal topography, ultrasound pachymetry, and wavefront aberration measurement. All patients underwent follow-up at 1 day, 1 week, 1 month, and 3 months and thereafter as required. Data from the last available postoperative visit are presented in this study. Manifest refraction, UDVA, CDVA, and slitlamp examinations were performed postoperatively.

All primary LASIK procedures were performed with the Visx Star S4 IR excimer laser (Abbott Medical Optics, Inc.) using a wavefront-guided or conventional ablation profile. The majority of eyes had corneal flaps created with a femtosecond laser (IntraLase iFS; Abbott Medical Optics, Inc.), and a mechanical microkeratome (Moria Evo3 One Use-Plus microkeratome; Moria SA) was used in the remaining eyes. Retreatment was carried out by lifting the original LASIK flap or by performing photorefractive keratectomy on the flap.

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Surgeon preference determined the type of enhancement procedure. Generally, surgeons preferred a flap lift enhancement in patients who were within 12 to 18 months of their primary treatment and often used PRK beyond 12 months (164 eyes). Other criteria for PRK included an unsuccessful attempted flap lift, fibrosis around flap margins after primary LASIK, and an insufficient residual stromal bed.

Surgical Technique

The surgerical procedures were performed at Optical Express Clinics in the United Kingdom by 20 surgeons. For the flap-lift retreatment, the eye was anesthetized with topical proxymetacaine hydrochloride 0.5%, and then the flap edge was identified and marked with a sterile pen at the slitlamp. From the slitlamp, the patient was moved to the laser room, and a Sinskey hook was used to separate the flap edge for several millimeters. Using a blunt spatula, the flap was dissected fully to the hinge and retracted, the excimer laser treatment was applied, and the flap was returned into place. A therapeutic contact lens was used overnight according to the surgeon's preference. Postoperative medication consisted of topical levofloxacin 0.5% and topical prednisolone acetate 1% 4 times a day for 1 week.

In eyes having surface ablation, the eye was anaesthetized with topical proxymetacaine hydrochloride 0.5%, and a 9 mm well was placed on the cornea and filled with 20% ethanol. Following a 30- to 40-second application, the alcohol was drained with a surgical spear and the eye was irrigated with a balanced salt solution. The epithelium was removed with a blunt spatula and the programmed treatment applied. In all cases, a circular sponge soaked in mitomycin C 0.02% was applied for 20 seconds. Subsequently, the ocular surface was thoroughly rinsed with 15 mL of balanced salt solution and a bandage contact lens was placed on the eye and left in place until the cornea re-epithelialized. Postoperative medication consisted of topical levofloxacin 0.5%, 4 times a day for 1 week, and 4 weeks of a tapering dose of topical fluorometholone ophthalmic solution 0.1% in the following sequence: 4 times a day for 1 week, 3 times a day for 1 week, 2 times a day for 1 week, and once a day for 1 week.

All retreatment procedures were performed with a wavefront-guided ablation derived from the iDesign Hartmann-Shack aberrometer (Abbott Medical Optics, Inc.). Features of this aberrometer have been previously described.[26] The ablation algorithm was derived from all aberrations, lower- and higher-order, as measured by the aberrometer. For all myopic treatments, the optical zone diameter was 6.0 mm with a transition zone of 8.00 mm, whereas hyperopic treatments had a 6.0 mm optical zone and a 9.0mm transition zone. For patients with astigmatism, 6.00 mm was the size of the minor axis of the elliptical ablation.

Statistical Analysis

Normality of data samples was evaluated by the Kolmogorov–Smirnov test. When normality condition could be assumed, a paired Student *t* test was used to compare preoperative and postoperative data, and an unpaired *t* test was applied for comparison between the 2 groups. When parametric analysis was not possible, the Wilcoxon rank sum test and Mann–Whitney test were applied in place of paired and unpaired *t* tests. The Fisher exact test was used to compare proportions. Vector analysis of refractive cylinder was performed using previously established guidelines.[27] All data were analyzed with Microsoft Office Excel 2007

program (Microsoft Corp.) and Statistica (Statsoft Inc.) on a personal computer. A P value of 0.05 was considered statistically significant.

RESULTS

In all, 290 eyes of 202 patients were divided into 2 groups, those having flap lift enhancement (Group A), and those having PRK performed on the flap (Group B). Initial data (pre-LASIK), pre-enhancement data, and postenhancement data are summarized in Table 1.

Figure 1 shows the distribution of postenhancement manifest spherical equivalent. At the last follow-up visit, 87.4% of eyes in Group A and 84.2% of eyes in Group B had manifest spherical equivalent within 0.50 D (P = .50, Fisher exact test), compared to 25.2% and 18.7% in Groups A and B before retreatment, respectively. The percentage of eyes with postoperative manifest spherical equivalent within ± 1.00 D was 99.2% and 97.7%, in Groups A and B respectively (P = .65, Fisher exact test). The reduction of refractive sphere, cylinder and manifest spherical equivalent was statistically significant in each group (Table 1). There was no statistically significant difference in pre-enhancement refractive sphere, cylinder, or manifest spherical equivalent between the 2 groups. Similarly, no statistically significant difference was found between Groups A and B in postenhancement sphere, cylinder, and manifest spherical equivalent. Figure 2 plots the attempted pre-enhancement manifest spherical equivalent against achieved postenhancement manifest spherical equivalent.

Figure 3 depicts cumulative monocular UDVA. The percentage of eyes with postenhancement UDVA 20/20 or better was 87.4% in Group A and 79.5 % in Group B (P = .09, Fisher exact test). The improvement in UDVA after enhancement was statistically significant in each group (Table 1). There was no statistically significant difference in the mean post-enhancement UDVA between Group A and B (P = .93, Mann–Whitney test).

Table 1. Refractive and visual outcomes of the 2 groups.

	Pre-Lasik	Pre-enhancement	Last Visit	P Value, Pre- to Postenhancement
Group A: Flap lift (n = 119 eyes)				
Age at the time of enhancement: 44.5 ± 11.8 y (22, 67 y)				
Sphere (D)				
Mean ± SD (Range)	−2.30 ± 3.68 (–10.50, +3.75)	–0.13 ± 0.92 (–1.50, +3.00)	+0.08 ± 0.33 (–1.00, +1.00)	.02
Cylinder (D)				
Mean ± SD (Range)	–1.03 ± 1.00 (–4.00, 0.00)	–0.59 ± 0.48 (–2.50, 0.00)	–0.18 ± 0.25 (–1.00, 0.00)	<.01
Manifest spherical equivalent (D)				
Mean ± SD (Range)	–2.82 ± 3.66 (–10.63, +3.50)	–0.43 ± 0.85 (–2.25, +2.75)	–0.01 ± 0.35 (–1.38, +1.00)	<.01
CDVA (logMAR)				
Mean ± SD (Range)	–0.06 ± 0.06 (–0.18, 0.10)	–0.06 ± 0.05 (–0.18, 0.10)	–0.07 ± 0.05 (–0.18, +0.10)	.13
UDVA (logMAR)				
Mean ± SD (Range)	0.94 ± 0.43 (0.10, 1.60)	0.22 ± 0.13 (0.10, 0.70)	–0.03 ± 0.10 (–0.18, +0.30)	<.01
Follow-up (mo)	Primary, enhancement	Enhancement, last visit		
	14.0 ± 14.1	4.0 ± 1.9		
Group B: PRK on flap (n = 171 eyes)				
Age at the time of enhancement: 38.3 ± 12.2 y (21, 68 y)				
Sphere (D)				
Mean ± SD (Range)	–2.48 ± 3.22 (–9.75, +3.75)	–0.21 ± 0.98 (–2.00, +2.50)	+0.17 ± 0.40 (–0.75, +1.75)	<.01
Cylinder (D)				
Mean ± SD (Range)	–0.88 ± 0.99 (–5.00, 0.00)	–0.52 ± 0.46 (–2.50, 0.00)	–0.22 ± 0.28 (–1.25, 0.00)	<.01
Manifest spherical equivalent (D)				
Mean ± SD (Range)	–2.92 ± 3.23 (–11.25, +3.63)	–0.47 ± 0.92 (–2.13, +2.25)	+0.06 ± 0.39 (–1.00, +1.63)	<.01
CDVA (logMAR)				
Mean ± SD (Range)	–0.05 ± 0.06 (–0.18, 0.10)	–0.06 ± 0.06 (–0.18, 0.22)	–0.06 ± 0.08 (–0.18, +0.40)	.57
UDVA (logMAR)				
Mean ± SD (Range)	0.97 ± 0.35 (0.10, 1.30)	0.26 ± 0.18 (0.10, 1.00)	–0.02 ± 0.13 (–0.18, +0.60)	<.01
Follow-up (mo)	Primary, enhancement	Enhancement, last visit		
	34.8 ± 17.2	4.2 ± 1.6		

D = diopter; SD = standard deviation; CDVA = corrected distance visual acuity; UDVA = uncorrected distance visual acuity.

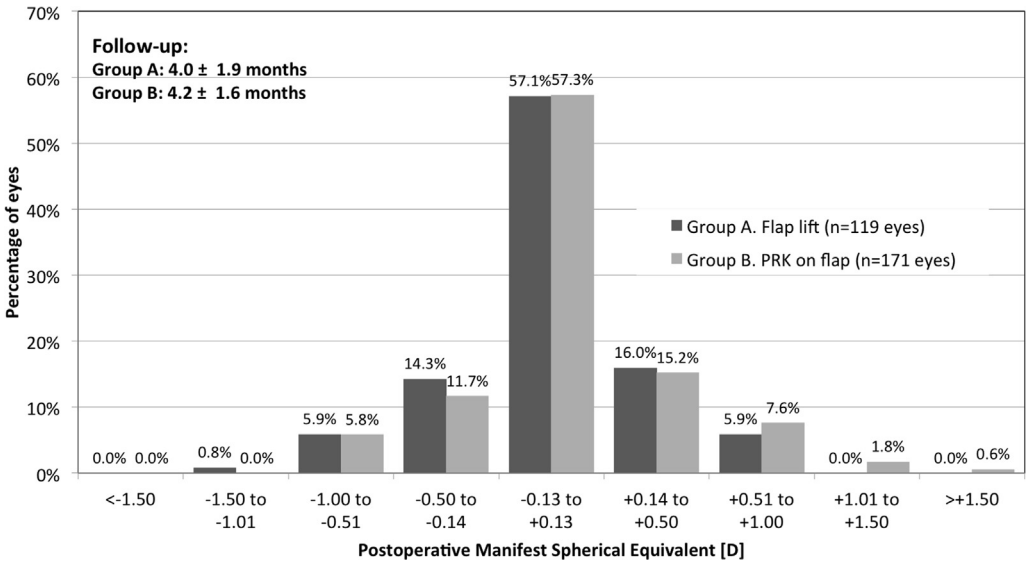

Figure 1. Distribution of manifest spherical equivalent post enhancement (D = diopter).

Figure 4 shows a comparison of pre-enhancement CDVA to postenhancement CDVA. There was no statistically significant difference in the mean postenhancement CDVA between the 2 groups (P = .81, Mann–Whitney test). There was also no statistically significant change when comparing pre- and postenhancement CDVA in each group (Table 1). Of all eyes, 0.8% (1 eye) in Group A and 2.3 % (4 eyes) in Group B lost 2 or more lines of corrected distance visual acuity (P = .65, Fisher exact test).

Figure 5 displays changes in UDVA, CDVA, and manifest spherical equivalent over time. There was faster visual recovery in the flap lift group, with significantly better UDVA at 1 day, 1 week, and 1 month (Figure 5*A*), but the difference in visual acuity between the 2 groups abated at 3 months postenhancement. A similar pattern was seen when analysing CDVA (Figure 5*B*). There was no statistically significant difference in the mean manifest spherical equivalent between the 2 groups at any follow-up

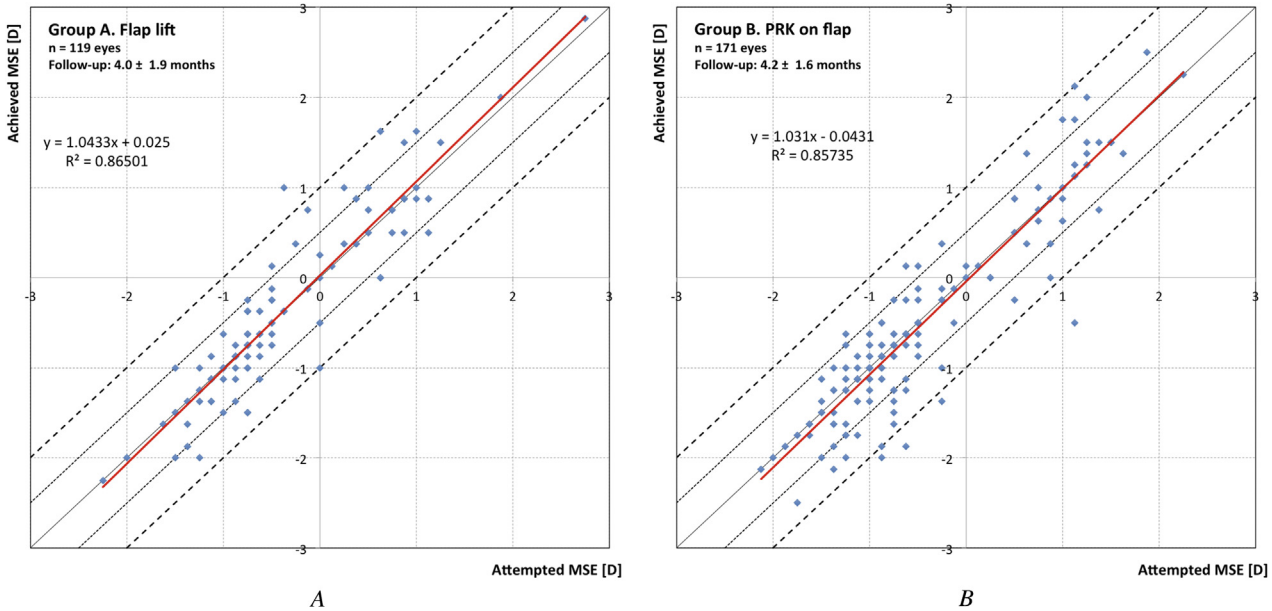

Figure 2. Scattergram of attempted versus achieved manifest spherical equivalent (manifest spherical equivalent) for the 2 study groups: flap lift enhancement (*A*) and PRK over flap enhancement (*B*). Solid red line is the linear regression (D = diopter).

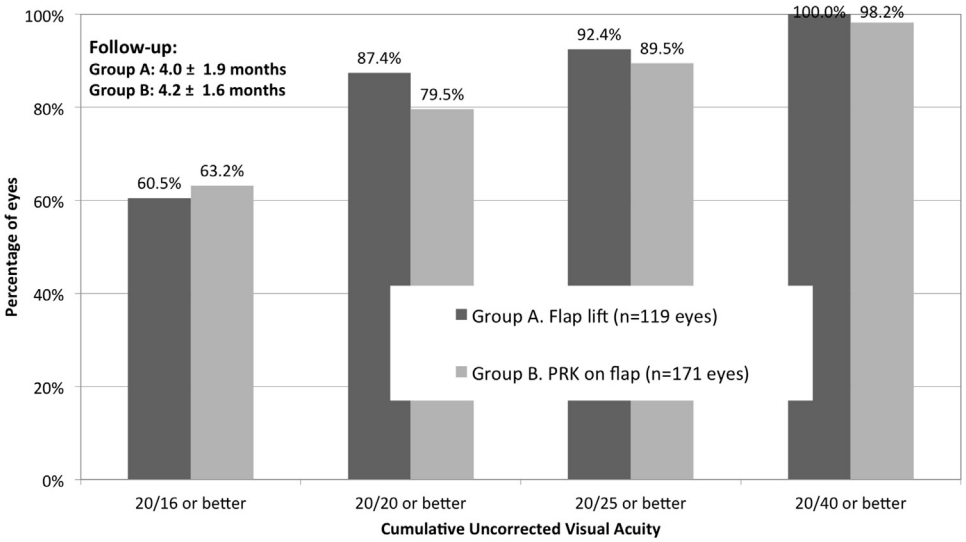

Figure 3. Cumulative monocular uncorrected distance visual acuity postenhancement.

visit (Figure 5C), but the PRK group exhibited a slight hyperopic shift, which was evident at the 3-month visit and the last available visit (4.2 ± 1.6 months). There was also higher standard deviation of manifest spherical equivalent at 1 week and 1 month postenhancement in the PRK group.

In Table 2, refractive and visual outcomes are subdivided between patients who had myopic manifest spherical equivalent before enhancement, and those with the hyperopic spherical equivalent. Improvement in refraction and UDVA was statistically significant in each subcategory, whereas the CDVA remained unchanged.

When analyzing the changes in refractive cylinder, the mean correction ratio (CR; ratio of the magnitude of surgically induced refractive correction [SIRC] to intended refractive correction [IRC]) was 1.03 ± 0.39 in Group A and 1.18 ± 0.69 in Group B (P = .45, Mann–Whitney test). The postoperative error of magnitude (arithmetic difference of the magnitudes between SIRC and IRC) was within 0.25 D in 80.4% of eyes in Group A and 80.6% of eyes in Group B. The error of angle (angular difference between attempted treatment and achieved treatment) was minimal in both groups (0.52 degrees ± 12.72 in Group A and 0.13 degrees ± 15.06 in Group B; P = .33, Mann–Whitney test).

Complications

Flap Lift In the flap-lift enhancement group (Group A), epithelial ingrowth was observed in 22 eyes

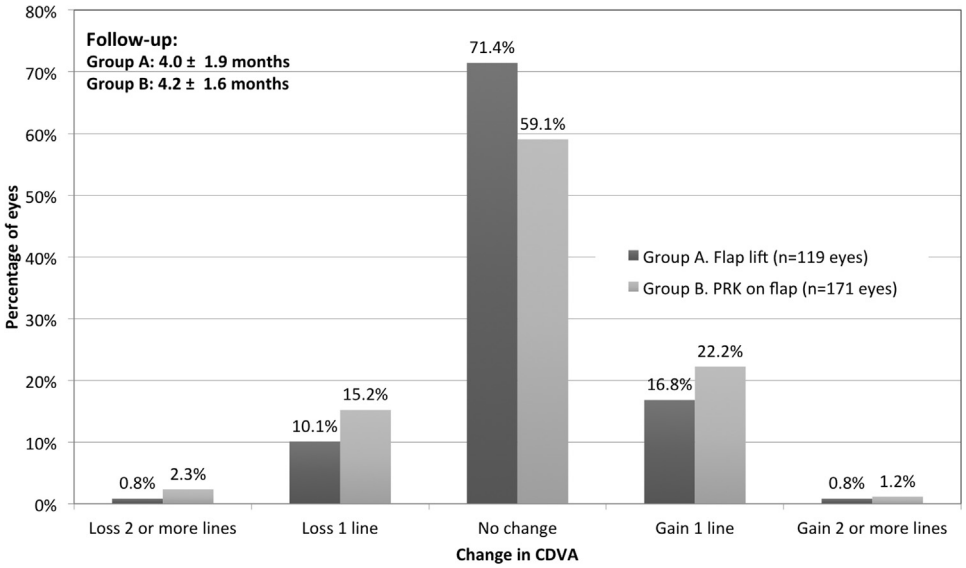

Figure 4. Safety comparison of preenhancement CDVA to postenhancement CDVA (CDVA = corrected distance visual acuity).

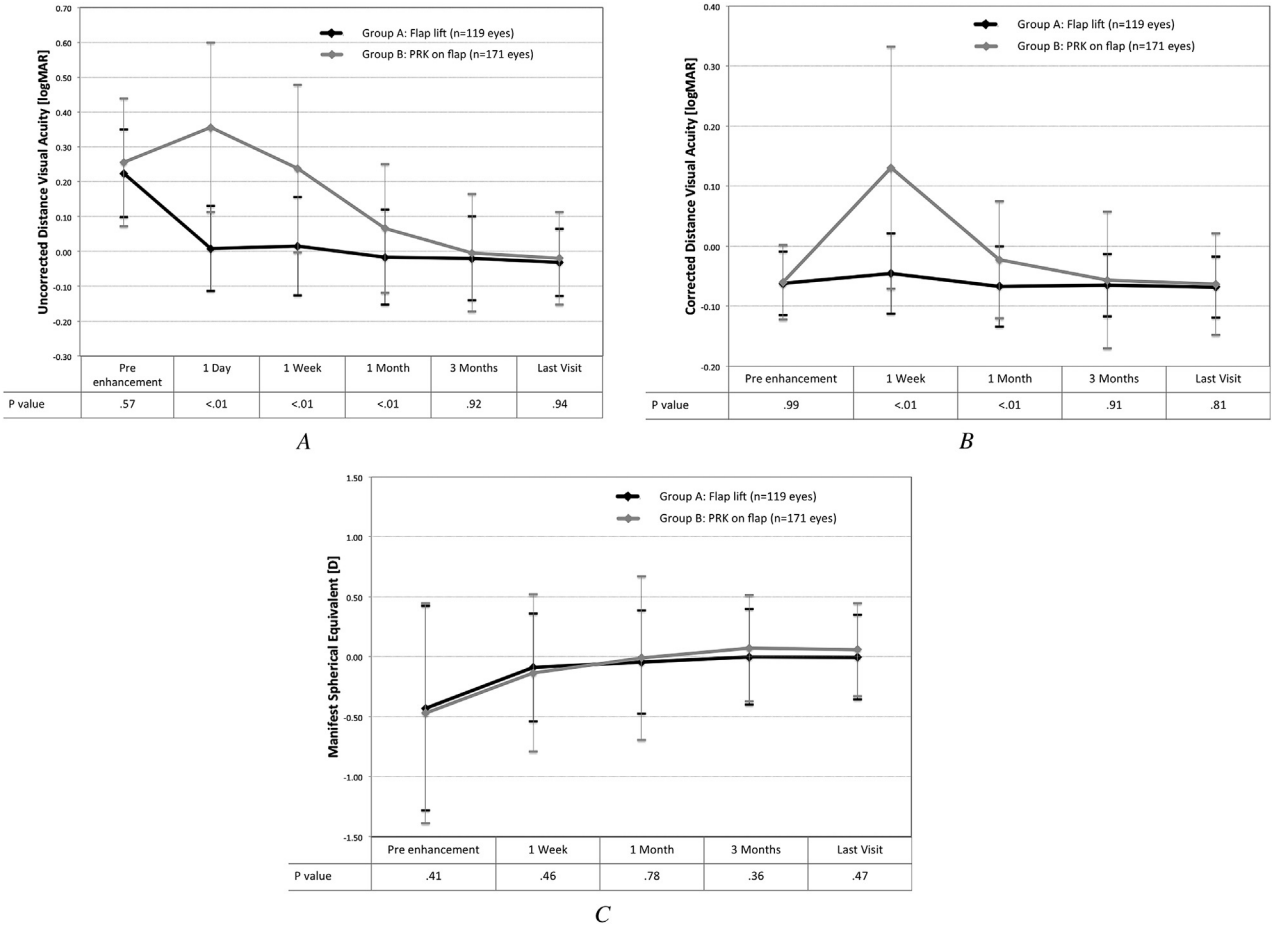

Figure 5. Change in uncorrected distance visual acuity (*A*), corrected distance visual acuity (*B*) and manifest spherical equivalent (*C*) over time. Error bars represent 1 standard deviation. The last follow up visit was 4.0 ± 1.9 months for Group A and 4.2 ± 1.6 months for Group B.

(18.5%). Of these cases, most (17 eyes) had small, nonprogressive epithelial ingrowth outside of pupillary area with both UDVA and CDVA 20/20 or better at the final visit. Three eyes had stable peripheral epithelial ingrowth, but slightly reduced postoperative UDVA due to the presence of refractive cylinder, ranging between −0.75 and −1.0 D. However, the residual astigmatism was not likely to be associated with the epithelial ingrowth because it was present before the ingrowth formation. Postoperative CDVA was 20/20 or better in all 3 cases.

In 2 eyes (1.7%), surgical intervention was performed for epithelial ingrowth. In the first case, epithelial ingrowth was observed 2 months postoperatively at the flap interface from the 4 o'clock to the 8 o'clock positions, with radial encroachment of 1 to 2 mm from the flap edge. Due to ongoing visual complaints, at 7 months postenhancement, the flap was lifted and the ingrowth was removed from the bed and back side of the flap. The ingrowth recurred 2 months later at the same position. The patient was monitored for another 3 months and the surgeon decided against any surgical intervention at that time, as the ingrowth appeared to be stable and outside of the pupillary area. There was no loss of CDVA compared to the pre-enhancement level.

In the second case patient who had surgical intervention, the epithelial ingrowth was first observed 1 month postenhancement. Initially, a 2 mm encroachment was noted at the 4 o'clock position, which gradually progressed, with the flap edge becoming irregular. Flap lift and debridement of epithelial cells was performed 3 months after the enhancement. To secure the flap, 10-0 nylon sutures were used but were removed 1 month later. At the last available visit, 3 months after this procedure, there was no recurrence of epithelial ingrowth. The patient had a slight myopic refractive error with an uncorrected vision of 20/32 and a corrected distance visual acuity of 20/16.

Table 2. Refractive and visual outcomes subdivided for myopic and hyperopic pre-enhancement manifest spherical equivalent.

	Myopic Manifest Spherical Equivalent Pre-enhancement			Hyperopic Manifest Spherical Equivalent Pre-enhancement		
	Pre-enhancement	Last Visit	*P* Value	Pre-enhancement	Last Visit	*P* Value
Group A: Flap lift	n = 84			n = 35		
Sphere (D)						
Mean ± SD (Range)	−0.65 ± 0.44 (−1.50, +0.50)	+0.07 ± 0.29 (−1.00, +0.75)	<.01	+1.11 ± 0.47 (+0.50, +3.00)	+0.10 ± 0.40 (−0.75, +1.00)	<.01
Cylinder (D)						
Mean ± SD (Range)	−0.50 ± 0.42 (−2.50, 0.00)	−0.15 ± 0.23 (−0.75, 0.00)	<.01	−0.82 ± 0.55 (−2.00, 0.00)	−0.23 ± 0.29 (−1.00, 0.00)	<.01
Manifest spherical equivalent (D)						
Mean ± SD (Range)	−0.90 ± 0.38 (−2.25, −0.13)	0.00 ± 0.32 (−1.38, +0.75)	<.01	+0.70 ± 0.56 (0.00, +2.75)	−0.01 ± 0.43 (−1.00, +1.00)	<.01
CDVA (logMAR)						
Mean ± SD (Range)	−0.06 ± 0.06 (−0.18, 0.10)	−0.07 ± 0.05 (−0.18, 0.10)	.05	−0.06 ± 0.04 (−0.18, 0.00)	−0.05 ± 0.04 (−0.08, 0.00)	.06
UDVA (logMAR)						
Mean ± SD (Range)	0.24 ± 0.13 (0.10, 0.70)	−0.04 ± 0.10 (−0.18, 0.30)	<.01	0.20 ± 0.11 (0.10, 0.54)	−0.01 ± 0.10 (−0.08, 0.22)	<.01
Group B. PRK on flap	n = 128			n = 43		
Sphere (D)						
Mean ± SD (Range)	−0.71 ± 0.46 (−2.00, +0.75)	+0.17 ± 0.38 (−0.75, +1.50)	<.01	+1.26 ± 0.48 (+0.50, +2.50)	+0.15 ± 0.45 (−0.50, +1.75)	<.01
Cylinder (D)						
Mean ± SD (Range)	−0.47 ± 0.42 (−2.00, 0.00)	−0.19 ± 0.24 (−0.75, 0.00)	<.01	−0.66 ± 0.54 (−2.50, 0.00)	−0.30 ± 0.37 (−1.25, 0.00)	<.01
Manifest spherical equivalent (D)						
Mean ± SD (Range)	−0.94 ± 0.39 (−2.13, −0.13)	+0.08 ± 0.36 (−0.75, +1.25)	<.01	+0.93 ± 0.50 (0.00, +2.25)	0.00 ± 0.47 (−1.00, +1.63)	<.01
CDVA (logMAR)						
Mean ± SD (Range)	−0.06 ± 0.06 (−0.18, 0.10)	−0.08 ± 0.06 (−0.18, 0.10)	.06	−0.05 ± 0.06 (−0.18, 0.22)	−0.02 ± 0.12 (−0.18, 0.40)	.18
UDVA (logMAR)						
Mean ± SD (Range)	0.26 ± 0.18 (0.10, 0.90)	−0.04 ± 0.10 (−0.18, 0.40)	<.01	0.25 ± 0.20 (0.10, 1.0)	0.05 ± 0.18 (−0.18, 0.60)	<.01

D = diopter; SD = standard deviation; CDVA = corrected distance visual acuity; UDVA = uncorrected distance visual acuity.

All 22 eyes with epithelial ingrowth had the original flap created by femtosecond laser. There was no statistically significant difference in epithelial ingrowth rate between patients who had bandage contact lens (BCL) inserted for 1 day after the flap lift retreatment and those who did not. Nine (22.0%) of 41 eyes with BCL, and 13 (16.7 %) of 78 eyes without BCL developed epithelial ingrowth (P = .47, Fisher exact test).

Other complications in Group A included 1 case of mild diffused lamellar keratitis, which resolved without any intervention. There were no cases of sterile or infectious keratitis, torn flaps, flap displacement, or flap macro-striae after retreatment.

At the last visit, a loss of 2 lines of CDVA was recorded in 1 eye (0.8%) in the flap lift group (Group A), and was caused by grade 1 superficial punctate keratitis observed at the last available postoperative visit (4 months). Corrected visual acuity changed from 20/12.5 to 20/20 in this eye. Of all eyes that had 20/20 or better CDVA prior to enhancement, 3 eyes did not achieve 20/20 at the last visit. In all 3 eyes, CDVA changed from 20/20 pre-enhancement to 20/25; the change was caused by fluctuation in vision due to a dry eye.

PRK Over the Flap

Where PRK was performed on the flap (Group B), 9 eyes (5.3%) developed mild haze (grade 1 of 4), which resolved within the first 6 months postoperatively. Both uncorrected and corrected visual

Table 3. Literature review on results of the flap-lift retreatment technique.

Author (year)	Follow-up	No. of Eyes	Pre-enhancement Manifest Spherical Equivalent (D), Mean ± SD (Range)	Postenhancement Manifest Spherical Equivalent (D), Mean ± SD (Range)
Pérez-Santonja et al. (1999)[10]	12 mo	59	−2.92 ± 1.22 (−6.75, −1.00)	−0.61 ± 0.82 (−3.50, +1.00)
Zadok et al. (1999)[1]	6 mo	53	−1.7 ± 1.1 (−5.0, +0.3)	−0.09 ± 0.29 (−1.0, +0.5)
Febbraro et al. (2000)[6]	12 mo	52	−0.77 ± 0.94 (—)	−0.13 ± 0.33 (—)
Lyle and Jin (2000)[2]	Mean 10 mo	157	−1.28 ± 0.57 (−3.25, −0.50)	−0.23 ± 0.41 (−2.55, +1.13)
Domniz et al. (2001)[7]	6 mo	55	−1.05 ± 1.49 D (—)	−0.45 ± 0.39 D (—)
Davis et al. (2002)[8]	Mean 4.8 mo	164	−0.85 ± 1.25 (—)	+0.35 ± 0.62 (—)
Netto and Wilson (2004)[4]	12 mo	334	−1.2 ± 0.6 (−4.2, +1.2)	+0.2 ± 0.4 (−3.1, +1.1)
Montague and Manche (2006)[9]	3 mo	120	−0.91 ± 0.40 (−2.38, −0.13)	−0.20 ± 0.32 (−0.75, +0.75)
Jin and Merkley (2006)[11]	Mean 7.8 mo	53	+0.51 ± 1.16 (—)	−0.11 ± 0.34 (−0.88, +0.63)
		101	−0.12 ± 1.21 (—)	−0.17 ± 0.42 (−1.75, +1.25)
Ortega-Usobiaga et al. (2007)[12]	5.3 mo	86	+1.09 ± 0.51 (+0.13, +3.00)	–0.07 ± 0.50 (–1.50, +1.50)
Saeed et al. (2007)[13]	22.3 mo	60	—	–0.33 ± 0.8 (–2.50, +2.25)
Santhiago et al. (2012)[14]	6 mo	78	–0.90 ± 1.20 (–3.75, –0.75)	—
Current Study	4.0 ± 1.9 mo	119	–0.43 ± 0.85 (–2.25, +2.75)	–0.01 ± 0.35 (–1.38, +1.00)

SD = standard deviation; D = diopter; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; WFG = wavefront guided.
*Absolute value of cylinder.

acuities were 20/20 or better in 8 of 9 cases. In 1 case, postoperative visual acuity was affected by other complications. This case was that of a 49-year-old patient with a history of psoriatic arthritis, which was well controlled on low-dose methotrexate. After consultation with her internist, the patient underwent bilateral LASIK for hyperopia and had undergone bilateral PRK enhancements 10 months after primary surgery for a slight hyperopic regression. However, her postoperative course was difficult. She initially developed central haze in the left eye, which was treated with topical steroids and eventually cleared. She also experienced dry eye and had central punctate epithelial erosions. Treatment regimens included preservative-free artificial tears, cyclosporine drops, low-dose topical steroids, and punctal plugs. At her last follow-up visit at 3.5 months, the refraction in the left eye was −1.0 D sphere, −0.50 D cylinder with a CDVA of 20/50 and central punctate epithelial erosions. The LASIK flap interface was clear, and the rest of the ophthalmic examination was normal. Her right eye continued to do well with an unaided vision of 20/25 and CDVA of 20/20.

In addition to the case described above, 3 eyes in the PRK group lost 2 lines of CDVA. All 3 eyes had dry eye and mild superficial punctate epithelial erosions at the last available visit. In all 3 cases, the change in CDVA was from 20/16 to 20/25.

In addition to the eyes that lost 2 lines of CDVA, 6 eyes that corrected to 20/20 before enhancement had postoperative CDVA less than 20/20 on the last available visit. In 5 eyes, reduced visual acuity was caused by dry eye symptoms, and in 1 eye, no obvious reason for visual acuity loss was found. In all 6 eyes, CDVA reduced from 20/20 to 20/25.

Further complications in the PRK group were recurrent epithelial erosions that were noted in 2 eyes and managed either with therapeutic contact lenses or ocular surface lubrication. There was 1 case of delayed epithelial healing, which resolved within 2 weeks without any consequences, and the eye had UDVA of 20/16 at the final visit.

DISCUSSION

Several factors can influence the predictability of excimer laser surgery and the need for retreatment. These include high initial correction, high astigmatism, older age, variations in wound healing, as well as the differences in ablation profiles and laser nomograms.[3,5] The flap lift enhancement technique provides good long-term stability and predictability of refractive correction.[8] However, with the upsurge of femtosecond laser technology, lifting the original

Table 3. (Cont.)

Pre-enhancement Cyl (D)*, Mean ± SD	Postenhancement Cyl (D)*, Mean ± SD	Manifest Spherical Equivalent Within 0.50 D	UDVA 20/20 or Better	Lost 2 Lines of CDVA
0.49 ±0.26 spherical ablation subgroup	0.46 ± 0.39	—	—	0%
1.25 ± 0.51 astigmatic ablation subgroup	0.52 ± 0.39			
0.9 ± 0.7	0.13 (mean)	90.6%	39.6%	0%
—	—	81%	62%	0%
0.66 ± 0.55	0.34 ± 0.47	81.5%	69%	1.3%
—	—	—	71.1%	—
0.72 ± 0.56	0.37 ± 0.32	—	44.4%	—
0.7 ± 0.6	0.4 ± 0.5	80.5%	58%	1%
0.41 ± 0.33	0.19 ± 0.19	83%	99%	0%
—	—	91%	75%	0%
—	—	87%	75%	0%
1.00 ± 0.55	0.38 ± 0.37	72.09%	51.49%	4.65%
—	—	77%	—	0%
—	—	—	82%	1.1%
0.59 ± 0.48	0.18 ± 0.25	87.4%	87.4%	0.8%

LASIK flap might become difficult years after the original refractive surgery, as was the case in 2 eyes that were 9 months postoperative in this study. Femtosecond flaps were found to have stronger adhesion compared to those created with a microkeratome,[28,29] resulting in better long-term corneal stability and integrity, but this might be seen as a disadvantage when flap lift enhancement is attempted. However, femtosecond flaps were able to be lifted in this study up to 65 months after the primary procedure. Surface ablation is considered in eyes in which flap-lift is not possible, and the success rate of this procedure varies in the literature.[17-23] In the current study, 2 groups of eyes were evaluated: eyes that underwent flap lift enhancement, and those in which surface ablation was performed over the LASIK flap.

We achieved favorable refractive outcomes with the flap lift enhancement technique, with 87.4% of eyes attaining postoperative manifest spherical equivalent within 0.50 D and 87.4% eyes achieving postenhancement UDVA of 20/20 or better. Table 3 provides a literature summary of refractive and visual outcomes of flap-lift retreatments for the past 15 years that report results of more than 50 cases. Predictability of refractive outcomes is comparable to those in the current study, with the percentage of eyes with spherical equivalent within 0.50 D ranging between 72.09% and 90.6%[1,2,4,6,9,11–13]; however, the percentage of eyes achieving UDVA of 20/20 or better was significantly lower in most of the studies. For example, in 1 of the earlier studies, Zadok et al.[1] found 90.6% of eyes within 0.50 D of emmetropia, with a minimal mean postoperative manifest spherical equivalent of −0.09 ± 0.29 D, but only 39.6% of eyes achieved postoperative UDVA of 20/20 or better. Although the later studies found better visual outcomes, the percentage of eyes with 0.50 D of emmetropia mostly did not correlate with the number of eyes achieving 20/20 visual acuity. Whether improved UDVA in this study could be attributed to the advances in wavefront-guided ablation profiles in recent years is difficult to establish, because change in higher-order aberrations was not evaluated in the current study.

One of the most discussed complications of flap lift enhancement is the possibility of epithelial ingrowth, which is more frequent than after the initial procedure. The incidence of epithelial ingrowth after relifting the old flap varies between 0% to 23.3%.[1–3,6–11,13,30] and was 18.5% in our study. Only 2 eyes in our dataset (1.7%) had epithelial ingrowth that required flap lift and debridement of the epithelial cells. Both of these eyes retained good corrected vision. This is consistent with the literature, in which the reported rate of epithelial

Table 4. Summary of studies presenting results of surface ablation over the LASIK flap.

Authors (Year), Reference	Follow-up	No. of Eyes	Pre-enhancement Manifest Spherical Equivalent (D), Mean ± SD (Range)	Postenhancement Manifest Spherical Equivalent (D), Mean ± SD (Range)
Carones et al. (2001)[17]	6, 14 mo	17	−2.48 ± 0.74 (−3.75 to −1.50)	−3.11 ± 0.93 D (−5.50, −1.75)
Shaikh et al. (2005)[18]	6 mo	15	—	—
Cagil et al. (2007)[19]	Median 11.5 mo	24	–1.38 ± 1.29 (–5.00, 0.88)	–0.50 ± 0.83 (–3.25, 0.75)
Beerthuizen et al. (2007)[20]	12 mo	18	−0.63 ± 0.87 (−2.00, +1.38)	+0.15 ± 0.39 (−0.50, +0.88)
Saeed et al. (2008)[21]	Mean 6.7 mo	22	−1.23 ± 0.95 (−2.50, +2.00)	–0.30 ± 1.25 (–5.00, +1.37)
Neira-Zalentein et al. (2008)[22]	Mean 14 mo	7	−0.59 ± 1.4 (–2.25, +1.00)	−0.21 ± 0.66 (–1.25, +0.75)
Ng-Darjuan et al. (2013)[23]	6 mo	16	−1.41 ± 1.43 (−4.93, +0.82)	—
Current study	4.2 ± 1.6 mo	171	–0.47 ± 0.92 (–2.13, +2.25)	+0.06 ± 0.39 (–1.00, +1.63)

D = diopter; SD = standard deviation; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity.
*Absolute value of cylinder.

ingrowth requiring surgical intervention is between 0% and 6.7%.[1,2,4,6,9–11,30]

Surface ablation over the LASIK flap is a good alternative when there is a need to preserve corneal stromal tissue or to avoid flap-related complications and surgical difficulty related to a strongly adherence LASIK flap. Surprisingly, very little has been published about the refractive predictability of this technique, and studies reporting outcomes of surface ablation over the flap usually contain only a small number of cases (typically less than 30). Studies that report refractive and visual outcomes of PRK or LASEK over the LASIK flap are summarized in Table 4. The percentage of eyes achieving 20/20 or better UDVA or having spherical equivalent within 0.50 D of emmetropia is generally lower than in flap-lift studies. However, in our current study, we found 79.5% of eyes with UDVA 20/20 or better and 84.2% of eyes within 0.50 D in a cohort of patients (n = 171 eyes) that was larger than in all other published studies combined.

One of the factors that can limit the outcomes of surface ablation on flap is the possibility of development of clinically significant haze. In an early report by Carones et al.,[17] 14 of 17 eyes with PRK over the flap developed dense haze, and the authors strongly advised against this technique. In later studies, prophylactic use of mitomycin-C led to significantly lower rates of haze development, although visually significant haze has been described despite the use of MMC.[31] No eye in our study group developed a haze score greater than grade 1. However, there are reports of late-onset haze in the literature[17,19] after PRK on LASIK flap, and some of the eyes in this study had only 3 months of follow-up. For that reason, it is difficult to establish whether the number of cases with corneal haze is final.

Vector analysis of refractive cylinder revealed high predictability of astigmatic correction, with most of the eyes having the error of magnitude (arithmetic difference of the magnitudes between SIRC and IRC) within 0.25 D (80.4% in Group A and 80.6% in Group B). The mean error of angle was minimal and close to 0 degrees in both groups, indicating a correct alignment of the ablation profile. Comparison with other studies is difficult, as most of them report only the mean value of residual cylinder rather than detailed vector analysis. Tables 3 and 4 show the mean pre-enhancement and postenhancement astigmatism in each study in which astigmatism outcomes were reported. The mean postoperative astigmatism in our study (0.18 ± 0.25 D and 0.22 ± 0.28 D in group A and group B, respectively) compared favorably to the literature review. The iDesign aberrometer was used in preoperative planning, which could have had an impact on astigmatic outcomes. The Hartmann-Shack wavefront sensor in the iDesign uses enhanced iris registration, and higher resolution of this device can potentially improve accuracy of aberrometer-derived refractions, including magnitude and axis of astigmatism.

One of the limitations of this retrospective study is a relatively short follow-up. The data from the last available visit were analyzed in this study, and the mean follow-up was 4.0 ± 1.9 months for the flap lift group and 4.2 ± 1.6 months for the surface ablation group. Although only patients with a minimum follow-up of 3 months were included in this study, we were un-

Table 4. (Cont.)

Pre-enhancement Cyl (D)*, Mean ± SD	Postenhancement Cyl (D)*, Mean ± SD	Manifest Spherical Equivalent Within 0.50 D	UDVA 20/20 or Better	Lost 2 Lines of CDVA
—	—	0%	0%	64.7%
—	—	—	40%	0%
0.75 (median)	0.38 (median)	62.5%	25%	0%
—	—	83%	58%	0%
0.51 ± 0.34	0.57 ± 0.48	55.4%	—	0%
0.69 ± 0.55	0.50 ± 0.35	71.4%	42.9%	0%
1.28 ± 1.0	0.84 ± 0.48	56%	38%	0%
0.52 ± 0.46	0.22 ± 0.28	84.2%	79.5%	2.3%

able to evaluate long-term stability of refractive outcomes. It is also possible that the slight hyperopic shift observed in the surface ablation group (Figure 5*C*) will reduce with time. Most of the eyes had myopic spherical equivalent before the enhancement (Table 2), and a slight hyperopic overcorrection might gradually regress.

When comparing the 2 techniques presented in this study, we found slightly better outcomes for flap lift enhancements. However, the difference did not reach statistical significance for any of the analyzed variables, apart from the early follow-up visits, at which the flap lift clearly outperformed PRK in visual recovery. The aim of this study was not to specifically compare the techniques, because different criteria were used to select the preferred retreatment method. There were various factors that determined the choice of enhancement technique, 1 of the main factors being the time interval between the primary procedure and the retreatment, which was significantly higher in the surface ablation group (34.8 ± 17.2 months) compared to the flap lift group (14.0 ± 14.1 months). Also, surgeon preference was 1 of the major factors determining the enhancement choice, which makes the comparison between the 2 groups difficult. The results demonstrated that both techniques are safe and that good outcomes can be achieved following a wavefront-guided ablation, regardless of whether the original flap was lifted or a surface ablation was performed. Analyzing the change in the pre- and postenhancement higher-order aberrations was not possible in this retrospective study, but it is intriguing and should be assessed in future prospective studies.

WHAT WAS KNOWN

- Various retreatment techniques have been proposed for the correction of residual refractive error after LASIK.
- Although numerous papers report results of flap lift enhancement techniques, studies presenting outcomes of PRK over the LASIK flap are scarce.

WHAT THIS PAPER ADDS

- Both flap lift and PRK over the flap were safe and effective retreatment options as analyzed in a large cohort of patients.
- Use of a wavefront-guided ablation profile in retreatments resulted in high predictability of refractive outcomes, including correction of astigmatism.

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