

Long-term results of hyperopic ablations using alcohol-assisted PRK and FS-LASIK: comparative study



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Purpose: To evaluate the long-term visual and refractive outcomes of hyperopic excimer ablation using alcohol-assisted photorefractive keratectomy (PRK) and femtosecond laser-assisted laser in situ keratomileusis (FS-LASIK).

Setting: American University of Beirut Medical Center, Beirut, Lebanon.

Design: Retrospective, matched comparative study.

Methods: Eyes that underwent alcohol-assisted PRK were compared to matched eyes that underwent FS-LASIK. All patients were followed up for at least 3 years after surgery. The refractive and visual outcomes of each group were compared at different postoperative time points. The main outcome measures were spherical equivalent deviation from target (SEDT), manifest refraction, and visual acuity.

Results: 83 eyes underwent alcohol-assisted PRK and 83 matched eyes underwent FS-LASIK. Preoperative manifest refraction spherical equivalent was 2.44 ± 1.18 diopters (D) and 2.20 ± 0.87 D

($P = .133$) in the PRK and FS-LASIK groups, respectively. Preoperative manifest cylinder was -0.77 ± 0.89 D and -0.61 ± 0.59 D ($P = .175$) for the PRK and LASIK groups, respectively. 3 years postoperatively, SEDT was 0.28 ± 0.66 D and 0.40 ± 0.56 D for the PRK and LASIK groups, respectively ($P = .222$), whereas manifest cylinder was -0.55 ± 0.49 D and -0.30 ± 0.34 D for PRK and LASIK, respectively ($P < .001$). The mean difference vector was 0.59 ± 0.46 for PRK and 0.38 ± 0.32 for LASIK ($P < .001$). 13.3% of PRK eyes and 0% of LASIK eyes had >1 D of manifest cylinder ($P = .003$).

Conclusions: Both alcohol-assisted PRK and FS-LASIK are safe and effective for the treatment of hyperopia. PRK induces slightly more postoperative astigmatism than LASIK. Larger optical zones and recently introduced ablation profiles that lead to a smoother ablation surface might improve the clinical results of hyperopic PRK.

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Excimer laser ablation for the correction of hyperopia remains a challenge for the refractive surgeon. Compared with myopic treatment, hyperopic treatment yields less predictable and stable refractive and visual outcomes.¹ Considerations particular to refractive laser treatment of hyperopia include the larger angle κ of hyperopic eyes, latent hyperopia and accommodation, and the dynamic and poorly predictable epithelial remodeling and biomechanical response that occurs at the peripheral zone of ablation.^{2–4}

Despite these challenges, the safety and efficacy of photorefractive keratectomy (PRK) and laser in situ keratomileusis (LASIK) in the treatment of low to moderate hyperopia has been well demonstrated.^{5–9} However, a Cochrane review in 2012 revealed the absence of randomized controlled trials and a paucity of retrospective comparative

studies comparing the outcomes of these 2 surgical procedures in the treatment of hyperopia.¹⁰

The few studies that have compared PRK and LASIK for the treatment of hyperopia examined the use of microkeratome-assisted LASIK and have shown that the 2 methods have similar refractive and safety outcomes.^{11–13} However, the advent of femtosecond laser-assisted LASIK (FS-LASIK) has optimized the predictability and stability of postoperative refractive outcomes compared with microkeratome-assisted LASIK.¹⁴ In this study, we compare the long-term visual and refractive outcomes of alcohol-assisted PRK and FS-LASIK in the treatment of low to moderate hyperopia over a period of 3 years.

METHODS

This retrospective chart review included all patients who underwent hyperopic FS-LASIK or hyperopic PRK treatment at the

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American University of Beirut Medical Center between June 2010 and June 2014 and had a postoperative follow-up period of at least 3 years. It was approved by the Institutional Review Board at the American University of Beirut (IRB Study ID: OPH.SA.20) and adhered to the tenets of the Declaration of Helsinki. All surgical treatments were performed by the same surgeon (S.T.A.), using the same excimer laser (Amaris, Schwind eye-tech-solutions GmbH & Co. KG) and the same femtosecond laser platform (LDV, Ziemer Ophthalmic Systems AG) for those who underwent FS-LASIK.

Exclusion criteria included a history of other corneal or intraocular surgery, a preoperative corrected distance visual acuity (CDVA) of less than 20/25, eyelid disease, a history of keratitis, corneal dystrophy or degeneration including keratoconus, and other ocular abnormalities such as retinal disease. 108 PRK eyes and 121 FS-LASIK eyes met the inclusion criteria. These eyes were then matched based on age, preoperative manifest and cycloplegic spherical equivalent (SE) and cylinder, attempted laser correction, and optical zone. A final 83 PRK eyes and 83 FS-LASIK eyes were included.

Patient Assessment

The baseline evaluation included uncorrected distance visual acuity (UDVA), CDVA, manifest refraction, cycloplegic refraction, slitlamp examination, corneal topography and tomography assessment using the Galilei dual Scheimpflug-Placido Analyzer (Ziemer Ophthalmic Systems AG), and a dilated fundus examination. Patients who were candidates for both procedures were educated about FS-LASIK and PRK and were asked to choose which procedure to undergo. These decisions were based largely on the price of the procedures and visual recovery time.^{12,13} Patients were instructed to discontinue the use of soft contact lenses for 2 weeks prior to their preoperative evaluation to decrease corneal warpage on topography. No patients had been hard contact lens wearers.

A maximal difference of 0.5 diopters (D) between preoperative manifest refraction and cycloplegic refraction was a prerequisite for surgery. In our clinic, as a routine protocol, all patients with a difference greater than 0.5 D are not operated on until their accommodative spasm is relaxed by the administration of incremental spectacle correction, and the difference between their manifest refraction and cycloplegic refraction is reduced to 0.5 D or less.

Patients were evaluated postoperatively at 1 day, 1 week, 1 month, 3 months, 6 months, and then annually after surgery. Follow-up evaluations included assessment of UDVA, CDVA, manifest refraction, slitlamp examination, and corneal topography and tomography, in addition to a dilated fundus examination at annual visits. Corneal transparency was assessed on the slitlamp based on Fantes classification and graded as follows: 0 for no haze, 0.5 for trace haze on oblique illumination, 1 for corneal cloudiness not interfering with the visibility of fine iris details, 2 for mild effacement of fine iris details, and 3 and 4, when details of the lens and iris were not discernible, respectively.¹⁵

Surgical Technique

In the PRK group, a 9.5 mm alcohol well was placed over the corneal center and filled with 20% alcohol. After 30 seconds of exposure, the alcohol was absorbed using a microsp sponge. A dry polyvinyl alcohol sponge (Meroceol, Medtronic Ophthalmics) was used to debride the corneal epithelium. Excimer laser ablation was then performed. 0.02% mitomycin-C (MMC) was subsequently applied to the stromal bed for 45 seconds after the ablation and was then irrigated with 20 mL of balanced salt solution. In the FS-LASIK group, a planned flap of at least 9.0 mm was created with a 110 μm target depth using the femtosecond laser, which focused spots with dimensions of less than 2 μm \times 2 μm \times 2 μm , a pulse rate of 5 MHz, a pulse width 250 fs, and a bed energy level of 100 nJ.

In both procedures, when the difference between the corneal vertex and the pupil centroid was less than 0.30 mm in cord length, measured using the Scout topographer (Keratron Scout, Optikon 2000 SpA), the excimer treatment was centered on the corneal vertex. If the difference was more than 0.30 mm, the laser treatment was

centered at three-quarters of the distance, closer to the vertex. A slight nomogram adjustment was applied to the sphere component when needed to offset long-term potential regression. The nomograms used were as follows: for corrections less than or equal to +2.00 D, +0.12 D was added; for corrections between +2.25 D and +4.00 D, +0.20 D was added; and for corrections greater than or equal to +4.25 D, +0.30 D was added. Partial monovision (targeting a final refraction of -1.50 D) or full monovision (targeting a final refraction of -2.50 D) in the nondominant eye was performed in many patients.

After laser ablation in the PRK eyes, a soft contact lens with a base curve of 8.4 mm (Acuvue Oasys, Johnson & Johnson Vision) was used to cover the cornea. The postoperative regimen of the PRK-treated eyes included 0.5% moxifloxacin hydrochloride (Vigamox, Alcon Laboratories, Inc.) 4 times a day for 2 weeks and 1% prednisolone acetate suspension (Pred Forte 1% Ophthalmic Suspension, Allergan, Inc.) 4 times a day for 1 week, followed by fluorometholone 0.1% (Allergan, Inc.) eyedrops 4 times a day, and tapered over a period of 2 months. In addition, nonsteroidal anti-inflammatory drops (Indocolllyre 0.1% ophthalmic solution, Laboratoire Chauvin, Bausch & Lomb France SAS) were given for pain, to be used 3 to 4 times a day for the first 3 days, and preservative-free 0.2% hyaluronic acid artificial tears (Artelac Advanced, Bausch & Lomb GmbH) to be used every hour for 1 week, and then used as needed over several months. The soft contact lens was removed at the 1-week postoperative visit, by which time epithelial closure was complete. Patients who underwent FS-LASIK were prescribed moxifloxacin hydrochloride 4 times a day for 1 week, prednisolone acetate 4 times a day for 1 week, and then tapered over 4 days, in addition to 0.2% hyaluronic acid artificial tears to be used as needed over several months.

Main Outcome Measures

Patients who underwent FS-LASIK were compared with those who underwent alcohol-assisted PRK. The main outcome measures were UDVA, CDVA, manifest refraction SE (MRSE), manifest refraction sphere, manifest refraction cylinder, and SE deviation from target (SED_T). These outcomes were recorded at every postoperative visit but were analyzed at 3 months, 6 months, and annually after surgery. SED_T was calculated by subtracting the target SE from the MRSE at every postoperative visit. SED_T represents the treatment error that is independent of other confounding factors such as nomogram or monovision adjustments and is thus more accurate in assessing treatment efficacy than the manifest SE.¹⁴ Stability was assessed based on the change in the main outcome measures over the postoperative follow-up period. Predictability was associated with the correlation coefficient and tightness of fit of the plot of attempted SE vs achieved SE. Vector analysis was performed to evaluate astigmatism, with the particular parameters of interest being target-induced astigmatism, surgically induced astigmatism, difference vector, magnitude of error, angle of error, correction index, and index of success.¹⁶ Safety and efficacy were determined based on the change in CDVA and UDVA and the percentage of patients who developed complications such as haze and epithelial ingrowth after surgery.

Statistical Analysis

The data were analyzed using SPSS (v. 21.0, IBM Corp./SPSS, Inc.). Descriptive analysis of mean and SDs was performed. Assessment and confirmation of the normal distribution of the data was performed using the Kolmogorov-Smirnov test. Independent *t* tests were then used to compare the 2 groups at each postoperative time point. For characteristics of a categorical nature, the chi-square test was used to compare the 2 groups. Correlation coefficients were compared by applying Fisher *Z* transformation. *P* values of less than 0.05 were considered statistically significant.

RESULTS

Of the original 108 eyes that underwent hyperopic PRK and 121 eyes that underwent hyperopic FS-LASIK, a total of 83

Table 1. Baseline characteristics of the PRK (n = 83) and FS-LASIK (n = 83) eyes

Parameter	PRK Mean ± SD (range)	FS-LASIK Mean ± SD (range)	P value
Age	47.33 ± 13.43 (18, 63)	50.08 ± 9.97 (21, 66)	.134
M:F ratio	30:53	25:58	.410 ^a
CCT	545.80 ± 33.40 (491, 604)	552.90 ± 27.33 (502, 599)	.136
CDVA (logMAR)	0.01 ± 0.03 (0, 0.10)	0.01 ± 0.03 (0, 0.10)	.272
MRSE (D)	2.44 ± 1.18 (0.38, 4.625)	2.20 ± 0.87 (0.375, 4.75)	.133
MR cylinder (D)	-0.77 ± 0.89 (-4, 0)	-0.61 ± 0.59 (-3, 0)	.175
CRSE (D)	2.74 ± 1.24 (0, 5.25)	2.42 ± 1.07 (0.375, 5.25)	.077
CR cylinder (D)	-0.69 ± 0.82 (-3.5, 0)	-0.53 ± 0.60 (-3, 0)	.165
Target SE (D)	-0.67 ± 0.64 (-3, 0)	-0.64 ± 0.63 (-2, 0)	.794
Attempted SE (D)	3.35 ± 1.05 (1.00, 5.44)	3.07 ± 1.15 (0.68, 5.87)	.101
SimK (D)	42.72 ± 1.75 (38.48, 46.83)	43.16 ± 1.14 (40.81, 45.50)	.060
Optical zone (mm)	6.74 ± 0.12 (6.7, 7)	6.73 ± 0.09 (6.7, 7)	.843

CCT = central corneal thickness; CR = cycloplegic refraction; MR = manifest refraction; MRSE = manifest refraction spherical equivalent; SE = spherical equivalent; SimK = simulated keratometry

^aChi-squared test

eyes were selected and included in each group after matching. In the PRK group, 77 eyes had a 1-year follow-up visit, 56 eyes had a 2-year follow-up visit, and all 83 eyes had a 3-year postoperative follow-up visit. In the FS-LASIK group, 74 eyes had a 1-year follow-up visit, 52 eyes had a 2-year follow-up visit, and all 83 eyes had a 3-year postoperative follow-up visit. The baseline characteristics of each group are summarized in Table 1. There were no statistically significant differences between the 2 groups in any of the baseline characteristics.

Refractive Results and Stability

The postoperative refractive and visual outcomes at 3 months, 6 months, 1 year, 2 years, and 3 years after surgery are shown in Table 2. Other than UDVA, all measured parameters were significantly different between the 2 groups at the third postoperative month (Table 2). In particular, FS-LASIK patients, with an SEDT of 0.09, were closer to the anticipated SE than PRK patients, who had an initial myopic shift (SEDT = -0.62 D). By 1 year after surgery, there was no significant difference in SEDT between the 2 groups ($P = .063$ D). Three years after surgery, no statistically significant difference was observed for any of the parameters, with the exception of astigmatism ($P < .001$). At 3 years, the PRK group displayed a greater amount of manifest refractive cylinder than the FS-LASIK group (-0.55 D and -0.30 D, respectively). In terms of treatment stability, the PRK group had 0.66 D of regression ($P < .001$), and the FS-LASIK group had 0.31 D of regression ($P = .003$) (Figure 1, A). Regression in the PRK group was significantly greater than regression in the FS-LASIK group ($P < .001$).

For the FS-LASIK group, mean simulated keratometry was 43.16 ± 1.14 D preoperatively and 45.33 ± 1.45 D, 45.39 ± 1.46 D, and 45.42 ± 1.48 D 1 year, 2 years, and 3 years postoperatively, respectively. For the PRK group, simulated keratometry was 42.72 ± 1.75 D preoperatively and 46.37 ± 1.70 D, 46.19 ± 1.90 D, and 46.01 ± 1.94 D 1 year, 2 years, and 3 years postoperatively, respectively.

Predictability

Three years after surgery, SEDT seemed to be more spread out in the PRK group than the FS-LASIK group, although there was no statistically significant difference in SEDT SD between the 2 groups ($P = .1$) (Figure 1, B). SEDT was mainly centered on the 0.14 to 0.50 D range in PRK-treated eyes, whereas the results of the FS-LASIK group were centered on the 0.50 to 1.00 D range. Nonetheless, the 2 procedures exhibited similar predictabilities, with 63% of eyes in the PRK group being within 0.5 D of their target SE, compared with 57% of eyes in the FS-LASIK group ($P = .43$) (Figure 1, B). Furthermore, there was no statistically significant difference in the percentage of eyes that had an SEDT of greater than 1.00 D or less than -1.00 D (14% in the PRK group and 8% in the FS-LASIK group, $P = .42$). In fact, both PRK and FS-LASIK eyes seemed to have similar plots of achieved vs attempted SE correction at 3 years postoperatively, with similar correlation coefficients of $R^2 = 0.769$ for the PRK group and $R^2 = 0.805$ for the FS-LASIK group ($P = .55$), indicating that both procedures had good predictabilities (Figure 1, C).

Safety and Efficacy

Most eyes after surgery had no change in best-corrected visual acuity in both groups; however, 12% of eyes in the PRK group and 4% in the FS-LASIK group lost 1 line of CDVA (Figure 1, D). In the subset of eyes that were corrected for distance vision (57 eyes in the PRK group and 56 eyes in the FS-LASIK group), 54% and 71% ($P = .06$) in the PRK and FS-LASIK groups, respectively, had a UDVA of 20/20 3 years after surgery (Figure 1, E and F). Complications such as epithelial ingrowth, flap-related complications, and haze were not seen in the FS-LASIK group. In the PRK group, mild, peripheral haze developed in 13.2% of eyes, with an average haze grading of 0.23 ± 0.58 at the first postoperative year and 0.26 ± 0.71 at the third postoperative year. Three eyes (3.6%) had grade 3 haze, and 2 eyes (2.4%) had grade 2 haze at 3 years postoperatively. The haze was exclusively peripheral, more pronounced nasally

Table 2. Postoperative characteristics at 3 months, 6 months, 1 year, 2 years, and 3 years after surgery in the PRK (n = 83) and FS-LASIK (n = 83) groups

Parameter	PRK Mean ± SD (range)	FS-LASIK Mean ± SD (range)	P value
3 mo postop			
UDVA (logMAR)	0.13 ± 0.16 (0, 0.70)	0.08 ± 0.18 (0, 0.70)	.138
CDVA (logMAR)	0.04 ± 0.05 (0, 0.10)	0.01 ± 0.03 (0, 0.10)	.035
MRSE (D)	-1.30 ± 0.95 (-3.5, 1.63)	-0.61 ± 0.92 (-2.38, 1.13)	<.001
SEDT (D)	-0.62 ± 0.88 (-3, 1.98)	0.09 ± 0.61 (-1.50, 1.50)	<.001
MR sphere (D)	-1.00 ± 0.85 (-2.75, 2.25)	-0.44 ± 0.93 (-2.5, 1.5)	<.001
MR cylinder (D)	-0.59 ± 0.66 (-2.5, 0.50)	-0.33 ± 0.42 (-1.25, 0.75)	.007
6 mo postop			
UDVA (logMAR)	0.09 ± 0.11 (0, 0.30)	0.05 ± 0.12 (0, 0.48)	.126
CDVA (logMAR)	0.02 ± 0.04 (0, 0.10)	0 ± 0 (0, 0)	.041
MRSE (D)	-0.84 ± 0.91 (-3.25, 2.50)	-0.54 ± 0.81 (-2.63, 0.50)	.071
SEDT (D)	-0.15 ± 0.82 (-2, 2.5)	0.14 ± 0.60 (-1.63, 1.38)	.034
MR sphere (D)	-0.53 ± 0.91 (-3, 3)	-0.32 ± 0.76 (-2.25, 0.75)	.173
MR cylinder (D)	-0.61 ± 0.49 (-1.75, 0)	-0.45 ± 0.44 (-1.75, 0)	.080
1 y postop			
UDVA (logMAR)	0.12 ± 0.19 (0, 0.88)	0.04 ± 0.11 (0, 0.54)	.011
CDVA (logMAR)	0.04 ± 0.06 (0, 0.18)	0.01 ± 0.03 (0, 0.10)	.041
MRSE (D)	-0.72 ± 1.04 (-3.63, 2)	-0.34 ± 0.92 (-3.63, 1.50)	.079
SEDT (D)	-0.03 ± 0.88 (-2.50, 2)	0.25 ± 0.71 (-2.63, 1.75)	.063
MR sphere (D)	-0.43 ± 0.99 (-3.50, 2.25)	-0.27 ± 0.93 (-3.50, 1.50)	.365
MR cylinder (D)	-0.58 ± 0.55 (-2, 0)	-0.25 ± 0.34 (-1, 0)	<.001
2 y postop			
UDVA (logMAR)	0.05 ± 0.09 (0, 0.30)	0.06 ± 0.13 (0, 0.60)	.797
CDVA (logMAR)	0.02 ± 0.04 (0, 0.10)	0.02 ± 0.04 (0, 0.10)	.921
MRSE (D)	-0.64 ± 0.77 (-2.50, 1.25)	-0.38 ± 0.79 (-2, 1)	.143
SEDT (D)	0.06 ± 0.48 (-1, 1)	0.31 ± 0.62 (-1.5, 1.7)	.049
MR sphere (D)	-0.47 ± 0.85 (-2.5, 1)	-0.19 ± 0.82 (-1.75, 1.25)	.143
MR cylinder (D)	-0.34 ± 0.41 (-1.5, 0)	-0.38 ± 0.41 (-1.5, 0)	.702
3 y postop			
UDVA (logMAR)	0.12 ± 0.19 (0, 1.30)	0.08 ± 0.12 (0, 0.54)	.081
CDVA (logMAR)	0.02 ± 0.04 (0, 0.18)	0.01 ± 0.04 (0, 0.10)	.911
MRSE (D)	-0.39 ± 0.92 (-3.25, 1.25)	-0.25 ± 0.81 (-2, 2)	.291
SEDT (D)	0.28 ± 0.66 (-1.63, 2.25)	0.40 ± 0.56 (-1, 2)	.222
MR sphere (D)	-0.11 ± 0.91 (-2.75, 1.75)	-0.09 ± 0.84 (-1.75, 2)	.878
MR cylinder (D)	-0.55 ± 0.49 (-2, 0)	-0.30 ± 0.34 (-1, 0)	<.001

MR = manifest refraction; MRSE = manifest refraction spherical equivalent; SEDT = spherical equivalent deviation from target; SimK = simulated keratometry

and temporally, and did not appreciably affect the CDVA of the involved eyes.

Astigmatism and Vector Analysis

15% of eyes in the PRK had more than 1.00 D of refractive cylinder 1 year after surgery, whereas none of the FS-LASIK eyes did (Figure 1, G and H). This decreased to 13% by 3 years after surgery; however, it remained significantly greater than the 0% of eyes in the FS-LASIK group (P = .003). In addition, vector analysis revealed significantly greater surgically induced astigmatism in the PRK group compared with the FS-LASIK group and a significantly larger difference vector and magnitude of error in the PRK group (Table 3). A correction index of greater than 1 (1.29) in PRK eyes indicates an overcorrection of astigmatism (Table 3). A plot of surgically induced astigmatism vs target-induced astigmatism and double-angle plots of the difference vectors for PRK and FS-LASIK eyes are shown in Figures 2 and 3, respectively.

DISCUSSION

Although the safety and efficacy of PRK and LASIK in the treatment of low to moderate hyperopia has been well established, to our knowledge, there have been no prospective studies comparing the 2 techniques and only a few retrospective comparisons.^{5,8,10,17-19} The few retrospective studies examined the use of microkeratome-assisted LASIK, and PRK without the use of MMC, and have shown that the 2 methods have similar refractive and safety outcomes.¹¹⁻¹³ However, the advent of FS-LASIK has optimized the predictability and stability of postoperative refractive outcomes compared with microkeratome-assisted LASIK in hyperopic treatments.^{14,20} In addition, newer-generation lasers such as the Amaris laser used for treating patients in this study, are centered on the visual axis/corneal vertex, which may improve outcomes in patients with a large angle κ.^{21,22} Furthermore, MMC has shown to lead to less peripheral stromal haze in hyperopic PRK treatments, with less spherical

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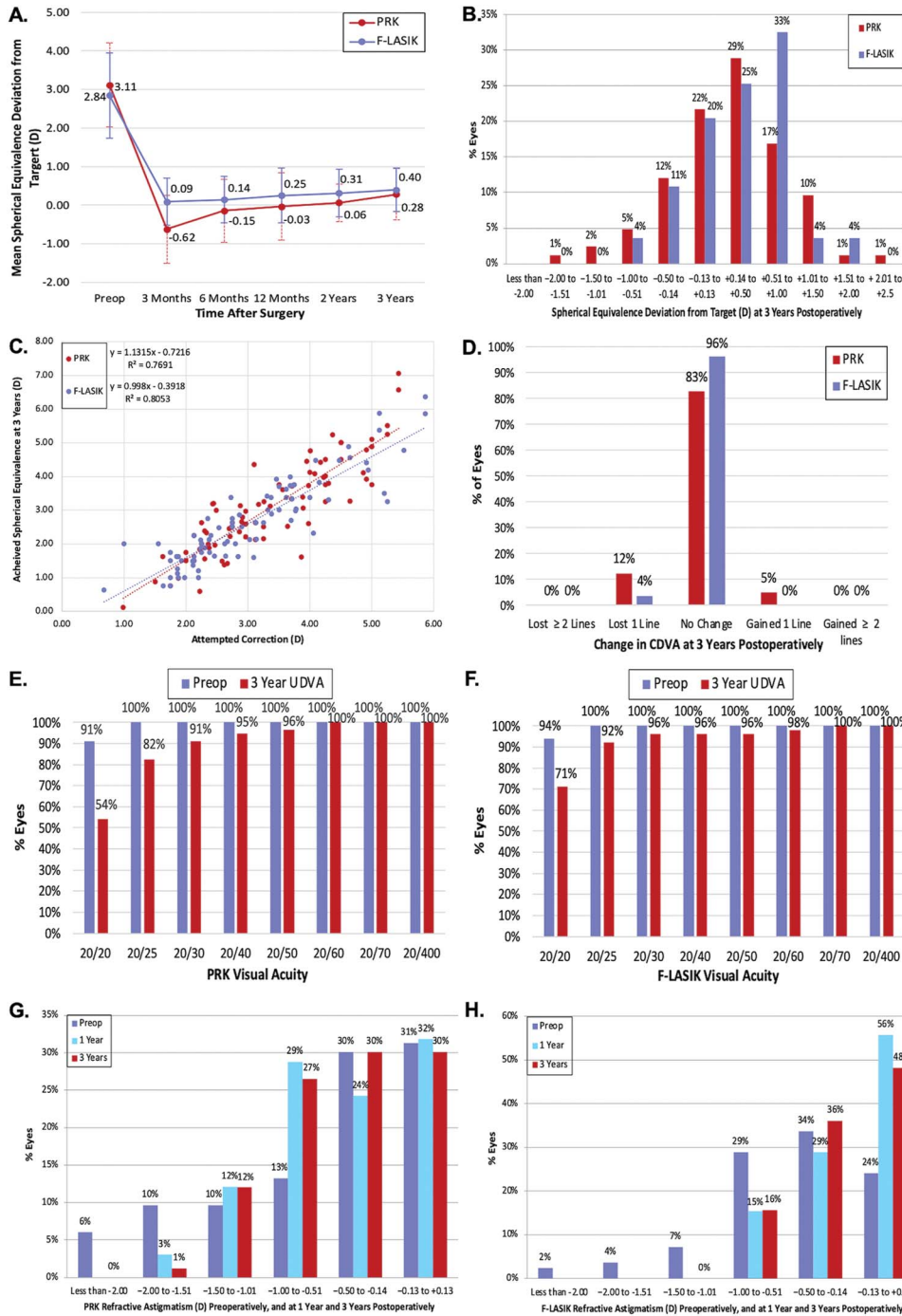


Figure 1. Refractive outcomes of hyperopic PRK and hyperopic FS-LASIK. A: Change in mean SEDT over time after surgery in PRK and FS-LASIK eyes. B: SEDT 3 years postoperatively in PRK and FS-LASIK eyes. C: Achieved spherical equivalence correction vs attempted spherical equivalence correction 3 years postoperatively in PRK and FS-LASIK eyes. D: Change in CDVA at 3 years postoperatively in PRK and FS-LASIK eyes. E: PRK group cumulative preoperative CDVA and 3-year postoperative UDVA in eyes intended for distance correction. F: FS-LASIK group cumulative preoperative CDVA and 3-year postoperative UDVA in eyes intended for distance correction. G: Percentage of eyes with refractive cylinder preoperatively and at 1 year and 3 years postoperatively after PRK. H: Percentage of eyes with refractive cylinder preoperatively and at 1 year and 3 years postoperatively after FS-LASIK. SEDT = spherical equivalent deviation from target

equivalence scatter and undercorrection.²³ In this study, we retrospectively compared the long-term visual and refractive outcomes of matched groups that underwent alcohol-assisted PRK with MMC or FS-LASIK, for the treatment of low to moderate hyperopia, over a period of 3 years.

As opposed to MRSE, which was used as a measure of correction and regression in previous studies, we used the SEDT. The latter is a better indicator of success and predictability because it factors in different individualized targets of treatments, such as monovision, partial treatments, and nomogram adjustments.¹⁴ Moreover, a maximum difference of 0.5 D between preoperative cycloplegic and MRSE

insured minimal latent hyperopia, which can contribute to late-onset regression. Our results showed that at 3 years postoperatively, PRK and FS-LASIK were comparable in terms of mean SEDT; however, PRK eyes had more manifest cylinder. The correlation between attempted correction and achieved spherical equivalence was moderately high in both groups, consistent with previous studies evaluating hyperopic laser treatments, but inferior to published results of myopic treatments.^{14,24–28} Although there was no statistically significant difference in SEDT between the PRK and FS-LASIK groups at 3 years postoperatively, the SEDT of PRK eyes was more spread out across a greater range than

Table 3. Vector analysis of astigmatic correction 3 years after surgery in the PRK (n = 83) and FS-LASIK groups (n = 83)

Parameter	PRK Mean ± SD (range)	FS-LASIK Mean ± SD (range)	P value
TIA	0.71 ± 0.88 (0.00, 3.50)	0.55 ± 0.59 (0.00, 3.00)	.163
SIA	0.97 ± 0.84 (0.00, 4.50)	0.66 ± 0.58 (0.00, 2.67)	.006
DV	0.59 ± 0.46 (0.00, 2.24)	0.38 ± 0.32 (0.00, 1.16)	.0009
MoE	0.27 ± 0.47 (−0.93, 1.50)	0.11 ± 0.38 (−0.67, 1.04)	.023
AoE	8.21 ± 31.80 (−84.25, 90.00)	1.84 ± 24.69 (−44.56, 90.00)	.254
IOS	0.91 ± 0.92 (0.02, 4.49)	0.71 ± 0.81 (0.03, 4.04)	.233
CI	1.29 ± 0.64 (0.40, 3.50)	1.09 ± 0.72 (0.00, 3.93)	.119

AoE = angle of error; CI = correction index; DV = difference vector; IOS = index of success; MoE = magnitude of error; SIA = surgically induced astigmatism; TIA = target-induced astigmatism

FS-LASIK eyes (Figure 1B). This variability is likely due to epithelial remodeling, which might be more predictable in LASIK than in PRK.⁴ The recent advent of OCT tomographers might shed light on this phenomenon by comparing the postoperative epithelial thickness profiles of the 2 procedures over time. In addition, variable keratocytic activity after PRK, primarily at the periphery, may also contribute to the large SEDT scatter of PRK-treated eyes.^{3,23,29}

In terms of refractive stability, the PRK group demonstrated a myopic shift over the first 3 to 6 months after surgery, similar to what has been reported by earlier studies on mechanical and alcohol-assisted PRK.^{13,30,31} Adib-Moghaddam et al. also demonstrated similar results with transepithelial PRK in eyes that were followed up for 1 year after surgery.⁹ The use of very large optical zones in alcohol-assisted PRK, larger than those of this study and of most published studies, has recently shown to result in less initial myopic shift, less regression, and better predictability.⁸ This phenomenon might be explained by the smaller curvature gradients associated with large optical zones, leading to less aggressive epithelial remodeling, which has been demonstrated by corneal OCT.^{4,8} Although the use of larger optical zones comes at the expense of delayed epithelial healing (more than 7 days in 15.7% of eyes) in alcohol-assisted PRK, transepithelial PRK can potentially lead to faster healing due to smaller and more circumscribed epithelial defects.³² The initial myopic shift observed in PRK eyes was subsequently followed by mild regression up until at least 3 years postoperatively and was comparable to the results of previous studies on hyperopic PRK.^{5,8,13} Similarly, but to a lesser degree, there was also some regression observed in the FS-LASIK group from 3 months up until 3 years postoperatively. Although the PRK group had less hyperopia than the FS-LASIK

group 3 years after surgery, it was not statistically significant. A similar outcome was reported by El Agha et al., comparing the 1-year postoperative results of microkeratome LASIK and PRK, using the VISX system, without radial compensation.¹³ This might be due to the biomechanical effect of the flap, which could potentially lead to slight flattening of the central cornea, and regression.^{14,33} The extent to which this is due to biomechanical regression as opposed to epithelial remodeling is to be determined.

The PRK group had noticeably greater postoperative astigmatism with a larger scatter compared with the FS-LASIK group. There was a large preponderance of difference vectors that were horizontally oriented in the PRK group, as opposed to a more random pattern in the FS-LASIK group (Figures 2 and 3). In eyes treated for hyperopia and with-the-rule astigmatism, the horizontal/flat meridian is subjected to more laser ablation than the vertical meridian. In addition, the nasal and temporal regions of the cornea are less protected than the superior and inferior regions from environmental impacts such as UV exposure. We believe that these reasons lead to increased keratocytic activity, which is more pronounced nasally and temporally, and is evidenced by the development of mild haze in the horizontal meridian in the PRK group. This would result in horizontal corneal flattening and subsequent with-the-rule astigmatism. All studies that have been published about hyperopic PRK, using the same excimer laser platform of this study, were performed before the SmartPulse technology. This innovation features a new laser pulse distribution algorithm that has been shown to produce a smoother stromal bed, with less activation of stromal keratocytes.³⁴ It is expected that new studies evaluating hyperopic PRK using this technology may

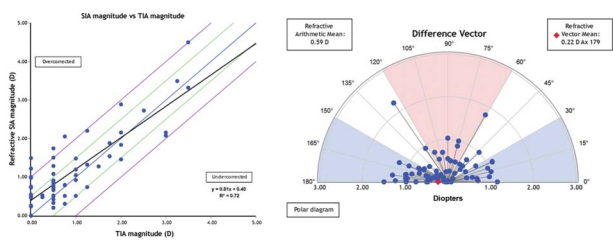


Figure 2. Surgically induced astigmatism vs target-induced astigmatism (left) and a double-angle plot of the difference vectors (right) for astigmatism 3 years after PRK.

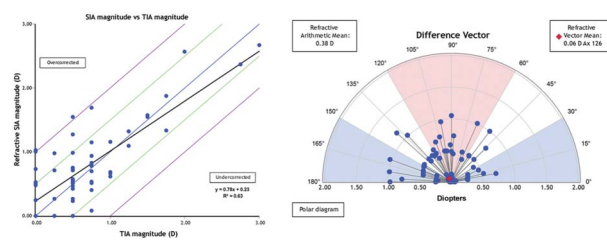


Figure 3. Surgically induced astigmatism vs target-induced astigmatism (left) and a double-angle plot of the difference vectors (right) for astigmatism 3 years after FS-LASIK.

potentially demonstrate better postoperative astigmatic results and less SE regression; however, this is still to be proven.

In terms of treatment safety, both treatments were comparable, with no significant intraoperative or postoperative complications. Only a small percentage of eyes lost 1 line of CDVA in each group, similar to what has been reported in previous studies evaluating the procedures.^{7,10,13,30} This could possibly be explained by the loss of the magnification effect of hyperopic spectacle correction. Although the difference between the 2 groups was not statistically significant, the greater proportion of PRK eyes who lost 1 line of CDVA may be explained by the development of mild peripheral haze in the PRK group, which likely induced postoperative astigmatism that may not have been regular in all patients, making simple spectacle correction challenging. The use of MMC in PRK has helped minimize postoperative haze, and the haze reported in our study is similar to what has been reported by other authors using MMC with alcohol, mechanical, and transepithelial PRK.^{8,9,23,35,36} In addition, it was significantly better than the haze reported in earlier studies in which PRK was performed without the use of MMC, resulting in up to 40% of eyes developing haze, including the development of Salzmann nodular degeneration in some eyes.⁵ In addition, the application of SmartPulse technology, and other excimer algorithms designed to optimize the ablated surface, is expected to lead to the development of less haze in the periphery of the stromal bed in PRK-treated hyperopic eyes.

One limitation of this study is its retrospective nature, which precludes knowledge about the outcomes of patients who were lost to follow-up between the time of surgery and their 3-year postoperative visit. Nonetheless, this study has the advantage of following the outcomes of 2 large, matched groups of eyes over a period of 3 years. Overall, both groups fared similarly and achieved good visual and refractive results with satisfactory safety, efficacy, and predictability. FS-LASIK appears to be better in terms of the stability of the initial refractive outcome and SE predictability and clearly better in terms of the induced postoperative astigmatism. We believe that the application of very large optical zones, potentially combined with a transepithelial approach to hasten epithelial healing over these large treatment zones, as well as the use of new ablation profiles that result in a smoother stromal bed and less keratocytic activity, would potentially further improve the outcomes of hyperopic PRK by shortening the initial myopic shift and improving spherical and astigmatic predictability.

WHAT WAS KNOWN

- Both PRK and LASIK are safe and effective for the treatment of hyperopia.

WHAT THIS PAPER ADDS

- FS-LASIK induces less postoperative astigmatism than PRK with mitomycin-C for the treatment of hyperopia.

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