Transepithelial Photorefractive Keratectomy for Hyperopia: A 12-Month Bicentral Study

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ABSTRACT

PURPOSE: To investigate the safety, efficacy, and stability of transepithelial photorefractive keratectomy (PRK) for hyperopia.

METHODS: This interventional case series study at two sites included 55 eyes (31 patients) with hyperopia (0.50 to 6.00 diopters [D]), with or without astigmatism (0.00 to -3.00 D), that underwent one-step transepithelial PRK with a Amaris 500-Hz excimer laser (SCHWIND eye-tech-solutions, Kleinostheim, Germany). A 12-month follow-up was conducted. Preoperative and successive postoperative visual acuity, manifest refraction, haze, and other complication data were analyzed.

RESULTS: The preoperative mean spherical equivalent of 2.56 ± 1.90 D improved to emmetropia (-0.08 ± 0.14 D) by 6 months, with subsequent slight mean regression of 0.024 D (range: -0.75 to 0.50) until month 12. Of the treated eyes, 75% and 76.2% were within the target refraction of ±0.50 D at 6 and 12 months postoperatively, respectively. The final mean cylindric refraction was comparable to the preoperative value (-0.94 ± 0.12 to -0.71 ± 0.12 D, $P = .17$); however, it was induced in 23% of eyes. The preoperative mean uncorrected distance visual acuity logMAR of 0.54 ± 0.05 significantly improved to 0.15 ± 0.03 by month 12 ($P < .0001$), and 64.2% of the treated eyes gained an uncorrected distance visual acuity of 20/25 or better. Ten eyes (23.8%) lost one line of preoperative corrected distance visual acuity (CDVA). No eye lost two or more lines of preoperative CDVA. Four eyes with a 3+ degree of haze were observed by the final visit. No other notable complications occurred. The low hyperopic eyes exhibited better overall results compared to the moderate hyperopic group.

CONCLUSIONS: One-step transepithelial PRK with the Amaris 500-Hz excimer laser provided reasonable outcomes for the correction of hyperopia with or without mild to moderate astigmatism.

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Complications of mechanical debridement in photorefractive keratectomy (PRK)[1] and flap-related consequences in LASIK[1] have rekindled interest in alternative surface ablation techniques. In the 1990s, a laser-assisted method for epithelium removal, called transepithelial PRK, was introduced.[2]

Since then, clinical studies have examined different platforms of two-step transepithelial PRK (epithelium removal by phototherapeutic keratectomy followed by conventional PRK for stromal ablation), reporting inconclusive results.[3-5] It was postulated that a lower laser energy delivered to the curved periphery of the cornea, as compared to the central parts in phototherapeutic keratectomy,[6] results in variable ablation depths and uneven epithelium removal, which, in part, accounts for the suboptimal results. Recently, a one-step, combined surface and stromal ablative variant of transepithelial PRK was examined and yielded promising results.[7,8] In this modification, an ablation depth based on a population-based profile of the epithelium thickness was used to adjust the energy delivered to the central and peripheral cornea, resulting in even epithelium removal. Additionally, it was postulated that it could reduce stromal dehydration.[8]

These studies have demonstrated the efficacy and safety of transepithelial PRK in myopia; however, in contrast to myopia correction with corneal flattening, the attempt to correct hyperopia with corneal steepening has always been challenging, owing to higher refractive regression and the resulting unpre-

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dictability.[9,10] To the best of our knowledge, no study has assessed transepithelial PRK in hyperopia correction. This is the topic that we investigated in this study.

PATIENTS AND METHODS

This two-center study was conducted as a chart review retrospective interventional case series. The patients were recruited from Bina Eye Hospital, Tehran, Iran, or Aschaffenburg Eye Clinic, Aschaffenburg, Germany, from December 2010 to May 2013. Informed consent was obtained from all patients (the nature of the study explained). The study followed the tenets of the Declaration of Helsinki and institutional review board approval from Shahid Beheshti University of Medical Sciences and Health Services was obtained.

Inclusion criteria were hyperopia, with or without mild-to-moderate astigmatism, which had been stable for at least 12 months prior to the procedure. Patients with high astigmatism (> 3.00 D), concurrent ocular disease, severe dry eyes, systemic diseases (with ocular involvement), previous corneal or ocular surgery, keratoconus, and night vision disturbances (eg, patients with retinitis pigmentosa and chorioretinal atrophic changes) were excluded. Four weeks before the surgery, the patients discontinued wearing hard or soft contact lenses.

Preoperative assessments included demographic data, baseline uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), refraction (manifest and cycloplegic), ultrasound pachymetry, and corneal topography.

To perform the ablation procedure, local anesthetic drops were applied, followed by periorbital scrubbing with povidone-iodine 10%, draping, and placing the speculum. The eyes were irrigated with balanced salt solution. No alcohol was used. All of the ablations were performed with an Amaris 500-Hz excimer laser (SCHWIND eye-tech-solutions, GmbH, Kleinostheim, Germany) with its integrated CAM software. For eyes with a pupillary offset (distance between pupil center and corneal vertex) greater than 0.35 mm (in Iran) and 0.2 mm (in Germany), the ablation profile was centered on the corneal vertex. For all other eyes, a pupil-centered profile was used. The excimer laser was administered in a single, continuous session to perform an aspheric aberration neutrally optimized profile to ablate the epithelium and stroma in a single-step procedure. The ablation plan using the population-based epithelium thickness profile uses 55 µm centrally and 65 µm peripherally, with further adjustment of the differential ablation rate in the epithelium compared to the stroma, which provides an even laser energy on the entire corneal surface. In Iran, an optical zone range of 6.8 to 7.6 mm was used, whereas in Germany the range was 6.8 to 7 mm. All treatments were performed by two surgeons (SA-Moghaddam in Iran and RW-F in Germany). After ablation, a soaked and squeezed sponge with 0.02% mitomycin C (MMC) was placed over the stromal bed for a minimum of 30 seconds (in Germany) or for 5 to 25 seconds (in Iran). The eye was flushed with 100 mL of chilled cold balanced salt solution. A soft bandage contact lens was subsequently applied. Overall, the mean ± standard deviation (SD) of the applied optical zone in all of the treated eyes was 7 ± 0.16 mm. Other registered surgical parameters are summarized in **Table A** (available in the online version of this article).

The postoperative medication regimens differed in the two centers. In Germany, one drop each of topical diclofenac (Voltaren; Novartis Pharmaceuticals, Basel, Switzerland), ofloxacin (Floxal; Bausch & Lomb, Rochester, NY), and dexamethasone (Bausch & Lomb) were applied immediately following the ablation. Ofloxacin and diclofenac were continued four times a day in addition to a lubricant and topical anesthetic drops as needed until the contact lens was removed on day 4. All of the drops were free of preservatives. Thereafter, only the lubricant drops were used as needed. No further corticosteroids were given.

In the Iran regimen, the epithelial healing was assessed by a slit lamp from the second day after the operation. Immediately after the operation until the removal of the soft contact lens, a chloramphenicol eye drop (0.5%) (Clobiotic; Sina Daru, Tehran, Iran) was administered every 4 hours, a vitamin C effervescent tablet (500 mg) (Osveh, Tehran, Iran) was taken daily, an Alperazolam tablet (1 mg) (Pursina Pharmaceutical Co., Tehran, Iran) was taken two to three times per day, and an ibuprofen capsule (400 mg) (Gelofen; Daana Pharmo Co., Tabriz, Iran) was prescribed four to six times a day. Three days after the operation, if no epithelial defects were identified, loteprednol eye drops (0.5%) (Lotemax; Bausch & Lomb) would be prescribed to be administered as one drop every 6 hours for 2 weeks, tapering then to once daily to be continued for up to 6 months. In addition, patients were prescribed one drop of chloramphenicol (0.5%) every 12 hours for a week, 500 mg of vitamin C daily for 1 month, and a preservative-free artificial tear (Artelac Advanced, Bausch & Lomb) for 6 months. All patients were advised to wear UV-400-blocker sunglasses for outdoor activity.

Postoperative visits were scheduled 1, 3, 6, and 12 months after the operation. Follow-up examinations included UDVA, CDVA, manifest refraction, and corneal haze grading using a slit lamp, according to the system previously described.[11]

We classified the eyes into low hyperopia (hyperopia ≤ 3.00 D) and moderate hyperopia (hyperopia >

3.00 D) groups. We assessed the stability by statistically comparing the spherical equivalents at two successive visits. Preoperative CDVA loss was reported for the safety parameters. We used Stata/SE 11.1 software (StataCorp, College Station, TX) for statistical analysis. A *P* value less than .05 was considered significant.

RESULTS

Fifty-five eyes of 31 patients (17 men and 14 women) were recruited for analysis. Thirty-six eyes were from Germany and 19 from Iran. The mean ± SD age of the patients was 39 ± 10 years (range: 20 to 54 years). All of the eyes were primary hyperopic (range: 0.50 to 6.00 D), with or without mild to moderate (0.00 to -3.00 D) astigmatism, undergoing transepithelial PRK. Thirty eyes (54.54%) had hyperopia greater than 3.00 D. The percentage of moderate hyperopic eyes was 47.3% in Iran and 58.3% in Germany (*P* = .24, chi-square). Mean ± SD pupil diameter of the German subgroup was also higher (5.06 ± 0.6 vs 4.33 ± 0.79 mm, *P* < .001). The number of eyes available for follow-up appointment after 1, 3, 6, and 12 months was 53, 52, 48, and 42, respectively. Other preoperative data, aggregated and categorized, are summarized in **Table A**.

The cycloplegic refraction data were not available for all visits, and we used the postoperative manifest refraction data for analysis. A verifying analysis, comparing preoperative manifest and cycloplegic mean refraction data, showed the cycloplegic mean to be 0.15 D more hyperopic, which was not statistically significant according to a paired *t* test (*P* = .45). Additionally, preoperative cycloplegic and manifest refraction means were significantly correlated (Pearson coefficient *r* = 0.83, *P* < .001). For further elucidation of our results, we subanalyzed visual acuity and refraction in patients younger than 45 years and 45 years and older.

VISUAL ACUITY

Efficacy. The preoperative UDVA logMAR (mean ± standard error [SE]) of 0.54 ± 0.05 significantly improved to 0.18 ± 0.03 (*P* < .001, Wilcoxon signed-rank test) 3 months after the operation and continued improving to 0.16 ± 0.03 and 0.15 ± 0.03 by months 6 and 12, respectively. Similarly, preoperative UDVA logMAR in separate patient subgroups (categorized by country and hyperopic error) significantly improved by 3 months postoperatively and continued improving up to month 12 (**Table 1**). One year after the operation, Iranian patients and patients with low hyperopia acquired better UDVA compared to the corresponding subgroups (**Table 1**). At all study time points, patients younger than 45 years had significantly better mean UDVA logMAR compared to patients 45 years and older (eg, 0.07 ± 0.03 vs 0.21 ± 0.06; *P* = .03, Mann–Whitney *U* test in final visit).

Within this 12-month interval, 17 (40%) eyes gained five or more logMAR lines of UDVA and 3 eyes (7%) gained more than 12 lines (max = 17 logMAR lines gain). The cumulative percentage of the total number of eyes achieving UDVA of 20/25 or better was 51.9%, 54.8%, and 64.2% by months 3, 6, and 12, respectively. One year after the operation, the Iranian subgroup had a higher proportion of eyes achieving UDVA of 20/25 or better compared to the German subgroup. The two subgroups had comparable proportions at 3 and 6 months postoperatively. A higher proportion of the low hyperopic subgroup achieved UDVA of 20/25 or better compared to the moderate hyperopic group at all follow-up visits, although the differences were not significant (**Table 1**). A summary of the 12-month postoperative UDVA and preoperative CDVA data is depicted in **Figure 1**.

Safety. After 12 months, no eye had lost two or more lines of CDVA and almost 76% (32 eyes) of all eyes had either preserved preoperative CDVA or gained up to two logMAR lines (**Figure 1**). The Iranian subgroup compared to the German group and the low hyperopia subgroup compared to the moderate hyperopia subgroup showed significantly better postoperative CDVA changes (**Table 1**).

REFRACTION

One month after the operation, the preoperative spherical equivalent of the patients decreased from 2.56 ± 0.19 (mean ± SE) to -1.1 ± 0.21 D (*P* < .001, Wilcoxon signed-rank test) due to myopic overcorrection but gradually returned to emmetropia by the end of follow-up (with mean spherical equivalent ± SE of -0.31 ± 0.14, -0.08 ± 0.14, and 0.05 ± 0.13 D at 3, 6, and 12 months, respectively). Mean values of postoperative refraction did not differ significantly between the subgroups at any of the studied time points (**Table 1**). Final spherical equivalent was significantly more hyperopic in patients 45 years or older (-0.23 ± 0.14 vs 0.37 ± 0.14 D; *P* = .006, *t* test). Ninety-seven percent of the preoperative mean spherical equivalent was corrected by this time point (the distribution of achieved spherical equivalent at the final visit is outlined in **Figure 1**).

Predictability. By the 6-month follow-up visit, 90.9% of low hyperopic eyes, 61.5% of moderate hyperopic eyes (*P* = .04, chi-square), and 75% of all eyes were within ±0.50 D of the targeted spherical equivalent. Notably, all low hyperopic eyes were within ±1.00 D of the target at this time, with 88.4% for moderate hyperopic eyes (*P* = .04, chi-square test) and 91.6% in aggregation. After 12 months, although target ±0.50 D predictability was similar to the 6-month data, the percentage of eyes within

TABLE 1

Visual Parameters of Separate Patient Subgroups

Parameter	Iran	Germany	*P*	Hyperopic Error (Low)	Hyperopic Error (Moderate)	*P*
logMAR UDVA (mean ± SE)						
Preoperative	0.37 ± 0.06	0.59 ± 0.06	.10[a]	0.35 ± 0.04	0.70 ± 0.07	< .001[a]
3 months	0.09 ± 0.05	0.22 ± 0.04	.22[a]	0.10 ± 0.03	0.25 ± 0.05	.03[a]
6 months	0.04 ± 0.04	0.21 ± 0.03	.01[a]	0.12 ± 0.04	0.19 ± 0.04	.44[a]
12 months	-0.02 ± 0.02	0.21 ± 0.04	< .001[a]	0.07 ± 0.03	0.20 ± 0.05	.02[a]
Eyes (%) with UDVA of 20/25 or better						
3 months	50	52.7	.91[b]	68.4	38.1	.05[b]
6 months	66.6	50	.45[b]	64.3	45.8	.27[b]
12 months	100	46.4	< .001[b]	77.3	52.4	.08[b]
Eyes (%) with different number of CDVA logMAR line change (12-month vs preoperative)			.02[b]			.01[b]
2 line loss	0	0		0	0	
1 line loss	14.8	30.2		14.3	35.1	
No change	62.5	53.3		66.9	46.9	
1 line gain	0	16.9		14.3	9.5	
2 line gain	21.4	0		9.5	4.7	
Manifest refraction (D) (mean ± SE)						
Preoperative	1.84 ± 0.39	2.84 ± 0.19	.02[c]	1.25 ± 0.17	3.65 ± 0.13	< .001[c]
3 months	-0.06 ± 0.39	-0.4 ± 0.16	.31[a]	-0.14 ± 0.11	-0.47 ± 0.24	.16[a]
6 months	-0.04 ± 0.07	-0.1 ± 0.17	.76[a]	0.10 ± 0.13	-0.22 ± 0.20	.31[a]
12 months	0 ± 0.06	0.08 ± 0.16	.13[a]	0.11 ± 0.07	0 ± 0.22	.92[a]
Target ± 0.50 D predictability (%)						
6 months	100	63.3	.02[b]	90.9	61.5	.04[b]
12 months	100	64.3	.02[b]	86.7	65.1	.10[b]
Target ± 1.00 D predictability (%)						
6 months	100	90	.06[b]	100	88.4	.04[b]
12 months	100	78.5	.08[b]	90.4	78.9	.30[b]
Regression rate (D/m) (mean ± SE)						
1 to 6 months	0.140 ± 0.03	0.180 ± 0.03	.82[c]	0.120 ± 0.04	0.220 ± 0.05	.09[c]
6 to 12 months	0.004 ± 0.01	0.004 ± 0.01	.57[c]	-0.004 ± 0.01	0.010 ± 0.85[c]	.85
Astigmatism (D) (mean ± SE)						
Preoperative	-0.86 ± 0.22	-0.98 ± 0.14	.84[a]	-0.97 ± 0.19	-0.92 ± 0.15	.71[a]
3 months	-0.27 ± 0.12	-0.59 ± 0.09	.13[a]	-0.39 ± 0.10	-0.57 ± 0.14	.52[a]
6 months	-0.28 ± 0.09	-0.72 ± 0.10	.04[a]	-0.54 ± 0.11	-0.65 ± 0.12	.61[a]
12 months	-0.3 ± 0.04	-0.86 ± 0.13	< .001[a]	-0.40 ± 0.09	-0.95 ± 0.08	.003[a]
Astigmatism induction (D) (mean ± SE)						
12-month vs preoperative	-0.2 ± 0.03	-0.87 ± 0.16	.04[c]	-0.31 ± 0.12	-1.0 ± 0.22	.02[c]

UDVA = uncorrected distance visual acuity; SE =standard error; CDVA = corrected distance visual acuity; D = diopters
[a]*Mann–Whitney* U *test.*
[b]*Chi-square test.*
[c]*Independent two sample* t *test.*

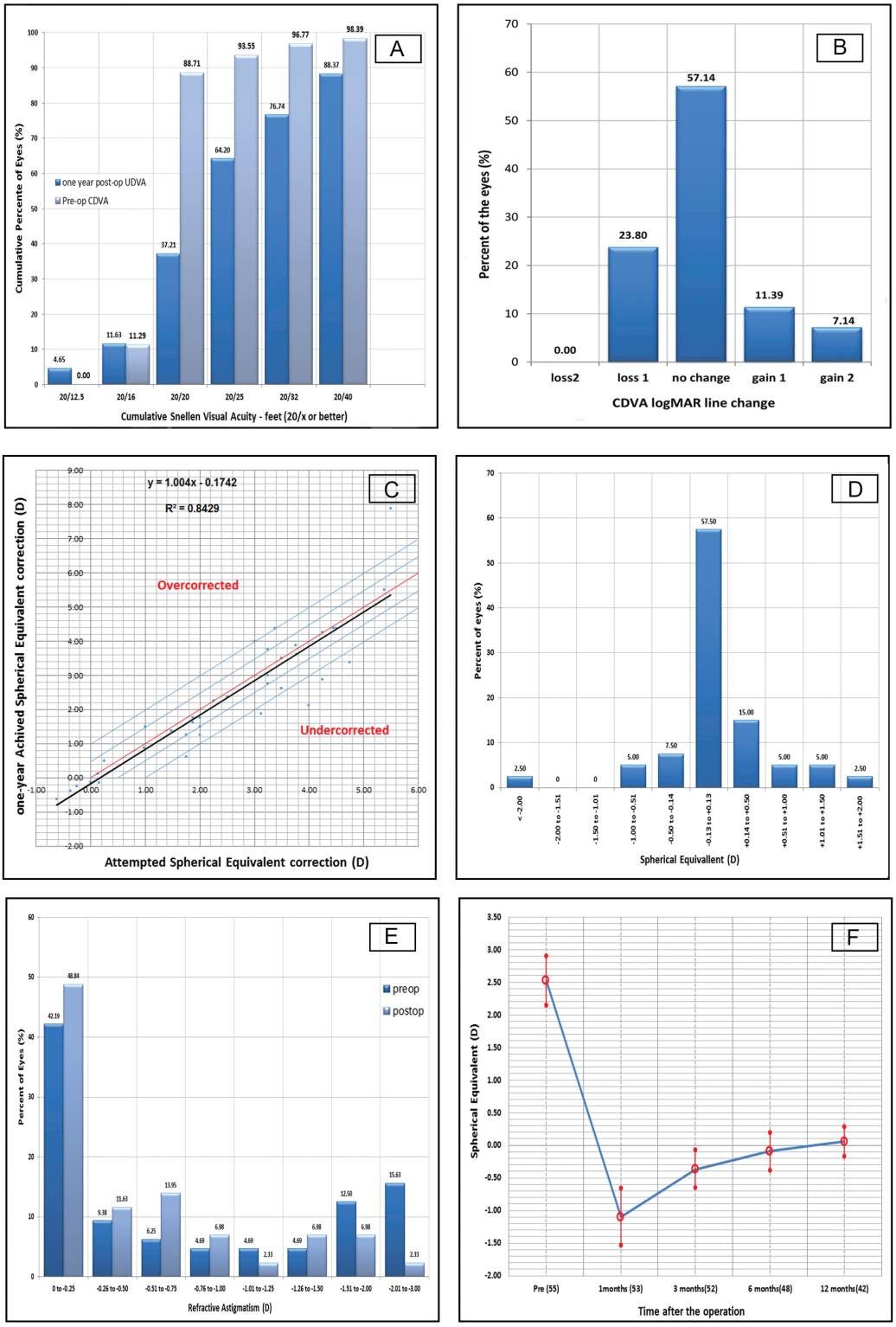

Figure 1. Visual outcomes of transepithelial photorefractive keratectomy in hyperopia. The figure demonstrates results of (A) uncorrected distance visual acuity, (B) change in corrected distance visual acuity, (C) spherical equivalent attempted vs achieved, (D) spherical equivalent refractive accuracy, (E) refractive astigmatism, and (F) stability of spherical equivalent refraction.

TABLE 2
Summary of Postoperative Corneal Haze[a]

	Low Hyperopic Group				Moderate Hyperopic Group			
Grade[b]	1 Month	3 Month	6 Month	12 Month	1 Month	3 Month	6 Month	12 Month
0	18	19	20	19	23	19	18	13
1+	5	4	2	0	5	9	4	4
2+	1	1	0	1	1	0	2	1
3+	0	0	0	0	0	0	1	4
4+	0	0	0	0	0	0	1	0
Total	24	24	22	20	29	28	26	22

[a]*The table shows number of eyes with different degrees of corneal haze, detected at successive postoperative time points, classified within the hyperopia group.*
[b]*The haze scores are according to grading system already introduced by Fantes et al.*[11]

target ±1.00 D was lower (85.7% vs 91.6% for all treated eyes); however, this difference was not significant (P = .97, exact McNemar's significance). The 6- and 12-month predictability results were significantly better in the Iranian subgroup compared to the German subgroup (**Table 1**). By the final (12-month) visit, all but one treated eye was within the target ±2.00 D refraction (this eye belonged to the moderate hyperopic group) and 83.3% of eyes had hyperopia less than 1.00 D. A correlation of the attempted versus achieved (12-month) data for all treated eyes is shown in **Figure 1**. The attempted mean of correction in all of the eyes is statistically comparable to the achieved mean of correction 1 year after the operation (P = .09, paired t test). The attempted correction was higher than achieved correction in the Iranian (1.57 ± 0.48 vs 1.45 ± 0.49; P = .02, paired t test) and low hyperopia (1.18 ± 0.22 vs 0.94 ± 0.19; P = .005, paired t test) subgroups. Achieved correction was comparable in patients younger than 45 years and 45 years and older.

Stability. The mean ± SE rate of regression of spherical equivalent between 1 and 6 months of follow-up was 0.17 ± 0.03 D per month for the total group of eyes. The regression slowed after 6 months (when near emmetropia was achieved) to 0.004 ± 0.01 D per month (**Figure 1**). The regression rate was significantly higher in the first 6-month interval compared to the next 6 months (P < .001, paired t test). The moderate hyperopic subgroup showed larger regression rates compared to the low hyperopic group; however, the differences were not statistically significant (**Table 1**).

The percentage of eyes with more than 0.50 D of spherical equivalent change within 1 to 3, 3 to 6, and 6 to 12 months was 58%, 28%, and 17%, respectively. For 1.00 D of spherical equivalent change, the corresponding values were 33%, 9%, and 0%, respectively. During the past 6 months, the change of spherical equivalent mean within all subgroups was not statistically significant (P = .76, .27, .96, .49, and .63, for all eyes, Iranian, German, moderate hyperopia, and low hyperopia subgroups, respectively, Wilcoxon signed-rank test), as shown in **Figure 1**.

Astigmatism Correction. The preoperative astigmatism (mean ± SE) of all eyes was -0.94 ± 0.12 D. By 3 months it significantly improved to -0.49 ± 0.08 D (P = .005, Wilcoxon signed-rank test), but increased to -0.71 ± 0.12 D at the end of 12 months, which was comparable to the preoperative value (P = .17, Wilcoxon signed-rank test). In the Iranian and low hyperopia subgroups, the 1-year postoperative astigmatism was significantly lower than the preoperative value (**Table 1**) (P = .009 and .003, respectively, Wilcoxon signed-rank test). During the 12-month period, an astigmatism induction of more than 0.50 D was detected in 23% of eyes. This induction was significantly higher in moderate hyperopia and German subgroups (**Table 1**). The overall preoperative and 1-year postoperative refractive astigmatism data is presented in **Figure 1**.

COMPLICATIONS

We detected some arcuate peripheral haze. By month 3, only 1 eye with grade 2+ haze was detected. The rest had none or grade 1+ haze. However, 3 months later, 1 eye developed 3+ and another developed 4+ haze; both had a CDVA of 20/20. After 12 months, the eye with grade 4+ haze had cleared, but 4 eyes had 3+ peripheral haze. These eyes had a minimum CDVA of 20/25. Also, none of the patients with haze complained of any subjective flaw in their quality of vision. All of these high-grade hazes belonged to the moderate hyperopia German group (**Table 2**). No haze was detected in the Iranian eyes.

In this study, the mean ± SE time for epithelial healing was 2.2 ± 0.09 days. No delayed reepithelialization was registered. No other notable complications were encountered throughout the 12 months of follow-up appointments.

DISCUSSION

This study demonstrated that one-step combined transepithelial PRK could correct hyperopia (up to 6.00 D) effectively by 6 months with a slight regression in the following 6 months. More than 90% of the treated eyes were within ±1.00 D of the intended target refraction within 6 months of the operation. The treated eyes gained a mean of four UDVA logMAR lines. No eye lost two or more lines of CDVA. A late occurrence of significant peripheral haze was found in 4 eyes, none of which had a reduction in CDVA.

The first attempts to correct hypermetropia began as early as 1898, when Lans examined thermokeratoplasty to increase the corneal power of rabbit eyes.[13] However, owing to low predictability, instability, and significant regressions reported, thermokeratoplasty and other modalities proposed to treat hyperopia, such as radial keratotomy, hexagonal keratotomy, keratomileusis, keratophakia, epi-keratoplasty, and hyperopic automated lamellar keratoplasty, failed to attain acceptable success.[9,14] So far, hyperopic PRK and LASIK have been suggested as good choices for the correction of mild to moderate hyperopia.[9,14-17] Clear lens extraction with intraocular lens implantation and phakic intraocular lens implantation have yielded good results for high hyperopia, but intraocular surgery complication risks cannot be ignored.[14] Recent studies with femtosecond laser-assisted hyperopic LASIK have demonstrated better results compared to hyperopic LASIK using a mechanical microkeratome.[17,18]

Earlier experiences with hyperopic PRK and LASIK did not produce satisfactory results owing to significant regression, low predictability, and CDVA loss.[19,20] This was mainly attributed to the smaller optical zones used in these studies and inaccurate centration of the treatment zone.[9,21] Small optical zones produce an abrupt transition between ablated and unablated areas, inducing aggressive tissue regeneration resulting in regression. In addition, a high probability of decentration with small optical zones causes CDVA deterioration.[9] Further studies conducted using larger optical zones confirmed this thesis and demonstrated promising results.[16,21,22] Accordingly, all of the procedures in our study used optical zones of 6.8 mm or more.

In our study, most of the treated eyes were overcorrected to myopia after 1 month (assuming the measured manifest refraction to be comparable with cycloplegic refraction verified, in part, by tests performed, as previously proposed[21]). Many other hyperopic PRK studies have reported similar myopic overcorrection.[15,21,23,24] Some authors recommend adjusting the algorithms to prevent this overcorrection,[23] but others consider this overcorrection to be beneficial for an expected regression.[15,24] Our data supported this second opinion, showing an initial overshoot that quickly resolved to emmetropia.

Almost 80% of the eyes reached ±0.50 D of emmetropia by 6 months after the operation. In the following 6 months, although some degree of regression presented (**Figure 1**), the change of spherical equivalent was not statistically significant. Some previous studies reported stabilization as early as the third month of follow-up[15,25] and some reported results similar to ours.[21,23] However, in their 5-year follow-up for hyperopic LASIK, Jaycock et al.[26] concluded that long-term stability for hyperopic LASIK is uncertain. By the final follow-up visit registered in our study, an almost 97% reduction in the preoperative mean spherical equivalent had been achieved, compared to an 83.4% reduction by hyperopic PRK.[27] Aspheric ablation profile, larger optical zones, and fast and more even tissue ablation provided by modern laser technology could account for the better results in our study.

A mean regression rate of almost 1.00 D occurred between 1 and 6 months of follow-up. However, in the next 6 months our treated eyes regressed by only a mean of +0.02 D. Similar trends of regression have been reported in hyperopic PRK studies[15,21] and could be justified by early overshooting. In both intervals, the regression was higher, numerically, in our moderate hyperopia group. This is in accordance with many previous reports, concluding that safety, stability, and regression indices are worse in moderate to high hyperopia compared to low hyperopia.[19,28] The mean rate of regression between months 6 and 12 was only 0.004 D per month in our study, which is promising.

Regarding the predictability, 100% of the eyes in the low hyperopia group were within ±1.00 D of the target refraction after 6 months and 90.4% after 1 year. In the moderate hyperopia group, the corresponding values were 87.5% and 78.9%, respectively. In the Iranian subgroup, 100% of the eyes were within ±1.00 D at both 6 and 12 months. These results are promising compared to previous reports. Reported ±1.00 D predictability for hyperopia correction in previous studies ranges from 33% to 98%.[16,19,21,22,25,26,28] This diversity could be justified by the degree of preoperative hyperopia, the size of optical zone and transitional zone used, the technique of the procedure, and the length of follow-up reported. Higher hyperopic corrections, smaller optical zones and transitional zones, and longer follow-up periods tend to be less predicatable.[16,19,26] Our results also demonstrated this trend.

The interpretations and discussion of refraction indices in this study are based on the manifest refraction,

which is one of the weaknesses of this study. Although our verifying preoperative tests and similar findings in prior studies were reassuring, our postoperative cycloplegic refraction measurements could have further strengthened the precision of our results. For further elucidation, we compared the refraction and visual acuity of patients younger than 45 years and 45 years and older. We found that the younger than 45 years subgroup achieved significantly better results in both visual acuity and refraction. We interpreted that although accommodation in younger ages could mask the real degree of hyperopia detected by manifest autorefractometry, good visual acuity in this subgroup implies that this modification has not notably altered the real face of our outcomes.

Astigmatism of eyes within the Iranian and low hyperopia subgroups improved by the final visit; however, for our aggregated data the postoperative mean cylindric refraction was comparable to the preoperative values, in agreement with most other studies.[15,17,21,24] Looking at the individual eyes, almost 23% of the treated eyes (mostly moderate hyperopic eyes) had notable astigmatism induction. Although astigmatism induction has already been introduced as an unwanted outcome in hyperopia correction,[24] our induction rate is higher than similar reports in hyperopia correction.[21] Appropriate addressing of kappa angle and efficient prevention of haze are important points to prevent induction of astigmatism.[17] Different ablation centration and different incidence of haze could have contributed to more astigmatism induction encountered in these subgroups of our study.

Of our treated eyes, 63.2% gained UDVA of 20/25 or better by month 12. This is acceptable compared to hyperopic PRK and hyperopic LASIK.[21,29] No eye lost more than one logMAR line of CDVA in this study, demonstrating the safety of the procedure. Many authors consider the loss or gain of one line of CDVA to be within the normal range of visual acuity fluctuations. Only 24% of the treated eyes lost one line of preoperative CDVA, which would be considered promising in the context of previously published reports. The hyperopic PRK study[21] reported 30% of eyes losing one line of CDVA. In the recent femtosecond laser-assisted LASIK study for hyperopia,[17] loss of two or more lines of preoperative CDVA was reported in almost 3% of treated cases.

Peripheral subepithelial corneal haze does not decrease visual acuity in hyperopic PRK as it does in myopic PRK, because it does not affect the visual axis.[9] Despite this difference, it could still induce astigmatism and refractive regression. We encountered 5 eyes with grades 3 to 4 arcuate peripheral hazes in our follow-up. These hazes were located in the periphery and all of them had full CDVA. They occurred in patients in the German and moderate hyperopia groups after 6 months and might explain the higher astigmatism induction detected in these subgroups. In addition, it could be a reason for higher values of regression in the moderate hyperopia subgroup. This haze might be prevented with a better peripheral distribution of MMC application. Different regimens of MMC application and postoperative medical treatment and different ultraviolet protection in the two centers could account for the different haze results.[30] No other notable complications were encountered, and no case had delayed corneal reepithelialization. Having prevented the occurrence of haze, this procedure could be considered safe for this group of patients.

Some differences existed between the two centers in method of procedure and medication, which could account for different visual outcomes. A larger optical zone in Iran, MMC being placed longer in Germany, and different centration in Germany appear to be the greatest differences in operative technique. The postoperative regimens also differed: in the Iran regimen, corticosteroid and nonsteroidal anti-inflammatory drops were not prescribed early after the operation and, when initiated after contact lens removal, corticosteroids were continued longer. Although there were more moderate hyperopic eyes in Germany (although not statistically significant) and the mean pupil diameter was larger, these results suggest that perhaps postoperative regimens may have some correlation with long-term results. The patients in Iran were also younger (38 vs 41 years), which may result in less presbyopia in this age group.

This 12-month study demonstrated the efficacy, predictability, and stability of one-step transepithelial PRK in hyperopia with and without astigmatism. The efficacy was more pronounced in low hyperopia (up to 3.00 D). Regardless of haze induction, other parameters assessed implied the safety of this procedure for hyperopia correction. Longer follow-up times are necessary to assess regression and postoperative cycloplegic refraction data could increase the precision of study findings.

AUTHOR CONTRIBUTIONS

Study concept and design (SA-Moghaddam, SA-Mosquera, RW-F); data collection (SA-Moghaddam, RW-F, FA-A); analysis and interpretation of data (SA-Moghaddam, SS-J); writing the manuscript (SA-Moghaddam, SS-J); critical revision of the manuscript (SA-Moghaddam, SA-Mosquera, RW-F, SS-J, FA-A); statistical expertise (SA-Mosquera, SS-J, FA-A); administrative, technical, or material support (SA-Moghaddam, RW-F); supervision (SA-Moghaddam, SA-Mosquera)

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TABLE A

Summary of Preoperative Parameters and Surgical Registered Data[a]

Parameter	All Cases	Iran	Germany	Hyperopic Error (Low)	Hyperopic Error (Moderate)
Preoperative assessments					
Age, y	39.83 ± 1.29 (20 to 54)	37.38 ± 1.49 (23 to 53)	40.97 ± 1.47 (20 to 54)	39.37 ± 1.98 (20 to 54)	40.26 ± 1.68 (21 to 51)
Manifest SEq (D)	2.56 ± 0.19 (-0.62 to 5.37)	1.84 ± 0.39 (-0.62 to 4.62)	2.84 ± 0.19 (-0.25 to 5.37)	1.25 ± 0.17 (-0.62 to 2.87)	3.65 ± 0.13 (2 to 5.375)
Astigmatism (D)	-0.94 ± 0.12 (-3.00 to 0.00)	-0.86 ± 0.22 (-3.00 to 0.00)	-0.98 ± 0.14 (-3.00 to 0.00)	-0.97 ± 0.19 (-3.00 to 0.00)	-0.92 ± 0.15 (-2.50 to 0.00)
logMAR UDVA	0.54 ± 0.05 (0 to 1.70)	0.37 ± 0.06 (0.15 to 0.70)	0.59 ± 0.06 (0 to 1.70)	0.35 ± 0.04 (0.25 to 0.70)	0.70 ± 0.07 (0.15 to 1.70)
logMAR CDVA	0.01 ± 0.01 (-0.08 to 0.40)	0.00 ± 0.02 (-0.08 to 0.22)	0.02 ± 0.01 (0 to 0.40)	0.00 ± 0.01 (-0.08 to 0.22)	0.02 ± 0.01 (-0.08 to 0.40)
Surgical parameters					
Optical zone (mm)	7.00 ± 0.02 (6.7 to 7.6)	7.11 ± 0.05 (6.8 to 7.6)	6.96 ± 0.01 (6.7 to 7)	7.04 ± 0.03 (6.7 to 7.6)	6.98 ± 0.01 (6.7 to 7.2)
Pupillary offset distance (mm)	0.23 ± 0.02 (0 to 0.66)	0.12 ± 0.02 (0 to 0.23)	0.27 ± 0.03 (0 to 0.66)	0.16 ± 0.04 (0 to 0.66)	0.32 ± 0.04 (0 to 0.65)
DCC-min	-1.05 ± 0.16 (-7.32 to 1.37)	-0.52 ± 0.18 (-2.12 to 1.37)	-1.30 ± 0.21 (-7.32 to 0.87)	-0.94 ± 0.23 (-5.88 to 1.37)	-1.15 ± 0.23 (-7.32 to 0.41)
DCC-max	1.17 ± 0.17 (0 to 7.21)	1.41 ± 0.37 (0 to 6.64)	1.05 ± 0.18 (0 to 7.21)	0.95 ± 0.16 (0 to 3.36)	1.37 ± 0.29 (0 to 7.21)

D = diopters; SEq = spherical equivalent; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; DCC = dynamic cyclotorsion correction
[a]Mean ± standard error and range of parameters are given for all cases.