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Original Article

8-to-10-Year Follow-Up Results of Photorefractive Keratectomy and Risk Factors for Myopia Regression (Including Near Work Activity) in Southeast Iran

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Abstract

Objectives: To evaluate the 8-to-10-year safety, efficacy, and predictability of photorefractive keratectomy (PRK) and to assess the risk factors for myopic regression and the role of near-work activity in myopia progression.

Methods: This retrospective study included patients who underwent mechanical PRK and were followed up for 8–10 years. Pre-operative clinical data, including visual acuity, refraction, tomography, optical zone, and ablation depth, were analyzed. Safety, efficacy, and predictability indices were evaluated, and astigmatism correction was assessed using Alpins' vector analysis. Myopic regression was defined as a spherical equivalent <−0.25 D. Risk factors for myopic regression were evaluated using regression analysis, and near-work activity was investigated as a potential factor for myopia progression.

Results: Eighty-two patients (mean age 30±5.8 years) completed the follow-up. Pre-operative and post-operative refractive errors were −3.61±1.80 D and −0.12±0.25 D, respectively (p<0.001). Seventy-four percent of patients had post-operative refractive errors within ±0.25 D. The safety, efficacy, and predictability indices were 1, 0.95, and 0.97, respectively. The astigmatism correction index was 1.02±0.78. Myopic regression occurred in 22% of patients. Regression analysis showed that the odds of myopic regression increased by 1.4 times (p=0.04) for each 1 D increase in myopia and by 1.05 times (p=0.04) for each micrometer increase in ablation depth. Conversely, the odds decreased by 0.14 times (p=0.03) with each millimeter increase in corneal diameter. The odds ratio for the time spent on near-work activity was insignificant.

Conclusion: PRK proved to be a safe, effective, and predictable procedure in the long term. Myopia and ablation depth were significant risk factors for myopic regression, while corneal diameter was protective. Near-work activity did not affect myopia progression. Under-corrected eyes for astigmatism exhibited a higher magnitude of pre-operative astigmatism compared to over-corrected eyes.

Keywords: Astigmatism, myopia, photorefractive keratectomy, refractive error

Introduction

Myopia and compound myopic astigmatism are the leading causes of reversible visual impairment, with increasing prevalence in the world (1). Laser refractive surgeries are the standard therapeutic modality for patients with myopia who do not choose optical corrections such as spectacles and contact lenses. Photorefractive keratectomy (PRK) and laser-assisted in situ keratomileusis are the two main cate-

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gories of laser refractive surgeries that are widely used (2).

PRK surgeries were first performed in the late 1980s and were considered a safe procedure; however, myopic regression would develop in some cases (3,4). This complication was mainly attributed to the wound healing response after the PRK procedure, but its exact mechanism is yet unclear (5,6). Many advancements in laser technology and photorefractive surgical procedures have been introduced in the past decades, and they have led to improved wound healing and reduced rates of myopic regression (7). Some of the more salient of these advancements are as follows: Higher-frequency lasers with more intensive impulse rates, (8) transition from broad beam laser technology to flying spot laser technology, (9) application of a wider optical zone diameter and transition zone, (10) application of aspheric ablation profiles and aberration-guided profiles, (8,11) introduction of an eye-tracking system to compensate for torsional eye movement in the supine position during PRK, (12) and administration of mitomycin-C after laser ablation and corticosteroids (13).

Studying the long-term safety and efficacy of treatments is paramount in all medical interventions, including PRK. Several long-term follow-up studies of PRK have been published from early PRK procedures, (14-17) but additional studies are required due to the lack of long-term studies after recent technological and methodological evolution in the area of PRK. In this comprehensive study, we aim to evaluate the safety, efficacy, and predictability of PRK in a group of patients who underwent this procedure 8-to-10 years ago. Furthermore, we aim to perform vector analysis for astigmatism using Alpin's method.

In addition, we deploy regression analysis to evaluate potential risk factors for myopic regression. Previous studies have evaluated the potential risk factors for myopic regression after PRK. These studies have revealed that a higher degree of refractive error, a smaller optical zone diameter, and a deeper ablation depth are associated with more aggressive wound healing, haze formation, and, consequently, myopic regression (18-21). In this study, we aim to evaluate potential risk factors of corneal characteristics and some surgical parameters for myopia regression. Since it is a long-term study, the risk factor of myopia progression should also be explored. Given the relationship between near-work activity and myopia progression, (22) we incorporate hours of near-work activity per day after PRK as a covariate in the regression model.

Methods

In this retrospective design, we reviewed the medical records of 500 myopic individuals with or without astigmatism who had undergone PRK at least 8 years ago between 2015 and 2017 in Motahari Ophthalmology Clinic, Shiraz, Iran. The study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics committee (IR. SBMU.RETECH.REC.1400.1193). The patients were called for a follow-up examination after 8 to 10 years. A total of 82 patients participated in the study, and all of them submitted their informed consent. The main reasons for not attending the follow-up examination were a change in address and phone number, as well as time limitations. Other cases did not attend the follow-up sessions because they were satisfied with their vision.

All participants had a comprehensive ophthalmic examination including uncorrected visual acuity (UCVA), best-corrected visual acuity (BCVA), dry and cycloplegic subjective refraction, tonometry, fundoscopy, and corneal imaging through Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany) and Shack-Hartmann aberrometry (Bausch & Lomb Zywave, Rochester, New York). Patients with ecstatic corneal disease, corneal ulcer and trauma, and residual stromal bed thickness <300 μm were initially excluded from the laser treatment. The patients with a history of other ocular surgeries or systemic conditions (e.g., diabetes and rheumatoid disease) were excluded from the study. Another complete ophthalmic examination was administered in the follow-up visits. Through an interview in the follow-up visit, the time spent on near-work activity was recorded for all patients. Near-work activity is characterized as any visual task performed from a habitual distance close to the eyes up to a distance of 70 cm away from the eyes. The assessment of near-work activity was based on self-reported data, participants' respective jobs, and daily routines. Participants were categorized into two groups: Those with near-work activity >8 h/day and those with near-work activity <8 h/day. Participants who performed office jobs and engaged in near-vision tasks for long hours were assigned to the near-work activity >8 h/day group. This group included accountants, bankers, computer technicians, engineers, educators, tailors, makeup artists, and similar occupations. On the other hand, participants working in service sectors, where near-vision tasks were not prolonged, were included in the near-work activity <8 h/day group. This group included housekeepers, nurses, firefighters, divers, guards, and others.

It should be clarified that we assessed visual acuity in logMAR units and considered dry and cycloplegic subjective refraction both before and after PRK.

Surgical Technique

For the ablation procedure, local anesthetic drops were applied, and periorbital scrubbing was performed using povidone–iodine 10.0%. The eyes were irrigated with a balanced salt solution, but no alcohol was used. The Technolas Teneo 317 model 2 excimer laser and its ProScan software

(Technolas Perfect Vision, GmbH) were used to perform the ablations. By default, ProScan uses its built-in nomogram to determine the target refraction and ablation indices after the patient's optical data are imported. However, some degree of overcorrection was applied depending on the patient's age. For the spherical component of the target refraction, 0.25 diopters (D) of overcorrection was applied in patients 30 years or younger and 0.125 D of overcorrection in those older than 30 years. In case of astigmatism, 0.125 D of overcorrection was applied in patients aged 30 years or younger. Astigmatism, however, was not over-corrected in older patients.

Blunt spatula debridement was performed to remove the corneal epithelium. Next, laser ablation was administered. Static and dynamic cyclotorsion corrections compensated for eye movements throughout the ablation. All procedures were performed using the same technique by the four surgeons at the academic center. After ablation, a sponge soaked with mitomycin-C 0.02% and then squeezed was placed over the stromal bed for 25 s for patients with myopia >4.0 D (23 patients). The eye was then irrigated with copious amounts of a chilled balanced salt solution. Eventually, a soft bandage contact lens with high oxygen permeability was placed over the cornea.

Post-operative Medication and Protocol

The protocol for post-operative medication was refined. Ciprofloxacin eye drops 0.3% was administered every 4 h for up to 7 days. The patients also received oral acetaminophen 500 mg 3 times daily and betamethasone 0.1% (as the topical steroid anti-inflammatory drug) during the epithelial healing phase. The contact lens was removed 5 days after the surgery when corneal re-epithelialization was complete. If no corneal epithelial defect was detected after 5 days, patients were prescribed betamethasone 0.1% every 6 h for 2 weeks, after which it was tapered every 2 weeks to once daily for up to 6 months. None of the patients had reported increased intraocular pressure during betamethasone consumption, and at an 8-to-10-year follow-up visit. After complete re-epithelialization, the patients were prescribed ciprofloxacin eye drops 0.3 % every 4 h for 1 week and preservative-free artificial tears for 6 months. All patients were instructed to protect their eyes from ultraviolet (UV) light by wearing sunglasses. Corneal haze was assessed with a slit lamp.

The safety, efficacy, and predictability indices of PRK were evaluated in this study. Safety index was defined as BCVA-post-PRK/BCVA-pre-PRK. Efficacy index was defined as UCVA-post-PRK/BCVA-pre-PRK. Moreover, predictability index was defined by comparing achieved refraction versus attempted refraction using linear regression analysis. The potential risk factors for myopic regression were evaluated, and the cut-off point for myopic regression was defined as spherical equivalent <−0.25 D from the plano. Potential risk factors of myopic regression that were considered in this study include age, pre-operative refractive error, mean keratometry, central corneal thickness, white-to-white corneal diameter, ablation depth, optical zone diameter, and near work activity >8 h.

Astigmatism analysis using Alpin's method was employed to evaluate the effectiveness of PRK correction for astigmatism (23). The correction index represents the ratio of achieved astigmatic correction to the intended correction, where a value of 1.0 indicates perfect correction, values >1.0 suggest overcorrection, and values <1.0 indicate undercorrection. The magnitude of error measures the difference between the achieved and target astigmatism correction, with values close to zero indicating optimal outcomes. The angle of error quantifies the misalignment between the intended and actual correction axis, with larger values indicating greater deviation. Finally, the index of success evaluates how closely the post-operative astigmatism matches the ideal correction, with values near zero reflecting better outcomes, values >0 suggesting overcorrection, and values <0 indicating undercorrection.

A correction index of ≥1.5 was classified as the over-corrected group, whereas a correction index of ≤0.5 was classified as the under-corrected group. The two groups were compared based on post-operative cylindrical error, visual acuity, ablation depth, and optical zone diameter, as well as pre-operative refraction, corneal characteristics, and ocular higher-order aberrations for 5 mm pupil.

Statistical analysis was performed using SPSS version 25 (IBM, Armonk, New York). Descriptive statistics were used to describe the data. The non-parametric Mann–Whitney U test was used to make comparisons between patients with and without myopic regression, and between patients with correction index of ≥1.5 (overcorrected for astigmatism), and correction index of ≤0.5 for astigmatism (undercorrected for astigmatism). Univariate regression analysis was performed to determine the association between myopic regression and the potential risk factors. In addition, the multivariable logistic regression analysis that was run included possible risk factors with a relevant $p<0.2$ ($p<0.05$ was considered statistically significant).

Results

The demographic, refractive, corneal characteristics, optical zone, and central ablation depth of the studied individuals are provided in Table 1. A comparison was made in the mentioned parameters between 418 patients (130 male and 288 female) with a mean age of 28.55±5.31 years at the time of PRK surgery who did not present for follow up visit, and 82 participants (25 male and 57 female) with a

Table 1. Patients' baseline visual characteristics and surgical parameters

Parameter	Patients did not present for follow-up visit	Patients presented for follow-up visit	p
Gender	418 (130 male and 288 female)	82 (25 male and 57 female)	0.65
Age	28.55±5.31 (18–40)	30.07±5.82 (20–40)	0.08
Spherical equivalent (D)	-3.83±1.70 (-10.00–-0.50)	-3.61±1.80 (-9.50–-1.00)	0.45
Astigmatism (D)	-1.01±0.9 (-4.50–0.00)	-0.95±0.80 (-3.00–0.00)	0.50
Mean keratometry (D)	43.81±1.32 (39.30–47.10)	44.05±1.24 (40.55–46.40)	0.30
Central corneal thickness (µm)	541.93±28.60 (477–650)	547.87±20.11 (505–600)	0.16
White-to-white corneal diameter (mm)	11.63±0.35 (10.60–13.20)	11.67±0.35 (10.90–12.50)	0.46
Optical zone (mm)	6.77±0.32 (6–7)	6.75±0.34 (6.00–7.00)	0.48
Central ablation depth (µm)	78.21±24.66 (23–139)	74.90±25.82 (26–133)	0.54

D: Diopter; mm: Millimeter; µm: Micrometer.

mean age of 30±5.80 years at the time of PRK surgery who attended for the 8-to-10-year follow-up visit. There were no significant differences in the mentioned parameters between the two groups (all p>0.05). The distribution of optical zone versus central ablation depth is shown in Figure 1. In addition, the regression lines illustrating the relationship between optical zone and ablation depth based on the severity of myopia in the studied subjects are presented in the accompanying figure.

There were significant improvements in visual parameters 8 to 10 years after PRK (Table 2). The pre-operative spherical equivalent was −3.61±1.80 D, and the post-operative spherical equivalent was −0.12±0.25 D in the 8-to-10-year

Table 2. Visual parameters of the patients 8-to-10 years after photorefractive keratectomy

Parameter	Pre-operative	Post-operative	p
Spherical equivalent (D)	-3.61±1.80	-0.12±0.25	<0.001*
Cylindrical refraction (D)	-0.95±0.80	-0.46±0.28	0.002*
UCVA (LogMAR)	0.62±0.49	0.03±0.05	<0.001*
BCVA (LogMAR)	0.005±0.02	0.002±0.01	0.50

UCVA: Uncorrected visual acuity; BCVA: Best-corrected visual acuity; logMAR: Logarithm of minimum angle resolution. *P-values indicated with an asterisk mark show statistically significant values. (P<0.05).

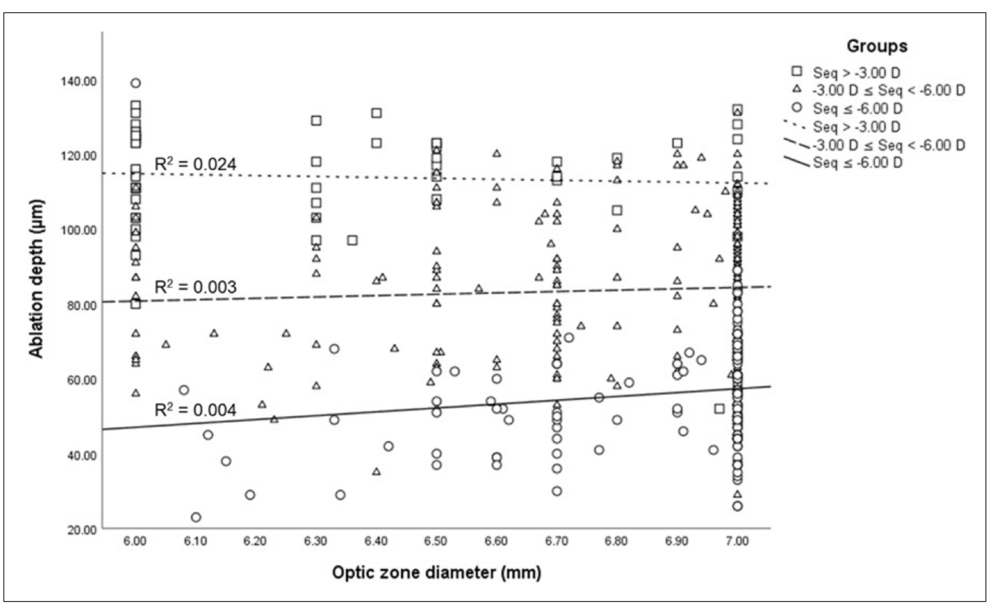

Figure 1. Distribution of optical zone versus central ablation depth. The figure represents the regression lines between optical zone and ablation depth based on the severity of myopia in the studied subjects.

follow-up visits (p<0.001). No eye lost one line or more of BCVA compared to pre-operative values. Furthermore, 72% of eyes had UCVA equal to 0 logMAR (=20/20 Snellen), and 100% had UCVA better than 0.2 logMAR (=20/30 Snellen) (Fig. 2). Besides, 74.4% of eyes showed spherical equivalent within ±0.25 D, and 73.2% showed astigmatic error within 0.00–−0.50 D in the 8-to-10-year follow-up visits (Figures 3 and 4). No eye showed a hyperopic or myopic spherical equivalent refractive error of >1 D and an astigmatism >1.25 D in the 8-to-10-year follow-up visits (Figs. 3 and 4).

The mean attempted correction as spherical equivalent was −3.61±1.80 D (range from −9.50 to −1.00 D), whereas the mean achieved correction after 8-to-10 years was −3.48±1.78 D (range: −9.25–−0.87 D), suggesting no statistically significant difference (p=0.2). Linear regression analysis of the achieved versus the attempted refraction correction revealed y = 0.97x + 0.23, (r^2 = 0.976) (Fig. 5). Meanwhile, the linear regression model of the achieved versus the pre-operative spherical equivalent myopia yielded y = 0.98x + 0.05 (r^2 = 0.98) (Fig. 6). The difference between

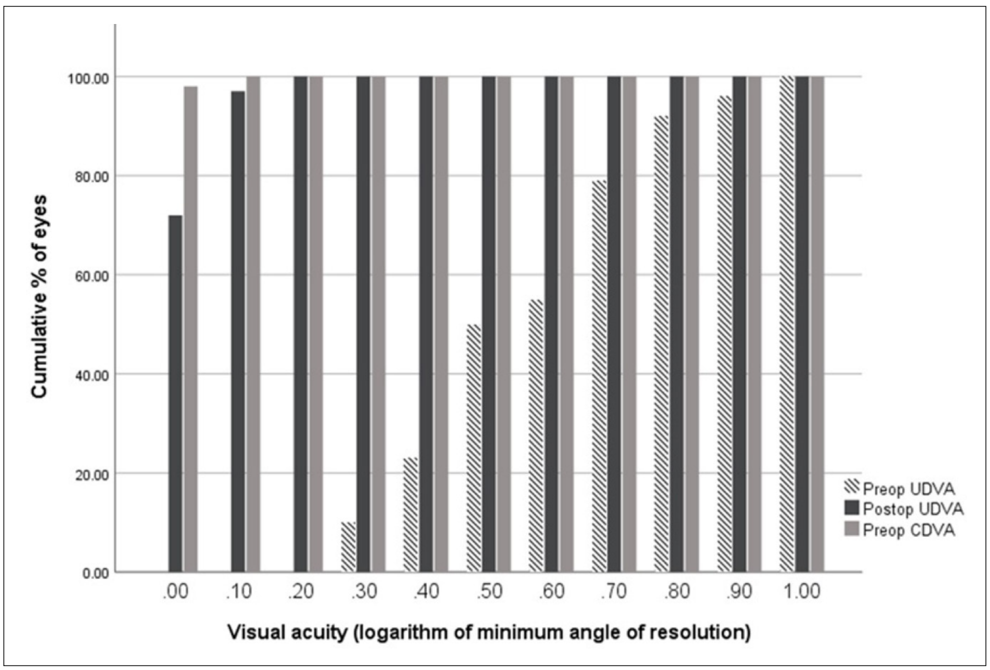

Figure 2. Cumulative frequency of pre-operative corrected and uncorrected distance visual acuity and 8-to-10-year post-operative uncorrected distance visual acuity.

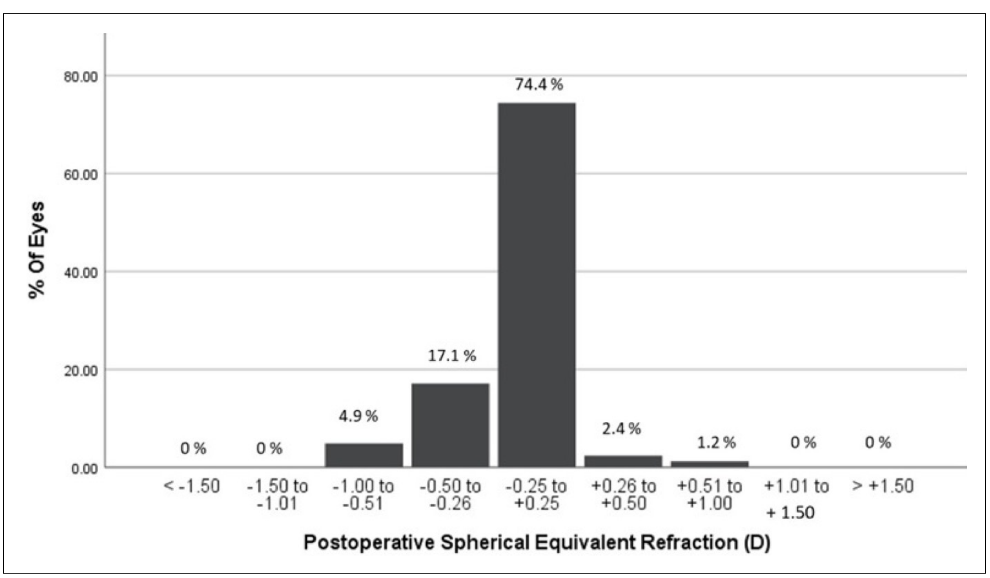

Figure 3. Distribution of spherical equivalent refractive categories 8-to-10 years after photorefractive keratectomy.

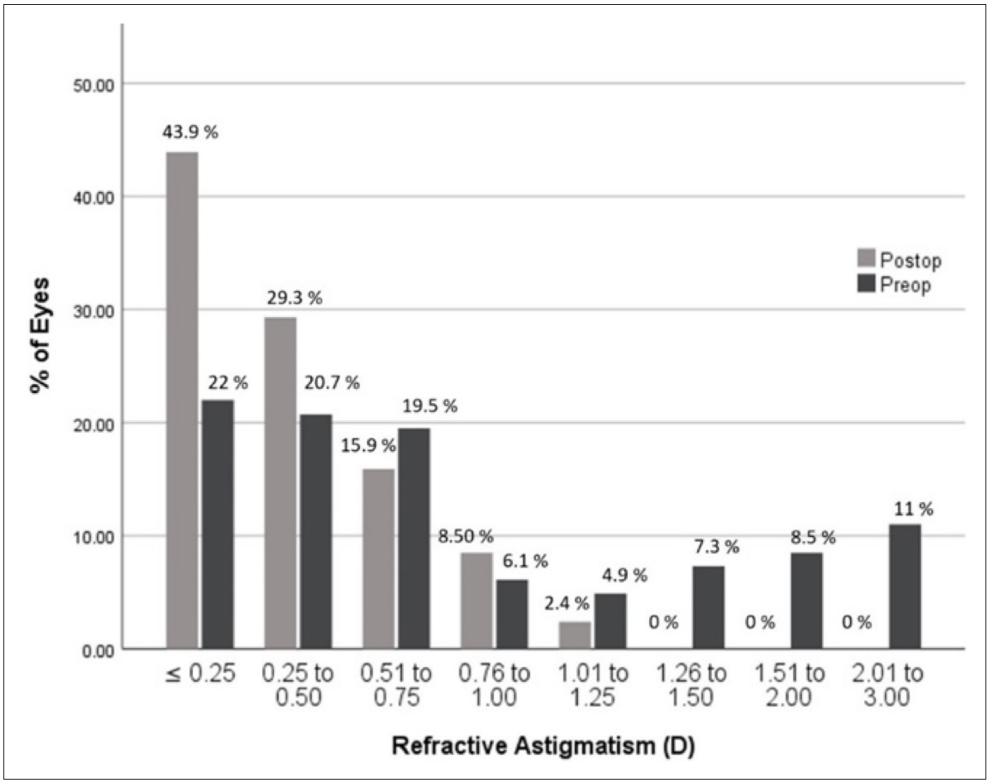

Figure 4. Distribution of refractive astigmatism before and 8-to-10 years after photorefractive keratectomy.

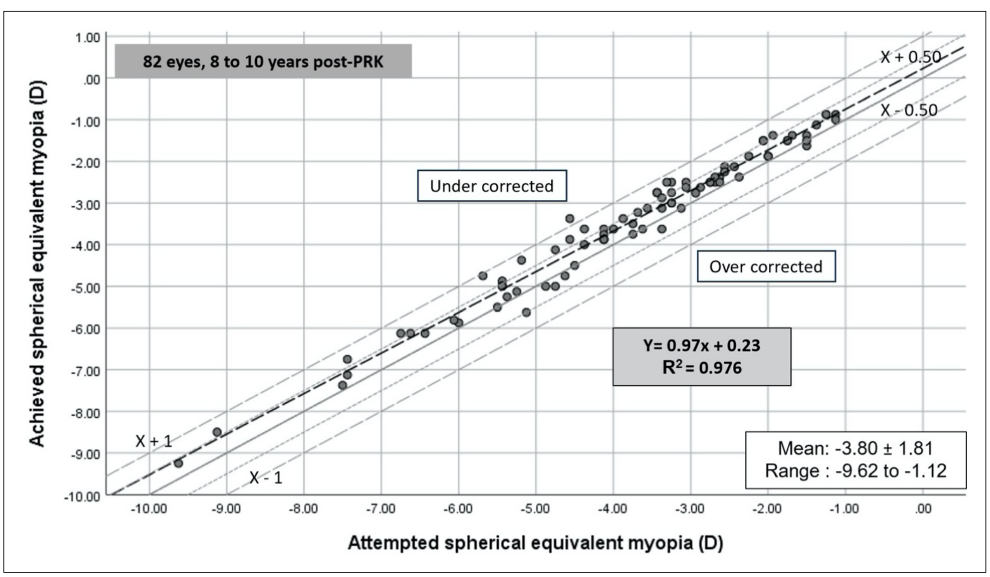

Figure 5. Linear regression analysis of attempted spherical equivalent refraction versus achieved spherical equivalent refraction. Each gray circle represents a treated eye. The black dashed line represents the generated trend line, whereas the black line represents the optimum setting at which the achieved correction would equal the attempted correction. Dots scattered above the black line are under-corrected eyes, and those scattered below the black line are over-corrected eyes.

the y-intercepts of the two models was related to the initial overcorrection in the attempted refraction. This result implies that after early overcorrection in attempted refraction, patients are very close to emmetropia in 8- to 10-year follow-up visits. The observed safety index, efficacy index, and predictability were 1, 0.95, and 0.97, respectively. In our follow-up of 82 cases, no signs of corneal haze were observed during slit-lamp biomicroscopy assessment. No patient reported glare or subjective haze 8-to-10 years postoperatively.

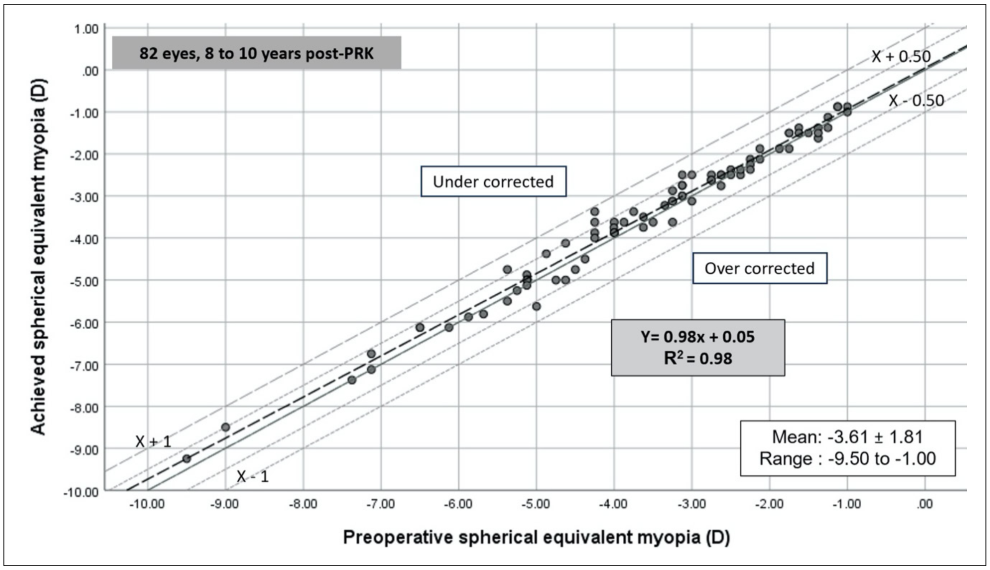

Figure 6. Linear regression analysis of pre-operative spherical equivalent refraction versus achieved spherical equivalent refraction. Each gray circle represents a treated eye. The black dashed line represents the generated trend line, whereas the black line represents the optimum setting at which the achieved correction would equal pre-operative the correction. Dots scattered above the black line are under-corrected eyes, and those scattered below the black line are over-corrected eyes.

Myopic regression in this study was defined as a change in spherical equivalent <−0.25 D from the plano. Accordingly, 22% of cases (four male and 14 female) showed myopic regression. Table 3 compares patients with and without myopic regression in terms of the pre-operative values of age, refractive components, cornea characteristics, ablation depth, optical zone diameter, and duration of near work activity. The two groups showed differences in pre-operative spherical equivalent refractive error, white-to-white corneal diameter, and ablation depth. (All p<0.05).

The results of univariate and multivariate binary logistic regression analysis are provided in Table 4. In binary logistic regression analysis, we considered age, pre-operative spherical equivalent refractive error, cylindrical error, mean corneal curvature, central corneal thickness, white-to-white corneal diameter, ablation depth, optical zone diameter, and near work activity. The level of myopia, ablation depth, and corneal white-to-white are three significant risk factors. The

Table 3. Comparison between the non-regressed and regressed groups

	Non-regressed group	Regressed group	p
Number of patients	n=64 (21 M/43 F)	n=18 (4 M/14 F)	-
Age (year)	30±5.81	29±5.86	0.30
Post-operative spherical equivalent refractive error (D)	-0.03±0.18	-0.47±0.14	< 0.001*
Pre-operative spherical equivalent refractive error (D)	-3.32±1.75	-4.62±1.70	0.005*
Pre-operative Astigmatism (D)	-0.99±0.83	-0.80±0.64	0.54
Mean front corneal curvature (D)	43.10±1.30	44.20±0.90	0.43
Central corneal thickness (µm)	547±20	551±21	0.40
White-to-white corneal diameter (mm)	11.75±0.38	11.46±0.34	0.008*
Ablation depth (µm)	68.31±25.20	90.66±20.52	0.01*
Optical zone diameter (mm)	6.78±0.33	6.67±0.40	0.14
Near work activity (hours)	n=24 near work ≥8 h	n=9 near work ≥8 h	0.50
	n=40 near work <8 h	n=9 near work <8 h	

*P-values indicated with an asterisk mark show statistically significant values. (P<0.05).

Table 4. Regression analysis of the risk factors for myopic regression following photorefractive keratectomy

	Odds ratio	95% CI	p	Odds ratio	95% CI	p
Age (year)	0.96	(0.87, 1.05)	0.40	-	-	-
Gender (male or female)	0.09	(-0.11, 0.28)	0.30	-	-	-
Pre-operative spherical equivalent refractive error (D)	1.50	(1.10, 2.00)	0.01	1.4	(1.00, 1.90)	0.04*
Astigmatism (D)	0.70	(0.35, 1.5)	0.40	-	-	-
Mean front corneal curvature (D)	1.20	(0.80, 1.85)	0.40	-	-	-
Central corneal thickness (µm)	1.0	(0.98, 1.03)	0.40	-	-	-
White-to-white corneal diameter (mm)	0.08	(0.01, 0.50)	0.006	0.14	(0.02, 0.90)	0.03*
Ablation depth (µm)	1.10	(1.00, 1.08)	0.02	1.05	(1, 1.1)	0.04*
Optical zone diameter (mm)	0.60	(0.2, 2.50)	0.50	-	-	-
Near work activity (hours)	0.07	(-0.13, 0.27)	0.50	-	-	-

*P-values indicated with an asterisk mark show statistically significant values. (P<0.05). CI: Confidence interval.

odds of myopic regression are anticipated to grow about 1.4 times larger for each 1 D increase in myopia level (p=0.04, CI: 1.00, 1.90) and 1.05 times larger for each 1 µm increase in ablation depth (p=0.04, CI: 1.00, 1.10). Besides, they are expected to decrease by a factor of about 0.02 with each additional millimeter of corneal white-to-white (p=0.03, CI: 0.02, 0.90).

Astigmatism analysis demonstrated a significant reduction in cylindrical error following PRK. Preoperatively, the mean cylindrical error was −0.95±0.79 D (range: −3.00–0.00 D), which improved postoperatively to −0.48±0.29 D (range: −1.25–0.00 D). Astigmatism analysis using Alpins' method also demonstrated that PRK effectively reduced astigmatism, with a mean correction index of 1.02±0.78 (median: 0.90), indicating a slight tendency toward overcorrection. The magnitude of error averaged 0.12±0.40 (median: 0.15), suggesting that while most cases were close to the intended correction, variability was present, with some under- and over-correction. The angle of error had a mean of 22.63±25.22° (median: 15.00°), with a range up to 115°, indicating that while many corrections were well-aligned, some exhibited significant axis misalignment. The index of success had a mean of 0.02±0.78 (median: −0.10), demonstrating that, overall, PRK provided effective astigmatism correction, with most cases achieving near-optimal outcomes. However, the wide range of correction index, magnitude of error, and index of success values highlights variability in individual responses.

A comparison between the over-corrected and under-corrected groups, based on the correction index according to Alpin's method, is presented in Table 5. The study included 15 patients in the under-corrected group (correction index ≤0.50) and 12 patients in the over-corrected group (correction index ≥1.50). Post-operative UCVA was significantly better in the under-corrected group (0.03±0.04 D vs. 0.08±0.05 D, p=0.02). In addition, the pre-operative astigmatism was significantly higher in the under-corrected group (−0.70±0.25 D) compared to the over-corrected group (−0.50±0.36 D, p=0.02). While other parameters, including age, post-operative astigmatism, corneal characteristics, and ocular HOAs, showed no significant differences between the two groups.

Discussion

In this retrospective study, we evaluated the 8-to-10-year outcomes of mechanical PRK performed between 2015 and 2017 in 500 patients with myopia and myopic astigmatism. The results showed that PRK is a very safe procedure with highly predictable and stable outcomes. Our long-term follow-up results showed that the safety, efficacy, and predictability indices were 1, 0.95, and 0.97, respectively. A recent meta-analysis study confirmed that surface laser refractive technologies have excellent safety, efficacy, and predictability at least in the short-term follow-up (2). The current study analysis showed that 72% of eyes had a visual acuity of 20/20, and 100% of eyes had a visual acuity of 20/30 in the 10-year follow-up visit. The results also showed that 74.4% of eyes were within ±0.25 D, 100% of eyes were within ±1.00 D of spherical equivalent refractive error, and no eye required retreatment. Previous long-term studies have reported different rates of retreatment, ranging from 2% of eyes in the study by Vestergaard et al. (24) to 24.5% in the study by Castro-Luna et al. (25)

In our study, no incidence of corneal haze was observed after 10 years post-PRK. Long-term follow-up data generally indicate that most haze occurs within the 1st year after

Table 5. Comparison between over-corrected and under-corrected groups for astigmatism according to the correction index based on Alpin's method

	Under-corrected group (correction index ≤0.50)	Over-corrected group (correction index ≥1.50)	p
Number of patients	15	12	
Age (year)	29.33±6.34	29.08±6.11	0.80
Post-operative Astigmatism (D)	-0.56±0.22	-0.73±0.34	0.15
Post-operative Uncorrected distance visual acuity (D)	0.03±0.04	0.08±0.05	0.02*
Pre-operative Astigmatism (D)	-0.70±0.25	-0.50±0.36	0.02*
Pre-operative spherical equivalent refractive error (D)	-3.60±2.41	-3.80±1.00	0.18
Mean front corneal curvature (D)	44.19±1.42	44.25±0.87	0.98
Mean back corneal curvature (D)	-6.35±0.21	-6.37±0.20	0.76
Central corneal thickness (μm)	552±16	552±21	0.98
White-to-white corneal diameter (mm)	11.63±0.33	11.67±0.40	0.96
Ablation depth (μm)	61.16±22.19	75.57±16.01	0.31
Optical zone diameter (mm)	6.63±0.43	6.88±0.20	0.28
Ocular horizontal coma (μm)	0.06±0.12	0.06±0.11	0.52
Ocular vertical coma (μm)	0.09±0.20	0.02±0.16	0.23
Ocular horizontal trefoil (μm)	0.007±0.10	-0.02±0.09	0.62
Ocular vertical trefoil (μm)	-0.10±0.20	-0.03±0.13	0.66
Spherical aberration (μm)	0.05±0.09	0.01±0.07	0.13
Total root mean square higher-order aberration (μm)	3.12±2.06	3.55±0.96	0.40

*P-values indicated with an asterisk mark show statistically significant values. (P<0.05).

surgery, with few cases persisting over time (26). The incidence of corneal haze after PRK has decreased with modern surgical techniques and post-operative management (27-29). Factors such as the degree of refractive error correction, (27) intraoperative use of MMC, (28) and adherence to post-operative care protocols, including the use of topical corticosteroids and protection against UV exposure, play a crucial role in minimizing haze development. Our findings align with these trends, suggesting that, with appropriate management, the long-term risk of corneal haze remains minimal.

Some previous studies that have evaluated the long-term results of PRK surgery are chronologically discussed in this section.

O'Brart et al. (14) published the 20-year follow-up results of early PRK on 42 eyes. In that study, the mean pre-operative refractive error was −5.13±1.86 D. The mean post-operative refractive error was −1.18±1.35 D at the 1-year follow-up and −1.72±1.69 D at the 20-year follow-up, and the efficacy index was 49% at the 20-year follow-up. Shalchi et al. (15) reported the 18-year follow-up results of 92 eyes. The mean pre-operative refractive error was −4.86±1.61 D, and the mean post-operative refractive error was −0.74±1.4 D. Besides, 30% of patients were within ±0.50 D refractive error after 18 years, and the efficacy index was 58% at 18-year follow-up, which was lower than the efficacy index in the current study. In these two studies, the laser technology and PRK procedure differed from those in the current study. Both studies used the UV200 excimer lasers (Summit Technology, Waltham, Massachusetts) to treat the eyes and used broad-beam laser and iris diaphragm technology. All treatments were spherical and used a 5 mm or 6.00 mm optical zone diameter with no transition zone and no aspheric profiles. Furthermore, no adjunctive mitomycin-C was used in these two studies.

In another study, Cennamo et al. (29) published the results of a 20-year follow-up of 85 eyes: The mean pre-operative refractive error was −5.90±3.56 D, and the mean post-operative refractive error was −1.60±2.10 D. The efficacy index was 63%, which was lower than in the current study, possibly due to differences in laser technology. In this study, the patients underwent PRK treatment for myopia with a 193-nm excimer laser (Aesculap, Meditec, Jana, Germany) operating in a scanning mode with a 7 × 1 mm slit. Only the spherical equivalent was considered. The iris diaphragm was set to 5 mm in some cases and 6 mm or 7 mm in others, with a tapered transition zone considered in all cases. Furthermore, the patients did not receive mitomycin or corticosteroid eye drops.

Zalentein et al. (16) reported the results of an 8-year follow-up of two PRK groups with a mean refractive error of −4.5±1.6 D. The first group consisted of 27 eyes that underwent PRK with a broad-beam laser system (Visx Star, version 2.5). The post-operative refractive error was −0.7±0.5 D, and 48% of eyes were within ± 0.5 D. The other group included 34 eyes that underwent PRK with a scanning-slit laser system (Nidek EC-5000, Nidek Technologies, Pasadena, California). The mean post-operative refractive error was −0.4±0.4 D, and 73% of eyes were within ±0.5 D. The optical zone diameter was between 5.0 mm and 6.5 mm. The results of the scanning-slit laser system were more similar to our results.

These studies represent the long-term outcomes of early PRK surgeries using older laser technology and PRK techniques. The efficacy index in the current study is 0.95, which is higher than in previous long-term studies. This high efficacy could be attributed to the more recent advancements in laser technology used for PRK procedures. The current study applied flying spot laser technology instead of earlier techniques of broad beam and scanning-slit systems. Furthermore, we applied a wider optical zone, aspherical ablation profile, and mitomycin-C after surface ablation, which led to more effective and predictable results than those of previous long-term studies. Recently, Castro-Luna et al. (25) published the results of a 10-year follow-up study on 509 eyes: The mean pre-operative refractive error was −7.18±1.13 D, and the mean post-operative refractive error was −1.22±1.54 D. The ablation procedure was conducted using Esiris excimer laser (Schwind eye tech-solutions GmbH, Kleinostheim, Germany). Mitomycin-C was administered in all cases of PRK with more than −6 D. The efficacy index was 83.3%, which is similar to the current study.

In the current study, myopic regression was defined as spherical equivalent <−0.25 D from the plano. Accordingly, 22% of patients had developed myopic regression. The results confirmed that a smaller white-to-white corneal diameter could be a risk factor for myopic regression. We found that the odds of myopic regression shrink 0.14 times by each 1 mm increase in white-to-white corneal diameter, and patients with myopic regression exhibited approximately 0.3 mm smaller white-to-white corneal diameter. Previous studies have revealed that higher levels of myopia are correlated with smaller white-to-white corneal diameters (30). The increased odds of myopic regression in smaller corneas may be due to the relationship between the level of myopia and the corneal white-to-white diameter. Myopic regression is attributed to the epithelial and stromal remodeling after PRK (5) It has been revealed that eyes experiencing myopic regression are highly susceptible to increased corneal epithelial thickness (31). Recent studies have shown the reverse relationship between white-to-white corneal diameter and central corneal thickness (32). The increased odds of myopic regression in smaller corneas may also be attributed to the relationship between corneal thickness and the size of the corneal diameter. Further investigation is required in this regard.

In line with previous studies, we found that spherical equivalent refractive error and ablation depth are two risk factors for myopic regression (18-21). The results of our analysis showed that a 1 D increase in myopia and a 1 µm increase in ablation depth will raise the odds of myopic regression by 1.4 and 1.05 times, respectively, Alió et al. (19) developed a model that predicted −2.00 D myopic regression for an ablation depth of 130 µm at 15 years after PRK. They reported that regression depended on both sphere and cylinder (18,19). Pokroy et al. (33) reported that the likelihood of retreatment would increase significantly in case of astigmatism ≥3.5 D. In the current study, cylindrical power was not a risk factor for myopic regression, but all patients had an astigmatism power <3.00 D.

In the current study, the optical zone was ≥6mm, and it was not a risk factor for myopic regression. However, previous studies suggest that a smaller optical zone could be a risk factor for myopic regression (35-37). It has been revealed that a 6 mm optical zone offers more effective results than a 5 mm optical zone does (36). Meanwhile, Shin et al. reported no significant difference in the refractive results of 6 mm and 6.5 mm optical zones. However, the 6.5 mm optical zone showed a smaller amount of higher-order aberrations, (7) which confirms our finding that optical zone ≥6 mm is not a risk factor for myopic regression. In terms of gender, some studies have introduced the female gender as a risk factor for myopic regression, (38) but our findings do not support this perspective. We did not find any predisposition according to gender.

The myopic shift after PRK reported in long-term studies is not only attributed to myopic regression but also to the tendency of myopia to progress in young adults (14,39) In a long-term study, O'Brart et al. (14) revealed that axial length increased by a mean of 0.84 mm between 6 months and 20 years after PRK in patients younger than 40 years old. In addition to genetic factors, the environmental factor of increased near-work activity is known as a potential risk factor for myopia progression in adults (22). In the current long-term study, this risk factor was evaluated using regression analysis. However, we did not find it to play a significant role in this context. In the literature review, we did not find any article specifically evaluating the risk factor of near-work activity on myopia progression in patients who have undergone PRK. Weng et al. (40) studied the effect of monocular myopia ablation on axial length elongation. The results of this study showed the inhibitory effect of myopic laser ablation on axial length elongation compared to the fellow eye. It is believed that near-work activity may contribute to myopia progression by altering the accommodation response and inducing negative changes in spherical aberration (41). After PRK, a positive shift occurs in spherical aberration, (42) which can potentially counteract the negative shift in spherical aberration caused by near-work activity. Further investigation is required to compare the rate of adult myopia progression in myopic patients who have undergone PRK with those in other myopic patient populations. It should be mentioned that in the current study, an initial overcorrection had been performed on patients under 30 years old, which could have brought about a compensatory effect on myopia progression over time.

This study confirmed that PRK effectively reduces astigmatism, significantly decreasing cylindrical error from −0.95±0.79 D to −0.48±0.29 D, in line with previous research (44). Alpins' vector analysis further validated PRK's effectiveness, showing a mean correction index of 1.02±0.78, suggesting a slight tendency toward overcorrection. The observed error magnitude was 0.12±0.40, with an error angle of 22.63°±25.22°. The variability suggests that some cases experience significant axis misalignment or overcorrection. Kapadia et al. revealed that spherical excimer laser PRK is associated with considerable surgically induced astigmatism, likely due to ablation decentration, irregularities in the excimer laser beam, and differences in wound healing across the ablated zone (45). However, the use of aspheric ablation and a larger optical zone has led to highly effective PRK outcomes for astigmatism. Studies suggest that the trans-PRK technique yields better results than mechanical PRK, particularly for moderate to high astigmatism (46). In the current study, the mechanical PRK procedure was used, and the 8-to-10-year results indicate that PRK provides effective and stable outcomes for astigmatism. No eyes required retreatment, and there was no significant decline in post-operative UCVA.

A comparison between undercorrected and over-corrected astigmatism groups showed significant differences in post-operative UCVA, with better outcomes in the under-corrected group (0.03±0.04 vs. 0.08±0.05). In addition, pre-operative astigmatism was significantly higher in the under-corrected group, suggesting that initial astigmatism levels influence surgical outcomes. Mimouni et al. (47) and Vajpayee et al. (48) similarly reported that higher pre-operative astigmatism is associated with undercorrection in post-operative results. Other parameters, including age, corneal characteristics, ocular higher-order aberrations, optical zone (≥6 mm), and ablation depth, did not show significant differences between groups. Lombardo et al. (49) suggest that individual biomechanical and healing factors contribute to variations in long-term change of anterior cornea after PRK. They found that the central curvature of the anterior cornea remained stable over the long-term post-operative period, with no significant changes. Major changes were observed only in the peripheral anterior cornea, which does not affect vision. Overall, PRK remains a reliable method for correcting astigmatism, with outcomes consistent with previous studies.

This study has some strengths and limitations. The strengths include its long-term follow-up period and its relatively large sample size. In addition, this study evaluated a wide range of risk factors for myopic regression. On the other hand, since it was a retrospective study, the 1-year post-operative results of the patients were not available for comparison, which is a limitation of our study.

Conclusion

The current study substantiates that mechanical PRK is a highly safe, stable, and predictable surgery for correcting myopic spherical equivalent up to −10 D, and cylindrical error up to −3.00 D, over a 10-year follow-up period. We found that refractive error in all cases fell within ±1D, and no patient required retreatment. The potential risk factors for myopic regression to −0.25 D within 10 years post-operation were the pre-operative level of myopic spherical equivalent, ablation depth, and white-to-white corneal diameter. However, increased time spent on near-work activity was not a risk factor for myopia progression after PRK in this study. The current study found that under-corrected eyes for astigmatism had a higher magnitude of pre-operative astigmatism compared to over-corrected eyes, and the same trend was observed in reverse.

Disclosures

Ethics Committee Approval: The study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics committee (IR.SBMU.RETECH.REC.1400.1193).

Conflict of Interest: None declared.

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References

1. Flaxman SR, Bourne RRA, Resnikoff S, Ackland P, Braithwaite T, Cicinelli MV, et al. Global causes of blindness and distance vision impairment 1990-2020: A systematic review and meta-analysis. Lancet Glob Health 2017;5:e1221–34.
2. Wen D, McAlinden C, Flitcroft I, Tu R, Wang Q, Alió J, et al. Postoperative efficacy, predictability, safety, and visual quality of laser corneal refractive surgery: A network meta-analysis. Am J Ophthalmol 2017;178:65–78. [CrossRef]
3. Taneri S, Weisberg M, Azar DT. Surface ablation techniques. J Cataract Refract Surg 2011;37:392–408. [CrossRef]
4. Taneri S, Knepper J, Rost A, Dick HB. Long-term outcomes of PRK, LASIK and SMILE. Ophthalmologe [Article in German] 2022;119:163–9. [CrossRef]
5. Moshirfar M, Desautels JD, Walker BD, Murri MS, Birdsong OC, Hoopes PCS. Mechanisms of optical regression following corneal laser refractive surgery: Epithelial and stromal responses. Med Hypothesis Discov Innov Ophthalmol 2018;7:1–9.
6. Tomás-Juan J, Murueta-Goyena Larrañaga A, Hanneken L. corneal regeneration after photorefractive keratectomy: A review. J Optom 2015;8:149–69. [CrossRef]
7. Moshirfar M, Wang Q, Theis J, Porter KC, Stoakes IM, Payne CJ, et al. Management of corneal haze after photorefractive keratectomy. Ophthalmol Ther 2023;12:2841–62. [CrossRef]
8. Chen LY, Manche EE. Comparison of femtosecond and excimer laser platforms available for corneal refractive surgery. Curr Opin Ophthalmol 2016;27:316–22. [CrossRef]
9. Krueger RR. Technology requirements for Summit-Autonomous CustomCornea. J Refract Surg 2000;16:S592–S601. [CrossRef]
10. O'Brart DP, Corbett MC, Lohmann CP, Kerr Muir MG, Marshall J. The effects of ablation diameter on the outcome of excimer laser photorefractive keratectomy. A prospective, randomized, double-blind study. Arch Ophthalmol 1995;113:438–43. [CrossRef]
11. Mello GR, Rocha KM, Santhiago MR, Smadja D, Krueger RR. Applications of wavefront technology. J Cataract Refract Surg 2012;38:1671–83. [CrossRef]
12. Ciccio AE, Durrie DS, Stahl JE, Schwendeman F. Ocular cyclotorsion during customized laser ablation. J Refract Surg 2005;21:S772–4. [CrossRef]
13. Pakbin M, Khabazkhoob M, Pakravan M, Fotouhi A, Jafarzadehpour E, Aghamirsalim M, et al. Duration of topical steroid application after photorefractive keratectomy with mitomycin C. J Cataract Refract Surg 2020;46:622–32. [CrossRef]
14. O'Brart DP, Shalchi Z, McDonald RJ, Patel P, Archer TJ, Marshall J. Twenty-year follow-up of a randomized prospective clinical trial of excimer laser photorefractive keratectomy. Am J Ophthalmol 2014;158:651–63. [CrossRef]
15. Shalchi Z, O'Brart DP, McDonald RJ, Patel P, Archer TJ, Marshall J. Eighteen-year follow-up of excimer laser photorefractive keratectomy. J Cataract Refract Surg 2015;41:23–32. [CrossRef]
16. Zalentein WN, Tervo TM, Holopainen JM. Long-term follow-up of photorefractive keratectomy for myopia: Comparative study of excimer lasers. J Cataract Refract Surg 2011;37:138–143. [CrossRef]
17. Saracoglu Yilmaz B, Agca A, Taskapili M. Comparison of long-term visual and refractive results of transepithelial and mechanical photorefractive keratectomy. Beyoglu Eye J 2022;7:121–5. [CrossRef]
18. Alió JL, Muftuoglu O, Ortiz D, Artola A, Pérez-Santonja JJ, De Luna GC, et al. Ten-year follow-up of photorefractive keratectomy for myopia of less than −6 diopters. Am J Ophthalmol 2008;145:29–36. [CrossRef]
19. Alió JL, Ortiz D, Muftuoglu O, Garcia MJ. Ten years after photorefractive keratectomy (PRK) and laser in situ keratomileusis (LASIK) for moderate to high myopia (control-matched study). Br J Ophthalmol 2009;93:1313–8. [CrossRef]
20. Shojaei A, Mohammad-Rabei H, Eslani M, Elahi B, Noorizadeh F. Long-term evaluation of complications and results of photorefractive keratectomy in myopia: An 8-year follow-up. Cornea 2009;28:304–10. [CrossRef]
21. Ramin S, Moallemi Rad L, Abbasi A, Rafatifard A, Rahimi Y, Ghorbani S, et al. Myopic regression after photorefractive keratectomy: A retrospective cohort study. Med Hypothesis Discov Innov Ophthalmol 2023;12:9–17. [CrossRef]
22. Bullimore MA, Lee SS, Schmid KL, Rozema JJ, Leveziel N, Mallen EAH, et al. IMI-onset and progression of myopia in young adults. Invest Ophthalmol Vis Sci 2023;64:2. [CrossRef]
23. Alpins N. Astigmatism analysis by the Alpins method. J Cataract Refract Surg 2001;27:31–49. [CrossRef]
24. Vestergaard AH. Past and present of corneal refractive surgery: A retrospective study of long-term results after photorefractive keratectomy and a prospective study of refractive lenticule extraction. Acta Ophthalmol 2014;92:1–21. [CrossRef]
25. Castro-Luna G, Jiménez-Rodríguez D, Pérez-Rueda A, Alaskar-Alani H. Long term follow-up safety and effectiveness of myopia refractive surgery. Int J Environ Res Public Health 2020;17:8729. [CrossRef]
26. Bricola G, Scotto R, Mete M, Cerruti S, Traverso CE. A 14-year follow-up of photorefractive keratectomy. J Refract Surg 2009;25:545–52. [CrossRef]
27. Møller-Pedersen T, Cavanagh HD, Petroll WM, Jester JV. Corneal haze development after PRK is regulated by volume of stromal tissue removal. Cornea 1998;17:627–39. [CrossRef]
28. Chang YM, Liang CM, Weng TH, Chien KH, Lee CH. Mitomycin C for the prevention of corneal haze in photorefractive keratectomy: A meta-analysis and trial sequential analysis. Acta Ophthalmol 2021;9:652–62. [CrossRef]
29. Cennamo G, Menna F, Sinisi F, Cennamo G, Breve MA, Napolitano P, et al. Twenty-year follow-up of excimer laser photore-

fractive keratectomy: A retrospective observational study. Ophthalmol Ther 2020;9:917–27. [CrossRef]
30. Xu G, Wu G, Du Z, Zhu S, Guo Y, Yu H, et al. Distribution of white-to-white corneal diameter and anterior chamber depth in Chinese myopic patients. Front Med (Lausanne) 2021;8:732719. [CrossRef]
31. Li H, Han Q, Zhang J, Shao T, Wang H, Long K. Role of corneal epithelial thickness during myopic regression in femtosecond laser-assisted in situ keratomileusis and transepithelial photorefractive keratectomy. BMC Ophthalmol 2022;22:481. [CrossRef]
32. Jiang L, Du Z, Tang C, Zhu S, Xiong L, Fang X, et al. Ocular biometrics in eyes with different white-to-white corneal diameter in young myopic adults. Sci Rep 2024;14:4720. [CrossRef]
33. Pokroy R, Mimouni M, Sela T, Munzer G, Kaiserman I. Predictors of myopic photorefractive keratectomy retreatment. J Cataract Refract Surg 2017;43:825–32. [CrossRef]
34. Rajan MS, O'Brart D, Jaycock P, Marshall J. Effects of ablation diameter on long-term refractive stability and corneal transparency after photorefractive keratectomy. Ophthalmology 2006;113:1798–806. [CrossRef]
35. Kim WJ, Chung ES, Lee JH. Effect of optic zone size on the outcome of photorefractive keratectomy for myopia. J Cataract Refract Surg 1996;22:1434–8. [CrossRef]
36. Mohammadi SF, Nabovati P, Mirzajani A, Ashrafi E, Vakilian B. Risk factors of regression and undercorrection in photorefractive keratectomy: A case-control study. Int J Ophthalmol 2015;8:933–7.
37. Shin DH, Lee YW, Song JE, Choi CY. Comparison of refractive outcomes after photorefractive keratectomy with different optical zones using Mel 90 excimer laser. BMC Ophthalmol 2020;20:270. [CrossRef]
38. Naderi M, Sabour S, Khodakarim S, Daneshgar F. Studying the factors related to refractive error regression after PRK surgery. BMC Ophthalmol 2018;18:198. [CrossRef]
39. Sasaki M, Hieda O, Wakimasu K, Yamamura K, Kinoshita S, Sotozono C. Myopia progression over a 4-year period after laser-assisted refractive surgery in patients in their 20s and 30s. Jpn J Ophthalmol 2020;64:450–4. [CrossRef]
40. Weng C, Xia F, Xu D, Zhou X, Wu L. Axial length growth difference between eyes after monocular laser refractive surgery: Eight patients who underwent myopic laser ablation for both eyes at intervals of several years. BMC Ophthalmol 2022;22:20. [CrossRef]
41. Collins MJ, Buehren T, Iskander DR. Retinal image quality, reading and myopia. Vision Res 2006;46:196–215. [CrossRef]
42. Hersh PS, Fry K, Blaker JW. Spherical aberration after laser in situ keratomileusis and photorefractive keratectomy. Clinical results and theoretical models of etiology. J Cataract Refract Surg 2003;29:2096–104. [CrossRef]
43. Mimouni M, Pokroy R, Rabina G, Kaiserman I. LASIK versus PRK for high astigmatism. Int Ophthalmol 2021;41:2091–8. [CrossRef]
44. Katz T, Wagenfeld L, Galambos P, Darrelmann BG, Richard G, Linke SJ. LASIK versus photorefractive keratectomy for high myopic (> 3 diopter) astigmatism. J Refract Surg 2013;29:824–31. [CrossRef]
45. Kapadia MS, Krishna R, Shah S, Wilson SE. Surgically induced astigmatism after photorefractive keratectomy with the excimer laser. Cornea 2000;19:174–9. [CrossRef]
46. Peyman A, Ghoreishi M, Babaei L, Noorshargh P, Forouhari A, Pourazizi M. Transepithelial versus epithelium-off photorefractive keratectomy in high compound myopic astigmatism: A contralateral eye study. J Refract Surg 2024;40:e956–65. [CrossRef]
47. Mimouni M, Kaiserman I, Spierer R, Spierer O, Rabina G, Varssano D, et al. Factors predicting the need for re-treatment after laser refractive surgery in patients with high astigmatism: A large database analysis. J Refract Surg 2021;37:366–71. [CrossRef]
48. Vajpayee RB, Ghate D, Sharma N, Tandon R, Titiyal JS, Pandey RM. Risk factors for postoperative cylindrical prediction error after laser in situ keratomileusis for myopia and myopic astigmatism. Eye (Lond) 2008;22:332–9. [CrossRef]
49. Lombardo M, Lombardo G, Ducoli P, Serrao S. Long-term changes of the anterior corneal topography after photorefractive keratectomy for myopia and myopic astigmatism. Invest Ophthalmol Vis Sci 2011;52:6994–7000. [CrossRef]