

Prognostic factors of visual quality after transepithelial photorefractive keratectomy in patients with low-to-moderate myopia

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Purpose: The aim of this study was to evaluate visual quality after high-frequency transepithelial photorefractive keratectomy (t-PRK) by assessing the relationship between the operational parameters and the first-year postoperative corneal higher-order aberrations (HOAs). **Methods:** This was a retrospective study of low-to-moderate myopic eyes treated with t-PRK. The files of 46 low-to-moderate myopic patients (90 eyes; myopia up to -5D) were included in the study. Eyes having a cylindrical refractive error more than 2D and the patients not having completed a 1-year follow-up were excluded from the study. Factors including age, preoperative mean spherical equivalent (MSE), mean keratometry (Km), central corneal thickness (CCT), scotopic pupil, optical zone (OZ), transition zone (TZ), ablation zone (AZ), central ablation depth (CAD), and static cyclotorsion correction (SCC) were analyzed for association with the first-year postoperative corneal HOAs. **Results:** Corneal HOAs were found to be increased postoperatively with a 6-mm pupil ($P < 0.05$). The increased spherical aberration had a positive correlation with patient age, preoperative MSE, Km, TZ, and CAD, whereas it had a negative relationship with OZ and AZ ($P < 0.05$). The corneal coma had a significantly positive correlation with preoperative MSE and a significantly negative relationship with OZ ($P < .05$). **Conclusion:** Postoperatively induced corneal HOAs may affect patients' scotopic vision (night time driving, cinema) when the pupils get larger. The relationship between patient age, preoperative MSE, Km, CAD, TZ, OZ, AZ, and postoperative corneal HOAs underlines the need to consider the effects of these parameters on the final vision quality.

Key words: 1050 Hz excimer laser, corneal high-order aberrations, low-to-moderate myopia, Transepithelial photorefractive keratectomy

Transepithelial photorefractive keratectomy (t-PRK) continues to be a preferred surgical method when used with appropriate patients. The absence of flap related complications is a highlight of t-PRK. The efficacy, safety, and accuracy of t-PRK in myopic patients reached a very distinguished level with advances in laser technology.^[1] On the other hand, all corneal laser refractive corrections may induce higher-order aberrations (HOAs)^[2-4] by remodeling the anterior cornea. Also, induced HOAs may affect the postoperative quality of vision and may be responsible for postoperative complaints such as blurred vision, poor image contrast, glare, halos, ghost images, and starbursts.^[5]

A wavefront-optimized (aspheric profile) mode delivers additional laser pulses to the peripheral cornea to maintain its original shape.^[6] The aberration-free profile developed by Schwind (SCHWIND eye-tech-solutions GmbH & Co., Kleinostheim, Germany) considers only the lower-order aberrations (LOAs) and works to lessen the induction of postoperative spherical aberrations. Several previous studies have verified the safety and efficacy of aberration-free ablations.^[7]

The purpose of this study was to examine the change in corneal HOAs after high-frequency (1050 Hz) transepithelial

photorefractive keratectomy (t-PRK) using an aspheric and aberration-free profile to treat low-to-moderate myopia and to investigate the relationship between preoperative/operative features and first-year postoperative corneal HOAs.

Methods

In a retrospective manner, we reviewed the files of myopic patients who underwent through t-PRK surgery from December 2015 to September 2017. Patients aged from 18 to 40 years having a myopic refractive error and having completed a 1-year follow-up period after t-PRK were included in the study. The exclusion criteria were a refractive error more than -5D in myopia and more than 2D in astigmatism. The procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975 as revised in 2000.

All patients underwent refractive surgery with the Schwind Amaris 1050-Hz excimer laser (SCHWIND eye-tech-solutions GmbH & Co., Kleinostheim, Germany). The Amaris laser complex is one of the last generations of

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floating-point lasers, performing at 1050-Hz repetition speed and producing a beam of "0.54-mm" spot size. In addition, the laser works with the ORK-CAM software using an aberration-free, aspheric profile. During the surgical process, topical anesthesia (proparacaine 0.5%) was administered, and the skin around the surgical area was cleaned with povidone-iodine 10 percent. After proper draping, an eyelid speculum was inserted and povidone-iodine 5% was applied to the conjunctiva. The patient was asked to fixate on the target. The epithelium and stroma were simultaneously ablated by laser excimer. After the completion of ablation, a Mitomycin-C-saturated (0.02%) sponge was applied to the stromal bed for 30 seconds; the stroma was irrigated with 100 ml of cold-balanced saline solution, and a highly oxygen-permeable silicone hydrogel contact lens was placed over the cornea. Moxifloxacin 0.5% (Vigamox, Alcon Inc., Canada) eye drops and artificial tear eye drops without preservatives (Tears Naturale Free, Alcon Inc., Canada) were prescribed to be used six times a day. After the closure of the epithelial defect, the bandage contact lens was removed; dexamethasone sodium phosphate (Dexasine-SE, Liba Laboratories, Turkey) eye drops were started at six times a day and used in a tapered fashion. The tapering did not vary from case to case, and all patients stopped using the topical steroids at the end of one month.

The preoperative and first-year postoperative data, including uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), manifest refraction, cycloplegic refraction, intraocular pressure (IOP), anterior segment examination (which included the grading of postoperative corneal haze according to Fantes *et al.*), and dilated fundus examination, were recorded from patients' files.^[8] A Topcon CT-80 non-contact tonometer (Topcon Medical Systems, Paramus, New Jersey, USA) was used to obtain IOP. The visual acuities noted as decimals were converted to LogMAR equivalents. Preoperative and postoperative records in terms of pachymetry, keratometry, and corneal high-order aberrations were assessed using a SIRIUS topo-tomography device (Costruzione Strumenti Ophthalmic, Florence, Italy). Corneal aberrations were investigated, choosing the pupillary diameter at either 3 or 6 mm. The other operational parameters, including optical zone, transition zone, ablation zone, static cyclotorsion correction, ablation time, and central ablation depth, which also incorporated epithelial ablation, were obtained from the output of ORK-CAM software.

Concerning statistical analysis, the continuous variables were interpreted by mean ± standard deviation, whereas the categorical variables were evaluated by frequency and percentage. The non-parametric Wilcoxon test was used to compare preoperative and postoperative values. The relationship among postoperative corneal higher-order aberrations, preoperative features, and surgical parameters was analyzed by the Spearman correlation test. A value of $P < 0.05$ was considered statistically significant. All analyses were made with SPSS version 23.0 (SPSS Inc, Chicago, IL, USA) software.

Results

The study included 90 eyes of 46 patients (24 female, 22 male). The mean age was 27.15 ± 5.69 years. The preoperative and operative features are presented in Table 1.

- *Refractive outcomes:* Visual acuity and refraction at first-year follow-up are presented in Table 2. UDVA and CDVA were improved ($P < 0.001$); the manifest spherical equivalent was decreased statistically significantly in the first postoperative year ($P < 0.001$)
- *Intraocular pressure:* Preoperative mean IOP was 14.29 ± 2.07 mm Hg, whereas postoperative mean IOP was 14.23 ± 2.42 mm Hg at first-year follow-up ($P = 0.71$)
- *Slit lamp examination:* At the first-year postoperative clinical examination, 74% of the eyes (67 eyes) did not have any haze, whereas 26% of them (23 eyes) had clinically insignificant haze. Nil patients had a corneal haze of + 2 or more according to Fantes' classification^[8]
- *Corneal high-order aberrations:* It has been known that the amount and character of corneal HOAs are considerably influenced by pupillary diameter.^[2,3] In our study, at 3-mm pupil size, the difference between preoperative and postoperative measures of corneal HOAs was not statistically significant ($P > .05$). However, at 6-mm pupil size, HOAs' total root-mean-square (RMS) error, corneal coma, trefoil, and spherical aberrations were all statistically significantly increased ($P < 0.001$, $P = 0.007$, $P = .003$, $P = .002$, respectively) [Tables 3 and 4]. The correlations between postoperative corneal HOAs and preoperative/operative features were analyzed. First of all, a statistically significant positive relationship was revealed between patient age, preoperative manifest spherical equivalent, preoperative Km value, transition zone, central ablation depth, and first-year postoperative corneal HOA RMS ($P = .002$, $P < .001$, $P = .001$, $P = .035$, $P = .023$, respectively). However, there was a statistically significant negative correlation between optical zone,

Table 1: Preoperative and operative data of 90 eyes

Parameters	Mean±SD	Min	Max
MSE (D)	-2.55±0.93	-4.75	-1.25
MCRE (D)	-0.58±0.55	-2.00	0
Km (D)	43.76±1.36	40.79	47.30
CCT (µm)	544.95±28.28	489	608
OZ (mm)	6.94±0.55	6.20	8.00
TZ (mm)	0.98±0.21	0.58	1.51
AZ (mm)	7.92±0.58	6.88	8.91
CAD (µm)	102.66±13.94	76.97	136.96
Ablation time (s)	27.72±4.33	17	37

MSE=Manifest spherical equivalent, MCRE=Manifest cylindrical refractive error, Km=Mean keratometry, CCT=Central corneal thickness, OZ=Optical zone, TZ=Transition zone, AZ=Ablation zone, CAD=Central ablation depth

Table 2: Refraction and visual acuity in the first postoperative year

	Preop (mean±SD)	Postop 1 st year (mean±SD)	Z	P
UDVA (LogMAR)	1.02±0.33	-0.005±0.02	-8.33	<.001*
CDVA (LogMAR)	-0.001±0.02	-0.02±0.03	-4.04	<.001*
MSE (D)	-2.55±0.93	-0.10±0.23	-8.25	<.001*

UDVA=Uncorrected distance visual acuity; CDVA=Corrected distance visual acuity; MSE=Manifest spherical equivalent; *Significance at the 0.01 level via Wilcoxon test

ablation zone, scotopic pupil, and first-year postoperative corneal HOA RMS ($P < .001$, $P < .001$, $P = .033$, respectively). No correlation was found between preoperative central corneal thickness and static cyclotorsion correction with first-year postoperative corneal HOA RMS ($P = .321$, $P = .644$). Second, a statistically significant positive relationship between patient age, preoperative manifest spherical equivalent, preoperative Km value, transition zone, central ablation depth, and first-year postoperative corneal spherical aberration ($P = .032$, $P < .001$, $P = .002$, $P = .030$, $P = .008$, respectively), as well as a statistically significant negative correlation between optical zone, ablation zone, and first-year postoperative corneal spherical aberration ($P < .001$ and $P < .001$, respectively), were revealed. No correlation between first-year postoperative corneal trefoil aberration and preoperative/operative features was seen ($P > .05$). Finally, there was a statistically significant positive correlation between preoperative spherical equivalent and postoperative corneal coma ($P = .019$), whereas there was a statistically significant negative correlation between optical zone and postoperative corneal coma aberration ($P = .005$) [Table 5]

- *Changes in keratometric values:* The mean keratometric (Km) value was 43.76 ± 1.36 D preoperatively and 41.19 ± 1.50 D in the first postoperative year ($Z = -8.23$, $P < 0.001$). Additionally, before surgery, the ORK-CAM software in the Schwind Amaris laser system determined a target Km value that the patient would have after myopic correction. The target Km value was calculated as 41.69 ± 1.38 D, which was statistically significantly steeper than the first-year postoperative Km value ($Z = -7.04$, $P < 0.001$).

Discussion

Many studies report that the efficacy, safety, and accuracy of transepithelial PRK reached a very high level in the treatment of low-to-moderate myopia.^[1,9-11] In our study, the evaluation of

first-year postoperative data following t-PRK performed with an Amaris 1050-Hz excimer laser has shown that this technique provides a significant improvement in manifest spherical equivalent, uncorrected distance visual acuity, and corrected distance visual acuity of low-to-moderate myopic eyes. We hypothesize that higher frequencies of the excimer laser with an aspheric and aberration-free treatment profile provide faster corneal ablation, hence there is better patient compliance with the therapy and better refractive results.

Induced corneal HOAs after laser ablations are one of the main factors affecting postoperative visual quality.^[4] Several studies have stated that coma- and spherical-like aberrations were significantly increased after myopic PRK.^[3,4,12] As the corneal contour shifts from prolate to oblate after a myopic laser ablation, the central light rays may focus behind the peripheral rays. According to Amigo *et al.*,^[13] postoperatively induced positive spherical aberrations may provoke night myopia. Also, Rajan *et al.*^[14] stated that the night vision problem was significantly less after PRK with a larger ablation zone. Furthermore, Oshika *et al.*^[14] stated that the augmented coma aberration might cause lower postoperative contrast sensitivity. In a recent study, Yildirim *et al.*^[15] noticed that HOAs' total RMS error, spherical, coma, and trefoil aberrations were found to increase over the 6-mm diameter central corneal zone after myopic t-PRK. In our study, we did not observe any statistically significant difference between preoperative and postoperative corneal wavefront aberrations at a 3-mm pupil size; however, there was a statistically significant increase of corneal HOAs' total RMS error, spherical, coma, and trefoil aberrations at a 6-mm pupil size. This may be caused by the fact that a larger pupil causes more image degradation in an optically aberrated system.

In terms of factors associated with postoperative corneal HOAs, we noticed that the increase in corneal HOAs' total RMS wavefront error was associated with increased age, high myopic correction, steep preoperative keratometric values, small ablation zone, small optical zone, small scotopic pupil, and increased central ablation depth. Moreover, the postoperatively induced positive spherical aberration correlated with increased age, high preoperative myopic error, steep preoperative keratometric values, small optical zone, large transition zone, small ablation diameter, and increased central ablation depth, whereas induced coma aberration had a relationship with high preoperative myopic error and small optical zone.

Regarding the literature, Amano *et al.*^[16] conducted a study on 75 healthy patients and stated that the corneal coma aberration increased with aging, whereas the corneal spherical aberration did not change with aging. Thus, increased age may alter the corneal structure and cause increased aberrations with or without surgery. Serrao *et al.*^[17] analyzed the HOAs during an eight-year follow-up after PRK, dividing the patients into three groups according to preoperative refraction as follows: low myopia, high myopia, and astigmatism. They noted that the effect of induced corneal HOAs tended to increase after the correction of high myopia with large pupils. Alarcon *et al.*^[18] found that retinal image quality was affected by pupil size only when the pupil size was larger than the optical zone. Zhou *et al.*^[19] stated that at 5-mm pupil size, the increased spherical aberration was associated with age and optical zone

Table 3: Corneal HOAs in first postoperative year (at 3-mm pupil)

Pupil diameter: 3 mm	Preop (mean±SD)	Postop (mean±SD)	Z	P
Corneal HOA RMS (µm)	0.09±0.04	0.09±0.04	-0.60	0.545
Corneal coma (µm)	0.03±0.02	0.03±0.02	-1.08	0.279
Corneal trefoil (µm)	0.06±0.04	0.06±0.03	-0.20	0.841
Corneal spherical (µm)	0.02±0.01	0.02±0.02	-1.56	0.117

HOA RMS=High-order aberration Root-mean-square

Table 4: Corneal HOAs in the first postoperative year (at 6-mm pupil)

Pupil diameter: 6 mm	Preop (mean±SD)	Postop (mean±SD)	Z	P
Corneal HOA RMS (µm)	0.42±0.11	0.53±0.19	-5.04	<.001*
Corneal coma (µm)	0.22±0.10	0.28±0.16	-2.67	0.007*
Corneal trefoil (µm)	0.19±0.11	0.23±0.16	-2.38	0.003*
Corneal spherical (µm)	0.22±0.07	0.28±0.16	-3.65	0.002*

HOA RMS=Root-mean-square of high-order aberration; *Significance at the 0.01 level via Wilcoxon test

Table 5: Correlation with postoperative corneal HOAs and clinical features

Pupil diameter: 6 mm	Corneal HOA RMS (μm)		Corneal coma (μm)		Corneal trefoil (μm)		Corneal spherical (μm)	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
Age	0.323	0.002 †	0.187	0.078	0.023	0.828	0.226	0.032 *
Preop SE	0.450	<.001 †	0.247	0.019 *	0.043	0.688	0.584	<.001 †
Preop Km	0.340	0.001 †	0.109	0.308	0.147	0.167	0.316	0.002 †
Preop CCT	-.101	0.321	-.192	0.062	-.013	0.893	-0.034	0.774
Scotopic pupil (mm)	-.223	0.033 *	-.098	0.374	-.008	0.944	-.136	0.211
Optical zone (mm)	-.567	<.001 †	-.294	0.005 **	0.019	0.858	-.615	<.001 †
Transition zone (mm)	0.222	0.035 *	0.146	0.170	0.102	0.337	0.229	0.030 *
Ablation zone (mm)	-0.423	<.001 †	-0.206	0.052	0.071	0.505	-0.465	<.001 †
Central ablation depth (μm)	0.239	0.023 *	0.193	0.068	0.003	0.980	0.276	0.008 †
SCC (degree)	-.055	0.644	-.077	0.500	-.555	0.611	-.933	0.399

HOA RMS=Root-mean-square of High-order aberration; SE=Spherical equivalent; Km=Mean keratometry; CCT=Central corneal thickness; SCC=Static cyclotorsion correction; Bold *Correlation is significant at the 0.05 level via Spearman test; †correlation is significant at the 0.01 level via Spearman test

diameter, whereas the increased coma was associated with age. Jun *et al.*^[20] noted that the application of a large optical zone in low myopia provided an excellent visual and refractive predictability and a reduction in HOAs. Moreover, Endl *et al.*^[21] noticed that corneal aberrations after PRK with a larger ablation zone were less noticeable. Fang *et al.*^[22] noted that the exact size, shape, and profile of the transition zone played a significant role in the induction of both spherical and coma aberrations postoperatively.

At the first-year follow-up, we encountered a more flattened cornea compared to the preoperative keratometric readings, as in similar studies.^[8,23] Moreover, we found that the first-year postoperative keratometric data were even flatter compared to the “target” keratometric value proposed by the ORK-CAM software before the surgery. Hence, a slightly more oblate cornea, which does not affect visual acuity, may be present in our postoperative patients. This may be due to the fact that the aspherical epithelial ablation profile-which ablates 55 μm of the epithelium at the center and 65 μm of the epithelium at the periphery, regardless of the actual thickness of the epithelial layer-may not be appropriate in some corneas.^[24] Therefore, in some patients, more stroma than required might be ablated. Second, the long application time of Mitomycin C may induce an overcorrection by regulating the healing process.^[25]

A limitation of this study is that it does not contain visual complaints of postoperative patients such as glare, halo, sunburst, night myopia, or a decrease in contrast sensitivity, which can be attributable to augmented corneal aberrations.

Conclusion

The results obtained after one-year follow-up showed that t-PRK performed with a high-frequency (1050-Hz) excimer laser device was effective and safe in the treatment of low-to-moderate myopia. Fast corneal ablation may help the patient to maintain intraoperative fixation, decrease stromal dehydration, and form a smooth ablation surface. Corneal high-order aberrations for the first postoperative year were acceptable when the pupil was 3 mm; however, they increased when the pupil was 6 mm. This issue may affect the quality of a patient’s vision in scotopic conditions (night time driving,

cinema, etc.) as the pupils tend to be larger. The observed relationship between patient age, degree of preoperative myopia, preoperative keratometric readings, central ablation depth, optic zone, and postoperative corneal HOAs’ RMS error underlines the need to consider the effects of these parameters on the quality of final vision when planning the refractive surgery.

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Conflicts of interest

There are no conflicts of interest.

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