Aspheric versus wavefront-guided photorefractive keratectomy: Contralateral eye study

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PURPOSE: To compare the refractive, visual, and aberrometric outcomes between wavefront-guided photorefractive keratectomy (PRK) and aspheric PRK in myopic patients.

SETTING: Khatam-al-Anbia Eye Hospital, Mashhad, Iran.

DESIGN: Prospective randomized clinical trial.

METHODS: One eye of each patient was randomly assigned to excimer laser wavefront-guided PRK (Zyoptix) and the other eye to excimer laser aspheric PRK (Technolas 217z). The preoperative and 3-month and 6-month postoperative refractive errors, visual acuity, contrast sensitivity, and higher-order aberrations (HOAs) were compared between the groups.

RESULTS: Ninety-six eyes (48 patients) were enrolled. At the last postoperative visit, there were no between-group differences in uncorrected distance visual acuity (UDVA) ($P = .987$) or corrected distance visual acuity ($P = .416$). The mean spherical equivalent was -0.076 diopter (D) $\pm$ 0.029 (SD) in the wavefront-guided group and -0.077 ± 0.075 D in the aspheric PRK group ($P = .684$). Postoperatively, the mean area under the log of contrast sensitivity function (AULCSF) with and without glare testing improved over preoperative values (both $P < .001$). There was no statistically significant between-group difference in the AULCSF with glare ($P = .903$) or without glare ($P = .978$). Total HOAs increased after PRK in both groups, although aspheric PRK induced fewer HOAs than wavefront-guided PRK ($P = .04$).

CONCLUSIONS: Both PRK methods equally improved postoperative UDVA and contrast sensitivity. The HOAs increased after treatment with both methods; however, aspheric ablation induced statistically fewer HOAs than wavefront-guided ablation.

Financial Disclosure: No author has a financial or proprietary interest in any material or method mentioned.

J Cataract Refract Surg 2015; 41:1441–1447 © 2015 ASCRS and ESCRS

Conventional keratorefractive surgery reduces the quality of vision and contrast sensitivity as a result of an increase in higher-order aberrations (HOAs).[1,2] Spherical aberration is the main aberration induced after conventional photorefractive keratectomy (PRK) and is the most important aberration in terms of degradation of visual quality.[3,4] It has been said that aspheric ablation can preserve the corneal asphericity by using a peripheral blend zone in the cornea.

Wavefront-guided treatment algorithms using advanced eye trackers are designed to reduce spherical aberration as well as other HOAs. Theoretically, this technology could reduce preexisting HOAs without inducing new aberrations. However, the postoperative epithelial and stromal healing process introduces variability in the final optical outcomes, potentially undermining detailed HOA corrections. In addition, because most types of HOAs (eg, coma and trefoil) are rotationally asymmetric, the results of a wavefront-guided treatment depend on the accuracy of the ablation's location on the *x*-, *y*-, and *z*-axes. Intraoperative saccadic movements and ocular cyclotorsion can affect the results. These practical considerations reduce the efficacy of wavefront-guided treatments in reducing HOAs.

Published by Elsevier Inc.

http://dx.doi.org/10.1016/j.jcrs.2014.10.038
0886-3350

The Technolas 217z platform (Bausch & Lomb) has 2 ablation profiles to reduce postoperative HOAs; that is, personalized (wavefront-guided) PRK and aspheric PRK. These algorithms are proposed to reduce preexisting HOAs and preserve corneal asphericity, respectively. The purpose of this prospective randomized fellow-eye study was to evaluate and compare the visual outcomes of myopia and myopic astigmatism correction using this laser platform with the 2 ablation profiles.

PATIENTS AND METHODS

Patients with myopia or myopic astigmatism who presented to Khatam-al-Anbia Eye Hospital, Mashhad, Iran, for refractive surgery were enrolled in this study. The study followed the tenets of the Declaration of Helsinki. All patients were appropriately informed before their participation in this study. After a complete ophthalmic examination and a thorough discussion of the risks and benefits of the surgery, all participants gave written informed consent. Full approval of the Ethics Committee, Mashhad University of Medical Science, was obtained.

Inclusion criteria were an age between 18 years and 40 years, spherical equivalent (SE) refraction between −1.00 diopter (D) and −7.00 D with a 3.00 D or less astigmatic error, stable refraction for at least 1 year, and preoperative corrected distance visual acuity (CDVA) of 10/10 or better.

Exclusion criteria included the presence of an ocular pathologic condition impairing visual function, corneal dystrophies or abnormalities, keratoconus or keratoconus suspect, previous ocular surgery, glaucoma or glaucoma suspect, diabetes mellitus, autoimmune disease, pregnancy, breastfeeding, and moderate to severe dry eye. All patients discontinued contact lens wear at least 1 month before refraction, topography, and aberrometric evaluation. Also excluded were patients with a minimum corneal thickness of less than 450 μm, calculated residual thickness of less than 400 μm, and higher-order wavefront root mean square (RMS) of more than 0.50 μm in a 6.0 mm optical zone.

All patients had PRK in both eyes, and the eyes were randomly assigned to aspheric PRK or wavefront-guided PRK. This allocation was regardless of ocular dominance, refraction, or aberrations. All patients received right-eye treatment first, with aspheric PRK and wavefront-guided PRK performed as the first treatment in alternating patients. Patients and examiners were masked to which treatment was performed in each eye. The target refraction was emmetropia in all eyes.

Preoperative and Postoperative Assessments

Before surgery, a detailed ocular examination was performed. It included uncorrected distance visual acuity (UDVA), CDVA, slitlamp examination, Goldmann applanation tonometry, indirect fundoscopy, manifest refraction, cycloplegic refraction, keratometry (KR8800 autokeratorefractometer, Topcon Corp.), topography (TMS-4, Tomey Corp.), scanning-slit corneal tomography (Orbscan IIz, Bausch & Lomb), central ultrasound pachymetry, contrast sensitivity (Vector Vision CSV 1000, Haag-Streit AG), and Hartmann-Shack aberrometry (Zywave aberrometer, Bausch & Lomb). Snellen acuity charts were used to measure UDVA and CDVA. The visual acuities were converted to logMAR notation for analysis.

Postoperatively, patients were reexamined at 2 and 5 days and 1, 3, and 6 months. Aberrometry, UDVA, CDVA, and contrast sensitivity were reevaluated at the 3- and 6-month visits.

Surgical Technique

Two surgeons (S.Z.G, H.G) performed all PRK procedures using a flying-spot 193 nm excimer laser (Technolas 217z) with a fixed pulse repetition rate of 100 Hz and a spot diameter of 1.0 to 2.0 mm. After sterile draping, the cornea was anesthetized with tetracaine 1.0% eyedrops and an eyelid speculum was placed. In the wavefront-guided PRK group, iris registration was performed before epithelial removal. Ethyl alcohol 20% was then applied in a 9.0 mm well for 20 seconds, and the epithelium was removed with a hockey-stick spatula.

For wavefront-guided PRK, tissue ablation was performed using the wavefront-guided personalized ablation PRK algorithm software driven by aberrometry data from the Zywave aberrometer, which was transferred to the excimer laser system by the Zylink system. For aspheric PRK, treatment was performed using the aspheric PRK algorithm software. Multidimensional rotational eye tracking was used during ablation in both groups. The minimum optical zone was 6.0 mm, and an equal optical zone was selected for both eyes of each patient.

In all patients, a sponge soaked with mitomycin-C 0.02% was applied over the ablated area for 5 seconds per each diopter of treatment. A bandage contact lens was placed after copious irrigation of the ocular surface with a balanced salt solution. Postoperatively, the patients were given chloramphenicol 0.5% and betamethasone 0.1% eyedrops every 6 hours. After complete reepithelialization (usually on the fifth day), the bandage contact lens was removed. Chloramphenicol was discontinued after 1 week. Betamethasone was used for 1 month, and then fluorometholone 0.1% eyedrops were started every 6 hours and gradually tapered over 2

Submitted: October 8, 2014.
Final revision submitted: October 22, 2014.
Accepted: October 26, 2014.

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Supported by research grant number 88708 from the office of Vice-Chancellor for Research Affairs of Mashhad University of Medical Sciences, Mashhad, Iran.

Pardis Eghbali, BSc, provided assistance with the Orbscan measurements. Maryam Kadkhoda, BSc, and Jalil Rahimi, BSc, assisted with optometric tests. Parisa Eghbali, MSc, assisted with statistical analysis.

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months. Preservative-free artificial tears were prescribed frequently in the first month and then tapered based on the ocular surface condition.

Aberrometry and Contrast Sensitivity Evaluations

Wavefront examinations were performed as 5 consecutive measurements under mesopic conditions (without pharmacologic cycloplegia) with a minimum pupil diameter of 6.0 mm. The 3rd- and 4th-order aberrations were expressed as Zernike coefficient values and measured in micrometers. The total higher-order wavefront error (ie, 3rd- and 4th-order aberrations) was expressed as the RMS of the wavefront errors, measured in micrometers. All RMS values were calculated and reported across an entrance pupil of 6.0 mm. Enantiomorphism was neutralized by inverting the sign of mirror-symmetric coefficients of the left eyes.

For contrast sensitivity evaluation, distance-corrected spectacles were placed for all patients and monocular contrast sensitivities with and without glare were evaluated and graphed. Sensitivity values were transformed into a logarithmic scale, and the area under the log contrast sensitivity function (AULCSF) was calculated.

Statistical Analysis

Statistical testing was performed using SPSS for Windows software (version 16, SPSS, Inc.). Variables were expressed as the mean ± standard deviation. Analysis of variance (ANOVA) with repeated measures was performed to compare the preoperative data and the postoperative data, including refractions, aberrations and contrast sensitivity, within each group. An independent-samples t test was used for comparisons between the groups. Differences were considered statistically significant when the P value was 0.05 or less.

RESULTS

Forty-eight patients (15 men, 33 women) with a mean age of 26.78 years ± 4.89 (SD) (range 19 to 38 years) were included. Table 1 shows the baseline characteristics. There were no statistically significant differences in preoperative sphere, cylinder, SE, keratometry values, central cornea thickness, total aberrations and HOAs, or predicted ablation depth between the wavefront-guided PRK group and the aspheric PRK group.

Visual Acuity

Six months after surgery, there was a statistically significant improvement in the mean UDVA, from 0.843 ± 0.053 logMAR to 0.002 ± 0.001 logMAR in the wavefront-guided PRK group and from 0.815 ± 0.064 logMAR to 0.002 ± 0.001 logMAR in the aspheric PRK group (both $P < .001$) (Figure 1). At 6 months, the mean CDVA was 0.004 ± 0.002 logMAR in the wavefront-guided PRK group and 0.002 ± 0.002 logMAR in the aspheric PRK group. There was no statistically significant difference in UDVA ($P = .98$) or CDVA ($P = .41$) between the 2 groups.

Refraction

The manifest refractions decreased significantly after PRK in both groups. There was no statistically significant difference in sphere ($P = 0.59$), cylinder ($P = .08$), or SE ($P = .79$) between groups 6 months after surgery (Table 2 and Figure 2). The patients were mildly hyperopic in the first month; however,

Table 1. Baseline characteristics by group.

Parameter	Wavefront-Guided PRK	Aspheric PRK	P Value*	Power
Sphere (D)				
Mean ± SD	−3.34 ± 0.269	−3.229 ± 0.269	.57	0.95
Range	−6.75, 0.00	−6.75, 0.00		
Cylinder (D)				
Mean ± SD	−0.535 ± 0.097	−0.590 ± 0.097	.83	0.99
Range	−4.00, 0.00	−4.00, 0.00		
SE (D)				
Mean ± SD	−3.603 ± 0.261	−3.524 ± 0.261	.61	0.23†
Range	−7.125, −0.750	−7.125, −0.725		
HOAs in 6.0 mm				
Mean ± SD (μm)	0.326 ± 0.096	0.322 ± 0.100	.48	0.16†
Range	0.15, 0.51	0.13, 0.50		
CCT (μm)				
Mean ± SD	542.486 ± 4.349	541.571 ± 4.349	.89	0.18†
Range	506, 589	504, 604		

CCT = central corneal thickness; HOAs = higher-order aberrations; PRK = photorefractive keratectomy; SE = spherical equivalent
*Student t test for wavefront-guided group versus aspheric group
†Difference not statistically significant

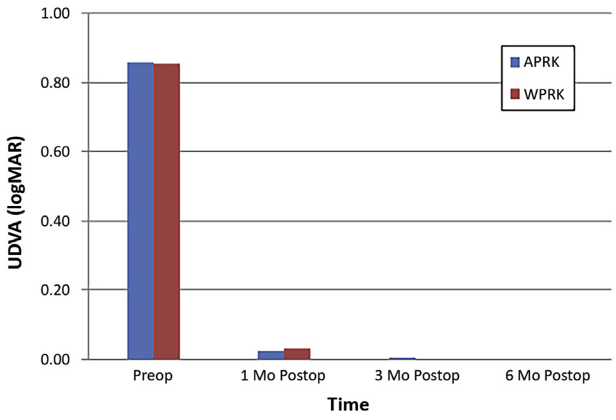

Figure 1. The UDVA in aspheric group versus wavefront-guided group before and after surgery (APRK = aspheric photorefractive keratectomy; UDVA = uncorrected distance visual acuity; WPRK = wavefront-guided photorefractive keratectomy).

Table 2. Refractive results 6 months postoperatively.

Parameter	Wavefront-Guided PRK	Aspheric PRK	*P* Value*	Power
Sphere (D)				
Mean ± SD	−0.09 ± 0.04	−0.06 ± 0.04	.59	0.95
Range	−0.50, +0.50	−0.50, +0.50		
Cylinder (D)				
Mean ± SD	−0.13 ± 0.03	−0.22 ± 0.03	.08	0.99
Range	−1.00, 0.00	−1.00, 0.00		
SE (D)				
Mean ± SD	−0.16 ± 0.04	−0.17 ± 0.04	.79	0.23†
Range	−0.62, 0.50	−0.62, 0.50		
CCT (μm)				
Mean ± SD	487 ± 6	478 ± 6	.36	0.99
Range	418, 561	417, 561		

CCT = central corneal thickness; PRK = photorefractive keratectomy; SE = spherical equivalent
*Student *t* test for wavefront-guided group versus aspheric group
†Difference not statistically significant

the refraction regressed 6 months postoperatively and all patients were in the ±0.50 D range.

Aberrometry

Total HOAs, RMS HOAs without spherical aberration Z(4,0), and spherical aberration Z(4,0) increased in both groups. The increase in total HOAs and spherical aberration was statistically significantly greater in the wavefront-guided PRK group than in the aspheric PRK group (Figures 3 and 4). Table 3 shows aberrometric results 6 months after surgery in the 2 groups. The mean cornea Q value (ie, asphericity of cornea) changed from negative to positive after surgery. The postoperative mean Q value was less positive in the aspheric PRK group than in the wavefront-guided PRK group, and the increase was significantly greater in the wavefront-guided PRK group than in the aspheric PRK group (Figure 5).

Contrast Sensitivity

Postoperatively, ANOVA showed a statistically significant improvement in the AULCSF with and without glare in both groups. Table 4 shows contrast sensitivity results over time. There was no statistically significant difference in the AULCSF with or without glare between groups (Table 5).

DISCUSSION

Although conventional laser vision correction (LVC) is effective for the correction of lower-order aberrations (defocus and astigmatism), some concerns

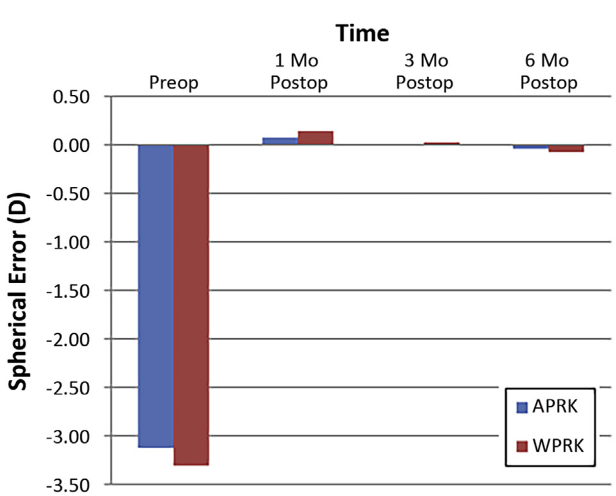

Figure 2. Refractive outcomes in aspheric before and after surgery (APRK = aspheric photorefractive keratectomy; WPRK = wavefront-guided photorefractive keratectomy).

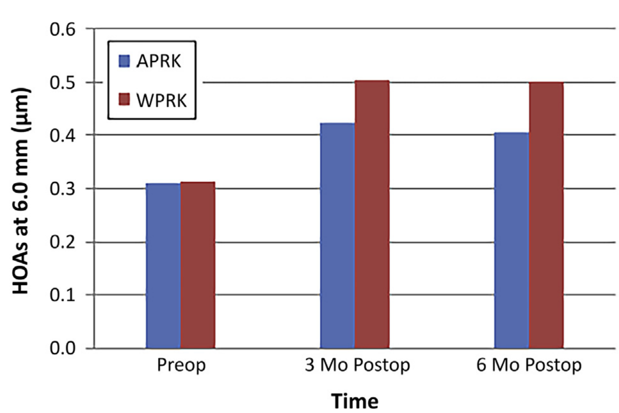

Figure 3. Increase in HOAs (APRK = aspheric photorefractive keratectomy; HOAs = higher-order aberrations; WPRK = wavefront-guided photorefractive keratectomy).

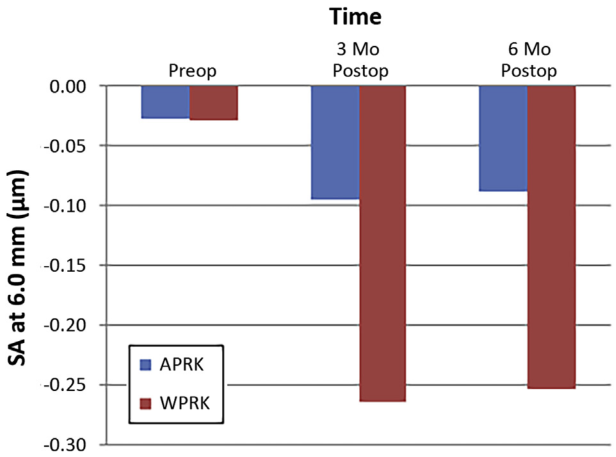

Figure 4. Increase in spherical aberration (APRK = aspheric photorefractive keratectomy; SA = spherical aberration; WPRK = wavefront-guided photorefractive keratectomy).

remain regarding the reduction in visual performance as a result of glare, halos, loss of visual quality, and alteration in night vision.[5–7] Newer wavefront-oriented LVC methods have been introduced to reduce the incidence of these unfavorable outcomes.

Visual acuity measurements and manifest refraction are the conventional and standard tests to evaluate refractive surgery results; however, some patients with relatively good Snellen visual acuity and minimal refractive error still report poor visual function after LVC. In these patients, other tests, such as contrast sensitivity and aberrometry, might be useful in determining the cause. Contrast

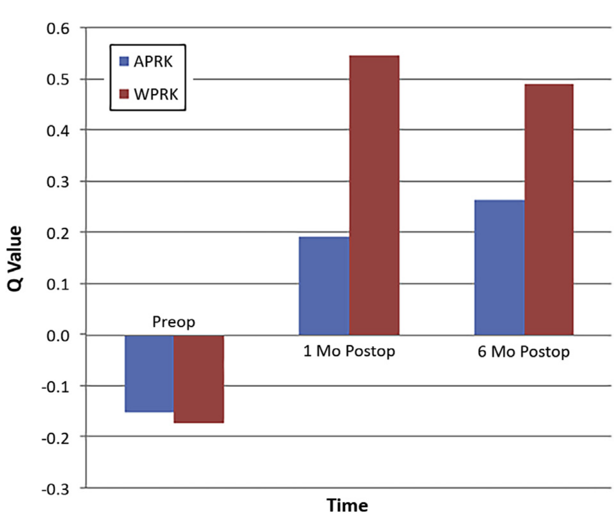

Figure 5. Change in Q value (APRK = aspheric photorefractive keratectomy; WPRK = wavefront-guided photorefractive keratectomy).

Table 3. Total HOAs, RMS of HOAs without spherical aberration and spherical aberration 6 months postoperatively.

Parameter	Wavefront-Guided PRK	Aspheric PRK	*P* Value*
Total HOAs (μm)			
Mean ± SD	0.440 ± 0.021	0.379 ± 0.021	.04
Range	0.16, −0.84	0.20, 0.69	
RMS of HOAs without SA Z(4,0) (μm)			
Mean ± SD	0.428 ± 0.020	0.375 ± 0.020	.06
Range	0.23, 0.79	0.19, 0.70	
SA Z(4,0) (μm)			
Mean ± SD	0.182 ± 0.023	0.070 ± 0.023	.001
Range	−0.64, 0.07	−0.32, 0.22	

HOAs = root mean square of higher-order aberrations; PRK = photorefractive keratectomy; RMS = root mean square; SA = spherical aberration

*Student *t* test for wavefront-guided group versus aspheric group

sensitivity measures visual performance under real-life conditions and evaluates how well a patient can distinguish detail under low-contrast conditions.[8] Aberrometry might also yield insight into limited visual quality after LVC because it represents a quantification of retinal image quality.[9–11]

This study was designed to evaluate the visual results of 2 types of wavefront-oriented LVC. After the intervention, there was no statistically significant between-group difference in conventional parameters, including postoperative UDVA, CDVA, sphere, and cylinder. It has been shown that even with conventional LVC, most patients achieve excellent UDVA and refractive results that are comparable to those with newer wavefront-guided methods.[12]

Conventional LVC increases HOAs, which can reduce visual performance. However, the data on the ability of wavefront-oriented LVC to reduce post-LVC HOAs are limited. In some studies, HOAs increased 1.3 to 1.91 times after wavefront-oriented PRK (wavefront-guided PRK and aspheric PRK) and 1.17 to 2.5 times after conventional treatment. This suggests that newer treatments might improve aberrometric results.[13–16]

Theoretically, personalized (wavefront-guided) treatment could reduce preexisting aberration. In contrast, aspheric treatments are designed to reduce induced spherical aberration after LVC. In our study, both wavefront-guided PRK and aspheric PRK increased HOAs. Aspheric treatment induced fewer HOAs than wavefront-guided treatment. The higher postoperative HOAs in the wavefront-guided group might reflect an inability of the wavefront-guided

Table 4. Area under the log contrast sensitivity function over time (both groups combined).

Parameter	Preoperative	Postoperative 3 Months	Postoperative 6 Months	*P* Value*
AULCSF with glare				
Mean ± SD	2.404 ± 0.091	2.877 ± 0.06	2.885 ± 0.045	<.001
Range	0.32, 3.99	0.32, 3.93	0.65, 3.78	
AULCSF without glare				
Mean ± SD	2.791 ± 0.076	3.034 ± 0.052	3.012 ± 0.049	.001
Range	0.32, 3.92	1.01, 4.15	1.19, 4.22	

AULCSF = area under the log contrast sensitivity function
*Repeated-measures test

algorithm to adequately treat preoperative HOAs. Another possible contributor to postoperative HOAs in the wavefront-guided PRK group is the inaccuracy of the eye tracker or an inappropriate time lag between sensing eye movements and the ablation position correction before starting treatment (static) and during treatment (dynamic). Because most types of aberrations are rotationally asymmetric, off-axis wavefront-guided treatment could induce more aberration. In addition, corneal epithelial and stromal healing might modify the ablation pattern and change the aberrometric result. In our study, the aberrometry outcomes suggest that aspheric treatment might be the better choice in normal eyes with fewer than 0.50 μm of HOAs (the upper limit of HOAs in this study).

Increased HOAs impair contrast sensitivity, which significantly affects many activities of daily living, such as the ability to read in dim light or drive at night. Several studies of contrast sensitivity after keratorefractive surgery have been published, with variable results.[17–20] In our study, we found a statistically significant increase in the mean AULCSF with and without glare after LVC in both groups and stable contrast sensitivity after 3 months. Tuan and Liang[18] reported similar results in their study and found that spectacle wearers experienced more improvement than soft contact lens wearers. Spectacle-related HOAs resulting from corrective lens tilt and decentration might be the reasons. In addition, image minification induced by spectacle correction of myopia increases the spatial frequency of the retinal image and reduces the contrast sensitivity function.[21] These factors might explain why the wavefront-oriented LVC ablation profiles improved contrast sensitivity despite increasing HOAs.

In our study, the differences in baseline SE, HOAs at 6.0 mm, and CCT and in the 6-month postoperative SE were not statistically significant between the 2 groups. A larger study might be needed due to the low power of the study.

In conclusion, these results indicate that aspheric and wavefront-guided PRK are effective for correction of myopia. Contrast sensitivity with and without glare improved after both procedures. Both techniques were associated with increased postoperative HOAs. However, the increase in HOAs, particularly in spherical aberrations, was less in the aspheric PRK group than in the wavefront-guided PRK group.

Table 5. Area under the log contrast sensitivity function 6 months postoperatively by group.

Parameter	Wavefront-Guided PRK	Aspheric PRK	*P* Value*	Power
AULCSF with glare				
Mean ± SD	2.716 ± 0.073	2.728 ± 0.073	.90	0.13†
Range	0.32, 3.92	0.32, 3.99		
AULCSF without glare				
Mean ± SD	2.947 ± 0.068	2.944 ± 0.068	.97	0.06†
Range	0.32, 4.22	1.01, 3.96		

AULCSF = area under the log contrast sensitivity function; PRK = photorefractive keratectomy
*Student *t* test for wavefront-guided group versus aspheric group
†Difference not statistically significant

WHAT WAS KNOWN

- Photorefractive keratectomy is safe and effective for the correction of refractive errors, mostly for myopia.
- Wavefront-guided PRK was introduced to reduce preexisting HOAs without inducing new aberrations.
- Aspheric PRK was introduced to preserve corneal asphericity.

WHAT THIS PAPER ADDS

- Wavefront-guided PRK and aspheric PRK improved postoperative UDVA and contrast sensitivity.
- Although wavefront-guided PRK and aspheric PRK were still associated with increased postoperative HOAs, the increase in HOAs, particularly spherical aberrations, occurred more with wavefront-guided PRK.

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