Original Article

Color Vision, Contrast Sensitivity and Higher Order Aberrations after Photorefractive Keratectomy

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Abstract

Purpose: To evaluate the effect of myopic photorefractive keratectomy (PRK) on color vision, contrast sensitivity and higher order aberrations (HOAs).

Patients and Methods: This prospective study was performed on 46 eyes of 23 patients with 3 to 6 diopter of myopia/myopic astigmatism undergoing PRK. Color vision using Fransworth-Munsell 100 hue test (©2011 X-Rite Inc., Michigan, U.S) and contrast sensitivity using CSV-1000 (Vector Vision, Dayton, OH) were tested preoperatively and 2 and 6 months postoperatively. HOAs were assessed using Zernike analysis map of Pentacam (OCULUS Optikgeräte GmbH, Germany) preoperatively and 6 months postoperatively.

Results: No significant change was observed in color vision following PRK. Contrast sensitivity function was also preserved except for an increase in 12 cycles per degree (cpd) spatial frequency 6 months after surgery ($P = 0.04$). Total HOAs and primary spherical aberrations (total, anterior and posterior surface) increased significantly ($P < 0.001$), however, primary coma showed no statistically significant change 6 months after surgery compared to baseline values. Induced total HOAs significantly correlated with change in primary vertical coma and total, anterior, and posterior primary spherical aberrations. No significant correlation was found between the changes in contrast sensitivity, color vision and HOAs with the amount of preoperative sphere and cylinder.

Conclusion: PRK with an aspheric profile in moderate myopia/myopic astigmatism does not affect color vision and contrast sensitivity at 3, 6 and 18 cpd spatial frequencies. It increases total HOAs and spherical aberration, but not coma. It remains a good option for refractive correction of moderate myopia.

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Introduction

Uncorrected refractive error is one of the most important causes of visual impairment worldwide [1]. Approximately 700000 people undergo refractive surgery each year to correct refractive errors [2].

Photorefractive keratectomy (PRK) is a safe and effective technique which uses excimer laser photoablation for correcting mild to moderate myopia [3-4]. There are many studies evaluating post PRK visual function using visual acuity parameters, however many factors other than visual acuity contribute to the visual performance in daily life as the visual environment is composed of objects with various spatial frequencies, contrasts and colors [5-7]. To our knowledge this is the first study to evaluate color vision among patients with moderate myopia/myopic astigmatism undergoing PRK. Also considering inconclusive results of previous studies regarding changes of contrast sensitivity and higher order aberrations (HOAs) after PRK, we designed the present study to assess the impact of PRK on color vision, contrast sensitivity function and also HOAs in patients with 3 to 6 diopter (D) of myopia/myopic astigmatism.

Patients and Methods

This was a prospective study on 23 consecutive patients undergoing bilateral PRK at Farabi Eye Hospital, Tehran University of Medical Sciences, Tehran, Iran. All surgeries were performed by one surgeon (AHB) from February 2017 through November 2017. The study protocol was approved by the ethics committee of Tehran University of Medical Sciences; and tenets of the Declaration of Helsinki were followed. Informed consent was obtained from all subjects after explanation of the nature and possible consequences of the study.

Inclusion criteria was age > 20 years, myopia/myopic astigmatism of 3 to 6 diopters, preoperative BCVA of 20/25 or better, no tomographic signs of keratoconus as well as normal slit lamp and fundoscopic examinations. Patients with a previous history of ocular surgery, glaucoma, ocular hypertension, herpetic keratitis, collagen vascular diseases, systemic corticosteroid usage, congenital color vision deficiencies, pregnant and lactating women, and postoperative uncorrected visual acuity (UCVA) of < 20/20 were excluded.

Ophthalmologic examinations including measurement of uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), anterior segment examination using slit lamp microscope, posterior segment examination using dilated fundoscopy, intraocular pressure measurement by Goldman applanation tonometer, refraction measurement with and without cycloplegia, corneal tomography and HOAs measurement by Pentacam HR (OCULUS Optikgeräte GmbH, Germany), contrast sensitivity function measurement using CSV1000 (Vector Vision, Dayton, OH), and color vision assessment using Farnsworth-Munsell 100-hue test (©2011 X-Rite Inc., Michigan, U.S) were performed preoperatively and at 2 and/or 6 months after surgery.

All PRK procedures were performed by one excimer laser system, Technolas Teneo (Bausch and Lomb, Perfect Vision GmbH, Germany) using PROSCAN treatment profile, which is based on an aspheric algorithm. PRK was performed based on manifest refraction for target of emmetropia. Optical zone of 6.3-6.5 mm was selected for all patients.

After topical anesthesia using tetracaine eye drop 0.5 %, an eye lid speculum was inserted and 9 mm of the central corneal epithelium was discarded using a blunt spatula. The ocular surface was irrigated with balanced salt solution and the cornea dried prior to laser ablation. Laser was applied centered on pupil. Mitomycin-C solution 0.02 % was used at the end of procedure if absolute magnitude of sphere and cylinder summation was greater than 4 D or if ablation depth was more than 60 micrometers. After irrigation of stromal bed with 20 ml of normal saline, a bandage contact lens (Johnson & Johnson Vision Care, Inc.) was applied to the eye. Topical betamethasone 0.1 %, chloramphenicol 0.5 % and ketorolac tromethamine 0.5 % were instilled every 6 hours for the first postoperative day then topical betamethasone and chloramphenicol were continued every 6 hours until 2 days after contact lens removal. Contact lens was removed when complete reepithelialization occurred. Topical fluorometholone 0.1 % (FML) was used 4 times a day during the next 2 months and then tapered to twice daily for one month. Artificial tear eye drop was also prescribed. Color vision was measured using Farnsworth-Munsell 100-hue test (FM 100 hue test) as described before [8]. This is a relatively sensitive test to evaluate color vision based on total error score (TES) [9]. The test was performed monocularly on right eye under photopic condition with spectacle preoperatively, and without refractive correction 2 and 6 months postoperatively.

Briefly this test consists of 85 colored caps split across four trays which vary only in hue, with constant lightness and saturation. Each tray has 21 removable caps (except the first tray where there are 22 caps). Standard administration procedures were followed: for each tray, the participant had to place the intermediate caps (which were randomly arranged by the examiner) between the two fixed caps in the correct order based on hue difference. The TES was calculated using FM 100 hue test scoring software (version 3.0). Results were classified into superior (TES < 16), average (TES = 16-100) and low (TES > 100) based on normative data of software.

Contrast sensitivity was tested using CSV1000 (Vector Vision, Dayton, OH). The test was performed with patients manifest refraction in place preoperatively and without refractive correction 2 months and 6 months postoperatively at 8 feet distance. The unit automatically adjusts light intensity to a standardized level of 85 candelas per square meter. Four spatial frequencies each with eight different levels of contrast were tested at each visit: 3 cycles per degree (cpd) (range, 0.70 –2.08 log units), 6 cpd (range, 0.91–2.29 log units), 12 cpd (range, 0.61–1.99 log units), and 18 cpd (range, 0.17–1.55 log units) [7]. The patients had to identify the grating pattern in each column. The contrast level of the last correct response was recorded as the contrast threshold in logarithmic values.

Ocular HOAs for a 6-mm pupil were measured with Pentacam HR (OCULUS Optikgeräte GmbH, Germany) preoperatively and 6 months postoperatively. Pentacam system has a rotating Scheimpflug camera which takes 100 images with 500 measurement points on anterior and posterior corneal surface and uses Zernike polynomials to convert the corneal elevation profile to wavefront data (up to 10th order) [10-11].

Ocular aberrations including total HOAs, primary vertical and horizontal coma (Z_3^{-1} and Z_3^{1} respectively) and primary spherical aberration (Z_4^{0}) were assessed using Zernike analysis of Pentacam scan. Data was recorded for total, anterior and posterior corneal surface in micrometers.

Statistical analysis

To describe data we used frequency, percent, mean, standard deviation, median, and range. Correlations were measured using Linear Mixed Model (LMM). Multiple comparisons were performed using Sidak method. To obtain the relation of the variables we used Pearson correlation coefficient. Also, to assess the relation of the different factors with contrast sensitivity, we used partial correlation. All statistical analysis were performed by SPSS software Version 22.0 (Armonk, NY: IBM Corp). P values less than 0.05 were considered statistically significant.

Results

Forty-six eyes of 23 patients including 17 females (73.9 %) and 6 males (26.1 %) were included in this study. The mean patient age was 31.0 ± 6.4 years (range, 22 to 43 years). The mean preoperative spherical equivalent was - 4.16 ± 0.77 D (range - 3.00 to – 6.00 D). The preoperative mean sphere and cylinder were - 3.77 ± 0.66 D and - 0.89 ± 0.67 D respectively.

The mean spherical equivalent was 0.08 ± 0.33 D at 2 months and 0.04 ± 0.22 D at 6 months postoperatively.

Color vision

Preoperatively 16 patients (69.6 %) had average color discrimination and 7 patients (30.4 %) had low color discrimination. At 2 months postoperative visit, superior discrimination was recorded in one patient (4.3 %), seventeen patients (73.9 %) had average discrimination and 5 (21.7 %) had low discrimination. At 6 months postoperative visit one patient (4.3 %) had superior discrimination, 16 patients (69.6 %) had average discrimination and low color discrimination was recorded for 6 patients (26.1 %).

The mean TES was 88.8 ± 57.4 (range, 24 to 256) preoperatively which changed to 74.9 ± 50.4 (range, 12 to 204) at 2 months and 90.6 ± 63.7 (range, 16 to 244) at 6 months postoperatively. No significant change in the TES was observed at 2 months (P = 0.86) and 6 months (P = 0.39) after PRK.

Contrast sensitivity

Figure 1 and table 1 show the details of contrast

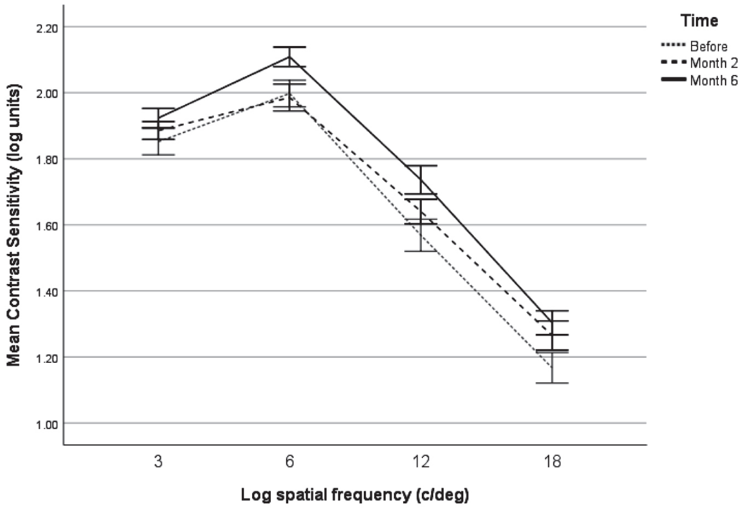

Figure 1: The mean contrast sensitivity log values before photorefractive keratectomy (PRK) and 2 and 6 months postoperatively

Table 1: Photopic contrast sensitivity analysis according to different levels of spatial frequencies

Log spatial frequency cycles per degree (cpd)	Preoperative	Month 2 postoperative		Month 6 postoperative	
	Contrast threshold log units (mean ± SD)	Contrast threshold log units (mean ± SD)	P value (Compared to preoperative)	Contrast threshold log units (mean ± SD)	P value (Compared to preoperative)
3	1.85 ± 0.19	1.89 ± 0.13	0.864	1.92 ± 0.14	0.393
6	2.00 ± 0.19	1.99 ± 0.19	0.995	2.11 ± 0.14	0.094
12	1.57 ± 0.23	1.64 ± 0.18	0.568	1.74 ± 0.20	0.038
18	1.17 ± 0.22	1.26 ± 0.21	0.347	1.30 ± 0.17	0.073

sensitivity measurements.

Contrast sensitivity did not change 2 months after surgery. But at 6 months there was a statistically significant change at the spatial frequency of 12 cpd ($P = 0.038$).

Higher order aberrations

As shown in table 2, The amount of total HOAs and primary spherical aberrations (total, anterior and posterior surface) increased significantly 6 months after surgery ($P < 0.001$). The amount of primary coma (total, anterior and posterior surface) did not change significantly.

Correlations

There was no significant correlation between changes in contrast sensitivity and preoperative sphere and cylinder. Also changes in contrast sensitivity were not correlated to changes of HOAs and color vision .

Change in root mean square (RMS) of total HOAs was significantly correlated with alterations in total, anterior and posterior surface spherical aberration and also anterior surface primary vertical coma (Table 3).

Discussion

In the present study we evaluated changes in color vision, contrast sensitivity and HOAs as important quality of vision parameters after PRK for patients with moderate myopia/ myopic astigmatism.

To our knowledge this is the first study evaluating color vision after PRK in English literature. We employed FM 100 hue test as a tool for testing color hue discrimination. FM hue 100 was designed by Fransworth in the early 1940 [12-13]. It is a standard measure of chromatic discrimination used by many visual scientists and physicians [8-14]. It has been used to show the impact of phacoemulsification on color perception (especially at 470-580 nm spectrums) in patients with age-related cataract [9].

We found that color vision was not affected 2 and 6 months after aspheric PRK for moderate myopia/myopic astigmatism. Similarly, it has been reported that color vision did not change after laser in situ keratomileusis (LASIK) [6] and radial keratectomy [15]. Color vision is an important part of visual ability in a wide variety of behavioral tasks and occupations and based on this study results PRK for moderate myopia will not alter color hue discrimination. Refractive surgery could induce aberrations due to alteration in corneal shape which can lead to degradation of image quality and symptomatic glare and halo. However, the relation between measured HOAs and subjectively reported quality of

Table 2: Comparison of ocular aberrations (total, anterior corneal surface and posterior corneal surface) before surgery and at 6 months postoperatively.

Higher order aberrations (µm)	Preoperative RMS (µm)	6 months postoperative RMS (µm)	P value
Total primary spherical aberration (Z_4^0) (mean ± SD)	0.199 ± 0.078	0.401 ± 0.101	< 0.001
Anterior primary spherical aberration (Z_4^0) (mean ± SD)	0.252 ± 0.074	0.443 ± 0.100	< 0.001
Posterior primary spherical aberration (Z_4^0) (mean ± SD)	- 0.160 ± 0.022	- 0.165 ± 0.027	< 0.001
Total primary horizontal coma (Z_3^1) (mean ± SD)	- 0.037 ± 0.143	- 0.056 ± 0.214	0.529
Anterior primary horizontal coma (Z_3^1) (mean ± SD)	- 0.028 ± 0.139	- 0.040 ± 0.220	0.659
Posterior primary horizontal coma (Z_3^1) (mean ± SD)	- 0.006 ± 0.029	- 0.010 ± 0.055	0.534
Total primary vertical coma (Z_3^{-1}) (mean ± SD)	- 0.028 ± 0.176	- 0.053 ± 0.338	0.497
Anterior primary vertical coma (Z_3^{-1}) (mean ± SD)	- 0.008 ± 0.164	- 0.067 ± 0.354	0.145
Posterior primary vertical coma (Z_3^{-1}) (mean ± SD)	- 0.012 ± 0.048	- 0.033 ± 0.126	0.392
Total higher order aberrations (mean ± SD)	0.371 ± 0.066	0.658 ± 0.154	< 0.001

RMS: Root Mean Square

vision is not clear [16-17]. Contrast sensitivity function is another important component of visual ability, which cannot be measured through standard visual acuity tests [18]. There are conflicting results regarding the effect of corneal refractive surgeries on HOAs and contrast sensitivity. There are many studies reporting an increasing trend in HOAs and decline in contrast sensitivity measurements [19-21], but some other studies have found no significant change in contrast sensitivity function [18,22], or even improvement of contrast sensitivity and reduction in HOAs [23-24]. In a large meta-analysis to compare visual quality after all major forms of laser corneal refractive surgeries no statistically significant difference

Table 3: Relation between changes in total higher order aberrations and changes in coma and spherical aberration.

Variable		Change in total Z_3^1	Change in total Z_3^{-1}	Change in anterior Z_3^1	Change in anterior Z_3^{-1}	Change in posterior Z_3^1	Change in posterior Z_3^{-1}	Change in total Z_4^0	Change in anterior Z_4^0	Change in posterior Z_4^0
Change in total higher order aberrations	R	- 0.051	- 0.231	- 0.036	- 0.380	- 0.022	0.092	0.579	0.497	0.373
	P value	0.754	0.152	0.824	0.016	0.895	0.527	0.000	0.001	0.018

Z_3^1: primary horizontal coma; Z_3^{-1}: primary vertical coma; Z_4^0: spherical aberration; R: Pearson Correlation coefficient

was found in either HOAs or contrast sensitivity among any pair of treatment analyzed [1]. We tested photopic contrast sensitivity in patients with moderate myopia (3 to 6 D) using CSV 1000 and compared the results at 2 and 6 months postoperatively. Contrast sensitivity changes were not significant at most tested spatial frequencies except for an increasing trend at 12 cpd at 6 months postoperatively. With advent of high tech equipment in field of laser refractive surgery more accurate ablation profiles have been achieved which might explain low changes in contrast sensitivity after PRK in our study. Another explanation could be the narrow range of myopia included in the present study, since previous studies have indicated higher postsurgical changes in HOAs and contrast sensitivity among patients with higher corrected refractive error [25].

Also we found no correlation between the amounts of preoperative myopia/astigmatism (in range of 3-6 D spherical equivalent) with the change in contrast sensitivity values.

There are reports of positive correlation between induced changes in contrast sensitivity and increasing HOAs after keratorefractive surgery [20, 26], but some studies have reported no correlation [27]. We did not find significant correlations between changes in contrast sensitivity and color vision or HOAs. Evaluation of ocular aberrations was performed using Zernike analysis of Pentacam. We included data of corneal back surface aberrations and found that the amount of total HOAs and spherical aberrations (total, anterior and posterior surface) increased after 6 months compared with baseline measurements. It could be explained by the flattening of the central cornea after myopic ablation and is in agreement with previous studies [28]. Increasing postoperative total HOAs might be mainly due to changes of spherical aberration and primary vertical coma. Fahim et al., [24] have reported similar results for spherical aberration but not coma. Several studies have reported that decline of contrast sensitivity following refractive surgery is a temporary problem and the measured amounts would return to baseline during several months [5, 28-30]. Also it seems that induced postoperative HOAs will become extremely minor after 10 years reaching preoperative measurements [31]. Serrao et al., [25] found that anterior corneal surface aberrations remained unchanged between 1 year and 8 years after myopic PRK, which means corneal remodeling will be completed 1 year after surgery.

Due to limited number of patients alterations in posterior corneal curvature after PRK, which could lead to changes of back surface corneal HOAs, could not be evaluated in this study. Changing in posterior surface corneal HOAs following laser surface ablation especially for higher amount of myopic ablation could be an interesting topic for future studies. Our study had several limitations including the small sample size and only including patients with moderate myopia, so the results cannot be generalized to a wide range of refractive errors. Also, the follow up time was relatively short.

Conclusion

PRK with an aspheric profile in moderate myopia/myopic astigmatism does not affect color vision and contrast sensitivity at 3, 6 and 18 cpd spatial frequencies. It increases total HOAs and spherical aberration, but not coma. It remains a good option for refractive correction of moderate myopia.

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Footnotes and Financial Disclosures

Conflict of interest:

The authors have no conflict of interest with the subject matter of the present study.