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Journal of Current Ophthalmology 29 (2017) 98–102

http://www.journals.elsevier.com/journal-of-current-ophthalmology

Original research

Astigmatic treatment with photorefractive keratectomy: Investigations of non-keratometric ocular astigmatism

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Received 17 June 2016; revised 28 November 2016; accepted 6 December 2016
Available online 4 February 2017

Abstract

Purpose: To evaluate the effect of non-keratometric ocular astigmatisms on visual and refractive outcomes after photorefractive keratectomy (PRK) for correction of myopic astigmatisms.

Methods: Seventy one eyes of 36 subjects were enrolled in this study. Patients underwent PRK for treatment of myopia. Subjects were evaluated for refractive error, keratometry, and visual acuity before and six months after surgery. Pre- and post-op non-keratometric astigmatisms were calculated by vectorial analysis of the difference between the corneal plane refractive astigmatism and keratometric astigmatism. Astigmatic analysis explored the contribution of non-keratometric astigmatisms.

Results: The pre-op spherical equivalent (SE) was -6.27 ± 1.48 with 1.16 ± 1.02 diopters of corneal plane refractive astigmatism and 1.44 ± 0.47 diopters keratometric astigmatism. Post-op values were -0.60 ± 0.85, 0.56 ± 0.47, and 1.06 ± 0.57, respectively, 6 months after surgery. Pre- and post-op non-keratometric astigmatisms were 0.76 ± 0.41 and 0.76 ± 0.46, respectively, ($P = 0.976$) with significant correlation ($r = 0.37$, $P = 0.002$). Pre-op non-keratometric astigmatisms correlated to the pre-op SE ($r = -0.25$, $P = 0.04$). Pre-op non-keratometric astigmatisms had significant correlation with keratometric difference vector of astigmatic correction ($r = 0.369$, $P = 0.002$). Post-op non-keratometric astigmatisms correlated to keratometric induced astigmatism ($r = 0.334$, $P = 0.006$), keratometric index of success ($r = 0.571$, $P < 0.001$), and post-op keratometric astigmatism ($r = 0.736$, $P < 0.001$).

Conclusions: Higher or lower non-keratometric ocular astigmatisms did not have any effect on refractive and visual outcome after PRK. PRK effectively corrected total refractive astigmatism through correction of keratometric astigmatism and additional adjustment to compensate for non-keratometric ocular astigmatisms.

Keywords: Keratometric astigmatism; Residual astigmatism; Photorefractive keratectomy; Myopia

Introduction

Current advances in surgical techniques and instruments especially modern excimer lasers with submicron surface ablation accuracy has resulted in remarkable developments in the correction of refractive errors.[1–3] One of the most common methods of ablative refractive surgery worldwide is photorefractive keratectomy (PRK) surgery, which is used for a wide range of refractive errors such as mild to high myopia, hyperopia, and astigmatism.[1,2,4,5]

Difference in curvature at different meridians of the cornea or internal ocular structures leads to ocular astigmatism.[3,6,7] Astigmatisms are a commonly encountered refractive error, which account for about 13% of refractive errors of the human eye.[6,7] Astigmatisms are divided into corneal keratometric and

Authors have no financial interest regarding the subject matter of this article.

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Peer review under responsibility of the Iranian Society of Ophthalmology.

http://dx.doi.org/10.1016/j.joco.2016.12.001

internal astigmatisms (a total astigmatism is the sum of keratometric and internal astigmatisms). Corneal keratometric astigmatisms are a result of unequal curvature along the two principal meridians of the anterior cornea. The ocular astigmatism is attributed to the posterior cornea, unequal curvatures of the front and back surfaces of the crystalline lens, or differing refractive indices across the crystalline lens are referred to as an internal astigmatism.[6–8] Internal astigmatisms are also called residual astigmatisms, which are quantified by magnitude and axis as the vector value of ocular residual astigmatisms.[9,10] Based on the term residual astigmatism introduced by Duke-Elder, ocular residual astigmatisms are defined as the vectorial difference between the keratometric and the refractive astigmatism calculated to the corneal plane.[10,11] The non-keratometric ocular astigmatisms are the result of an astigmatism arising from the crystalline lens and the posterior corneal surface.[10,11] Non-keratometric ocular astigmatisms are reported to be higher with greater refractory errors.[12]

We conducted this research to define the effect of pre- and postoperative non-keratometric ocular astigmatisms on visual and refractive outcomes after PRK for correction of myopic astigmatisms.

Methods

This study was a retrospective observational clinical study on patients who underwent excimer laser PRK for treatment of myopia and myopic astigmatism. The study followed the tenets of the Declaration of Helsinki.

Seventy one eyes of 36 subjects were enrolled in the study. Surgery was performed on both eyes during the same session. Patients selected for the study met the following criteria: age 20 years or older, documented stable refraction (defined as less than 0.5 diopter of refractive change for at least 1 year before surgery), central corneal thickness of at least 490 micron, spherical equivalent (SE) refraction between −0.25 and −8.0 diopters, refractive astigmatism of 5 diopters or lower, and corrected distance visual acuity (CDVA) 20/25 or better. Exclusion criteria were history of refractive or other anterior segment surgery, cataracts, ectatic corneal disorders, collagen vascular disease, and diabetes.

Preoperative assessment

The preoperative ophthalmic examination included vision measurement with the Snellen acuity chart, manifest and cycloplegic refractions, slit-lamp biomicroscopy, applanation tonometry, and indirect ophthalmoscopy in addition to cornea evaluation using a Scheimpflug corneal tomography (Oculus Pentacam, USA). We used Pentacam SIM-K value for analysis of keratometric changes.

Surgical technique

After topical tetracaine 0.5% drops were administered to anesthetize the eye, an eyelid speculum was inserted. The surface corneal epithelium in a 9 mm diameter area was loosened using a 20% alcohol solution and removed using a blunt spatula (Hockey knife). Surgery was performed using a Technolas 217z100 excimer laser system (Bausch & Lomb). In this study, patients scheduled to have PRK using the Tissue-saving algorithm software for the treatment. In all cases, the optical zone was 6.0 mm, and the primary goal was emmetropia. The dynamic eye-tracker system of excimer machine was set to track horizontal (x, and y), altitude (z), and torsional movements during surgery. The final refraction treatment determined in each case according to the surgeon's individually optimized nomogram (for astigmatism the goal of treatment was total correction, for spherical error an over-correction between 0 and 10% applied with regard to the age of the subjects). Acuvue Advance HydraClear soft contact lens (Johnson & Johnson Vision Care, Inc.) were placed over the cornea at the end of procedure.

Postoperative protocol

After surgery, a soft bandage lens and standard postoperative antibiotic and corticosteroid regimen used similarly in all patients. Patients were prescribed ciprofloxacin 0.5% drop 4 times a day for 5 days and a diclofenac sodium 0.1% drop 2 times a day for the first day. The contact lens was removed when re-epithelialization was complete (between 5 and 7 days postoperatively). Betamethasone 0.1% drops were applied 4 times a day for 1 week and then decreased to 3 times a day for another 3 weeks. Preservative-free single dose unit hypromellose 0.32% artificial tears (Artelac, Bausch & Lomb) were prescribed 4 times a day for 3 weeks and then tapered over 8 weeks. Postoperative follow-up was on day 1 and day 5 after surgery. Patients underwent ophthalmic evaluation at 1, 3, and 6 months after the operation. We did not have any serious complication like cornea haziness or infections precluding measurements.

Calculation of the non-keratometric ocular astigmatisms

Pre- and postoperative non-keratometric astigmatisms were calculated by analyzing of astigmatic vectors. The total refractive astigmatism is considered a vectorial summation of corneal keratometric and non-keratometric ocular astigmatisms. To calculate non-keratometric ocular astigmatisms, we determined the vectorial differences between corneal plane refractive astigmatisms and keratometric astigmatisms. Astigmatism treatment vectors and indices calculated with the method developed by Dr. Alpins.[13]

Statistical analysis

Data analysis was performed using the Statistical Package for the Social Sciences (SPSS) for Windows software (version 18.0; SPSS, Inc.). Quantitative variables were summarized by their mean and standard deviation before and after surgery. The Shapiro-Wilk test was used to evaluate the normality assumptions of data. Comparisons of pre- and postoperative

values were done with a paired-sample *t* test. Correlations between non-keratometric ocular astigmatisms and surgical outcomes including efficacy of astigmatic treatment were determined using the Pearson correlation coefficient. A *P*-value of <0.05 was considered significant.

Results

This study was performed on 71 eyes of 36 patients with 20 (55.5%) of patients were females and 16 (44.5%) were males. The mean age of the patients was 26.3 ± 3.2 years (range: 20−42 years). Preoperative SE refractory error at spectacle plane was −6.27 ± 1.48 with 1.16 ± 1.02 diopters of corneal plane refractive astigmatism and 1.44 ± 0.47 diopters keratometric astigmatism. Six months postoperative values were −0.60 ± 0.85, 0.56 ± 0.47, and 1.06 ± 0.57 diopters for SE, refractive corneal plane astigmatisms, and keratometric astigmatisms, respectively. Table 1 summarizes patient refractive data before and after surgery. Preoperative logMAR corrected acuity was 0.04 ± 0.07 and 6 months postoperative uncorrected visual acuity was 0.07 ± 0.12.

Figs. 1−3 show the distribution of total refractive astigmatism, keratometric astigmatisms, and non-keratometric ocular astigmatisms before and after PRK. Total refractive astigmatisms decreased after surgery, keratometric astigmatisms show the biggest change when comparing pre- and postoperative values, and non-keratometric ocular astigmatisms showed no change after surgery. There was no significant difference in non-keratometric ocular astigmatisms before and after surgery. Preoperative and postoperative non-keratometric ocular astigmatisms were 0.76 ± 0.41 and 0.76 ± 0.46 diopters, respectively, two values were not different statistically ($P = 0.976$) and had a significant linear correlation ($r = 0.37$; $P = 0.002$). We found statistically significant correlations between non-keratometric ocular astigmatisms and some visual and refractive parameters. Preoperative non-keratometric ocular astigmatisms correlated to preoperative SE ($r = -0.25$; $P = 0.04$), and had correlation to keratometric difference vector of astigmatic correction (r = 0369, $P = 0.002$), but pre-operative non-keratometric ocular astigmatisms were not correlated to pre- and postoperative logMAR corrected acuity, and no significant correlation was found with refractive difference vector or refractive astigmatism correction index of success. Postoperative non-keratometric ocular astigmatisms correlated to keratometric induced astigmatism ($r = 0.334$; $P = 0.006$), keratometric index of success ($r = 0.571$; $P < 0.001$), and postoperative keratometric astigmatism ($r = 0.736$; $P < 0.001$).

Categorizing astigmatism type (±30° of horizontal or vertical meridians) to with the rule (WTR), against the rule (ATR), and oblique types revealed that 56.7% of samples had WTR, 23.9% ATR, and 19.4% oblique astigmatic errors. Preoperative non-keratometric ocular astigmatisms were 0.69, 0.81, and 0.92 diopters in WTR, ATR, and oblique groups. We were not able to find statistical significant differences for non-keratometric ocular astigmatisms in different types of astigmatisms.

We divided patients to high non-keratometric ocular astigmatisms and low non-keratometric ocular astigmatisms subgroups. The low non-keratometric ocular astigmatisms subgroup were defined as subjects with the amount of preoperative non-keratometric ocular astigmatisms less than the arithmetic mean of this value in our own study (0.76 diopters), and the high non-keratometric ocular astigmatisms subgroup were defined as patients with pre-operative non-keratometric ocular astigmatisms greater than or equal to 0.76 diopters. We were unable to identify any difference for *refractive* astigmatic treatment indices and visual outcome between high and low non-keratometric ocular astigmatisms groups but analyzing *keratometric* values demonstrated differences between the subgroups. The keratometric difference vector of astigmatic correction was 0.88 ± 0.37 diopters in low non-keratometric ocular astigmatisms and 1.33 ± 0.71 diopters in high non-keratometric ocular astigmatisms subgroups, respectively. A comparison of keratometric astigmatism treatment indices revealed a statistically significantly higher difference vector of astigmatic treatment in the higher non-keratometric ocular astigmatisms subgroup ($P = 0.001$).

Table 1
Refractive data before and after surgery (mean ± SD).

	Pre-operative (diopters)	6 months after surgery (diopters)	*P* value
Sphere[a]	−5.60 ± 1.57	−0.32 ± 016	<0.05
Cylinder[a]	−1.35 ± 1.18	−0.57 ± 047	<0.05
Refractive astigmatism[b]	1.16 ± 1.02	0.56 ± 0.47	<0.05
Keratometric astigmatism[c]	1.44 ± 0.92	1.06 ± 0.57	<0.05
Non-keratometric astigmatisms[d]	0.76 ± 0.41	0.76 ± 0.46	0.97

[a] Spectacle plane values.
[b] Converted to corneal plane value.
[c] Measured at corneal plane.
[d] Vectorial difference between corneal plane refractive astigmatism and keratometric astigmatism.

Discussion

In this study, we found that PRK is effective for treating total refractive astigmatism. The calculated non-keratometric ocular astigmatisms were unchanged after surgery, which seems sensible as excimer ablation only adjusts front corneal power. We found that there is a greater change in *keratometric* astigmatisms when compared to *refractive* astigmatisms when looking into the components of astigmatisms. We also discovered an increase in difference vector of keratometric astigmatic correction, which was significantly correlated to non-keratometric ocular astigmatisms. This apparent increase in error of keratometric correction values may be generated for adjustment of non-keratometric ocular astigmatisms to decrease the total refractive astigmatism. We were unable to find any correlation between non-keratometric ocular astigmatisms and *refractive* correction indices.

Frings et al have reported the mean non-keratometric ocular astigmatisms of 0.75 diopters for myopic subjects, and our

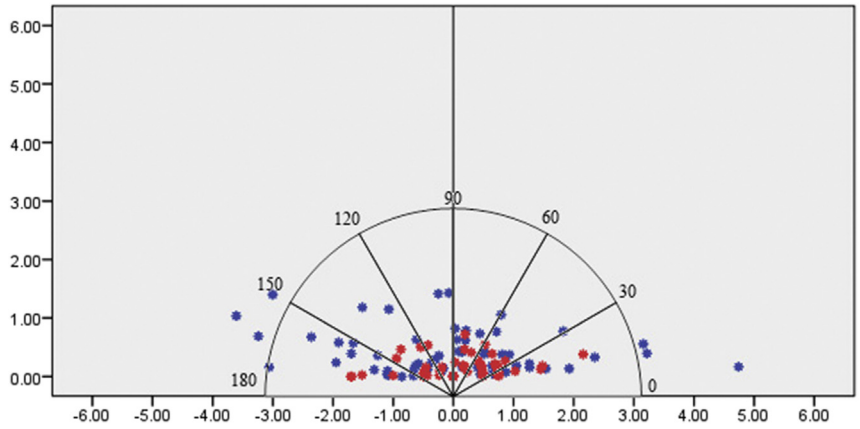

Fig. 1. Distribution of total refractive astigmatism before (blue) and 6 months after (red) photorefractive keratectomy (PRK).

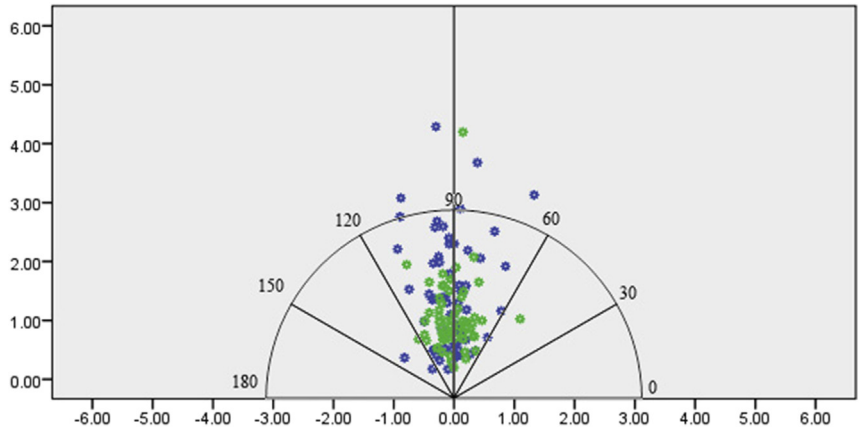

Fig. 2. Distribution of keratometric astigmatism before (blue) and 6 months after (green) photorefractive keratectomy (PRK).

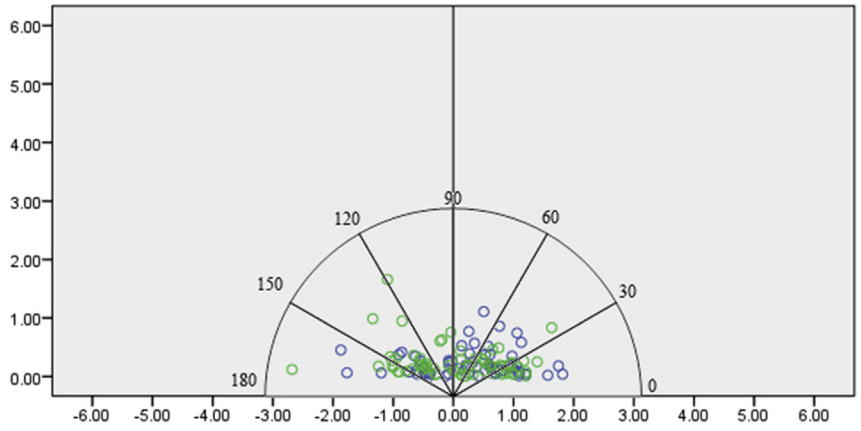

Fig. 3. Distribution of NonKORA before (blue) and 6 months after photorefractive keratectomy (PRK).

study does not differ significantly from these results.[14] Labiris et al published effective treatment of non-keratometric ocular astigmatisms with LASIK and PRK with wavefront optimized and wavefront guided methods of the Allegretto excimer system.[15] Qian et al evaluated the efficacy of LASIK for treatment of high and low non-keratometric ocular astigmatisms and found decreased success for treatment in patients with non-keratometric ocular astigmatisms greater than 1 diopter. This was different from the results of our study. Less effective treatments for higher non-keratometric ocular astigmatisms may be due to the confounding effects of treatment problems in higher astigmatic errors.[16] In this study, we were not able to find any significant difference between high and low non-keratometric ocular astigmatisms subgroups for total

refractive treatment and visual outcome. Kugler et al also reported less success for surgery in patients with a high ratio of non-keratometric ocular astigmatisms to refractive astigmatism.[9]

This study has several limitations. We used simulated keratometry readings from the topographer for calculations, which may not be a truly precise representative of the real corneal effect on refraction based on modified calculation of power according to front curvature. A negligible error was also expected due to differences in measurement precision of refraction and keratometry that was in steps of 0.25 and 0.1 diopters, respectively. Evaluation of contrast sensitivity and wavefront aberrations might add valuable data for research of this type that was not done in the current work.

According to our results, PRK does not affect non-keratometric astigmatisms. The *keratometric* astigmatic change is correlated to non-keratometric ocular astigmatisms, but *refractive* astigmatic correction vectors and indices are not correlated with non-keratometric ocular astigmatisms. It seems that PRK effectively adjusts keratometric astigmatisms to compensate for non-keratometric astigmatisms and front corneal astigmatisms were changed by PRK by a deceased effect of non-keratometric astigmatisms. Non-keratometric ocular astigmatisms have no effect on refractive and visual outcome after PRK.

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