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Original research

Correlation of higher order aberrations and components of astigmatism in myopic refractive surgery candidates

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Abstract

Purpose: To evaluate the correlation between refractive, corneal, and residual astigmatism and higher order aberrations (HOA) in refractive surgery candidates.

Methods: Three hundred and seventy-five eyes of 188 patients aged 28.2 ± 6.24 years with a predominance of females (62.7%) were enrolled in this study. Refraction, topography (Orbscan IIz, Bausch & Lomb, Rochester, NY, USA), and aberrometry (Zywave, Bausch & Lomb, Rochester, NY, USA) were performed to determine refractive and corneal astigmatism and HOA for all participants. Ocular residual astigmatism was calculated using vector analysis.

Results: The mean spherical equivalent was −3.59 ± 1.95 D and the mean refractive astigmatism was −1.97 ± 1.3 D. The mean HOA was 0.38 ± 0.15 μm in all cases, which increased with spherical equivalent ($p < 0.05$). There was a positive significant correlation between both corneal and refractive astigmatism and HOA ($p < 0.05$), but there was no significant correlation between residual astigmatism and HOA ($p = 0.122$).

Conclusion: The results of the study showed significant correlations between corneal and refractive astigmatisms and HOA.

Keywords: Higher order aberrations; Refractive astigmatism; Corneal astigmatism; Residual astigmatism; Zywave

Introduction

Refractive errors are the most common vision problem in the world. According to different studies, astigmatism comprises about 13% of the refractive errors of the human eye.[1–4] Numerous investigations have reported the prevalence of astigmatism at different ages in both rural and urban populations.[5–7] Image distortion and blurring are different according to the type of astigmatism (refractive, corneal, or ocular residual astigmatism).

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In the past, refractive errors were corrected only with glasses and contact lenses, but with the availability of a variety of lasers today, different surgical procedures are employed. According to some studies, complaints such as halo and double vision may be encountered with a prevalence of 3–43% even when surgery is successful. Aberrations are the main reason for post-surgical dissatisfaction and low visual quality.[8,9]

High-order aberrations (HOA) cannot be corrected by conventional refraction parameters (sphere, cylinder, and axis). Now, with the development of lasers methods and surgical procedures, Wavefront technology can examine and correct optical errors better.[10,11] Customized ablation can reduce aberrations and improve the visual quality to achieve a super-normal vision (a normal vision of 20/15 or better).[8]

The best method to evaluate the effect of refractive surgery on the general image quality is by measuring aberrations prior to surgery. Accordingly, corneal surface changes for the correction of the retinal image can be predictable.[12–14] Many studies have compared different methods of surgery with different lasers, but there is no standard method; therefore, some surgeons correct all HOAs while others correct only certain ones, indicating the need for more research to improve the laser algorithms.[15,16]

Although it is now accepted that HOA affect refractive errors, there is controversy about the correlation between the two.[17–19]

The aim of the present study was to evaluate the correlation of HOA with the type and the amount of astigmatism in eyes with astigmatism.

Methods

In this cross-sectional descriptive study, we examined 188 patients (375 eyes) from May 2011 to June 2013 at Farabi Eye Hospital. The study protocol was completely explained to the patients, and informed written consent forms were signed by all.

All the participants had normal ocular examinations except for refractive error. The mean age of patients was 28.2 years ± 6.24 (range: 20–52 years), and 62.7% of them were female. Spherical refraction was between −1.70 D and −9.23 D.

Inclusion criteria were age 20 years or older, regular astigmatism with cylinder ≤6D, and a best spectacle-corrected visual acuity (BCVA) of 20/25 or better.

Exclusion criteria were a history of ocular or corneal surgery or trauma, corneal scar, lens or media opacity (might alter vision and Wavefront measurements), irregular astigmatism on corneal topography, keratoconus, dry eye, lid abnormalities, pregnancy, and consumption of certain drugs.

The Institutional Review Board of Tehran University of Medical Sciences approved the study, and the study protocol complied with the Declaration of Helsinki.

Refraction, topography, and aberrometry were done to determine refractive, corneal, and residual astigmatism and HOA for all participants. Preoperative examinations included the measurement of visual acuity with an Snellen E chart and refractive astigmatism by manifest refraction using Zywave aberrometry predicted phoropter refraction (PPR) (Bausch & Lomb, Rochester, NY, USA). Zywave's estimate of refractive error was then compared with subjective manifest refraction and confirmed with the HEINE BETA 200 retinoscope (Herrsching, Germany) and Topcon RM8800 auto-refracto meter (Tokyo, Japan). The repeatability and validity of Zywave's refractive error measurements were previously confirmed.[9] Corneal topography with the Orbscan IIz (Bausch & Lomb, Rochester, NY, USA) was done to determine corneal astigmatism based on simulated keratometry (Sim K). Residual astigmatism was calculated through subtraction of refractive from corneal astigmatism using vector analysis (the Kaye and Patterson method).[20,21]

The patients were divided into three groups according to the amount of refractive astigmatism (Astigmatism ≤ 0.75 D, 0.75 < Astigmatism ≤ 2.00 D, Astigmatism > 2.00 D).[22]

The correlation between the amount of astigmatism and HOA was evaluated in three astigmatic groups. Aberrometry was performed using the Zywave II Hartman Shack Aberrometer (Bausch & Lomb) in a dark room when a pupil diameter of 6 mm was achieved.[23,15] The system computed the average of three best compatible measurements after rejecting the two measurements with higher deviations from the mean. All measurements were performed by one experienced optometrist. Zernike polynomials were used for data analysis. The analyzed parameters included HOA in all cases.

Statistical analysis

Descriptive and statistical analyses including mean and standard deviation were analyzed with SPSS version 20. Analysis of variance (ANOVA) was performed to evaluate the effect of preoperative refractive error on HOA in the three groups.

Linear regression was used to investigate the relationship between the variables. In addition, the astigmatism power vector analysis was used for analysis. Both eyes were defined as clusters and the Generalized Estimating Equations (GEE) analysis was performed. All the analyses were adjusted for age and gender.

A p value < 0.05 was considered statistically significant.

Results

According to the cylinder power, 315 eyes (78.9%) had refractive astigmatism, 340 eyes (85.4%) had corneal astigmatism, and 159 eyes (39.1%) had residual astigmatism more than 0.75 D. The mean spherical equivalent refractive error and HOA in patients was −3.59 ± 1.95 D and 0.38 ± 0.15 μm, respectively (Table 1).

Table 2 shows the association between the amount of astigmatism and HOA. Accordingly, HOA increased with the increase in the amount of astigmatism in the sub groups.

As Fig. 1 shows, there was a positive significant correlation between corneal astigmatism and HOA (Pearson Correlation = 0.157; p = 0.003).

Table 1
Patient characteristics.

Total number = 375 eyes	Mean ± SD	Range
Sphere (diopter)	−2.6 ± 2.03	−9.23 to −1.70
Refractive astigmatism (diopter)	−1.97 ± 1.3	−6.45 to −0.05
Corneal astigmatism (diopter)	−1.85 ± 1.02	−5.1 to −0.07
Higher order aberration (μm)	0.38 ± 0.15	0.09 to 1.27
Ocular residual astigmatism (diopter)	0.66 ± 0.37	0.05 to 1.93
Spherical equivalent (diopter)	−3.59 ± 1.95	−10.22 to −0.54

Table 2
The association between amount of astigmatism and HOA.

Total number = 375 eyes		N	HOA	p value*
			Mean ± SD	
Refractive astigmatism	Astigmatism ≤ 0.75	76	0.32 ± 0.11	0.003
	0.75 < Astigmatism ≤ 2	131	0.38 ± 0.15	
	Astigmatism > 2	168	0.4 ± 0.16	
Corneal astigmatism	Astigmatism ≤ 0.75	53	0.32 ± 0.08	<0.001
	0.75 < Astigmatism ≤ 2	177	0.37 ± 0.15	
	Astigmatism > 2	145	0.41 ± 0.16	
Ocular Residual Astigmatism	Astigmatism ≤ 0.75	232	0.37 ± 0.15	0.117
	0.75 < Astigmatism ≤ 2	143	0.39 ± 0.15	

HOA = Higher Order Aberrations.
*p value was calculated by ONE WAY ANOVA.
* Scheffe Post Hoc test revealed in both refractive and corneal astigmatism groups, HOA significantly increased in patients with higher than 2 diopter astigmatism ($p < 0.05$).

Fig. 2 shows, there was a positive but not significant correlation between residual astigmatism and HOA (Pearson Correlation = 0.083; $p = 0.122$).

Fig. 3 shows a statistically significant correlation between refractive astigmatism and HOA (Pearson Correlation = 0.170; $p < 0.001$).

The association between HOA and other variables are shown in Table 3. Accordingly, HOA was significantly correlated with both refractive and corneal astigmatism ($p < 0.05$).

Discussion

Our results showed that HOA increased with the increase in the components of ocular astigmatism including refractive and corneal astigmatism. The difference between refractive and corneal astigmatism is related to the posterior or anterior surface of the cornea or the crystalline lens. The magnitude of ocular residual astigmatism is usually clinically negligible.[24] However, we found a significant correlation between ocular residual astigmatism and refractive astigmatism in previous researches.[25,26]

Since refractive surgery changes the natural shape of the cornea (prolate), visual performance reduces, and HOA increases; therefore, it is important to use Wavefront technology.

These results are in line with the findings reported by Paquin et al, who found increased aberrations in myopic eyes and a worse optical quality in high myopic eyes using the Shack-Hartmann aberrometer.[27] Similarly, Zheng et al used the Shack-Hartmann aberrometer to measure aberrations in 226 eyes of 113 myopic and astigmatic patients in order to evaluate the effect of pure astigmatism on HOA. They found that an increase in astigmatism was associated with an increase in coma aberrations, third-order, fifth-order, and total HOA. This finding was similar to our results.[22]

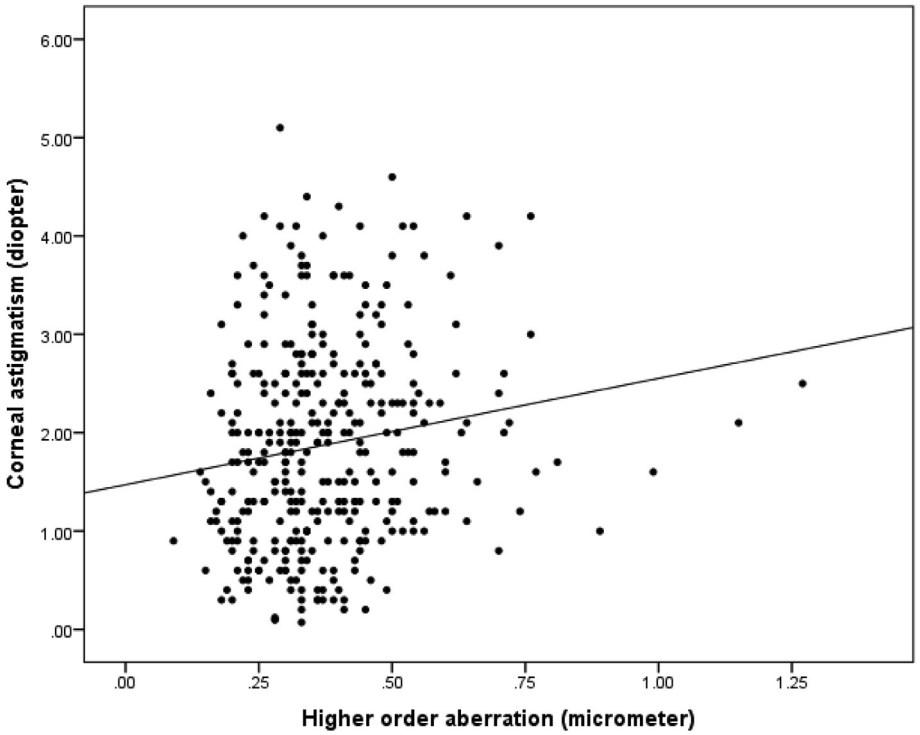

Fig. 1. Correlation between corneal astigmatism and higher-order aberration.

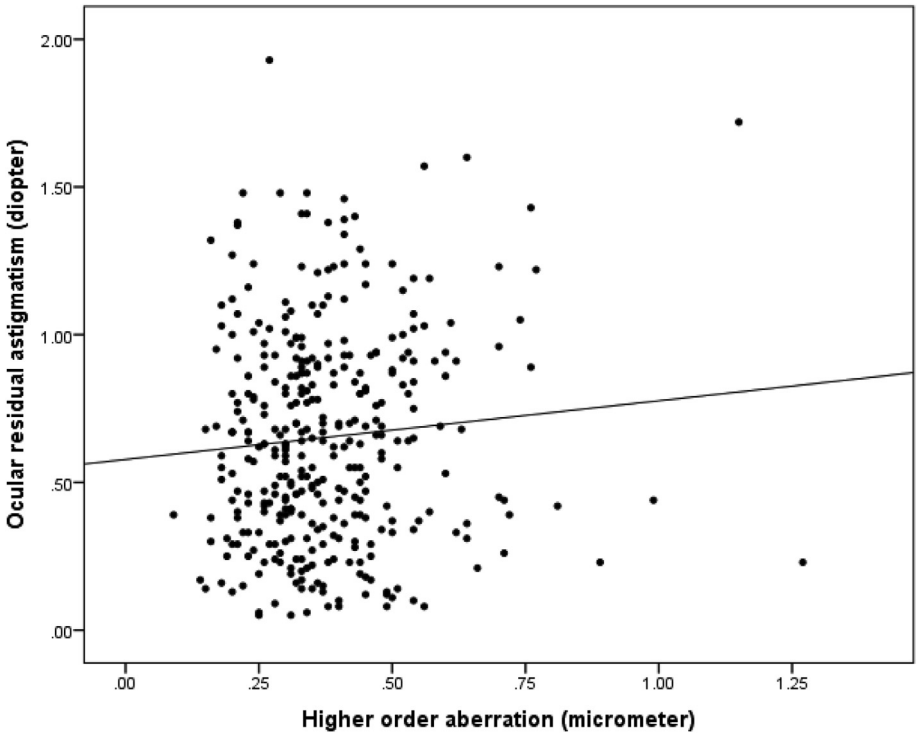

Fig. 2. Correlation between residual astigmatism and higher-order aberration.

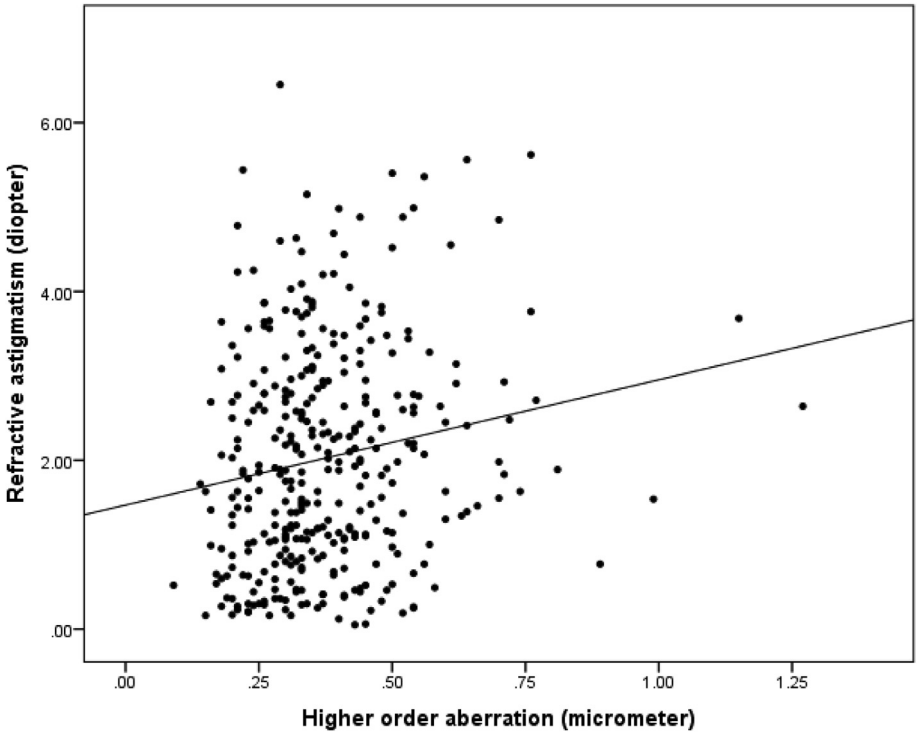

Fig. 3. Correlation between refractive astigmatism and higher-order aberration.

Despite these findings, the correlation between refractive errors and HOA remains a matter of controversy. Collins et al reported that aberrations were unrelated to refractive errors using an objective double-pass aberroscope.[19] Cheng et al also found no correlation between Wavefront aberrations and refractive errors in 200 eyes.[18]

Porter et al also conducted a study on 109 normal eyes with different refractive errors but found no association in different

Table 3
The association between variables and Higher Order Aberrations in a simple linear regression model.

Variables	Coefficient (95%CI)	pvalue
Age (years)	0.001 (−0.002 to 0.004)	0.631
Gender (female/male)	0.001 (−0.032 to 0.033)	0.959
Sphere (diopter)	−0.009 (−0.017 to −0.002)	[a]0.017
Spherical equivalent (diopter)	−0.015 (−0.023 to −0.007)	[a]<0.001
Ocular residual astigmatism (diopter)	0.034 (0.009–0.078)	0.122
Cylinder power (diopter)	0.02 (0.008–0.031)	[a]0.001
Corneal astigmatism (diopter)	0.023 (0.008–0.038)	[a]0.003

[a] In all cases, astigmatism was recorded with positive sign.

groups with HOA.[28] This difference may be due to different anatomical mechanisms and unique aberrations in each person. Later studies did not address residual astigmatism and its relationship with HOA.

A possible explanation for the contradiction may be the fact that there is no standard method for HOA measurement and interpretation. It may be due to the variety of sample size utilizations and research methodologies. A systematic approach is necessary to clarify this contradiction.

The strength of the present study is its large sample size and the consideration of the major components of ocular astigmatism in detail.

To the best of our knowledge, the correlation between HOA and the type and amount of astigmatism has not been studied before. We found no correlation between residual astigmatism and HOA, possibly due to more contribution of the corneal astigmatism to total ocular astigmatism.

Our study was conducted on refractive surgery candidates who had astigmatism, and the results may be different in normal populations without any refractive errors.

The major limitation of our study was that posterior corneal surface power and components of HOA, such as coma, trefoil, etc., were not measured, which could be explained by the retrospective nature of this study.

In summary, we found positive significant correlations between corneal and refractive astigmatism and HOA. Therefore, to achieve better vision and prevent significant HOA increase after surgery, we recommend that HOA should be evaluated in refractive surgery candidates, especially in patients who have significant corneal or residual astigmatism.

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