

Contralateral Eye Study On The Characteristics of Corneal Aberration In Patients With Bilateral Keratoconus And Unilateral Corneal Vogt's Striae

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Research Article

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Abstract

Purpose: To assess the corneal high-order aberration(HOA) and its correlation with corneal morphological parameters in patients with bilateral keratoconus (KCN) and unilateral Vogt's striae.

Methods: A total of 168 eyes of 84 patients with KCN, whose corneas had definite signs of unilateral Vogt's striae were enrolled. Corneal HOA and morphological parameters were measured using Pentacam HR.

Results: The corneal morphological parameters between KCN eyes with and without Vogt's striae were evidently different ($P < 0.001$). The 3rd coma 90° , 4th spherical aberration, 5th coma 90° , RMS (total), and RMS (HOA) in the front, back surfaces and total cornea in KCN eyes with Vogt's striae were significantly higher than those in KCN eyes without Vogt's striae ($P < 0.001$). In KCN eyes with Vogt's striae, the 3rd coma 90° and 4th spherical aberration in the front surface and total cornea were negatively correlated with K1, K2, Km, Kmax, ACE, and PCE ($P < 0.05$). The 3rd coma 90° , 4th spherical aberration in back surface and RMS (total), RMS (HOA) in the front, back surfaces, total cornea were positively correlated with K1, K2, Km, Kmax, ACE, and PCE ($P < 0.05$).

Conclusions: Corneal HOA especially vertical coma and spherical aberration may increase when Vogt's striae appeared in KCN eyes. The scale of increase was significantly related with changes in corneal shapes.

Introduction

Keratoconus (KCN) is an ectatic noninflammatory and progressive corneal disorder described by the gradual thinning and steepening of cornea that lead to corneal protrusion, irregular astigmatism, uncorrected visual acuity (UCVA), and best corrected visual acuity (BCVA) diminution [1–4]. The exact etiology of KCN has not been unified so far, and some previous articles reported its relationship to hereditary, environmental, and biomechanical factors [5]. In clinics, mild KCN can be difficult to detect in a routine eye examination. Given the progress of KCN, Fleischer's ring and Vogt's striae can be seen using slit-lamp biomicroscopy [6]. Vogt's striae or stress lines are vertical lines in the posterior stroma and Descemet's membrane that are parallel to the anterior corneal steep axis of the cone [7, 8], which is one of the typical clinical signs of KCN [9–12]. A previous study [6] stated that 30% of patients with KCN have unilateral and bilateral Vogt's striae. UCVA and BCVA significantly decrease, and the refractive error worsens in eyes with Vogt's striae [13]. One reason for this result is that alterations in the corneal morphology increase irregular astigmatism. Another reason may be associated with increased high-order aberrations (HOA), which can result in blurry and distorted vision [14].

Several previous studies reported that aberrations especially coma aberration are significantly increased in patients with KCN [15–17]. Sedaghat et al. [18] found that the presence of Vogt's striae may trigger changes in corneal morphology, which may increase the corneal HOA. However, studies on whether the increase in corneal HOAs is related to the appearance of Vogt's striae in KCN eyes are few.

This study aims to compare the characteristics of corneal HOA measured using the Pentacam HR and its correlation with corneal topographic indices in patients with bilateral KCN and unilateral corneal Vogt's striae.

Methods

Subjects and Methods

The records of 465 eyes of 276 patients diagnosed with KCN in the center of corneal refractive surgery at Xi'an People's Hospital (Xi'an NO.4 Hospital) in Shaanxi province from February 2016 to September 2020 were obtained. In this contralateral eye study, 84 patients with KCN (168 eyes, mean age = 23.85 ± 5.93 years), bilateral KCN, and unilateral corneal Vogt's striae were included. This study adhered to the tenets of the Declaration of Helsinki and received approval from the Institution Review Board and Ethics Committee of Xi'an People's Hospital (Xi'an Fourth Hospital). All patients signed informed consents before participating in this study.

The inclusion criteria were as follows: All participants were between the ages of 17 and 35, and each patient was diagnosed with bilateral KCN through corneal topography and unilateral corneal Vogt's striae through slit-lamp biomicroscopy.

The exclusion criteria included viral keratitis, central corneal opacities, nystagmus, history of corneal trauma, corneal refractive surgery or intraocular surgery, and systemic diseases, such as diabetes or connective tissue diseases.

For all patients, comprehensive ophthalmic examinations were conducted. The UCVA, BCVA, intraocular pressure, axial length, and cycloplegic refraction were recorded. The Pentacam HR (Pentacam HR, Oculus, Inc., Wetzlar, Germany) based on the Scheimpflug principle was used to obtain corneal morphological indices, including flat keratometry value (K1), steep keratometry value (K2), mean keratometry value (Km), maximum keratometry value (Kmax), central corneal thickness (CCT), thinnest corneal thickness (TCT), anterior corneal elevation (ACE), posterior corneal elevation (PCE), and corneal HOAs. The anterior and posterior corneal surfaces and total corneal HOAs were extracted. These indices included 3rd-order trefoil 0°, 3rd-order trefoil 30°, 3rd-order coma 0°, 3rd-order coma 90°, 4th-order astigmatism 0°, 4th-order astigmatism 45°, 4th-order spherical aberration, 5th-order trefoil 0°, 5th-order trefoil 30°, 5th-order coma 0°, 5th-order coma 90°, root-mean-square (RMS, total), and RMS (HOA).

During the Pentacam HR examination, the patient's chin was placed on the chin rest and the forehead against the forehead strap. The patient was asked to blink a few times, open both eyes, and stare at the fixation target. After attaining perfect alignment, the instrument automatically captured 25 Scheimpflug images by rotating 360° around the optical axis of the eye within 2 s. Three consecutive measurements on each eye were performed. Only cases with acceptable-quality images were included in the study. All measurements were done by an experienced examiner.

Statistical Analyses

The Statistical Package for Social Sciences version 26.0 (SPSS 26.0, Chicago, IL, USA) was used for statistical analysis. The data of corneal morphological parameters, Zernike coefficients, and RMS were expressed as mean \pm standard deviation. The normal distribution of the parameters was assessed using the Kolmogorov–Smirnov test. The paired sample t-test and the Wilcoxon signed rank test were used to compare corneal morphological parameters, Zernike coefficients, and RMS. Pearson's correlation tests were used to examine correlations between scale values, which fit a normal distribution, whereas Spearman's correlation tests were used to determine correlations between data with a skewed distribution or ranked ordinal data. $P < 0.05$ was considered significant.

Results

A total of 84 patients with bilateral KCN and unilateral corneal Vogt's striae were selected from 276 patients with KCN, including 39 males (46%) and 45 females (54%). Significant differences were obtained in refractive outcomes between KCN eyes with and without Vogt's striae (all $P < 0.001$). As shown in Table 1, significant differences were observed in the corneal morphological data (such as K1, K2, Km, Kmax, CCT, TCT, ACD, ACE, and PCE) measured using the Pentacam HR between eyes with and without Vogt's striae ($P < 0.001$). KCN eyes with Vogt's striae had statistically higher absolute values of sphere, cylinder, and spherical equivalent compared with KCN eyes without Vogt's striae ($P < 0.05$). The UCVA and BCVA in KCN eyes with Vogt's striae were significantly lower than those without Vogt's striae ($P < 0.001$).

Table 1
 Contralateral comparison of basic parameters and morphological parameters between KCN eyes with and without Vogt's striae(Mean±SD)

Parameters	Groups		t/S-Values	P-Values
	With Vogt's striae	Without Vogt's striae		
K1(D)	48.71±3.94	44.57±1.80	554.000b	<0.001*
K2(D)	52.90±4.53	47.54±3.00	8.844a	<0.001*
Km(D)	50.70±4.04	45.99±2.20	9.130a	<0.001*
Kmax(D)	60.71±7.81	51.46±4.86	9.166a	<0.001*
CCT(µm)	450.09±31.16	480.11±30.40	-8.991a	<0.001*
TCT(µm)	443.43±31.34	472.11±29.23	-9.050a	<0.001*
ACD(µm)	3.45±0.24	3.48±0.80	437.500b	<0.001*
ACE(µm)	33.57±16.12	16.24±10.48	8.398a	<0.001*
PCE(µm)	68.57±28.88	38.72±19.76	7.720a	<0.001*
Sph(D)	-7.43±4.54	-4.67±2.53	-3.055a	0.004*
Cyl(D)	-4.32±3.11	-2.22±2.04	-3.867a	<0.001*
SE(D)	-9.59±4.53	-5.78±3.08	-4.405a	<0.001*
UCVA(logMAR)	1.11±0.40	0.79±0.40	4.891a	<0.001*
BCVA(LogMAR)	0.49±0.45	0.11±0.15	411.500b	<0.001*

Abbreviations: Sph: Sphere, Cyl: Cylinder, SE: Spherical equivalent, UDVA: Uncorrected Visual Acuity, BCVA: Best Corrected Visual Acuity, logMAR: Logarithm of the minimum angle of resolution, K1: Flat Keratometry, K2: Steep Keratometry, Km: Mean Keratometry, Kmax: maximum keratometry, CCT: Central Corneal Thickness, TCT: Thinnest Corneal Thickness, ACD: Anterior Chamber Depth, ACE: Anterior Corneal Elevation, PCE: Posterior Central Elevation, D: Diopter; µm, micron

Notes: a-Paired-samples t-test. b-Wilcoxon signed ranks test.**P-value* <0.05 is statistically significant

Corneal HOAs

Mean corneal HOAs are shown in Table 2. The studied aberrations in the front and back corneal surfaces and total cornea, such as 3rd-order coma 90°, 4th-order spherical aberration, 5th-order coma 90°, RMS (total), and RMS (HOA), in KCN eyes with Vogt's striae were significantly greater compared with those in KCN eyes without Vogt's striae (*P* < 0.001, Fig. 1). In addition, the back 4th-order astigmatism 0° in KCN

eyes with Vogt's striae was significantly higher than that in KCN eyes without Vogt's striae ($P < 0.05$). The other evaluated corneal HOAs had no significant difference between two groups ($P > 0.05$).

Table 2

Contralateral comparison of corneal HOAs were measured by the Pentacam HR between KCN eyes with and without Vogt's striae(Mean±SD)

Aberration parameters	Groups		t/S-Values	P-Value
	With Vogt's striae	Without Vogt's striae		
Front 3rd order trefoil 0°	0.05±0.46	-0.01±0.29	0.733a	0.467
Front 3rd order trefoil 30°	0.15±0.64	0.18±0.38	-40.000b	0.657
Front 3rd order coma 0°	-0.08±1.27	-0.29±0.84	2.500b	0.978
Front 3rd order coma 90°	-2.14±1.63	-1.29±1.15	-4.454a	<0.001*
Front 4th order astigmatism 0°	0.19±0.56	0.08±0.39	1.459a	0.151
Front 4th order astigmatism 45°	0.08±0.40	0.04±0.25	0.618a	0.540
Front 4th order spherical aberration	-1.59±1.25	-0.44±0.63	-467.500b	<0.001*
Front 5th order trefoil 0°	-0.02±0.10	-0.01±0.06	-0.696a	0.490
Front 5th order trefoil 30°	-0.05±0.12	-0.04±0.08	6.500b	0.941
Front 5th order Coma 0°	0.02±0.27	0.05±0.15	28.000b	0.756
Front 5th order Coma 90°	0.43±0.42	0.23±0.23	4.132a	<0.001*
Front RMS(total)	14.85±6.85	6.60±4.03	9.061a	<0.001*
Front RMS(HOA)	3.33±1.62	1.70±1.23	8.501a	<0.001*
Back 3rd order trefoil 0°	0.01±0.18	-0.01±0.14	30.500b	0.735
Back 3rd order trefoil 30°	-0.12±0.25	-0.11±0.12	2.000b	0.982
Back 3rd order coma 0°	0.03±0.29	0.07±0.20	-2.500b	0.978
Back 3rd order coma 90°	0.53±0.35	0.34±0.26	4.571a	<0.001*
Back 4th order astigmatism 0°	-0.07±0.14	-0.02±0.10	-217.000b	0.010*
Back 4th order astigmatism 45°	-0.01±0.10	-0.01±0.07	-0.430a	0.669
Back 4th order spherical aberration	0.24±0.25	0.01±0.14	479.500b	<0.001*
Back 5th order trefoil 0°	0.00±0.04	0.00±0.03	-0.819a	0.417
Back 5th order trefoil 30°	0.02±0.05	0.01±0.03	59.000b	0.497
Back 5th order Coma 0°	-0.01±0.06	-0.01±0.04	0.097a	0.923

Aberration parameters	Groups		t/S-Values	P-Value
	With Vogt's striae	Without Vogt's striae		
Back 5th order Coma 90°	-0.09±0.08	-0.06±0.05	-3.120a	0.003*
Back RMS(total)	3.36±1.55	1.87±0.92	7.214a	<0.001*
Back RMS(HOA)	0.85±0.39	0.50±0.27	6.256a	<0.001*
Total 3rd order trefoil 0°	0.06±0.41	-0.03±0.25	1.073a	0.289
Total 3rd order trefoil 30°	0.05±0.50	0.08±0.32	-56.500b	0.516
Total 3rd order coma 0°	-0.05±1.04	-0.23±0.67	9.500b	0.916
Total 3rd order coma 90°	-1.71±1.39	-0.99±0.95	-4.413a	<0.001*
Total 4th order astigmatism 0°	0.11±0.47	0.05±0.31	0.823a	0.415
Total 4th order astigmatism 45°	0.06±0.33	0.03±0.20	0.654a	0.516
Total 4th order spherical aberration	-1.21±0.99	-0.31±0.50	-466.500b	<0.001*
Total 5th order trefoil 0°	-0.02±0.09	-0.01±0.06	-0.988a	0.328
Total 5th order trefoil 30°	-0.03±0.10	-0.03±0.07	26.000b	0.765
Total 5th order Coma 0°	0.01±0.22	0.04±0.12	23.500b	0.794
Total 5th order Coma 90°	0.34±0.36	0.17±0.19	4.069a	<0.001*
Front RMS(total)	13.3±6.31	5.72±3.68	9.236a	<0.001*
Front RMS(HOA)	3.02±1.55	1.50±1.38	504.000b	<0.001*

Notes: a-Paired-samples t-test. b-Wilcoxon signed ranks test.**P-value* <0.05 is statistically significant

Correlation between corneal HOA and corneal morphological data in eyes with Vogt's striae

Table 3 shows the correlation of corneal HOAs with corneal morphological parameters. For the front corneal surface and total cornea, 3rd-order coma 0°, 3rd-order coma 90°, and 4th-order spherical aberration were positively correlated with CCT and TCT ($P < 0.05$), and the 3rd-order coma 90° and 4th-order spherical aberration were negatively correlated with K1, K2, Km, Kmax, ACE, and PCE ($P < 0.05$). RMS (total) and RMS (HOA) were positively correlated with K1, K2, Km, Kmax, ACE, and PCE ($P < 0.05$). For the back corneal surface, the 3rd-order trefoil 0° was negatively correlated with K1, K2, and Km ($P < 0.05$), and the 3rd-order trefoil 30° was negatively correlated with Kmax and PCE ($P < 0.05$). The 3rd-order coma 90° was positively correlated with K1, Km, Kmax, ACE, and PCE ($P < 0.05$) and negatively correlated

with CCT and TCT ($P < 0.05$). The 4th-order astigmatism 0° was negatively correlated with K1, K2, Km, Kmax, ACE, and PCE ($P < 0.05$), and the 4th-order spherical aberration, RMS (total), and RMS (HOA) were positively correlated with K1, Km, Kmax, ACE, and PCE ($P < 0.05$).

Table 3

Correlation between corneal HOAs and morphological parameters measured by the Pentacam HR in the KCN eyes with Vogt's striae

Aberration parameters	corneal morphological parameters							
	K1	K2	Km	Kmax	CCT	TCT	ACE	PCE
Front 3rd order trefoil 0°	0.002	0.025	0.007	0.040	-0.020	-0.029	-0.086	-0.103
Front 3rd order trefoil 30°	-0.056	0.029	-0.034	0.042	0.038	0.048	0.057	0.125
Front 3rd order coma 0°	-0.244	-0.110	-0.213	-0.009	0.294*	0.273*	-0.089	-0.118
Front 3rd order coma 90°	-0.423*	-0.310*	-0.337*	-0.506*	0.273*	0.273*	-0.618*	-0.468*
Front 4th order astigmatism 0°	0.085	0.247	0.265	0.173	-0.154	-0.089	0.072	0.212
Front 4th order astigmatism 45°	0.045	0.054	0.032	-0.024	0.019	0.015	0.061	0.074
Front 4th order spherical aberration	-0.714*	-0.813*	-0.810*	-0.897*	0.287*	0.308*	-0.808*	-0.809*
Front RMS(total)	0.512*	0.531*	0.534*	0.752*	-0.102	-0.145	0.814*	0.704*
Front RMS(HOA)	0.561*	0.508*	0.545*	0.722*	-0.170	-0.211	0.833*	0.718*
Back 3rd order trefoil 0°	-0.270*	-0.287*	-0.302*	-0.231	0.157	0.194	-0.105	-0.073
Back 3rd order trefoil 30°	-0.015	-0.075	-0.035	-0.283*	0.093	0.048	-0.234	-0.271*
Back 3rd order coma 0°	0.268	0.200	0.245	0.081	-0.338*	-0.332*	0.087	0.131
Back 3rd order coma 90°	0.406*	0.202	0.298*	0.408*	-0.351*	-0.339*	0.560*	0.497*
Back 4th order astigmatism 0°	-0.279*	-0.525*	-0.435*	-0.525*	0.118	0.07	-0.322*	-0.467*
Back 4th order astigmatism 45°	0.027	0.029	0.036	0.037	-0.144	-0.156	-0.028	-0.02

Aberration parameters	corneal morphological parameters							
	K1	K2	Km	Kmax	CCT	TCT	ACE	PCE
Back 4th order spherical aberration	0.616*	0.754*	0.726*	0.854*	-0.219	-0.237	0.759*	0.847*
Back RMS(total)	0.465*	0.490*	0.486*	0.671*	-0.143	-0.168	0.690*	0.702*
Back RMS(HOA)	0.524*	0.508*	0.517*	0.710*	-0.157	-0.212	0.799*	0.729*
Total 3rd order trefoil 0°	-0.067	-0.001	-0.054	0.072	0.057	0.064	-0.087	-0.089
Total 3rd order trefoil 30°	-0.04	0.005	-0.037	-0.077	0.023	0.023	-0.041	0.002
Total 3rd order coma 0°	-0.223	-0.081	-0.189	0.015	0.275*	0.277*	-0.077	-0.105
Total 3rd order coma 90°	-0.434*	-0.322*	-0.349*	-0.517*	0.271*	0.271*	-0.628*	-0.463*
Total 4th order astigmatism 0°	0.052	0.176	0.232	0.087	-0.123	-0.068	0.029	0.164
Total 4th order astigmatism 45°	0.049	0.029	0.035	-0.076	-0.026	-0.032	0.041	0.057
Total 4th order spherical aberration	-0.718*	-0.815*	-0.814*	-0.896*	0.291*	0.315*	-0.810*	-0.786*
Cornea RMS(total)	0.499*	0.524*	0.524*	0.744*	-0.085	-0.125	0.816*	0.692*
Cornea RMS(HOA)	0.543*	0.506*	0.538*	0.712*	-0.129	-0.169	0.847*	0.709*

Notes: **P-value* < 0.05 is statistically significant

Discussion

HOAs especially corneal HOAs were studied in several previous articles and found to be increased in patients with KCN [19–22]. Naderan et al. [23] reported that the ocular aberration, i.e., vertical and total coma and total HOA, increases in KCN and FFKC, and Colak et al. [24] showed that anterior corneal HOAs are significantly increased in eyes with moderate and advanced KCN. To the best of our knowledge, corneal aberrations are the predominant cause of vision dysfunction in KCN. Few articles studied corneal HOAs in different grades of KCN. The present study was designed to investigate the corneal HOAs of the

anterior surface, posterior surface, and total cornea in KCN eyes with and without Vogt's striae to explore which part of the HOA is prone to increase with the progress of KCN.

Vogt's striae or stress lines are a typical clinical sign of progressive KCN [25]. Significant correlations between the appearance of Vogt's striae and changes in diopters and between visual acuity and corneal morphological parameters are observed [13]. Our study also confirmed the same results by comparing corneal morphological parameters between eyes with and without Vogt's striae. The UCVA and BCVA in KCN eyes with Vogt's striae were significantly lower than those in eyes without Vogt's striae.

As presented in Table 2, the vertical coma, spherical aberration, RMS (total), and RMS (HOA) in the front and back corneal surfaces and total cornea in KCN eyes with Vogt's striae were significantly higher compared with those in KCN eyes without Vogt's striae. These results were similar to those in previous studies [16, 26, 27] and due to the inferior position of the corneal cone in most patients with KCN [14, 28] and cone protrusion as the disease progresses. Feizi et al. [29] demonstrated that vertical and horizontal coma in the KCN group were significantly higher than those in normal cases. However, this finding was not consistent with our research. In the present study, the horizontal coma in the front and back corneal surfaces and total cornea in KCN eyes with and without Vogt's striae was not significantly different. We believe that the horizontal coma may have less to do with the severity of KCN and that the appearance of Vogt's striae in KCN eyes may significantly affect the vertical coma and has minimal influence on the horizontal coma.

The other finding of our study is that the vertical coma and spherical aberration of the back corneal surface are the opposite of that of the front corneal surface and total cornea in KCN eyes with and without Vogt's striae. Similar findings were observed by Shokrollahzadeh et al. [30], who reported that the changes in the vertical coma of the front and back corneal surfaces have opposite signs because the front corneal surface converges, and the posterior surface diverges [31]. Although the aberrations of front and back corneal surfaces compensate each other, the exact relationship remains uncertain.

In the association between the presence of Vogt's striae and corneal HOAs, the front and total corneal 3rd-order vertical coma and spherical aberration were negatively correlated with K1, K2, Km, Kmax, ACE, and PCE. Given that the vertical coma on the front corneal surface and total cornea was negative, the RMS of 3rd-order vertical coma was positively correlated with K1, K2, Km, Kmax, ACE, and PCE. Colak et al. [24] compared corneal morphological parameters and front corneal HOAs in KCN and concluded a high correlation between the corneal curvature and total aberrations. In the present study, we evaluated corneal topographic indices and found that RMS (total) and RMS (HOA) were positively correlated with K1, K2, Km, Kmax, ACE, and PCE in front and back corneal surfaces and total cornea. Interestingly, these correlations were consistent with corneal morphological parameters and corneal HOAs comparisons between the KCN eyes with and without Vogt's striae. These observations indicated that the appearance of Vogt's striae may change the corneal shapes, further lead to increased corneal HOAs, and trigger visual diminution.

One limitation of our study is that grouping was not performed on the basis of corneal curvature, which may lead to potential bias. However, our study focuses on the influence of Vogt's striae on corneal HOAs and the potential correlations between corneal HOAs and corneal morphological indices in KCN eyes with Vogt's striae. Therefore, the curvature has little effect on our study.

In conclusion, we demonstrated that corneal HOAs especially vertical coma and spherical aberration in front and back corneal surfaces and total cornea may increase when Vogt's striae appears in the KCN eyes. The scale of corneal HOAs is significantly related to changes in corneal shapes.

Declarations

Funding

Not applicable

Conflicts of interest/Competing interests

Neither author has a financial nor proprietary interest in any material or method mentioned.

Availability of data and material

The data used to support the findings of this study are available from the corresponding author upon request.

Code availability

Not applicable

Authors' contributions

Concept and design (JL, YHZ, and SSW); analysis of the data (JL, YHZ, and SSW); writing the article (JL and YHZ); critical revision of the article (JL, YL, and SSW); data collection (JL, YHZ, YL, and YC); provision of materials, patients, or resources (SSW); and administrative, technical, or logistic support (JD, JGL and SSW). All authors have reviewed the manuscript. All authors read and approved the final manuscript.

Ethics approval

The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Xi'an People's Hospital's Ethics Committee.

Consent to participate

Written informed consent was obtained from at least one parent or legal guardian of each subject.

Consent for publication

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Figures

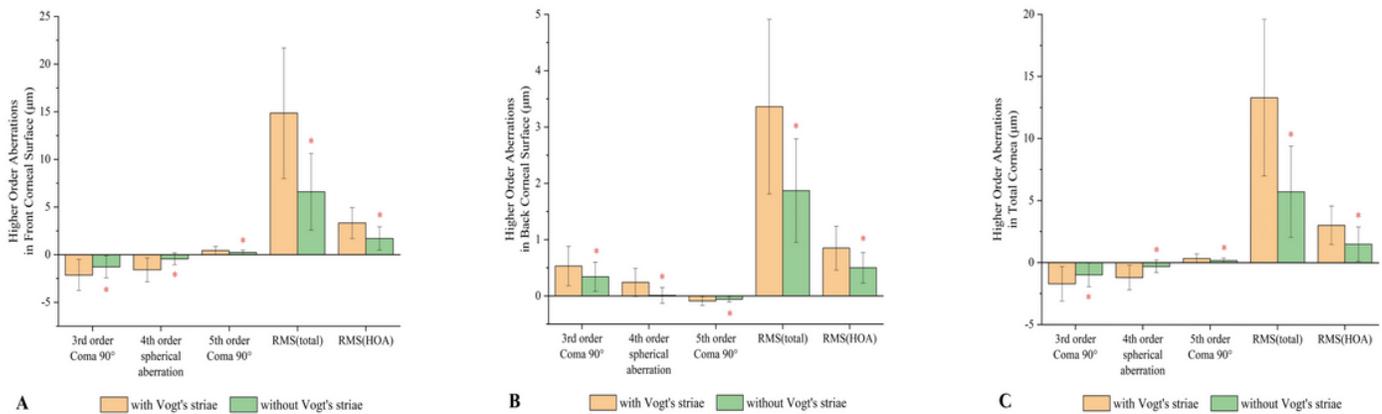


Figure 1

Front corneal HOAs (A), back corneal HOAs (B) and total Corneal HOAs (C) in the KCN eyes with and without Vogt's striae HOAs: high-order aberrations; KCN: keratoconus; *P < 0.05