• Brief Report •

Characteristics of corneal aberration in patients with bilateral keratoconus and unilateral corneal Vogt's striae

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Abstract

● **AIM:** 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°, root-mean-square (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 flat keratometry value (K1), steep keratometry value (K2), mean keratometry value (Km), maximum keratometry value (Kmax), anterior corneal elevation (ACE), and posterior corneal elevation (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).

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

● **KEYWORDS:** keratoconus; cornea; corneal aberration; corneal morphological; Vogt's striae
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INTRODUCTION

Keratoconus (KCN) is an ectatic non-inflammatory and progressive corneal disorder described by the gradual thinning and steepening of the cornea that leading 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 have reported its relationship to hereditary, environmental, and biomechanical factors[5]. Vogt's striae or stress lines are vertical lines in the posterior stroma and Descemet's membrane, which are parallel to the anterior corneal steep axis of the cone[6-7], which is one of the typical clinical signs of KCN[8]. The UCVA and BCVA significantly decrease, and the refractive error worsens in eyes with Vogt's striae[9]. One reason for this result is that alterations in the corneal morphology increase irregular astigmatism. Another reason may be associated with increased high-order aberration (HOA), which can result in blurry and distorted vision[10-11]. Several previous studies have reported that aberrations, especially coma aberration, are significantly increased in patients with KCN[12-13]. However, there are few studies on whether the increase in corneal HOAs is related to the appearance of Vogt's striae in KCN eyes.

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.

PARTICIPANTS AND METHODS

Ethical Approval This study adhered to the tenets of the Declaration of Helsinki and received approval from the

Institutional Review Board and Ethics Committee of Xi'an People's Hospital (Xi'an Fourth Hospital) (Ethical Approval Number: KJLL-Z-K-2023004). All patients signed informed consent before participating in this study.

Participants In this contralateral eye study, 84 patients (168 eyes) aged 17–35y (mean age 23.85±5.93y) were included. All participants were 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, and systemic diseases such as diabetes or connective tissue diseases.

Ophthalmologic Examinations 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; software version: 1.21r43) 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 chamber depth (ACD), anterior corneal elevation (ACE), posterior corneal elevation (PCE), and corneal HOAs. Pentacam HR extrapolates corneal HOAs Zernike coefficients of anterior and posterior from corneal elevation data obtained through Scheimpflug imaging. The anterior and posterior corneal surfaces and total corneal HOAs were extracted. To maintain the consistency of the methodology, corneal aberrations of 6-mm pupils were measured. All measurements were done by an experienced examiner.

Statistical Analysis 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 root-mean-square (RMS) were expressed as mean±standard deviation (SD). The paired sample *t*-test and the Wilcoxon signed-rank test were used to compare corneal morphological parameters, Zernike coefficients, and RMS. Pearson's and Spearman's correlation tests were used to determine correlations between corneal HOA and corneal morphological 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) 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 in 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*	*P*
	With Vogt's striae	Without Vogt's striae		
K1 (D)	48.71±3.94	44.57±1.80	554.000[b]	<0.001
K2 (D)	52.90±4.53	47.54±3.00	8.844[a]	<0.001
Km (D)	50.70±4.04	45.99±2.20	9.130[a]	<0.001
Kmax (D)	60.71±7.81	51.46±4.86	9.166[a]	<0.001
CCT (μm)	450.09±31.16	480.11±30.40	-8.991[a]	<0.001
TCT (μm)	443.43±31.34	472.11±29.23	-9.050[a]	<0.001
ACD (μm)	3.45±0.24	3.48±0.80	437.500[b]	<0.001
ACE (μm)	33.57±16.12	16.24±10.48	8.398[a]	<0.001
PCE (μm)	68.57±28.88	38.72±19.76	7.720[a]	<0.001
Sph (D)	-7.43±4.54	-4.67±2.53	-3.055[a]	0.004
Cyl (D)	-4.32±3.11	-2.22±2.04	-3.867[a]	<0.001
SE (D)	-9.59±4.53	-5.78±3.08	-4.405[a]	<0.001
UCVA (logMAR)	1.11±0.40	0.79±0.40	4.891[a]	<0.001
BCVA (logMAR)	0.49±0.45	0.11±0.15	411.500[b]	<0.001

Sph: Sphere; Cyl: Cylinder; SE: Spherical equivalent; KCN: Keratoconus; CCT: Central corneal thickness; TCT: Thinnest corneal thickness; ACD: Anterior chamber depth; ACE: Anterior corneal elevation; PCE: Posterior corneal elevation; UCVA: Uncorrected visual acuity; BCVA: Best corrected visual acuity; K1: Flat keratometry value; K2: Steep keratometry value; Km: Mean keratometry value; Kmax: Maximum keratometry value. [a]Paired samples *t*-test; [b]Wilcoxon signed ranks test. $P<0.05$ is statistically significant.

Corneal HOAs 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 ($P<0.001$; Figure 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 the two groups ($P>0.05$).

Correlation Between Corneal HOA and Corneal Morphological Data in Eyes with Vogt's Striae 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 3rd-order coma 90° and 4th-order spherical aberration were negatively

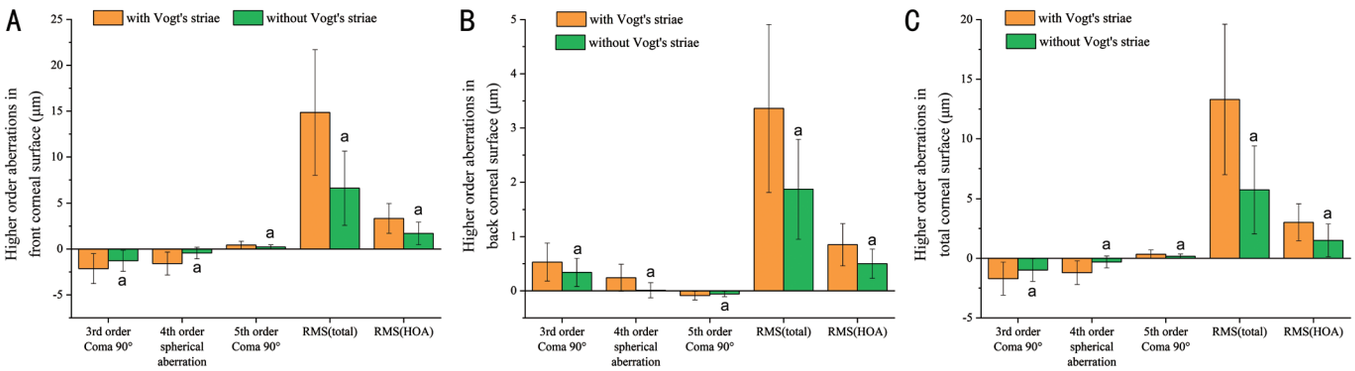

Figure 1 Corneal HOAs in the KCN eyes with and without Vogt's striae A: Front corneal HOAs in the KCN eyes with and without Vogt's striae; B: Back corneal HOAs in the KCN eyes with and without Vogt's striae; C: Total corneal HOAs in the KCN eyes with and without Vogt's striae. Error bars represent 2 SD from the mean. [a]Significant change compared with corneal HOAs in the KCN eyes with Vogt's striae (P<0.05). KCN: Keratoconus; HOA: High-order aberration; RMS: Root-mean-square.

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, 3rd-order trefoil 0° was negatively correlated with K1, K2, and Km (P<0.05), and 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 4th-order spherical aberration, RMS (total), and RMS (HOA) were positively correlated with K1, Km, Kmax, ACE, and PCE (P<0.05).

DISCUSSION

HOAs were studied in several previous articles and found to be increased in patients with KCN[14-15]. Naderan *et al*[16] reported that the ocular aberration, *i.e.*, vertical and total coma and total HOA, increases in KCN and forme fruste KCN patients, and vertical coma, in particular, has reference value in distinguishing normal cornea from KCN and in the classification of KCN. To the best of our knowledge, few articles have studied corneal HOAs in different grades of KCN. Although some studies have shown that the aberrations of both the anterior and posterior corneal surfaces exhibit poor repeatability in patients with severe KCN[17]. However, in this study, we excluded severe KCN classified as Amsler-Krumeich stage 4, and only cases with acceptable-quality image were included, ensuring the reliability of the data as much as possible. 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, and to explore the changing rule of the corneal HOAs with the progress of KCN.

Vogt's striae, or stress lines, are a typical clinical sign of progressive KCN[18-19]. Significant correlations between the appearance of Vogt's striae and changes in diopters, and between visual acuity and corneal morphological parameters, are observed[9]. 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.

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[12,20] and are due to the inferior position of the corneal cone in most patients with KCN[21] and cone protrusion as the disease progresses. Feizi *et al*[22] 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 have 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*[23], 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[24]. 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*[25] 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 appear in the KCN eyes. The scale of corneal HOAs is significantly related to changes in corneal shapes.

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