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Predictive Role of Paracentral Corneal Toricity Using Elevation Data for Treatment Zone Decentration During Orthokeratology

Zhouyue Li, Dongmei Cui, Wen Long, Yin Hu, Liying He, and Xiao Yang

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ABSTRACT

Purpose: To investigate the influence of paracentral corneal toricity using elevation data on the treatment zone decentration of spherical and toric orthokeratology (Ortho-k) lens.

Methods: Corneal elevation difference (CED) was defined as the difference of corneal elevation between the two principle meridians at 8-mm chord, representing the paracentral corneal toricity. Seventy-five subjects included in this prospective study were divided into a low CED (LCED) group (LCED<30 μm, n = 25) and a high CED (HCED) group (HCED≥30 μm, n = 50). All subjects in the LCED group and 25 subjects in the HCED group (HCED I) were fitted with spherical Ortho-k; the other 25 subjects in the HCED group (HCED II) were fitted with toric Ortho-k. Corneal topography data from the right eyes were obtained at baseline and after 1 month of lens wear. The amount and direction of treatment zone decentration among the three groups were compared, and their relationships with corneal shape parameters, including central and paracentral corneal toricity, corneal asymmetry, flat-k and eccentricity, and lens diameter were analyzed using univariable and multivariate linear regression models.

Results: The magnitude of treatment zone decentration was the greatest in the HCED I group ([LCED vs. HCED I vs. HCED II: 0.47 ± 0.15mm vs. 0.73 ± 0.15mm vs. 0.47 ± 0.19mm, respectively; ANOVA, p < 0.01]). Among participants fitted with spherical Ortho-k, the magnitude of treatment zone decentration was significantly correlated to paracentral CED after adjusting for the other corneal parameters and lens diameter (standard β = 0.599, p < 0.01). No significant correlation between these parameters was found among those fitted with toric Ortho-k.

Conclusions: Eyes with greater paracentral CED tend to have increased decentration of spherical Ortho-k lens, whereas toric Ortho-k appears to reduce the amount of lens decentration in eyes with CED at 8-mm chord above 30 μm.

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KEYWORDS

Orthokeratology; decentration; paracentral corneal toricity; corneal elevation difference; treatment zone

Introduction

Orthokeratology (Ortho-k), with a reverse-geometry design, has been shown effective in improving unaided visual acuity during daytime after removal of the lens. Recent studies have demonstrated the efficacy of Ortho-k in slowing the axial elongation in myopic children by approximately 50% compared with single-vision spectacles or soft contact lens. However, despite successful lens fitting, decentration of the Ortho-k lens treatment zone is common, potentially causing visual disturbance due to the induction of astigmatism, higher-order aberrations and reduction in contrast sensitivity.

The exact mechanism of treatment zone decentration is still unclear, but appears to be multifactorial. Greater baseline corneal toricity was recently reported to cause a higher amount of treatment zone decentration after single overnight use of spherical Ortho-k lens in eyes with minimal (<1.50 diopters cylinder [DC]) and moderate (1.50–3.50 DC) corneal toricities. Lens diameter appears to be another influencing factor. Thus, a smaller lens diameter is related to greater amounts of treatment zone decentration. Data from paracentral corneal region, where the first alignment curve of an Ortho-k lens mostly likely falls (between the chords of 7 and 9 mmm), may also play a critical role in treatment zone decentration. The relationship between lens decentration and corneal elevation asymmetry at 8-mm chord was confirmed by a recent study showing that both direction and magnitude of lens decentration were influenced by paracentral corneal toricity. Compared to corneal curvature data, paracentral corneal elevation difference (CED) between the two principle meridians reflects paracentral corneal toricity in a more straightforward manner. The relation between central corneal toricity and treatment zone decentration suggests that difference between two principle meridians may be an important predictor for treatment zone decentration. However, to our knowledge, no previous study has investigated the relationship between paracentral corneal toricity using elevation data and treatment zone decentration. Furthermore, it is important to identify the main contributor to treatment zone decentration because that can help us provide better Ortho-k lens fitting in clinical practice. Therefore, the aim of this study was to investigate the influence of paracentral corneal toricity using elevation data at 8-mm chord on the treatment zone decentration of spherical and toric Ortho-k lens. In addition, multiple linear regression models were used to evaluate the relative
contribution of potential factors in determining the treatment zone decentration of spherical and toric Ortho-k lens.

Subjects and methods

Participants

This study was conducted at Zhongshan Ophthalmic Center (Guangzhou, China) between December 2016 and March 2017. The study adhered to the tenets of the Declaration of Helsinki and was approved by the ethical committee of Zhongshan Ophthalmic Center, Sun Yat-sen University. Written consent was obtained from guardians of all children before enrollment.

The inclusion criteria included age between 8 and 18 years, mean sphere between −1.00 and −4.00 D, refractive astigmatism no greater than −1.50 D and visual acuity correctable to 20/20 or better. The exclusion criteria included ocular surface diseases, fundus diseases, or a history of Ortho-k treatment. Seventy-five right eyes of 75 subjects were enrolled. Twenty-five subjects fitted with spherical Ortho-k, of which the CED at 8-mm chord was less than 30 μm, were categorized as the low CED (LCED) group. Fifty subjects with CED at 8-mm chord more than 30 μm were categorized as the high CED (HCED) group. Twenty-five subjects in the HCED group were fitted with spherical Ortho-k lens (served as the HCED I group); the other 25 subjects were fitted with toric Ortho-k lens (served as the HCED II group).

Lens fitting

Lenses used in this study were the spherical and toric four-zone reverse-geometry gas-permeable rigid contact lenses (Emerald series; Euclid, Herndon, VA). For both lens types, the back optic zone diameter was 6.2 mm, the width of the reverse curve was 0.5 mm and the width of the peripheral curve was 0.5 mm. The total lens diameter for a typical trial lens was 10.6 mm. All these lenses were made by BOSTON EQUALENS II (oprifocona) and had a nominal Dk of 127 × 10−11 (cm2/s) (ml O2/ml_mmHg) (ISO/Fatt) according to the fitting guidelines supplied by the manufacturer.

For spherical lens fitting, subtraction of the spherical refractive error and a Jessen factor of 0.75 from the baseline corneal flat-k were used to determine the back optical zone radius. The baseline corneal flat-k and eccentricity over the 8-mm chord of the corneal topography were used to determine the alignment curve radius of the first lens. Lens diameter (about 90% HVID) was determined according to the method reported by Chen et al.13 The lens-fitting evaluation was performed using fluorescein. The alignment curve was determined until a classic bull’s eye was shown, with a central touch surrounded by a narrow and deep annulus of tears trapped in the reverse curve area. Ideal lens fitting was defined as Ortho-k lens with good centration (lens edge should not go beyond the limbus) and appropriate movement (approximately 1 mm on a blink). If the corneal response after the first overnight was poor, showing, for example, displacement, smiley and frowny face topographic pattern, a new lens with adjusted parameters would be used. Subjects who could not show satisfactory fits despite repeated modifications (three pairs of lenses) were excluded from the study. In the current study, only two subjects in the HCED I group required a second pair of lenses due to poor lens decentration at the overnight visit. All the participants were instructed to return for a follow-up visit one day, one week and one month after the primary lens fitting. Ortho-k lens fitting, visual acuity, ocular health and corneal topography (Medmont E-300, Australia) were evaluated at each visit. After lens dispensing, all subjects were requested to wear their Ortho-K lenses every night for at least seven consecutive hours.

Determination of CED and corneal asymmetry vector

Corneal topography was conducted using the Placido ring-based Medmont E300 (Australia, Medmont Company) before and after lens delivery at each visit. The baseline CED at 8-mm chord was obtained from at least four topography readings. First, the mean of average height from the flat and steep meridians at 8-mm chord were recorded. In this manner, the flat and steep meridians determined for CED calculation were the same as those from K readings. CED values were then determined by subtracting the average height at the flat meridian from the average height at the steep meridian. The asymmetry between different corneal quadrants was calculated according to the method reported by Chen et al.13 The elevation difference of the two principle meridians of corneal astigmatism at 8-mm chord was recorded. Then, vector analyses based on these differences were conducted to determine the magnitude and direction of the corneal asymmetry vector. The angle acquired by counterclockwise rotating around the keratometry center from 3 o’clock of the cornea to the vector was defined as the direction of the corneal asymmetry vector.

Determination of the decentration of the treatment zone

The magnitude and direction of treatment zone decentration were determined using Image-Pro Plus (IPP) software (produced by Media Cybernetics Corporation, USA). Our previous study15 has demonstrated that both the magnitude and direction of treatment zone decentration could be determined using IPP software with good repeatability and reproducibility. After one month of Ortho-k lens treatment, a difference map was obtained by subtracting the pre-orthokeratology (pre-Ortho-k) tangential curvature map from the post-orthokeratology (post-Ortho-k) tangential curvature map. Figure 1 illustrates how the decentration of the treatment zone was determined. The step diopter of the tangential subtractive map was set to 0.01 D in custom settings, and the whole image was captured with a format setting at a maximum resolution of 1366×768 pixels. Various points surrounding the border of the treatment zone area on which the powers are all zero were indicated manually and then connected to be a closed zone using IPP software. The distance from the center of the depicted circle (defined as the center of the treatment zone) to the corneal vertex normal was defined as...
treatment zone decentration. The angle (0 ~ 359°) acquired by counterclockwise rotating around the vertex normal from 3 o’clock was defined as the angle of treatment zone decentration. In the current study, one experienced observer who was masked to the study groups assessed treatment zone centration.

Data analysis

Only data from the right eye were used for statistical calculation. Statistical analysis was performed using SPSS Version 16.0 (SPSS 16.0, Inc., Chicago, IL). \( p < 0.05 \) at two tails was considered to be statistically significant. The baseline corneal shape and lens parameters in this study included baseline corneal asymmetry vector and CED at 8-mm chord, corneal flat-k, toricity based on the simulated keratometry or Sim K calculated approximately at a 3-mm chord diameter, eccentricity and lens diameters. Data were first tested for normality using a Sample K-S test. Chi-squared test or one-way ANOVA was used to test the difference in demographic data, baseline corneal shape and lens parameters among three groups where appropriate. Paired t-test was used to analyze the change in corneal flat-k, toricity and eccentricity after Ortho-k. Differences in the magnitude and direction of treatment zone decentration, change of corneal flat-k, toricity and eccentricity after Ortho-k among the three groups were also analyzed using one-way ANOVA, with Bonferroni post hoc testing on indication and correction for multiple comparisons.

The association between corneal shape and lens parameters and treatment zone parameters was tested using univariable linear regression analyses. High correlations among explanatory variables are likely to cause multicollinearity, which artificially inflates the variance of the estimated regression coefficients and thus makes the estimators less trustworthy for prediction. The multiple linear regression models included only independent factors based on the result of univariable linear regression analyses, which were performed to test the association among all the baseline corneal shape and lens variables. In this study, CED was significantly correlated to corneal toricity in both spherical Ortho-k (LCED and HCED I groups combined) (adjusted \( R^2 = 0.525, \) ANOVA, \( F = 52.972, \) \( p < 0.01 \)) and toric Ortho-k (HCED II group) groups (adjusted \( R^2 = 0.134, \) ANOVA, \( F = 4.707, \) \( p = 0.041 \)). Two multiple linear regression models were established for participants fitted with spherical (LCED and HCED I groups combined) and toric Ortho-k. Model 1 explored the association of treatment zone decentration with the magnitude of baseline CED at 8-mm chord, adjusting for the corneal asymmetry vector at 8-mm chord, flat-k, eccentricity and lens diameter against the magnitude of treatment zone decentration. Model 2 explored the association of treatment zone decentration with the magnitude of baseline corneal toricity, adjusting for the corneal asymmetry vector at 8-mm chord, flat-k, eccentricity and lens diameter against the magnitude of treatment zone decentration.

Results

All the 75 subjects completed this one-month study. Baseline information with respect to the demographic data, corneal shape and lens parameters are summarized in Table 1. At baseline, there was no statistically significant difference of gender (Chi-squared test, \( p = 0.913 \)), age, refractive sphere, flat-k, corneal eccentricity along the flattest meridian, amount and angle of corneal asymmetry vector at 8-mm chord, HVID and lens diameter in the three groups (ANOVA, all \( p > 0.05 \)). There was no significant difference in baseline refractive cylinder (post hoc multiple comparisons, \( p = 0.846 \)), corneal toricity (post hoc multiple comparisons, \( p = 0.162 \)) and CED at 8-mm chord (post hoc multiple comparisons, \( p = 0.303 \)) between the HCED I and HCED II groups. Baseline refractive cylinder, corneal toricity and CED at 8-mm chord in the LCED group were significantly smaller than those in the HCED I and HCED II groups (post hoc multiple comparisons, all \( p < 0.01 \)).
After one month of Ortho-k treatment, both the flat-k and corneal eccentricity along the flattest meridian significantly decreased from baseline in the three groups (paired t-test, all \( p < 0.01 \)). The magnitude of change in the flat-k (ANOVA, \( p = 0.170 \)) and corneal eccentricity along the flattest meridian (ANOVA, \( p = 0.505 \)) were similar among the three groups (Table 2). Corneal toricity did not significantly change from baseline in the LCED group (paired t-test, \( p = 0.204 \)), but significantly decreased from baseline in the HCED I and HCED II groups (paired t-test, both \( p < 0.01 \)) (Table 2). The magnitude of corneal toricity change in the HCED I group was significantly smaller than that in the HCED II group (post hoc multiple comparisons, \( p = 0.045 \)).

As shown in Figure 2A, there was no significant difference in the magnitude of treatment zone decentration between the LCED and HCED II groups (post hoc multiple comparisons, \( 0.47 \pm 0.15 \text{ mm vs. } 0.47 \pm 0.18 \text{ mm, respectively; } p = 0.965 \)). The magnitude of treatment zone decentration in the HCED I group (\( 0.73 \pm 0.15 \text{ mm} \)) was significantly greater than that in the other two groups (ANOVA, \( p < 0.01 \)). As shown in Figure 2B, the mean angle of treatment zone decentration was similar among the three groups (LCED vs. HCED I vs. HCED II: \( 206.01 \pm 52.91^\circ \text{ vs. } 210.11 \pm 45.50^\circ \text{ vs. } 202.02 \pm 58.55^\circ \), respectively; ANOVA, \( p = 0.863 \)). For overall displacement, inferotemporal decentration was the most common (LCED vs. HCED I vs.

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**Table 1.** Comparison of demographic data, baseline corneal shape parameters and orthokeratology lens diameter among the three groups (mean ± SD).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>LCED, n = 25</th>
<th>HCED I, n = 25</th>
<th>HCED II, n = 25</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (F/M)</td>
<td>12/13</td>
<td>11/14</td>
<td>13/12</td>
<td>0.913</td>
</tr>
<tr>
<td>Age (years)</td>
<td>11.68 ± 2.01</td>
<td>12.72 ± 2.01</td>
<td>11.88 ± 1.94</td>
<td>0.154</td>
</tr>
<tr>
<td>Sphere (D)</td>
<td>-2.67 ± 0.80</td>
<td>-2.94 ± 0.91</td>
<td>-2.57 ± 0.82</td>
<td>0.278</td>
</tr>
<tr>
<td>Cylinder (D)</td>
<td>-0.16 ± 0.29</td>
<td>-0.53 ± 0.38</td>
<td>-0.35 ± 0.41</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Flat-K (D)</td>
<td>42.90 ± 1.38</td>
<td>42.52 ± 1.18</td>
<td>42.67 ± 1.25</td>
<td>0.504</td>
</tr>
<tr>
<td>Corneal toricity (D)</td>
<td>0.71 ± 0.36</td>
<td>1.38 ± 0.43</td>
<td>1.54 ± 0.36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Corneal eccentricity</td>
<td>0.66 ± 0.07</td>
<td>0.66 ± 0.08</td>
<td>0.64 ± 0.07</td>
<td>0.612</td>
</tr>
<tr>
<td>CED at 8-mm chord (μm)</td>
<td>15.92 ± 7.00</td>
<td>37.96 ± 6.18</td>
<td>40.07 ± 10.36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Corneal asymmetry vector (μm)</td>
<td>29.17 ± 12.69</td>
<td>31.05 ± 11.52</td>
<td>29.02 ± 12.70</td>
<td>0.507</td>
</tr>
<tr>
<td>Angle of asymmetry vector (°)</td>
<td>192.22 ± 43.50</td>
<td>193.68 ± 54.15</td>
<td>194.21 ± 49.49</td>
<td>0.589</td>
</tr>
<tr>
<td>HVID (mm)</td>
<td>11.61 ± 0.25</td>
<td>11.56 ± 0.36</td>
<td>11.54 ± 0.33</td>
<td>0.728</td>
</tr>
<tr>
<td>Lens diameter (mm)</td>
<td>10.49 ± 0.22</td>
<td>10.47 ± 0.28</td>
<td>10.42 ± 0.28</td>
<td>0.667</td>
</tr>
</tbody>
</table>

Corneal eccentricity: corneal eccentricity along the flattest meridian; CED at 8-mm chord: corneal elevation difference at 8-mm chord; HVID: horizontal visible iris diameter. Difference in gender was tested using the Chi-squared test, and difference in the other variables was tested using ANOVA analysis with post hoc multiple comparisons. \( p < 0.05 \) at two tails was considered to be statistically significant. Statistically significant numbers are in bold face.

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**Table 2.** Change of corneal flat-k, toricity and corneal eccentricity after one month of Ortho-k lens wear among the three groups (mean ± SD).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Spherical</th>
<th>Toric</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat-K (D)</td>
<td>-2.10 ± 0.52*</td>
<td>-2.31 ± 0.64*</td>
<td>0.170</td>
</tr>
<tr>
<td>Corneal toricity (D)</td>
<td>-0.10 ± 0.40</td>
<td>-0.32 ± 0.46*</td>
<td>0.001</td>
</tr>
<tr>
<td>Corneal eccentricity</td>
<td>-0.35 ± 0.11*</td>
<td>-0.33 ± 0.15*</td>
<td>0.505</td>
</tr>
</tbody>
</table>

\*Corneal eccentricity: change of corneal eccentricity along the flattest meridian. *: paired t-test \( p < 0.01 \).

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Figure 2. **Distribution of treatment zone decentration.** A: Comparison of the magnitude of treatment zone decentration among three groups. B: Overview of treatment zone lens decentration. 0–360 degrees represent the meridian degree set on the corneal topography map. Dashed and solid circles outline the distance of 0.5 mm and 1 mm to the corneal vertex, respectively. **: \( p \)-value was less than 0.01.
HCED II: 68% vs. 76% vs. 56%, respectively), whereas superionasal decentration was the rarest (LCED vs. HCED I vs. HCED II: 4% vs. 4% vs. 8%, respectively) for the three groups (Figure 2B). The angle of treatment zone decentration and the baseline angle of the corneal asymmetry vector were significantly correlated in the spherical group (LCED and HCED I groups combined) (adjusted $R^2 = 0.074$, ANOVA, $F = 4.889, p = 0.032$), but not in the toric group (HCED II) (adjusted $R^2 = 0.018$, ANOVA, $F = 1.439, p = 0.243$).

Results of univariable and multiple linear regression analyses evaluating the relationship between the amount of treatment zone decentration and corneal shape and lens parameters in the spherical Ortho-k group (LCED and HCED I groups combined) are summarized in Table 3. In the spherical Ortho-k group, the magnitude of lens decentration was significantly associated with baseline CED at 8-mm chord, corneal toricity and corneal asymmetry vector at 8-mm chord according to the results of univariable analyses (all $p < 0.01$). In multiple linear regression model 1, both the CED (standard $\beta$ (95% CI): 0.737 (0.563, 0.910), $p < 0.01$) and corneal asymmetry vector at 8 mm (standard $\beta$ (95% CI): 0.245 (0.071, 0.418), $p = 0.007$) significantly contributed to the magnitude of treatment zone decentration (adjusted $R^2 = 0.645$, ANOVA, $F = 45.458, p < 0.01$), whereas the other factors, including corneal flat-k, eccentricity and lens diameter, did not influence the treatment zone decentration (all $p > 0.05$). In multiple linear regression model 2, both of the corneal toricity (standard $\beta$ (95% CI): 0.599 (0.387, 0.811), $p < 0.01$) and corneal asymmetry vector at 8 mm (standard $\beta$ (95% CI): 0.298 (0.086, 0.510), $p = 0.007$) significantly contributed to the magnitude of treatment zone decentration (adjusted $R^2 = 0.463$, ANOVA, $F = 22.105, p < 0.01$), whereas the other factors, including corneal flat-k, eccentricity and lens diameter, did not influence treatment zone decentration (all $p > 0.05$). In the toric Ortho-k group (HCED II group), both univariable and multiple linear regression analyses showed no significant association between the magnitude of treatment zone decentration and any corneal shape and lens parameters (all $p > 0.05$).

**Discussion**

Despite the efficacy of Ortho-k lens in reducing refractive error, visual disturbance due to treatment zone decentration remains a problem in clinical practice. Corneal toricity, corneal asymmetry and eccentricity are some of the factors that may influence lens centration. To our knowledge, this is the first study that investigates the potential effect of paracentral corneal toricity using elevation data on treatment zone decentration with different spherical Ortho-k lens designs. In addition, the effect of toric Ortho-k lens on treatment zone decentration in eyes with greater paracentral corneal toricity was also investigated.

It is reasonable to assume that good alignment of the lens back-surface with the corneal surface will enhance lens-fitting stability. Maseedupally et al. found that the difference of corneal curvature between temporal versus nasal sectors or inferior versus superior sectors in the central 5-mm zone was significantly smaller than that in the paracentral corneal zone between the chords of 5 and 8 mm. In addition, the alignment curve, which supports most of the weight of the Ortho-k lens, plays an important role in the stabilization of an Ortho-k lens on the cornea. Thus, data from the peripheral corneal region between the chords of 7 and 9 mm, where the first alignment curve of the Ortho-k lens most likely falls on, are critical for lens centration and needs to be examined carefully. Instead of using the curvature data, we used a simplified method based on paracentral corneal toricity elevation. The magnitude of treatment zone decentration in eyes with CED at 8-mm chord above 30 μm was greater than that in eyes with minimal CED at 8-mm chord with spherical Ortho-k. This finding is further supported by the positive relationship when all the data from eyes fitted with spherical Ortho-k were combined between baseline CED at 8-mm chord and the magnitude of treatment zone decentration after adjustment for baseline corneal asymmetry, flat-k, eccentricity and lens diameter.

Most myopic children are also astigmatic. Conventional fitting of spherical Ortho-k lens is mainly based on the matching of lens sag height with the corneal back-surface along the flattest corneal meridian. When the amount of corneal toricity increases, this method of selecting lens parameters is thought to influence lens-fitting stability due to the unequal alignment of the Ortho-k lens along the principle meridians. Swarbrick et al. found that eyes with a higher amount of central corneal toricity display greater amounts of treatment zone decentration during spherical Ortho-k. Consistent with Swarbrick’s result, we found a significant association between central corneal toricity and treatment zone decentration. However, paracentral corneal toricity using elevation data may be a better predictor for decentration than central corneal toricity, as the standard coefficients of univariable and multiple linear regression analyses for paracentral CED were greater than those for central corneal toricity. The relative contribution of central and paracentral corneal toricity to spherical lens decentration could be further investigated by their significant correlation. However, as also...
found by Maseedupally et al., these parameters did not correspond one to one. Thus, it appears that the curvature in the central corneal zone is significantly different from that in the paracentral region. During Ortho-k lens fitting, it is therefore important to assess paracentral CED in eyes with high central corneal toxicity or in cases where bad lens centration occurs despite low central corneal toxicity.

Another important finding in the current study was that when fitted with toric Ortho-k, the magnitude of treatment zone decentration was significantly smaller than when fitted with spherical Ortho-k in eyes with similar great CED at 8-mm chord (above 30 μm). This indicates that the toric fitting technique improves lens-fitting stability in eyes with greater paracentral CED. Interestingly, the association between treatment zone decentration and other potential factors showed that all factors, including CED, corneal asymmetry and central corneal toricity, were independent of lens decentration in toric Ortho-k subjects. The absence of any association between the amount of treatment zone decentration and the magnitude of corneal shape parameters in spherical Ortho-k subjects versus toric Ortho-k subjects suggests that the toric fitting technique may help improve lens centration by weakening the influence of these corneal shape parameters, especially for CED at 8 mm more than 30 μm. It should be noticed here that the sample size in the toric Ortho-k group was relatively small, and further studies with larger sample size are therefore warranted.

In a previous study, we found that the amount of lens decentration with a lens diameter of 11.0 mm was significantly smaller than that with lens diameters between 10.2 and 10.6 mm (0.41 mm vs. 0.77 mm, respectively). Hiraoka et al.8 found a relatively higher amount of lens decentration of 0.85 mm when all the eyes were fitted with the same lens diameter of 10.0 mm. This suggests that a larger lens diameter may help limit lens decentration. However, uniform lens size is not feasible in clinical practice because the corneal size varies with different subjects. Lens diameter in the current study was determined according to the HVID result. In contrast, both our current data and Chen et al.’s data16 showed that the HVID and lens diameter were independent of lens decentration during spherical Ortho-k when lens diameter was tailored to the subject’s corneal size.

Regarding the direction of decentration for overall displacement, inferotemporal decentration was the most common, whereas superonasal decentration was the rarest for all the three groups. This is consistent with results from previous studies.6-8,16 Baseline corneal asymmetry vector has been suggested as a possible explanation.16 In the current study, the mean directions of the corneal asymmetry vector among the three groups were all inferotemporal, and both the amount and direction significantly contributed to the magnitude and angle of treatment zone decentration.

Eyelid force is one potential factor influencing the alignment between the lens and the corneal surface that was not investigated in the current study. During Ortho-k lens fitting, many factors should be taken into account, including corneal parameters, lens design and eyelid forces. Further studies are needed to investigate how a combination of these factors may influence Ortho-k lens fitting.

In conclusion, the amount of paracentral corneal toricity using elevation data at 8-mm chord appears to be a better predictor of lens decentration than central corneal toricity and corneal asymmetry. When the CED at 8-mm chord was above 30 μm, a toric Ortho-k fitting appears to improve lens centration and should therefore be recommended.

Disclosure Statement
All the authors declare that they have no competing interests.

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