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The influence of orthokeratology on peripheral refraction during accommodation

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Abstract

Significance The change in peripheral refraction from hyperopic to myopic defocus following orthokeratology (OK) has been recognized as a main factor in myopia control. However, the impact of OK lenses on peripheral refraction at nearpoints in myopic eyes still requires further investigation.

Purpose This study aims to investigate changes in peripheral refraction during accommodation in myopic adults after orthokeratology (OK) wear.

Methods Twenty-four selected myopic adults (mean spherical equivalent: -2.70 ± 1.04 D) participated in this study. Peripheral refractions were measured by an auto-refractor with targets located at 25 cm and 50 cm from the eye. Measurements were performed across ± 30º of the horizontal field in 5º steps from the visual axis of subject's right eye before and after wearing the OK lens. The statistical package SPSS was used to analyze the data to determine the relationship between peripheral refractions and accommodation.

Results After wearing the OK lens, the peripheral refraction became more myopic with increasing eccentricity during accommodation (t > 2.80, $p < 0.01$, N30º, N25º, N20º, T15º, T20º, T25º and T30º, for 25 cm and 50 cm). While relative hyperopic reflective errors were observed in the central (accommodative lag) and near peripheral (=< 15 º) retinal fields (t < -2.5, $p < 0.02$, for 0º, N5º, N10º, N15º and T10º for 25 cm and 50 cm), relative myopic refractive errors were evident in the farther periphery (> 15 º). (for 25 cm, -0.45 ± 1.18, -0.71 ± 1.47, -1.00 ± 1.31 and -1.70 ± 2.16D, for N30º, T20º, T25º, and T30º; for 50 cm, -0.76 ± 1.28, -0.84 ± 1.05; -1.17 ± 1.30 and -2.15 ± 1.81D, for N30º, T20º, T25º, and T30º; t > 2.5, $P < 0.02$).

Conclusion The myopic shift of peripheral refraction from the OK lens was partly counteracted by an insufficient change in refractive power of the eye during accommodation. Even though the refractive errors become relative hyperopic in the central and near peripheral retinal fields, relative myopic refraction was still maintained in the farther periphery for the accommodated myopic eyes treated with OK lenses.

Keywords Orthokeratology, Peripheral Refraction, Accommodation, Myopia, Refractive error

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Introduction

Myopia is a problem worldwide, but especially in East Asia. Although the mechanism underlying the development of myopia is not well understood, animal studies have suggested that a hyperopic refractive error can stimulate a young eye to abnormally elongate during early development resulting in myopia in adulthood [1]. Some animal studies have further demonstrated that off-axis hyperopic refractive error, in addition to the on-axis central visual field, also contributes to the process of myopia development [2, 3]. For the human eye, near-work has long been associated with the development of myopia [4, 5]. Near-work linked accommodation has been hypothesized to be a major component involved in myopia development because of an accommodative lag, due to an inaccurate response by the accommodation system to near visual targets, produces a hyperopic refractive error in the central visual field. However, in a longitudinal study of children [6, 7], accommodative lag was shown not to be a primary cause of myopia. Additionally, peripheral refraction in accommodated eyes has been measured in two studies of young myopic adults to investigate the influence of accommodation on peripheral refraction [8, 9], but the results were inconsistent between the two studies. No significant change in the relative peripheral refractive error was observed between far and near viewing distances in one study [8], whereas the other study found that peripheral error became more myopic/less hyperopic for near vision than for central vision [9].

Orthokeratology (OK) is an effective treatment to slow myopia progression in clinical practice [10–13], while simultaneously correcting the myopic refractive error. Refraction in the peripheral fields has been shown to change from hyperopic defocus to myopic defocus after OK contact lens wear, and it has been suggested that OK-induced peripheral myopia is responsible for the myopia control seen with the use of OK lenses [14–16]. While the influence of OK contact lenses on peripheral refraction for far vision has been measured in previous studies, the peripheral refraction at nearpoints for myopic eyes with OK contact lenses has not been investigated. During near vision, the ocular refractive state changes uniformly over the central 30° diameter of the visual field as the eye accommodates [17]. This change causes the refractive profile across the visual fields to be moved overall in a more hyperopic direction and thus neutralizes a certain amount of the OK-induced myopic peripheral refraction. Because of this neutralization, measuring the peripheral refraction of accommodated eyes after OK lens wear becomes important. A better understanding of the influence of OK lens wear on peripheral refraction during accommodation can help us to more thoroughly investigate the mechanisms underlying myopia control by the use of OK lenses. Accordingly, the aim of this study is to measure peripheral refraction during accommodation in a group of young myopic adults before and after OK lens wear.

Method

Subjects and soft contact lens corrections

The research followed the tenets of the Declaration of Helsinki and was approved by the Sciences Ethics Committee of Wenzhou Medical University. The informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study. In total, 24 young adults (age ranged from: 18 to 31 years, mean age = 24.4 ± 3.0 years) myopic subjects (spherical equivalent ranged from: -1.50D to -4.00D, mean refraction = -2.70 ± 1.04 D) voluntarily participated in the experiments. The subjects were recruited from the student cohort of Wenzhou Medical University.

Before they were enrolled in this study, subjects were pre-screened by routine eye examinations, including subjective refraction, visual acuity determination, and general eye health examination with a slit-lamp microscope and direct ophthalmoscope. Subjects who had best-corrected acuity better than 20/20, normal binocular function (no manifest strabismus or amblyopia), and bilateral mild to moderate myopia were recruited. All subjects reported comparable daily near-work durations (4–6 h), minimizing potential confounding effects of lifestyle differences on accommodative responses. Those with astigmatism greater than 0.75D or refractive error greater than -4.00D were excluded from the study. For the baseline measurements, all subjects' eyes were fitted with spherical soft contact lenses (Acuvue 2 Contact Lenses, etafilcon 2, 58% water content, Vistakon/Johnson & Johnson, USA). The refraction followed a criterion of maximum plus for best visual acuity. The power of the contact lens was defined as the best spherical equivalent value of the subjective refraction. In this study, all subjects attained acuities of at least 20/25 through the contact lens.

Lens characteristics and fitting of OK contact lenses

Subjects were fitted with overnight OK lenses (Euclid Systems Corporation, America) in both eyes and did not wear lenses during the day. Euclid OK lenses (Euclid Systems Corporation, America) were manufactured with Boston Equalens II material ($DK = 90 \times 10^{-11}$ [cm^2/s] [ml O_2/ml × mm Hg], Polymer Technology Corporation). All these lenses possess a reverse-geometry design [18]. The overall diameter range of the OK lenses was 10.2 mm to 11.2 mm, and the central thickness was 0.22 mm to 0.23 mm. Fitting of the lens was evaluated through fluorescein patterns, topographical evaluations, and refractive and visual outcomes. Lens centration was confirmed via fluorescein patterns and topographic symmetry, with all lenses demonstrating centration within

0.5 mm of the corneal apex. Those who had optimal fittings and visual acuity better than 20/20 were recruited in this study.

All the subjects underwent treatment for at least 30 days (mean 40 ± 2.3 days) to guarantee that the treatment was completely stable [19]. The measurements were performed between 10:00 and 12:00 A.M. and at least 2 h after the OK lens removal to minimize the influence of treatment regression [20].

Measurement of peripheral refraction

The measurements of on- and off-axis refraction were obtained with an open-field infrared Grand Seiko Auto-Refractor/Keratometer WAM-5500 (Grand Seiko Co. Ltd, Hiroshima, Japan). This model of instrument has been found to be repeatable and accurate in the central and peripheral fields [21, 22], and also has been applicable to the measurement of the eyes with multifocal contact lenses [23].

During the experiment, the illumination in the room was adjusted to obtain a pupil diameter greater than 4.0 mm so that the peripheral retinal field could be measured up to 30° without pharmacological dilation. The fixation target was placed at a distance of 50 cm or 25 cm from the subject's corneal vertex and consisted of 13 charts in the horizontal direction: one central, six to the right and six to the left side. All targets were placed in a circular arc to ensure that they provided the same accommodative stimulus and were separated from each other by an angular distance of 5^0at the patient's position. Fixation targets consisted of two different-sized high-contrast standard letters (E). Each of the letters was sized for the corresponding viewing distances (for 25 cm and 50 cm; the actual letter sizes were 9 pt and 18 pt respectively) to form a constant visual angle of 0.729° [24–27].

Experimental procedures

The subject was seated with his or her head stabilized in a chinrest so that the eye was aligned with the central chart. All testing was monocular using the subject's right eye. The fixation of an object positioned on the right side of the central point projected to the temporal retina, while the target on the left side projected to the nasal retina. Throughout this paper, nasal and temporal refer to nasal and temporal retinal locations. The left eye was occluded, and the subjects rotated their right eyes to view the fixation targets.

Autorefraction was performed centrally and in the horizontal visual field. No cycloplegia was used in order to preserve accommodation for the near-vision measurements. Both the viewing distance and visual angle of the targets were selected in a randomized order by Latin square. Ten measurements were made from each visual angle. Each sphero-cylindrical refractive error measurement was decomposed into vector components using the following equations derived by Thibos et al.: [28]

$$J_{180} = -C\cos 2\theta/2 \quad (1)$$

$$J_{45} = -C\sin 2\theta/2 \quad (2)$$

$$M = S + C/2 \quad (3)$$

where J_{180} and J_{45} are the 90° to 180° astigmatic components and the 45° to 135° astigmatic components, respectively. M is the spherical equivalent error, and S, C and θ are the spherical, cylindrical and cylindrical axis components of the sphero-cylindrical refractive error. In this study, we examined the values of the spherical equivalent M and the astigmatism magnitudes C, J_{180} and $J_{45.}$

The test comprised two parts: baseline and one-month follow-up. For the baseline measurements, the vision of each subject was corrected with a soft contact lens before the subject wore the OK lens. Peripheral refraction was measured at two distances (25 cm and 50 cm). Then each subject was instructed to wear the OK lens every night for at least one month, and the same measurements were repeated within one hour after the subject removed the OK lens in the morning. All results were recorded by the same optometrist.

Data analysis

Paired t-tests were used to compare both central and peripheral refraction before and after OK lens wear. Repeated-measure ANOVA was used to compare the effect of OK lens wear on peripheral refraction between the two accommodative conditions.

Results

Table 1 presents the mean refractive components M, C, J_{180}, and J_{45} in the center of the retina at baseline and after 1 month of OK lens wear for the 24 subjects. As shown in Table 1, the absolute value of the spherical equivalent M increases as the viewing distance of the visual target becomes closer. No significant differences were found

Table 1 The mean (± *SD*) refraction of M, C, J_{180} and J_{45} for primary gaze at two viewing distances before and after OK lens wear

	Pre-25 cm	Post-25 cm	Pre-50 cm	Post-50 cm
M	-3.47 ± 0.42	-3.29 ± 0.52	-1.54 ± 0.64	-1.72 ± 0.58
C	-0.66 ± 0.41	-0.69 ± 0.35	-0.60 ± 0.42	-0.55 ± 0.32
J_{180}	0.11 ± 0.26	0.20 ± 0.29	0.17 ± 0.24	0.14 ± 0.18
J_{45}	0.08 ± 0.19	0.07 ± 0.27	0.02 ± 0.17	-0.01 ± 0.19

between the baseline and 1-month follow-up measurements for the spherical equivalent M (paired t-test, t = -2.01 and 1.54, $p = 0.06$ and 0.14 for 25 cm and 50 cm, respectively) or astigmatism C' (paired t-test, t = 0.357 and -0.564, $p = 0.72$ and 0.58 for 25 cm and 50 cm, respectively).

Power vector M (spherical equivalent) of the accommodated myopic eyes before and after OK lens wear

Measurements of the refraction obtained directly from the instrument at each eccentricity are demonstrated in Table 2, where the mean M components are listed for the two accommodation levels, along with the statistical t-test results for the differences before and after OK lens wear. As shown in Table 2, the mean M values varied as a function of eccentricity at both viewing distances. The changes in mean M values induced by OK lenses were significant in the periphery (paired t-test, t > 2.34, $p < 0.03$, N30°, N25°, N20°, T15°, T20°, T25° and T30°, for both 25 cm and 50 cm).

As the measurement obtained directly from the instrument represents the refractive error with respect to a distant visual target, it doesn't directly measure the refractive error with respect to the near visual target. In Fig. 1, two gray lines were added to indicate the vergences of the viewing distances (-2.0D for 50 cm and -4.0D for 25 cm) from which the refractive errors could

Table 2 The mean refraction of spherical equivalent M (± *SD*) with nasal (N) and temporal (T) visual angles at two viewing distances before and after OK wear, along with the paired t-test results. (* $p < 0.05$)

		Pre-25 cm	Post-25 cm	t	*p*	Pre-50 cm	Post-50 cm	t	*p*
Nasal	30	-2.81 ± 1.13	-4.45 ± 1.18	5.66	< 0.01*	-0.33 ± 1.33	-2.76 ± 1.28	6.67	< 0.01*
	25	-3.09 ± 1.00	-3.90 ± 1.16	3.23	< 0.01*	-0.62 ± 1.17	-2.02 ± 1.02	5.85	< 0.01*
	20	-3.12 ± 0.64	-3.53 ± 0.73	2.34	0.03*	-0.85 ± 0.99	-1.71 ± 1.13	3.65	< 0.01*
	15	-3.30 ± 0.52	-3.40 ± 0.68	1.39	0.18	-1.38 ± 0.82	-1.56 ± 0.82	1.14	0.27
	10	-3.28 ± 0.52	-3.39 ± 0.65	1.32	0.20	-1.49 ± 0.78	-1.55 ± 0.74	0.50	0.62
	5	-3.43 ± 0.51	-3.31 ± 0.65	-1.12	0.27	-1.58 ± 0.79	-1.69 ± 0.71	0.74	0.47
Central	0	-3.47 ± 0.42	-3.29 ± 0.51	-2.04	0.06	-1.54 ± 0.64	-1.72 ± 0.58	1.54	0.14
Temporal	5	-3.53 ± 0.69	-3.33 ± 0.52	-1.54	0.14	-1.61 ± 0.88	-2.08 ± 0.80	2.75	0.01*
	10	-3.52 ± 0.65	-3.68 ± 0.65	1.41	0.17	-1.64 ± 0.78	-1.70 ± 0.71	0.69	0.50
	15	-3.48 ± 0.66	-4.09 ± 0.83	3.01	< 0.01*	-1.66 ± 0.81	-2.55 ± 0.97	3.85	< 0.01*
	20	-3.39 ± 0.65	-4.71 ± 1.47	4.06	< 0.01*	-1.45 ± 0.81	-2.84 ± 1.05	5.14	< 0.01*
	25	-2.75 ± 0.84	-5.00 ± 1.31	5.82	< 0.01*	-1.02 ± 0.71	-3.17 ± 1.30	6.52	< 0.01*
	30	-2.70 ± 1.00	-5.70 ± 2.16	6.42	< 0.01*	-0.84 ± 0.95	-4.15 ± 1.81	8.01	< 0.01*

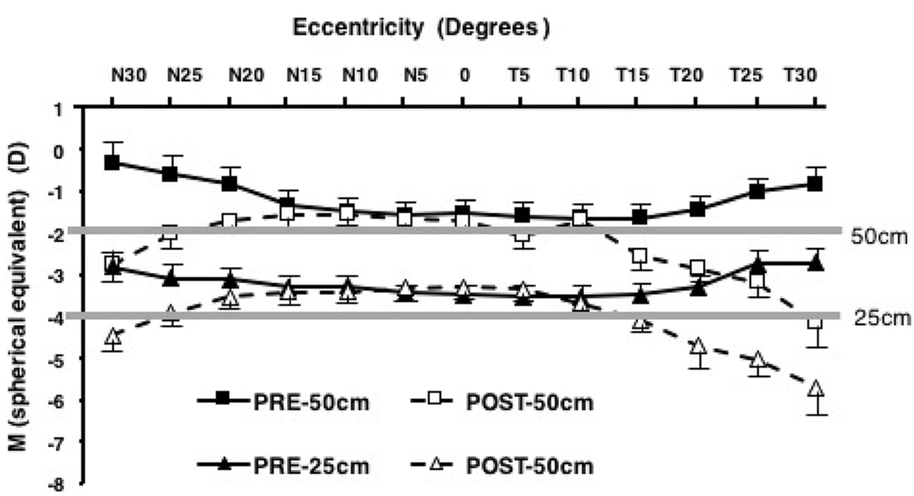

Fig. 1 The M values with eccentricity of the retinal sides under two different accommodative stimuli before and after OK lens wear. The horizontal gray lines represent the accommodative stimuli. (-2.0D for 50 cm, and -4.0D for 25 cm). The M values above their respective gray lines e represented relative hyperopic defocus, while the M values below the gray lines showed relative myopic defocus. Error bars indicate ± *SEM*

be calculated by subtracting the measurements from the vergences. The M values above their respective gray lines represented relatively hyperopic defocus (or accommodative lag for central refraction) to accommodative stimuli, while the M values below the gray lines showed a relatively myopic defocus (or accommodative lead for central refraction). As shown in Fig. 1, before wearing the OK lens, the refractive error was found to be positive (above the gray line) in all of the retinal fields ($p<0.05$ always). After wearing the OK lens, a significant relative hyperopic refractive error was also observed for a large range of retinal fields near the center under both accommodative conditions. (one-sample t-test, t = -2.90, -3.35, -2.61, -2.71, and -2.53, $P=0.008$, 0.003, 0.015, 0.013, and 0.019 at N15°, N10°, N5°, 0 and T10° for 50 cm; and t = -2.70, -4.87, -4.72, -5.82, -7.26, and -2.54 and $P=0.013$, < 0.001, < 0.001, < 0.001, < 0.001, 0.018 at N20°, N15°, N10°, N5°, 0 and T5°, T10° for 25 cm). However, for the farther periphery, the M values were negative (below the gray line), and thus the refractive errors became significantly myopic (one-sample t-test, t = 2.95, 2.55, 3.86, 4.19, and 5.95 and $P=0.007$, 0.018, 0.001, < 0.001, and < 0.001 at N30°, T15°, T20°, T25° and T30° for 50 cm; and t = 2.71, 3.85, 4.02, and 5.18, $P=0.012$, 0.001, < 0.001, and < 0.001 at N30°, T20°, T25° and T30° for 25 cm).

Relative peripheral refractive error before and after OK lens wear

Relative peripheral refractive error is shown in Fig. 2. The baseline peripheral refractive error became progressively hyperopic relative to central error as eccentricity increased at both accommodation levels. After wearing the OK lens, relative peripheral refractive error shifted in the negative direction as eccentricity increased. There was no significant difference in the relative peripheral refractive error between the two accommodation levels on the temporal retinal side. However, at the nasal retinal side, it was more negative with the 4D accommodative stimulus than with the 2D accommodative stimulus before or after OK lens wear (paired t-test, before OK lens wear, t = 2.57, 2.62 and 2.02 and $p=0.018$, 0.016 and 0.039 for N30, 25 and 15, respectively; after OK lens wear, t = 2.28 and 2.25 and $p=0.034$ and 0.035 for N30 and 25, respectively).

Substantial asymmetry of relative peripheral refractive error about fixation was apparent at both viewing distances. As shown in Fig. 2, after wearing the OK lens, relative peripheral refractive errors in corresponding temporal and nasal eccentricities were statistically significantly different with temporal side being more myopic. (paired t-test, t > 2.36, $p<0.05$, compare with N30°-T 30°, N25°-T25°, N20°-T20°, N15°-T15°, for both 25 cm and 50 cm).

Peripheral astigmatism J180 and J45 of the accommodated myopic eyes before and after use of OK contact lens wear

The mean values of the astigmatic components, J_{180} and $J_{45,}$ of the accommodated myopic eyes before and after OK wear are shown in Figs. 3 and 4 respectively. The astigmatic component J_{180} changed significantly after OK

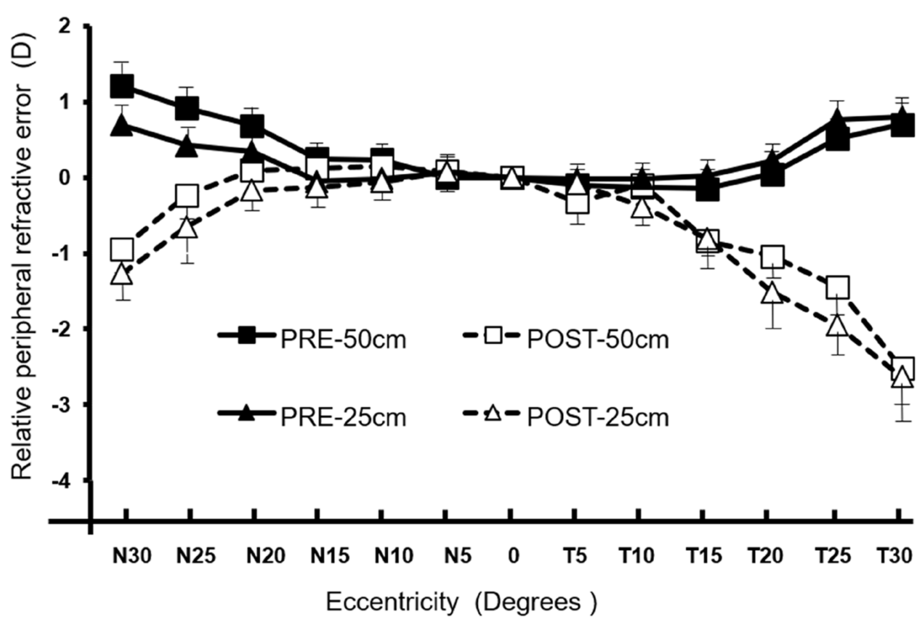

Fig. 2 Variations in relative peripheral refractive error with eccentric nasal (N) and temporal (T) retinal sides at two viewing distances before and after OK lens wear. Error bars indicate ± *SEM*

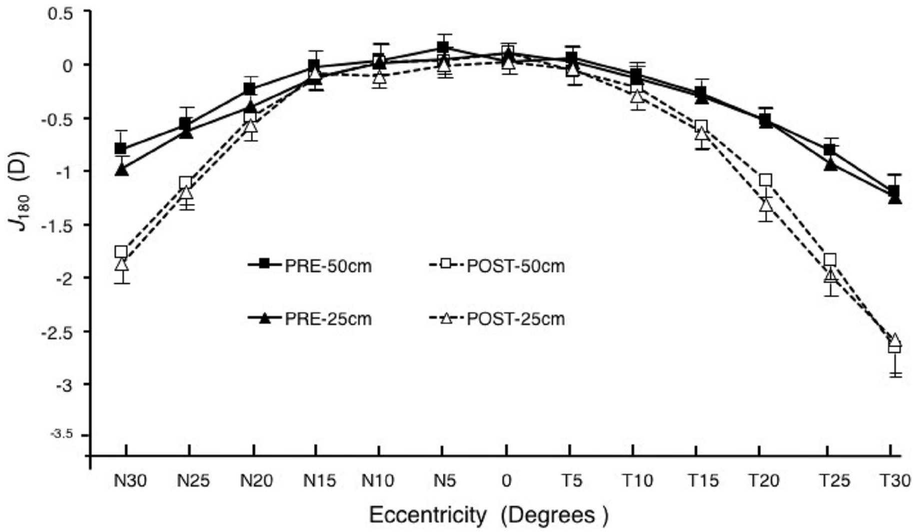

Fig. 3 Astigmatism component J_{180} with eccentricity on the retinal sides at two viewing distances before and after OK lens wear. Error bars indicate ± *SEM*

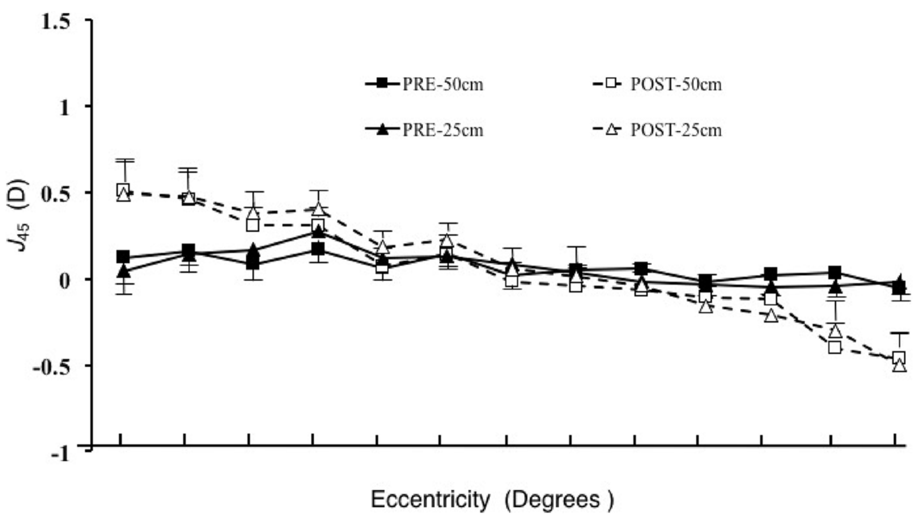

Fig. 4 Astigmatism component J_{45} with eccentricity on the retinal sides at two viewing distances before and after OK lens wear

lens wear (repeated-measures ANOVA, F = 28.12 and 29.65, $p < 0.001$ for 50 cm and 25 cm, respectively), especially at large eccentricities (paired t-test, t = 4.33, 3.17, 2.31, 2.91, 3.36, 4.49, and 5.18 and $P < 0.001$, 0.004, 0.029, 0.007, < 0.001, < 0.001, and < 0.001 at N30°, N25°, and N20° and T15°, T20°, T25°, and T30° for 50 cm; t = 4.18, 3.20, 2.84, 4.01, 4.50, and 5.22 and $P = < 0.001$, < 0.001, 0.009, < 0.001, < 0.001, and < 0.001 at N30° and N25° and T15°, T20°, T25°, and T30° for 25 cm). A paired t-test showed that the change in J_{180} after OK lens wear between the viewing distances was significant on the nasal side (paired t-test, t = 2.95, 2.45 and 2.43 and $p = 0.007$, 0.02 and 0.02 for N30°, N25° and N20°, respectively).

The absolute values of astigmatic component J_{45} increased with eccentricity after OK lens wear in both the nasal and temporal peripheral regions at the two viewing distances, with nasal side being hyperopic and temporal side being myopic. (paired t-test, for 50 cm, t = -3.40, -2.16, -2.78, 3.60, 3.38 and 2.18 and $p = 0.002$, 0.04, 0.01, 0.001, 0.003 and 0.04 for N30°, N25°, N20°, T30°, T25° and T20°, respectively; for 25 cm, t = -3.48, -2.82, 3.93, and 2.57 and $p = 0.002$, 0.01, 0.002, and 0.017 for N30°, N25°, T30° and T25°, respectively). No significant differences in J_{45} were observed between the different viewing distances either before or after OK lens wear.

Discussion

Myopic eyes have been well documented to demonstrate relative hyperopic refractions in the peripheral visual fields as myopia is corrected for distant visual targets in the central visual field for persons wearing spectacles or contact lenses [29, 30]. However, OK contact lens wear induces relative myopic peripheral refractions while correcting central myopia [14–16]. It has been suggested that the correction of central myopia, but not peripheral myopia, by OK lens wear is due to a more effective change in the curvature of the anterior corneal surface at the pupil center area than in the peripheral cornea [31]. The aim of this study was to test if there is any change in the refractive status in the accommodated eyes with OK treatment. The results clearly demonstrated that after OK lens wear, the refractive errors in the central and near central fields become hyperopic, while for the far periphery, the refractive errors remained myopic for both accommodative conditions (Fig. 1). While our findings suggest that OK lenses maintain peripheral myopic defocus during accommodation in young adults, extrapolation to pediatric populations requires caution due to potential differences in accommodative dynamics, pupil size, and corneal biomechanics. Future studies should validate these effects in children [6, 7, 10]. The results indicate that during near work the myopic eyes corrected with OK contact lenses still have myopic refractive error in the far periphery, while the refractive error of central fields remain somewhat hyperopic. OK-induced peripheral myopic refraction has been suggested to be the mechanism responsible for slowing myopia progression, as widely observed in current clinical myopia control studies. This study, therefore, provides additional evidence to support this hypothesis because the OK-induced myopic refraction is high enough to guarantee a myopic refraction relative to the accommodative demands in the far periphery.

The peripheral refractions at two accommodation levels were measured in this study. Compared with a 2 diopter accommodative demand, the relative peripheral refraction for a 4 diopter demand was not significantly changed at the temporal retinal side, but it was significantly, albeit slightly, shifted toward myopia on the nasal side (see Fig. 2). This shift in peripheral refraction with increasing accommodation is consistent with the results of a previous report [9]. To speculate on the source of this myopic shift, the change in the anterior segments during accommodation should be considered. Accommodative shortening of the anterior chamber depth and increasing of the anterior lens curvature have been repeatedly reported in previous studies. These changes in the anterior segment were theoretically modeled to generate myopic peripheral refraction in a recent study [32]. The slight peripheral myopic shift at increasing accommodative demand, therefore, could be a change in the refractive components of the lens. Changes in aberrations with accommodation have been well documented in previous studies and the contribution of the changed aberrations to peripheral refraction in the eyes with OK lens wear could be another influential factor. Further study on the sources of myopic peripheral refraction in the eyes with OK lens wear is required.

More myopic shifts were found in the temporal retinal field than in the nasal field (Fig. 2). Asymmetry of the peripheral refractive errors with respect to the visual axis has been commonly observed in previous studies, with the nasal peripheral refraction being more hyperopic relative to temporal side. This is attributed to angle lambda of the visual system [9, 33], caused by the asymmetries, rotation, or misalignment of the curvatures of the surfaces of the optical components such as the cornea and lens [34–37]. After OK lens wear, this asymmetry is further amplified by corneal reshaping and lens design effects. Consistent with previous research, this study revealed strong asymmetry of both M and J_{180} (Figs. 1, 2 and 3). These findings suggest that OK lens-induced corneal curvature changes and anatomical factors collectively drive nasal-temporal refractive disparities. A deeper understanding of these mechanisms will aid in tailoring OK lenses to maximize myopia control while minimizing optical side effects.

In this study, accommodation was found to increase the peripheral astigmatic component J_{180} (Fig. 3). This increase in peripheral astigmatism with increasing accommodation is consistent with the results of a previous report [9]. At baseline, J_{180} increased in the 15° temporal and 20° nasal periphery retina at higher levels of accommodation but without changes in the central or near peripheral retinal fields. After OK lens wear, J_{180} increased in both the middle and farther periphery. Currently, whether increased peripheral astigmatism can influence the process of emmetropization remains controversial. Queiro et al. [16] found a negative increase in astigmatism beyond 20° in both the temporal and nasal retina, and Kang et al. [15] found a negative increase from 30° in the temporal VF (nasal retina) and 20° in the nasal VF (temporal retina). Similarly, we found a negative increase from 15° in the temporal field and 20° in the nasal field, which is the same as the change in the M value. Refraction measurements in these areas correspond to the treatment zone of the OK lens. Therefore, the increase in astigmatism observed after OK lens wear can be due to changes in optical properties (curvature and refractive index) in the cornea after lens wear.

This study provides valuable insights into the effects of orthokeratology (OK) lenses on peripheral refraction during accommodation. However, it is important to acknowledge some limitations. The exclusion criteria were not clearly defined, which might influence the generalizability of the findings. A more detailed outline of the exclusion criteria could help ensure the homogeneity of the study population and the robustness of the results. Additionally, accommodative dysfunctions were not assessed or excluded, which could potentially affect the peripheral refraction measurements. Future studies should consider including assessments of accommodative function to better understand its impact on peripheral refraction and myopia control [38]. The sample size was not calculated, as this was an observational study primarily focused on observing trends. While the sample size was sufficient to observe the trends, a formal sample size calculation would provide a stronger basis for the statistical analysis and the interpretation of the results. Lastly, the impact of pupil size was not discussed. Pupil size can significantly affect peripheral refraction. Notably, pupil diameter may modulate the efficacy of peripheral defocus in myopia control. In pediatric populations, larger pupils under mesopic or near-vision conditions could enhance the overlap between the mid-peripheral plus power ring (PPRD) and the pupillary area, thereby amplifying myopic defocus signals [39]. Studies demonstrate that smaller back optic zone diameters (BOZDs) generate narrower PPRDs, which, when aligned within the pupil boundary, significantly reduce axial elongation (0.04 ± 0.10 mm/year) compared to cases where the PPRD extends beyond the pupillary margin (0.17 ± 0.12 mm/year). However, larger pupils may also increase sensitivity to lens decentration due to asymmetric corneal reshaping [40]. While our study controlled lens centration within 0.5 mm of the corneal apex in adults, dynamic interactions between pupil size, accommodative responses, and corneal biomechanics in children necessitate further investigation. Quantitative characterization of the relationship between peripheral refraction asymmetry and corneal changes is critical for optimizing OK lens designs, particularly in pediatric cohorts where these factors may synergistically influence clinical outcomes. Future studies should address these limitations to provide a more comprehensive understanding of the effects of OK lenses on myopia control.

Conclusions

The myopic shift of peripheral refraction from the OK lens was partly counteracted by an insufficient change in refractive power of the eye during accommodation. For eyes treated with OK lenses, even though the refractive errors become relative hyperopic in the central and near peripheral retinal fields, due to the accommodative lag, the relative myopic refraction was still maintained in the farther periphery during the accommodation.

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Authors' contributions

Z.L. and X.J. wrote the main manuscript text. M.G., X.Z., and X.G. performed data collection and statistical analysis. T.P. supervised the project and acquired funding. Y.W. conceptualized the study, managed resources, and acquired funding. All authors reviewed the manuscript.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study. This study involving human participants was approved by the Ethics Committee of Ningbo Eye Hospital, with the approval number 2023–51(K)-C2.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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