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Binocular Visual Performance Improvement in Children Following Overnight Orthokeratology Lens Wearing

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Background: Orthokeratology (OK) lenses are used to control myopia progression in children. Few studies have described the changes in stereoacuity scores and fusion ranges in OK-treated children.

Objectives: This study sought to investigate the effects of short-term OK lens wearing on binocular visual function, including fusion and stereoacuity, in children successfully fit with OK lenses.

Methods: This prospective study included 36 children with ideal lens fitting (treatment zone decentration <1 mm) and was conducted between September 2020 and December 2021. Thirty-six patients were assessed before treatment, after 3 months of follow-up, and after 6 months of follow-up for contrast sensitivity (CS), fusion function, and stereopsis and calculation of the accommodative convergence/accommodation (AC/A) ratio.

Results: Compared with those at baseline, the stereoacuity score and convergence amplitude were significantly improved after 3 months of OK lens wear ($P<0.05$) but did not further increase after 6 months of lens wear. By contrast, the CS and AC/A ratio did not significantly change from baseline to either follow-up date ($P>0.05$).

Conclusions: The CS and AC/A ratio remained unchanged after OK lens wear, while the stereoacuity score and fusion range improved in the pediatric population. These findings suggest that OK lens wearing improves or maintains binocular vision function in myopic children who achieve good visual performance with OK lenses (ChiCTR2000038600, registered September 24, 2020).September 24, 2020).

Key Words: Orthokeratology—Contrast sensitivity—Stereoacuity—Fusion range—Visual performance.

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Contributors T. Qiao and W.-T. Luo conceived and designed the study. Y. Huang, Y. Di, and X. Du collected, analyzed, and interpreted the data. W.-T. Luo wrote the first draft of the article. T. Qiao reviewed and edited the manuscript.

Written informed consent was obtained from the parents or guardians of all the participants. Oral assent was obtained from all the children before the examination.

This study was approved by the Institutional Review Board (approval no. 2020R124) and was performed in accordance with the tenets of the Declaration of Helsinki.

Data are available upon reasonable request.

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Overnight orthokeratology (OK) employs specially designed and fitted rigid contact lenses (CLs) to reshape the cornea and correct refractive errors during sleep, particularly in myopic patients. In addition to increased standardization for the OK lens, software supporting lens fitting and for creating new lens designs is becoming readily available, and technological improvements are allowing measurement of the shape of the anterior cornea; also, few studies have reported the risk of adverse events for patients receiving OK lens interventions.[1–6]

The main goal of OK lenses is to control myopia progression in children and adolescents, with the added benefit of granting the ability to achieve clear vision without glasses. Several studies have reported the use of novel OK lenses to increase exposure to peripheral defocus and higher-order aberrations by altering the relationship between pupil size and the effective OK treatment zone.[7,8] This approach allows vision through a corneal surface with a larger change in higher-order aberrations, hence addressing the progression of myopia.[1] However, OK lenses increase corneal irregularities and ocular high-order aberrations, which can lead to deterioration of the contrast sensitivity (CS) function of the eye, even in patients successfully managed with OK lenses.[9] Orthokeratology lenses have also been shown to cause decreases in visual quality.[10,11] Such changes are associated with pupil size,[12] the amount of refractive error correction, quality of lens fit, lens design, and so on.[13,14]

Visual acuity is often measured under high-contrast conditions, but this single measure is not a good indicator of visual quality.[15] Contrast sensitivity measures the minimal amount of contrast needed to distinguish details in low contrast. A CS test can better reflect the actual visual state than a visual acuity test. As the contrast sensitivity function (CSF) is positively correlated with vision-related quality of life, it is essential to determine whether the current CLs affect CS.[16,17] Measurement of CS[18,19] can provide useful information about visual function that may not be revealed by standard visual acuity testing. Previous studies have reported significant visual quality changes after OK lens wear, with a significant reduction in CS depending on the degree of myopic correction.[20] When the reverse curve zone is used at the periphery of the OK lens, the image created by the central part of the lens is focused precisely on the retina and can be clearly observed. Simultaneously, light beams refracted by the peripheral portion of the lens (the treatment zone) are focused in front of the retina, making the resulting retinal image blurry. In other words, the central image, which is the most important image for CL wearers, can be distinguished more easily from the blurred background noise created by the peripheral defocus ring of the OK lens. It may be easier for OK lens wearers to ignore peripheral defocused images that are

significantly blurred. However, the blurred image in the center is unacceptable, and it is difficult to ignore the peripheral defocused ring, which is only partially obscured in the central zone. This explanation aligns with the blur ignored hypothesis,[21] which suggests that selective attention allows neglecting of unique regions of blurring. In recent studies, the magnitude of treatment zone decentration was similar: Ding et al.[22] reported 0.74±0.32 mm, and Chen et al.[23] reported 0.72±0.26 mm. Tsai and Lin[24] proposed that in corneal refractive surgeries, ablation decentration of less than 0.5 mm (mild decentration) is optimal, that between 0.5 and 1.0 mm (moderate decentration) is acceptable, and that greater than 1.0 mm (severe decentration) should be avoided. According to this classification, only well-fitting OK lens wearers, defined as those with a decentration of less than 1.0 mm, were included in our research.

Furthermore, only a few studies[25,26] have investigated the vision levels of children who wear OK lenses under conditions other than high contrast and luminance visual acuity. Moreover, few studies have reported changes in stereoacuity scores or fusion ranges in OK-treated children, and only one study has investigated the effects of short-term OK lens wear on accommodation and binocular visual function in young adults.[27]

There is no current evidence demonstrating that lags in accommodation cause myopia progression according to the correction of myopia evaluation trial[28] and International Myopia Institute[29] papers on binocular vision. Orthokeratology lens wear has previously been shown to improve near accommodative function, as reflected by a reduction in the accommodative convergence/accommodation (AC/A) ratio.[6,30,31] However, these studies are limited by differences in the lens-fitting criteria. In summary, there is still a lack of research on CSF, accommodation, and binocular visual functions of OK lens fitting.

In this study, we investigated the effects of short-term OK lens wear on binocular visual function, including the fusion range and stereoacuity, in children successfully fit with OK lenses.

METHODS

This prospective cohort study was conducted between September 2020 and December 2021 and involved the use of ophthalmic data from patients who underwent OK treatment at the Department of Ophthalmology, Shanghai Children's Hospital. The clinical data of 36 children, including 8 boys and 28 girls ranging from 8 years to 12 years 6 months (9.68±1.26 years) in age, were collected, and 64 eyes underwent OK treatment in this study. The study was approved by the Institutional Review Board of Shanghai Children's Hospital (approval no. 2020R124) and was performed in accordance with the tenets of the Declaration of Helsinki. Written informed consent was obtained from the parents or guardians of all the participants. Oral assent was obtained from all the children before the examination.

The inclusion criteria included a manifest refraction of −1.0 to −5.0 diopter (D), anisometropia less than or equal to 1.50 D, with-the-rule astigmatism ≤1.50 D, or against-the-rule astigmatism ≤1.00 D, with keratometry values between 39.50 and 46 D. We list the patients' demographic and clinical characteristics in Table 1. The patients all had good ocular health and no contraindications for OK lens wear.[32] After treatment with OK lenses, the patients achieved an unaided distance visual acuity of −0.1 (logarithm of the minimum angle of resolution [logMAR]) or better. The residual refractive error (noncycloplegic distance static retinoscopy) as objective refraction with subjective refraction was measured with maximum plus to maximum visual acuity. We measured the synoptophore test and binocular vision measurements with the residual refraction. Well-fitting OK lenses were defined as those with decentration of less than 1.0 mm. The exclusion criteria included the presence of pathological myopia; corneal pathologies such as dry eyes; healed keratitis; ocular surgery; systemic comorbidities such as diabetes mellitus and thyrotoxicosis; and constant or intermittent strabismus. Patients who used atropine eye drops (0.01%) were also excluded. All patients were fitted with spherical Alpha OK lenses (Boston EM lenses; Bausch and Lomb, Alpha Corporation, Nagoya, Japan) according to the manufacturer's guidelines.

TABLE 1. *Baseline Characteristics*

No. of patients	36
Sex, M:F	8:28
Age, mean±SD (year)	9.68±1.26
Corrected visual acuity (logMar)	0±0.10
Spherical component of the refraction (DS)	−2.58±1.15
Axial length (mm)	24.44±0.74
Astigmatism (DC)	−0.71±1.15

DC, diopter cylinder; DS, diopter sphere; F, female; LogMar, logarithm of the minimum angle of resolution; M, male.

Routine slitlamp, cycloplegic refraction, and fundus examinations were performed on each subject. Cycloplegia was induced with 0.5% tropicamide eye drops to measure ametropia accurately before OK lens fitting. We placed three drops of tropicamide in each eye at 5-min intervals, and refraction experiments were performed 30 min after three drops.

The evaluated parameters included cycloplegic refraction (measured with a Topcon autorefractor [model KR-8900 Topcon Co, Ltd, Japan]), uncorrected visual acuity, best-corrected visual acuity, axial length according to an IOL Master 500 (Zeiss, German), corneal topography and keratometry according to an Oculus Keratography 5M (Oculus Topographer, German), CS, fusion range, stereopsis (assessed with the Randot test), and the AC/A ratio. The baseline tests for CS, accommodation, and vergence were performed with spectacle correction (preorthokeratology fitting). At the follow-up visit, including the 3- and 6-month follow-up, we tested binocular visual performance after fitting OK lenses with the residual correction.

The ideal shape of the cornea after OK lens wear includes a centrally flattened zone and a bullseye pattern on the corneal tangential difference map. However, the center of the OK lens treatment zone is often inconsistent with the center of the pupil in OK lens wearers. The distance between the center of the ellipse and the center of the pupil was defined as the decentration distance. An in-house developed computer program (Python) was used to measure the distance of OK lens decentration. We evaluated the corneal tangential topographic data obtained after 3 months of Ortho-K lens wear (Fig. 1). The inside of the red ring surrounding the central flattened area aligned with the treatment zone is the fitted ellipse. The ellipse was fitted through eight points on top of the treatment zone with Python software, and the center of the ellipse was defined as the center of the treatment zone. The yellow line represents the

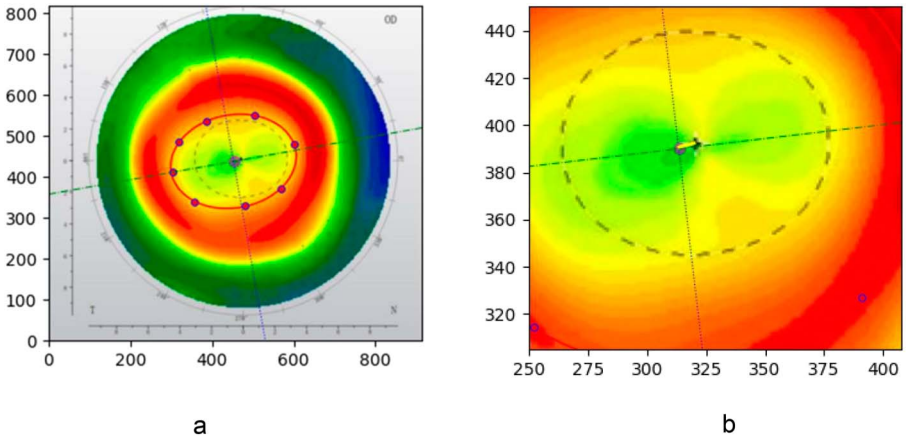

FIG. 1. Distances between the center of the pupil and the treatment zone in the different corneal tangential topographies obtained with Python software (a). The yellow line represents the decentration distance between the pupil center and the center of the fitted ellipses. The distance between the two points was 0.17 mm after conversion (b).

decentration distance between the pupil center and the center of the fitted ellipse. We measured the treatment zone decentration equivalent to the measured length of the yellow line segment. To eliminate the effect of decentration on visual function, patients with severe lens decentration distance greater than 1.0 mm were excluded. All the patients in this study were chosen according to a lens-fitting decentration distance of less than 1.0 mm. In real life, most lenses are eccentric, and the decentration distance is greater than 0.5 mm and less than 1.0 mm.[33]

Stereoacuity was measured at a distance of 40 cm with a random-dot Stereotest, scaled to match the visual angle of the dots and shapes used in the commercially available Randot test (Stereo Optical Company, Chicago, IL), and recorded in seconds of arc for each subject. Each measurement was repeated twice. The best score was recorded at 40 or less than 40 sec of the arc. Stereoacuity scores were ranked as good (scores ≤40, 60, 80, and 100), medium (scores 200 and 400), low (score of 800), or no stereoacuity.[34] To determine the chi-square statistics, we divided the stereoacuity scores into three levels: good stereoacuity (stereo score ≤100), medium stereoacuity (100<stereo score ≤400), and low stereoacuity (stereo score >400).

In our study, the AC/A ratio was determined with the gradient method, which measures the convergence generated by a diopter of accommodative effort. The AC/A ratio and fusion range were both measured with a synoptophore (Inami, L-2510B, Tokyo, Japan). The participant was positioned on the synoptophore and instructed to fixate on a foveal image with residual refractive correction. The lens strength used for accommodation manipulation was −3.0 D. The AC/A ratio was then calculated with the following formula:

Gradient AC/A ratio=measurement with accommodation (prism diopter [PD]) − measurement without accommodation (PD)/lens strength (D).

We divided the AC/A ratio into three levels: insufficient convergence (AC/A<3), medium convergence (3≤AC/A≤5), and high accommodative convergence (AC/A>5).[35]

The fusional convergence amplitude was defined as the breakpoint at which the eye position shifted from phoria to exotropia and was measured using the synoptophore. Suppression was assessed by whether crossed diplopia was perceived after the cover was removed when the patient fixated on a monitor target 40 cm in front of the eyes. The slide sizes for the fusion measurements were 10° V and 10° H. The subjects were requested to fuse the targets when seeing each slide separately according to the corresponding eye. The subjective angle was subsequently obtained when the targets were fused and when a car was seen in the middle of the screen. Motor fusion was measured with the synoptophore set at the position of the SA with slides of a butterfly and a cat. When the synoptophore tubes were slowly abducted or adducted, the subjects had to diverge or converge their vision to maintain target fusion for as long as possible. When the subjects indicated that a disruption of fusion occurred (the subjects saw two cats), divergence and convergence were subsequently measured.

The CSF was measured monocularly under photopic (85 cd/m^2) conditions with an Optec 6500 vision testing system (Stereo Optical Co, Inc, Chicago, IL) with the best correction. After 3 and 6 months of overnight OK lens use, CS was reassessed with the same process. The Optec 6500 CS chart test provides five rows of sine-wave gratings at spatial frequencies of 1.5, 3, 6, 12, and 18 cycles/degree (cpd).

All the measurements were performed by the same experienced observer (X.D.). All patients were assessed for keratography, CS, AC/A ratio, vergence range, and stereoacuity before treatment and at the 3- and 6-month follow-up visits.

Statistical Analysis

We conducted a power analysis to determine the minimum sample size needed to detect a significant effect, with a power of 0.80 and an alpha level of 0.05. The calculated sample size was based on previous studies in the field, which indicated a medium effect size. The calculated sample size was 30. All the statistical analyses were performed with IBM SPSS Statistics version 21. Continuous variables are expressed as the means±SD, and categorical variables are expressed as frequencies and percentages. The visual acuity data were transformed to logMAR[36] values for statistical analysis. The CSF and stereoacuity scores were log-transformed to fit normal distributions. The nonparametric repeated-measures Friedman M test was used to perform pairwise comparisons across the three time points for the preoperative values and the 3- and 6-month postoperative values. If the repeated measurements at the three time points had different distributions, we performed a *P* test for pairwise comparisons of multiple related samples. Pearson χ^2 Fisher tests were performed to compare

pretreatment and posttreatment AC/A ratios and stereoacuity scores. $P<0.05$ indicated statistical significance.

RESULTS

We enrolled 36 children, including eight boys and 28 girls, aged 9.68±1.26 years (8–12.5 years), and 64 eyes underwent OK in this study. Table 1 lists the patients' demographic and clinical characteristics. Among the 36 patients, before treatment, the mean average best-corrected visual acuity (logMAR) was 0±0.10 (range, 0–0.4). The mean spherical component of the refractive error was −2.58±1.15 D (range, −5.00 to −1.50 D), and the mean astigmatism was −0.71±1.15 D (range, −1.50 to 0 D). After treatment, the uncorrected visual acuity (logMAR) was −0.02-±0.03 (range, −0.15 to 0).

The data were assessed at three time points: before treatment, after 3 months of OK treatment, and after 6 months of OK treatment. The mean values of the parameters listed in Table 2, including the log contrast sensitivity (logCS), vergence amplitude, stereoacuity, and AC/A scores, were comparable pre- and posttreatment. Friedmann test was used to compare the CSF and vergence amplitudes at different time points, whereas chi-square tests were used to compare the AC/A ratios and stereoacuity scores at the three time points (Table 3).

The results did not reveal a significant difference in the CSF distribution among the patients at the three time points at 1.5 cpd (P=0.368), 3 cpd (P=0.779), 6 cpd (P=0.368), 12 cpd (P=0.947), or 18 cpd (P=0.368). The gray area represents the CS distributions at the five frequencies in the normal adult population (Fig. 2). Currently, there is no comparable database for normal children. The CS distributions were within the normal range at all three time points. Especially at low (1.5, 3 cpd) and medium (6 cpd) frequencies, after 3 months or 6 months, the logCS values following lens wear were slightly greater than those at baseline, but the differences were not significant. As shown in Figure 2, no significant increase was observed in the CSF after treatment with the OK lens, indicating that CSF was maintained or slightly increased after OK treatment. Thus, OK lenses do not reduce CS in the absence of significant lens decentration.

The divergence amplitude (baseline: −5.97±3.66; after 3 months: −5.94±2.19; after 6 months: −5.97±1.97) did not differ among the patients at the three time points (P=0.862). The divergence amplitude was normal before treatment and remained unchanged after OK lens wearing. However, the convergence amplitude ($P<0.05$) exhibited different distributions from the baseline value (8.08±6.77) to after 3 months (10.63±7.53) and 6 months (8.16±5.25) of lens wearing. The convergence range significantly increased after 3 months of lens wear (P=0.043) but did not further increase after 6 months of lens wear (P=0.662). This finding indicates that OK may improve the convergence function over short periods.

The stereoacuity scores were significantly different across the baseline and 3- and 6-month time points (χ^2=18.543, P=0.001). Moreover, we found that the stereoacuity scores significantly improved after three ($P<0.05$) and 6 months of lens wearing ($P<0.05$) with respect to those at baseline. However, they did not significantly improve further after 6 months of lens wear compared with 3 months ($P>0.05$). As shown in Figure 3a, 26 patients (72.22%) had good stereoacuity, 8 patients (22.22%) had medium stereoacuity, and two patients had low stereoacuity before treatment. After 3 months of OK lens wearing, 35 patients (97.22%) showed good stereoacuity, and only one patient had medium stereoacuity (Fig. 3b). As shown in Figure 3c, every patient achieved good stereoacuity after 6 months of lens wearing. This finding indicated that stable stereoacuity scores could be maintained after wearing OK lenses (Fig. 3).

None of the patients demonstrated high accommodative convergence at the three time points in our research. As shown in Table 2, 9 patients (25%) had a medium AC/A, and 27 patients (75%) had a low AC/A. After 3 months of OK lens wear, 13 patients (36.11%) presented a medium AC/A, and 23 patients (63.89%) presented a low AC/A. Nine patients (25%) had a medium AC/A, 27 patients (75%) had a low AC/A after 6 months of lens wearing. There were no significant differences in the AC/A ratio among the patients at baseline, after 3 months of lens wearing, or after 6 months of lens wearing (χ^2=1.448 P=0.485). This finding indicated that the AC/A ratio was maintained after OK treatment.

In conclusion, the stereoacuity score and convergence amplitude significantly improved after 3 months of OK lens wearing ($P<0.05$) relative to baseline but did not further increase after 6 months of lens wearing. By contrast, the CS and AC/A ratio

TABLE 2. *Mean Values of Parameters in Orthokeratology Lens Wearers*

	Baseline		3 ms		6 ms	
1.5 CPD	1.93±0.37		2.00±0.02		2.00±0	
3 CPD	2.15±0.41		2.22±0.03		2.23±0	
6 CPD	2.14±0.41		2.21±0.03		2.22±0.06	
12 CPD	1.87±0.41		1.91±0.19		1.88±0.21	
18 CPD	1.45±0.39		1.46±0.29		1.44±0.27	
Decentration (mm)			0.54±0.20		0.68±0.46	
Divergence amplitude (°)	−5.97±3.66		−5.94±2.19		−5.97±1.97	
Convergence amplitude (°)	8.08±6.77		10.63±7.53		8.16±5.25	
Stereopsis, log (random dot)	2.07±0.27		1.94±0.08		1.88±0.13	
Good stereoacuity, no. (%)	26	72.22%	35	97.22%	36	100%
Medium stereoacuity, no. (%)	8	22.22%	1	2.78%	0	0%
Low stereoacuity, no. (%)	2	5.56%	0	0%	0	0%
High AC/A	0	0%	0	0%	0	0%
Medium AC/A	9	25%	13	36.11%	9	25%
Low AC/A	27	75%	23	63.89%	27	75%

AC/A, accommodative convergence/accommodation; CPD, cycles/degree.

TABLE 3. P *Value for Changes in Visual Function Across the Three Time Periods*

	Overall Distribution		Baseline Versus 3 ms	Baseline Versus 6 ms
logCS				
1.5		P=0.368		
3		P=0.779		
6		P=0.368		
12		P=0.947		
18		P=0.368		
Divergence amplitude		P=0.862		
Convergence amplitude		**P=0.049**	**P=0.043**	P=0.662
AC/A	χ^2=1.448	P=0.485	P>0.05	P>0.05
Stereoacuity	χ^2=18.543	**P=0.001**	**P<0.05**	**P<0.05**

AC/A, accommodative convergence/accommodation; logCS, log contrast sensitivity. The Friedman M test was used to perform pairwise comparisions among three time points. Pearson Fisher tests were performed to compared pretreatment and posttreatment AC/A ratio and stereoacuity scores. P<0.05 indicated statistical significance.

did not significantly change across the baseline, 3-month follow-up, or 6-month follow-up time points (P>0.05).

DISCUSSION

The purpose of OK lenses is to control myopia progression in children. Few studies have described changes in stereoacuity scores and fusion ranges in children treated with OK lenses. This study was designed to evaluate the visual performance of OK lens wearers. Compared with those at baseline, the stereoacuity score and convergence amplitude were significantly improved after 3 months of OK lens wear (P<0.05) but did not further increase after 6 months of lens wear. By contrast, the CS and AC/A ratio did not significantly change across the baseline, 3-month follow-up, or 6-month follow-up time points (P>0.05).

Interestingly, there was no significant reduction in CS in patients with ideal lens fitting (decentration within 1.0 mm) when evaluated with the Optec 6500 vision testing system at the three different visits.

The research by Enns and MacDonald[37] showed that fixations occurred more rapidly and frequently in a local region of clarity than in a comparable blurred region in all tasks, which aligns with the blur ignored hypothesis. Similarly, we discovered no reduction in CS at any frequency in the OK lens–wearing children across the three visits. However, moderate decentration improves control over axial elongation.[38] An increase in OK-based decentration resulted in decreased CS after treatment.[39] Balancing CS and control axis elongation is essential for the participants. For young children, myopia control is urgently needed because of the rapid progression of the condition. Moreover, CS should still be considered a priority for adolescents, although myopia progresses more slowly for these individuals. The fusion range is the basis of binocular vision. Few studies have focused on the specific binocular vision of people wearing OK lenses while controlling the decentration of the treatment zone. Kang et al.[27] reported no significant difference in the divergence or convergence ranges of young adults who wore OK lenses for 28 days. In the present study, we found that the convergence range increased after 3 months of lens wearing and was maintained after 6 months of lens wearing. The divergence range was normal before treatment and remained unchanged at the investigated time points. In conclusion, OK with ideal lens fitting may improve convergence range over short periods.

Furthermore, we found that stereoacuity improved significantly in the patients. Twenty-six of 36 (72.22%) children had normal stereoacuity, 8 of 36 (22.22%) had medium stereoacuity, and 2 of 36 (5.56%) had low stereoacuity at the baseline visit with spectacle

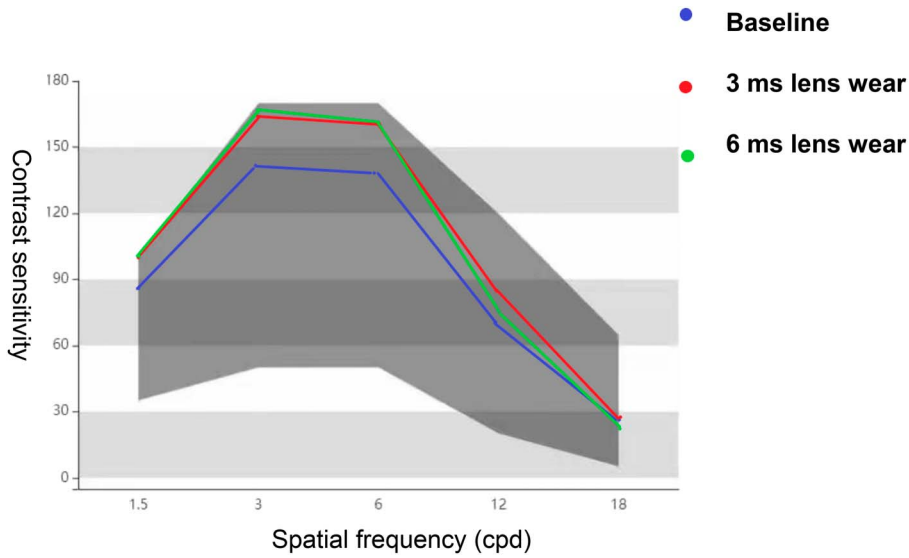

FIG. 2. Contrast sensitivity (in logCS) at five spatial frequencies of logCS for the three time points. logCS, log contrast sensitivity.

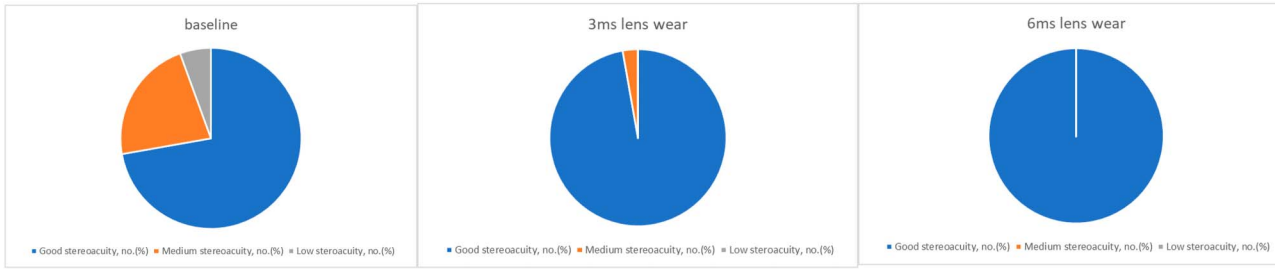

FIG. 3. Distributions of stereoacuity scores across the three time points. (a) Baseline; (b) 3 months after lens wear; and (c) 6 months after lens wear.

lens wearing before OK lens fitting. The stereoacuity score significantly improved after 6 months of lens wear. All patients achieved good stereoacuity scores at the 6-month follow-up visit. These findings agree with those of Kang et al.[27] and Song et al.[40] This phenomenon is evident in children with visual developmental plasticity. We excluded patients with anisometropia greater than 1.50 D. The following possible reasons for the improvement were considered: similar image sizes for the two eyes and more realistic images. We hypothesize that OK lens correction is similar to perceptual learning in real-life scenes. Moreover, we propose that children possess neural adaptations that better compensate for the optical aberrations induced by OK lens use. Some studies[41–43] have demonstrated that most patients who use OK lenses are satisfied with their vision-related quality of life. In our research, the ideal lens-fitting treatment significantly improved visual performance.

The AC/A ratio reflects the relationship between accommodation and vergence. Recent studies have shown that patients with myopia usually have higher AC/A ratios, and patients with progressive myopia have even higher AC/A ratios than patients with stable myopia.[44,45] In this study, the AC/A ratio remained unchanged in patients who wore OK lenses across the three periods. This finding is consistent with the findings of Kang et al.,[27] who reported no significant change in the AC/A ratio after 28 nights of OK lens wear compared with baseline. The changes in the AC/A ratio did not significantly differ after OK treatment (accommodation and vergence function in children treated with atropine combined with OK lenses). In our study, the AC/A values of all patients were intermediate or low, and no patient had a high AC/A ratio before OK lens use. Therefore, after wearing the OK lenses, there was no significant reduction in the AC/A ratio.

Several limitations of this study warrant consideration. A relatively small number of patients were included. Other limitations of this study include the lack of use of a random double-mask design, which prevents extrapolation of our results to all patients wearing OK lenses. Nevertheless, to our knowledge, this is the first study to report increased stereoacuity scores and enlarged fusion ranges in patients with ideal lens fitting.

CONCLUSIONS

Orthokeratology lenses can greatly improve the vision of patients with myopia, improve their stereoscopic vision, and increase their convergence range. However, the CS and AC/A ratio remained unchanged after OK lens wearing. These findings suggest that wearing OK lenses results in good visual quality with ideal lens fitting.

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REFERENCES

1. Guo B, Cheung SW, Kojima R, et al. One-year results of the Variation of Orthokeratology Lens Treatment Zone (VOLTZ) Study: A prospective randomised clinical trial. *Ophthalmic Physiol Opt* 2021;41:702–714.
2. Jakobsen TM, Moller F. Control of myopia using orthokeratology lenses in Scandinavian children aged 6 to 12 years. Eighteen-month data from the Danish Randomized Study: Clinical study Of Near-sightedness; TReatment with Orthokeratology Lenses (CONTROL study). *Acta Ophthalmol* 2022; 100:175–182.
3. Kinoshita N, Konno Y, Hamada N, et al. Efficacy of combined orthokeratology and 0.01% atropine solution for slowing axial elongation in children with myopia: A 2-year randomised trial. *Sci Rep* 2020;10:12750.
4. Lyu T, Wang L, Zhou L, et al. Regimen study of high myopia-partial reduction orthokeratology. *Eye Contact Lens* 2020;46:141–146.
5. Tan Q, Ng AL, Choy BN, et al. One-year results of 0.01% atropine with orthokeratology (AOK) study: A randomised clinical trial. *Ophthalmic Physiol Opt* 2020;40:557–566.
6. Tarrant J, Liu Y, Wildsoet CF. Orthokeratology can decrease accommodative lag in myopes. *Invest Ophthalmol Vis Sci* 2009;50:4294.
7. Carracedo G, Espinosa-Vidal TM, Martinez-Alberquilla I, et al. The topographical effect of optical zone diameter in orthokeratology contact lenses in high myopes. *J Ophthalmol* 2019;2019:1082472.
8. Gifford P, Tran M, Priestley C, et al. Reducing treatment zone diameter in orthokeratology and its effect on peripheral ocular refraction. *Cont Lens Anterior Eye* 2020;43:54–59.
9. Chang CF, Cheng HC. Effect of orthokeratology lens on contrast sensitivity function and high-order aberrations in children and adults. *Eye Contact Lens* 2020;46:375–380.
10. Ma W, Liao M, Jin HZ, et al. Evaluation of visual quality after overnight orthokeratology in pre-adolescent myopes. *Zhonghua Shiyan Yanke Zazhi* 2012;30:1104–1109.
11. Chen CM, Zhong H, Cheng LB, et al. Clinical research on overnight orthokeratology for vision quality. *Guoji Yanke Zazhi* 2015;15: 2127–2129.
12. Wang Y, Zhao K, Jin Y, et al. Changes of higher order aberration with various pupil sizes in the myopic eye. *J Refract Surg* 2003;19:S270–S274.
13. Nti AN, Berntsen DA. Optical changes and visual performance with orthokeratology. *Clin Exp Optom* 2020;103:44–54.
14. Llorente L, Barbero S, Cano D, et al. Myopic versus hyperopic eyes: Axial length, corneal shape and optical aberrations. *J Vis* 2004;4:288–298.
15. Comerford JP. Vision evaluation using contrast sensitivity functions. *Am J Optom Physiol Opt* 1983;60:394–398.

16. Karadeniz Ugurlu S, Kocakaya Altundal AE, Altin Ekin M. Comparison of vision-related quality of life in primary open-angle glaucoma and dry-type age-related macular degeneration. *Eye (Lond)* 2017;31:395–405.
17. Roh M, Selivanova A, Shin HJ, et al. Visual acuity and contrast sensitivity are two important factors affecting vision-related quality of life in advanced age-related macular degeneration. *PLoS One* 2018;13:e0196481.
18. Perez-Santonja JJ, Sakla HF, Alio JL. Contrast sensitivity after laser in situ keratomileusis. *J Cataract Refract Surg* 1998;24:183–189.
19. Verdon W, Bullimore M, Maloney RK. Visual performance after photorefractive keratectomy. A prospective study. *Arch Ophthalmol* 1996;114: 1465–1472.
20. Hiraoka T, Okamoto C, Ishii Y, et al. Contrast sensitivity function and ocular higher-order aberrations following overnight orthokeratology. *Invest Ophthalmol Vis Sci* 2007;48:550–556.
21. Peterson J. *The Effect of Blur on Visual Selective Attention*. Manhattan, Kansas: Department of Psychology, Kansas State University, 2016.
22. Ding W, Lu W, Ji R, et al. Effects of orthokeratology lens decentration induced by paracentral corneal asymmetry on axial length elongation. *Eye Contact Lens* 2023;49:181–187.
23. Chen Z, Xue F, Zhou J, et al. Prediction of orthokeratology lens decentration with corneal elevation. *Optom Vis Sci* 2017;94:903–907.
24. Tsai YY, Lin JM. Ablation centration after active eye-tracker-assisted photorefractive keratectomy and laser in situ keratomileusis. *J Cataract Refract Surg* 2000;26:28–34.
25. Lu W, Song G, Zhang Y, et al. The effect of orthokeratology lenses on optical quality and visual function in children. *Front Neurosci* 2023;17:1142524.
26. Yin Y, Zhao Y, Wu X, et al. One-year effect of wearing orthokeratology lenses on the visual quality of juvenile myopia: A retrospective study. *PeerJ* 2019;7:e6998.
27. Kang P, Watt K, Chau T, et al. The impact of orthokeratology lens wear on binocular vision and accommodation: A short-term prospective study. *Cont Lens Anterior Eye* 2018;41:501–506.
28. Gwiazda JE, Hyman L, Norton TT, et al. Accommodation and related risk factors associated with myopia progression and their interaction with treatment in COMET children. *Invest Ophthalmol Vis Sci* 2004;45:2143–2151.
29. Logan NS, Radhakrishnan H, Cruickshank FE, et al. IMI accommodation and binocular vision in myopia development and progression. *Invest Ophthalmol Vis Sci* 2021;62:4.
30. Brand P. The effect of orthokeratology on accommodative and convergence function: A clinic based pilot study. *Optom Vis Perform* 2013;1:162–167.
31. Gifford K, Gifford P, Hendicott PL, et al. Near binocular visual function in young adult orthokeratology versus soft contact lens wearers. *Cont Lens Anterior Eye* 2017;40:184–189.
32. Swarbrick HA. Orthokeratology review and update. *Clin Exp Optom* 2006; 89:124–143.
33. Sun L, Li ZX, Chen Y, et al. The effect of orthokeratology treatment zone decentration on myopia progression. *BMC Ophthalmol* 2022;22:76.
34. Kattan JM, Velez FG, Demer JL, et al. Relationship between binocular summation and stereoacuity after strabismus surgery. *Am J Ophthalmol* 2016;165:29–32.
35. von Noorden GK, Campos EC. *The Near Vision Complex*. 6th ed. St. Louis: CV Mosby, 2002.
36. Gregori NZ, Feuer W, Rosenfeld PJ. Novel method for analyzing snellen visual acuity measurements. *Retina* 2010;30:1046–1050.
37. Enns JT, MacDonald SC. The role of clarity and blur in guiding visual attention in photographs. *J Exp Psychol Hum Percept Perform* 2013;39: 568–578.
38. Zhang S, Zhang H, Li L, et al. Effect of treatment zone decentration on axial length growth after orthokeratology. *Front Neurosci* 2022;16:986364.
39. Hiraoka T, Mihashi T, Okamoto C, et al. Influence of induced decentered orthokeratology lens on ocular higher-order wavefront aberrations and contrast sensitivity function. *J Cataract Refract Surg* 2009;35:1918–1926.
40. Song Y, Zhu S, Yang B, et al. Accommodation and binocular vision changes after wearing orthokeratology lens in 8- to 14-year-old myopic children. *Graefes Arch Clin Exp Ophthalmol* 2021;259:2035–2045.
41. Santodomingo-Rubido J, Villa-Collar C, Gilmartin B, et al. Myopia control with orthokeratology contact lenses in Spain: A comparison of vision-related quality-of-life measures between orthokeratology contact lenses and single-vision spectacles. *Eye Contact Lens* 2013;39:153–157.
42. Zhao F, Zhao G, Zhao Z. Investigation of the effect of orthokeratology lenses on quality of life and behaviors of children. *Eye Contact Lens* 2018;44:335–338.
43. Santolaria E, Cervino A, Queiros A, et al. Subjective satisfaction in long-term orthokeratology patients. *Eye Contact Lens* 2013;39:388–393.
44. Mutti DO, Mitchell GL, Hayes JR, et al. Accommodative lag before and after the onset of myopia. *Invest Ophthalmol Vis Sci* 2006;47: 837–846.
45. Mutti DO, Mitchell GL, Jones-Jordan LA, et al. The response AC/A ratio before and after the onset of myopia. *Invest Ophthalmol Vis Sci* 2017;58: 1594–1602.