Zhong et al. BMC Ophthalmology (2025) 25:145
https://doi.org/10.1186/s12886-025-03974-4

BMC Ophthalmology

RESEARCH

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Age and initial spherical equivalent influence the axial length elongation in children aged 9–17 years undergoing orthokeratology therapy

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Abstract

Background Orthokeratology (Ortho-K) lenses are increasingly used in children to manage myopia by reshaping the cornea and potentially influencing axial length changes. This study investigated factors affecting axial length changes in children aged 9–17 years wearing Ortho-K lenses, focusing on age, initial spherical value, and other parameters.

Methods This retrospective analysis included 84 children (49 males, 35 females, aged 9–17 years) who wore Ortho-K lenses at the Tenth Affiliated Hospital of Southern Medical University between January 2018 and December 2019, with a minimum follow-up of 12 months. Subjects met specific inclusion criteria, including myopia ≤ 6.00 DS and astigmatism ≤ 1.75 DC. Comprehensive ocular examinations were conducted, and axial length changes were measured using an IOL-Master500.

Results Univariate analysis revealed significant factors influencing axial length changes, including age ($F = -5.476$, $P < 0.001$) and initial equivalent spherical value ($F = 8.314$, $P = 0.004$). Mixed-effects model analysis confirmed that the duration of lens wear (mean: 18.3 ± 5.4 months), age, initial spherical lens value, and initial axial length significantly impacted axial length ($P < 0.05$). The mean axial length elongation was 0.18 ± 0.09 mm/year overall, with the low-elongation group showing 0.10 ± 0.05 mm/year and the high-elongation group showing 0.27 ± 0.06 mm/year. Children with lower initial spherical values and older individuals demonstrated less axial elongation.

Conclusion Age and initial equivalent spherical value are critical factors influencing axial length changes in children aged 9–17 years who use Ortho-K lenses. Understanding these factors can enhance the effectiveness of Ortho-K treatment in managing myopia progression. Further studies are needed to optimize lens design and treatment protocols for personalized myopia control.

Keywords Orthokeratology, Myopia progression, Axial length, Peripheral defocus, Refractive error

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Introduction

The use of orthokeratology (Ortho-K) lenses in children has garnered significant interest due to their potential to influence axial length changes, a critical factor in the progression of myopia. Ortho-K involves the use of specially designed contact lenses to temporarily reshape the cornea, aiming to reduce refractive errors [1]. This method is thought to work by altering peripheral defocus, potentially reducing stimuli for axial elongation and myopia development [2].

Research has identified several factors that may influence axial length changes in patients wearing Ortho-K lenses. Age has been shown to play a significant role, with Holmes et al. demonstrating a significant inverse correlation between age and axial elongation [3]. Other studies have suggested that initial equivalent spherical value may also be important [4, 5]. Additionally, the duration of lens wear, initial spherical lens value, and initial axial length have been associated with varying degrees of axial length change in children undergoing Ortho-K treatment [6].

Studies have further demonstrated the efficacy of Ortho-K in controlling myopia progression, particularly in children with moderate to high astigmatism [7]. The impact of Ortho-K on corneal curvature and spherical refraction has also been investigated, highlighting the potential of these lenses to induce changes in peripheral retinal defocus that may contribute to myopia control [8, 9].

While previous studies have examined various factors influencing axial length changes during orthokeratology treatment, this study uniquely focuses on a Chinese pediatric population in a clinical setting with standardized follow-up protocols. Comprehensive analysis of multiple potential factors, including age, refractive parameters, and treatment duration, provides valuable insights for clinical practice in populations with high myopia prevalence. Additionally, our approach of examining both binocular and monocular factors offers a more nuanced understanding of treatment effects.

This study aims to enhance our understanding of the factors influencing axial length changes during orthokeratology treatment, which may help clinicians optimize treatment protocols for individual patients and improve the predictability of treatment outcomes. By identifying key predictors of axial elongation, we hope to contribute to the development of more personalized approaches to myopia management in young patients.

Methods

Subjects

This retrospective study analyzed 84 children (49 males, 35 females) aged 9–17 years (mean age: 12.41 ± 2.18 years) who were fitted with orthokeratology lenses at the Tenth Affiliated Hospital of Southern Medical University (Dongguan People's Hospital) between January 2018 and December 2019 and completed a minimum follow-up period of 12 months. The sample size of 84 participants was determined based on previous similar studies investigating factors affecting axial length changes in orthokeratology treatment. A post-hoc power analysis using G*Power (Version 3.1) confirmed that this sample size achieved 85% power to detect medium effect sizes (f^2=0.15) with $\alpha = 0.05$ in our mixed-effects model with 8 predictors.

The inclusion criteria were age ≥ 9 years, intraocular pressure < 21 mmHg, myopia ≤ 6.00 DS, with-the-rule astigmatism ≤ 1.75 DC, against-the-rule astigmatism ≤ 0.75 DC, minimum follow-up period of 12 months with at least two axial length measurements separated by 12 months, and the ability to adhere to orthokeratology lens care standards, including proper lens handling and maintenance. Exclusion criteria included a history of eye diseases (e.g., ophthalmia, high myopia, keratoconus, dacryocystitis), active ocular surface lesions, corneal or fundus lesions, ocular hypertension, systemic diseases (e.g., autoimmune disorders, diabetes), or the use of medications affecting vision correction.

Orthokeratology lens fitting and follow-up

All participants underwent comprehensive examinations, including visual acuity, external eye, anterior segment, corneal topography, intraocular pressure, mydriatic fundus, and refraction tests. These included assessments of the maximum plus-to-maximum visual acuity (MPMVA), red–green balance, precise astigmatism using the Jackson Cross Cylinder (JCC), and binocular balance. Basic axial length and corneal endothelial cell density were measured. The mydriatic subjective refraction, corneal K values, asphericity of the corneal surface, and iris diameter were evaluated, followed by trial lens fitting.

Customized orthokeratology lenses (Mengdaiwei, Hefei OVCTEK Company; Boston XOP, oxygen permeability coefficient: 100 × 10^-11 [cm².mlO$_2$]/[s.ml.mmHg]; four-zone five-arc design; diameter: 10.2–11.0 mm; corneal curvature: 42.00-45.5 D) were fitted by professional optometrists based on these parameters. Patients received training on lens care, insertion, and removal and were reminded of necessary precautions. Follow-ups were scheduled on the first day and at 1 week, 1 month, 3 months, 6 months, and then biannually thereafter. The mean follow-up duration was 18.3 ± 5.4 months (range: 12–30 months).

Uncorrected visual acuity, intraocular pressure, refraction under small pupils, corneal curvature, and corneal health (via slit lamp examination) were assessed. Axial length was measured every 6 months using the IOL-Master 500.

Outcome measures

Patient demographics (age, sex, family history), baseline refractive error (spherical and cylindrical components), average corneal K value, and axial length were recorded. Axial length change was calculated as the difference between the initial and final measurements. The cohort average for axial length elongation (0.18 ± 0.09 mm/year) was calculated from the 84 participants in this study and used as the threshold for dividing participants into low-elongation and high-elongation groups. This approach allows for the identification of factors associated with above-average and below-average elongation rates within our clinical population.

Statistical analysis

The data were analyzed using SPSS 22.0. Descriptive statistics are presented as the mean ± SD. Student's t test and one-way ANOVA were used to compare continuous variables between groups. A mixed-effects model was employed to assess the influence of various factors on axial length change.

The mixed-effects model was constructed with patient ID as a random intercept to account for the correlation between measurements from the same individual. Fixed effects included eye (left vs. right), sex, initial age, family history of myopia, baseline spherical equivalent refraction (SER), baseline cylindrical power, baseline average K value, and baseline axial length. The duration of Ortho-K lens wear was included as a continuous variable (in years). Model assumptions, including normality of residuals and homoscedasticity, were verified using diagnostic plots. The model was selected based on the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Statistical significance was defined as $p < 0.05$.

Table 1 Participant characteristics and Follow-up information

Characteristic	Value
Total participants	84
Sex	
- Male	49 (58.3%)
- Female	35 (41.7%)
Age groups	
- Late childhood (9–11 years)	41 (48.8%)
- Early adolescence (12–14 years)	32 (38.1%)
- Mid adolescence (15–17 years)	11 (13.1%)
Mean age (years)	12.41 ± 2.18
Family history of myopia	56 (66.7%)
Initial refractive error	
- Mean spherical equivalent (D)	3.64 ± 1.27
- Mean cylindrical power (D)	0.51 ± 0.45
Follow-up duration (months)	18.3 ± 5.4 (range: 12–30)
Axial length elongation (mm/year)	
- Overall	0.18 ± 0.09
- Low-elongation group	0.10 ± 0.05
- High-elongation group	0.27 ± 0.06
Inter-eye difference in axial elongation (mm)	0.12 ± 0.08

Results

Participant characteristics and Follow-up information

The demographic and clinical characteristics of the 84 participants are presented in Table 1. The study population consisted of 49 males (58.3%) and 35 females (41.7%) with a mean age of 12.41 ± 2.18 years. The participants were distributed across age groups as follows: 41 (48.8%) in late childhood (9–11 years), 32 (38.1%) in early adolescence (12–14 years), and 11 (13.1%) in mid adolescence (15–17 years). The mean follow-up duration was 18.3 ± 5.4 months, ranging from 12 to 30 months.

The mean axial length elongation for all participants was 0.18 ± 0.09 mm/year. The low-elongation group ($n = 46$) demonstrated a mean elongation of 0.10 ± 0.05 mm/year, while the high-elongation group ($n = 38$) showed a mean elongation of 0.27 ± 0.06 mm/year. This difference was statistically significant ($p < 0.001$) and clinically meaningful in terms of myopia progression control.

Univariate analysis of factors influencing axial length elongation during orthokeratology therapy in children

The change in axial length (AL) was calculated as the difference between the initial and final measurements for each participant. Patients were divided into two groups: those with AL elongation below the cohort average ("low-elongation group") and those with AL elongation above the cohort average ("high-elongation group"). Univariate analysis was conducted to identify factors associated with AL elongation in both eyes of children undergoing Ortho-K.

The analysis revealed significant differences between the low- and high-elongation groups with respect to age and baseline SER (Table 2). Specifically, the high-elongation group was significantly younger (mean ± SD; 10.49 ± 1.42 years vs. 12.27 ± 2.17 years, respectively; $p < 0.001$) and had a more myopic baseline SER (mean ± SD; 2.95 ± 1.42 D vs. 3.53 ± 1.18 D, respectively; $p = 0.004$) than the low-elongation group. These findings suggest that younger age and greater baseline myopia may be risk factors for greater AL elongation during Ortho-K in children.

Univariate analysis of factors influencing unilateral axial length elongation

Univariate analysis was conducted to identify factors associated with right and left eye axial length (AL) elongation in children undergoing Ortho-K. Similar to the findings for binocular AL elongation, significant differences were observed between the low- and

Table 2 Univariate analysis of the influencing factors of wearing orthokeratology lens on binocular axial length changes in children

Variables	Low-elongation group	High-elongation group	F value	P value
Average corneal curvature				
Mean ± SD	43.25 ± 1.24	43.23 ± 1.28	0.017	0.897
Range	39.85 ~ 46.27	40.18 ~ 46.37		
Interquartile range	42.43 ~ 44.10	42.36 ~ 44.13		
Median	43.47	43.13		
Initial spherical equivalent (D)				
Mean ± SD	3.53 ± 1.18	2.95 ± 1.42	8.314	0.004
Range	1.00 ~ 6.13	0.50 ~ 5.75		
Interquartile range	2.75 ~ 4.25	1.78 ~ 4.25		
Median	3.50	2.50		
Initial axial length (mm)				
Mean ± SD	24.96 ± 0.77	24.77 ± 0.82	2.567	0.111
Range	23.16 ~ 27.14	22.87 ~ 26.72		
Interquartile range	24.43 ~ 25.39	24.12 ~ 25.44		
Median	24.97	24.65		
Initial age (years)				
Mean ± SD	12.27 ± 2.17	10.49 ± 1.42	-5.476	< 0.001
Range	8.00 ~ 17.00	8.00 ~ 15.00		
Interquartile range	11.00 ~ 14.00	10.00 ~ 11.00		
Median	12.00	10.00		
Initial cylindrical power (D)				
Mean ± SD	0.55 ± 0.50	0.46 ± 0.40	0.880	0.379
Range	0.00 ~ 2.00	0.00 ~ 1.50		
Interquartile range	0.00 ~ 1.00	0.00 ~ 0.75		
Median	0.50	0.50		
Mean axial elongation (mm/year)				
Mean ± SD	0.10 ± 0.05	0.27 ± 0.06	17.92	< 0.001

Table 3 Distribution of eyes in elongation groups

Category	Number	Percentage
Both eyes in low-elongation group	36	42.9%
Both eyes in high-elongation group	33	39.2%
Right eye in low, left eye in high	8	9.5%
Right eye in high, left eye in low	7	8.4%
Total	84	100%

high-elongation groups regarding age and baseline spherical equivalent refraction (SER) of the left eye ($p < 0.001$ and $p = 0.018$, respectively). For the right eye, only age was identified as a significant factor influencing AL elongation ($p < 0.001$).

Among the 84 participants, 15 (17.9%) had their right and left eyes categorized in different elongation groups. The distribution of eyes in different elongation categories is presented in Table 3.

Mixed-Effects model analysis of factors influencing axial length elongation

A mixed-effects model was used to examine the influence of various factors on axial length (AL) elongation in children undergoing Ortho-K. Patient characteristics (sex, initial age, family history of myopia, baseline spherical equivalent refraction [SER], baseline cylindrical power, baseline average K value, and baseline AL) were included as fixed effects, while the duration of Ortho-K lens wear (in years) and intereye differences in AL elongation were included as random effects.

The mixed-effects model revealed that several factors significantly influenced AL elongation ($p < 0.05$) (Table 4). These factors included the eye (left vs. right), duration of Ortho-K lens wear, age, baseline SER, and baseline AL.

The specific influence of each variable on AL elongation is detailed in Table 5. Notably, each year of Ortho-K lens wear was associated with an estimated 0.027 mm increase in AL (95% CI, 0.013 to 0.040), while each one-year increase in age was associated with a 0.086 mm decrease in AL elongation (95% CI, -0.110 to -0.062). Additionally, for each diopter increase in baseline SER, AL elongation increased by an estimated 0.084 mm (95% CI, 0.016 to 0.153). These findings underscore the importance of considering age, baseline refractive error, and duration of lens wear when assessing the risk of AL elongation in children undergoing Ortho-K.

Discussion

The new material of orthokeratology lenses provides oxygen delivery that can minimize or even eliminate hypoxic stress and corneal edema during the night. Therefore, therapy involving nighttime wearing has become feasible [9, 10]. Using this technology, patients can wear lenses while sleeping at night to temporarily reshape their cornea and reduce myopia. Orthokeratology lens treatment allows myopia patients to experience significant alleviation of their symptoms upon waking, allowing for clear vision throughout the day without the need for correction. This approach has great advantages and is an attractive solution for young myopic patients in their daily learning and daily life [11, 12]. Studies have confirmed that the progression rate of myopia in children is closely related to changes in the axial length of the eye, and reducing the rate of change in the axial length of the eye is conducive to delaying the development of myopia [13]. Therefore, this study aimed to explore the factors influencing the effect of wearing orthokeratology lenses on AL changes in children aged 9–17 years and to provide a scientific basis for the use of orthokeratology lenses in the treatment of pediatric myopia.

In this study, 84 children aged 9–17 years who wore orthokeratology lenses at our hospital were selected. The subjects' sex, initial age at which they wore

Table 4 Test results of fixed effects in the mixed effects model

Effects	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Chi-square	F value	Pr > Chi-square	Pr > F
EYE	1	78.2	4.94	4.94	0.0263	0.0292
Group	2	81.9	7.13	3.57	0.0282	0.0327
Sex	1	80.6	0.35	0.35	0.5525	0.5542
AGE	1	84.4	35.14	35.14	< 0.0001	< 0.0001
ESPH	1	119	4.96	4.96	0.0259	0.0278
AK	1	113	0.98	0.98	0.3218	0.3240
FHCATN	1	78.7	0.15	0.15	0.6939	0.6950
BAXISOC	1	104	205.20	205.20	< 0.0001	< 0.0001

Note: EYE: eye; Group: number of years wearing orthokeratology lens; Sex: sex; AGE: age; ESPH: initial equivalent spherical lens value; AK: initial average corneal curvature; FHCATN: Family history; BAXISOC: initial axis length value

Table 5 Solutions of fixed effects in the mixed effects model

Effects	Eye	Number of years wearing orthokeratology lens	Estimated value	Standard error	Degree of freedom	t value	Pr >|t|
EYE	0		-2.6431	3.3853	110	-0.78	0.4366
EYE	1		-2.6863	3.3848	110	-0.79	0.4291
Group		1	-0.2707	0.1124	83.2	-2.41	0.0183
Group		2	-0.1841	0.07869	80.8	-2.34	0.0218
Group		3	0	.	.	.	.
Sex			-0.03709	0.06245	80.6	-0.59	0.5542
AGE			-0.08622	0.01454	84.4	-5.93	< 0.0001
ESPH			0.08438	0.03788	119	2.23	0.0278
AK			0.04062	0.04100	113	0.99	0.3240
FHCATN			0.01563	0.03971	78.7	0.39	0.6950
BAXISOC			1.1079	0.07734	104	14.32	< 0.0001

Note: EYE: eye; Group: number of years wearing orthokeratology lens; Sex: sex; AGE: age; ESPH: initial equivalent spherical lens value; AK: initial average corneal curvature; FHCATN: Family history; BAXISOC: initial axis length value

orthokeratology lenses, family history, initial equivalent spherical lens value, initial cylindrical lens value, initial average K value, and initial axial length value were collected. Single-factor and mixed-effect models were used to analyze the factors influencing axial length changes in the patients. According to the average axis length change before and after wearing the orthokeratology lens, the patients were divided into two groups: the group with less than average axial length change and the group with greater than average axial length change. The results confirmed that in the two groups, the influencing factors of axial length changes in both eyes and only the left eye were age and initial equivalent spherical lens value, while the influencing factor of axial length change in the right eye was age. This finding is consistent with previous literature reports showing that the axial length of the eye further increases with age and that growth and development are accelerated in childhood and early adolescence, further exacerbating the increase in axial length during this period [14, 15].

Our findings regarding the influence of age on axial length elongation are consistent with several previous studies [3, 14, 15], supporting the notion that younger children experience faster axial elongation despite orthokeratology treatment. This consistency across different populations strengthens the evidence for age as a critical factor in predicting treatment outcomes.

Our finding that the duration of orthokeratology lens wear was positively associated with axial elongation may seem counterintuitive, as one might expect a cumulative protective effect over time. However, this result likely reflects the natural growth pattern of the eye during childhood and adolescence, which continues despite treatment. Similar patterns have been reported by Charm and Cho [16], who suggested that while orthokeratology may slow myopia progression relative to no treatment, the absolute axial elongation still increases with time, particularly in younger children.

To further identify the influencing factors of axial length changes in children after wearing orthokeratology lenses, we established a mixed effect model based on the changes in axial length between the last and first visits. The results showed that the difference between the left and right eyes, the number of years spent wearing orthokeratology lenses, age, initial equivalent spherical lens value, and initial axial length affected the change in axial length after wearing orthokeratology lenses. The influence of the difference between the left and right eyes and age on axial length changes was consistent with the results of previous single-factor analyses in this study, and the length of time wearing orthokeratology lenses mainly affected the treatment cycle. Patients with different initial equivalent spherical lens values and axial lengths may have different axial length changes because orthokeratology lenses have different effects on patients with varying degrees of myopia. In this study, we analyzed the factors influencing the effect of wearing orthokeratology lenses on axial length changes in Chinese myopic children, providing a theoretical basis for analyzing the corrective effect of wearing orthokeratology lenses in clinical practice.

The inter-eye differences observed in our study (17.9% of participants had eyes categorized in different elongation groups) highlight the importance of considering each eye individually in clinical practice. These differences may reflect asymmetric myopia progression or differential responses to orthokeratology treatment between eyes. Our mixed-effects modeling approach appropriately accounted for these differences by including the eye (left vs. right) as a fixed effect.

This study has several limitations that should be acknowledged. First, the retrospective design limits our ability to control for all potential confounding factors. Second, the sample size, while sufficient for our primary analyses based on power calculations, may limit the detection of smaller effect sizes or complex interactions between variables. Third, the follow-up duration varied among participants (range: 12–30 months), although we attempted to account for this variation in our mixed-effects model. Fourth, we did not measure compliance with lens wear, which could significantly impact treatment outcomes. Additionally, the myopia and development of children are closely related to their environment [17–19]; therefore, in future studies, we plan to include the patient's height, weight, growth region, close-range eye use, eye use time, time spent engaging in outdoor activities, and diet in the comprehensive analysis. Future prospective studies with larger sample sizes, standardized follow-up protocols, and measures of compliance are needed to confirm and extend our findings.

In conclusion, this study suggested that differences between the left and right eyes, number of years wearing orthokeratology lenses, age, initial equivalent spherical lens value, and initial axial length value may influence the effect of wearing orthokeratology lenses on axial length changes in children aged 9–17 years. This study provides a theoretical reference for analyzing the therapeutic effect of wearing orthokeratology lenses in myopic children and may help clinicians optimize treatment protocols for individual patients.

Acknowledgements
Not applicable.

Author contributions
Guangbin Zhong: Conceptualization, Data curation, Formal analysis, Methodology, Investigation, Writing– original draft preparation. Ruinian Zheng: Conceptualization, Data curation, Formal analysis, Methodology, Investigation, Writing– original draft preparation. Linyi Luo: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing– review & editing.

Funding
This research was funded by the Guangdong Basic and Applied Basic Research Foundation (2021A1515010156 and 2022A1515140134).

Data availability
The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study adhered to the tenets of the Declaration of Helsinki and was conducted in accordance with institutional and national ethical standards. The Ethics Committee of the Tenth Affiliated Hospital of Southern Medical University (Dongguan People's Hospital) approved this retrospective chart review and waived the requirement for specific research consent due to the retrospective nature of the study. All patients and their guardians had previously provided standard clinical informed consent for orthokeratology treatment and the use of de-identified clinical data for research purposes at the time of initial treatment.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 22 October 2024 / Accepted: 10 March 2025
Published online: 19 March 2025

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