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LONGITUDINAL EVALUATION OF AXIAL LENGTH CHANGES DURING ORTHOKERATOLOGY TREATMENT IN MYOPIC CHILDREN: A PROSPECTIVE OBSERVATIONAL STUDY

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ABSTRACT

Background: Orthokeratology is widely used for myopia management in children. Although axial elongation may continue during orthokeratology treatment, the magnitude of elongation varies among individuals and may be influenced by demographic, clinical, and behavioral factors.

Objective: To longitudinally evaluate changes in axial length over 12 months in myopic children undergoing orthokeratology treatment and to identify factors associated with greater axial elongation.

Methods: This prospective longitudinal observational study was conducted from July 2024 to June 2026 at Shifa Eye Care Clinic, Mardan, Pakistan. A total of 120 myopic children aged 8–14 years were enrolled and fitted with overnight orthokeratology lenses. Participants were followed for 12 months, with axial length measured in the right eye at baseline and at 3, 6, and 12 months using the same optical biometer and measurement protocol. Longitudinal changes in axial length were evaluated, and demographic, clinical, and behavioral factors associated with 12-month axial elongation were assessed using univariable and multivariable analyses.

Results: The mean age was 10.8±1.9 years, mean baseline spherical equivalent was −3.21±1.24 D, and mean baseline right-eye axial length was 24.63±0.82 mm. Mean axial length increased to 24.66±0.82 mm at 3 months, 24.70±0.83 mm at 6 months, and 24.82±0.85 mm at 12 months, corresponding to a mean 12-month axial elongation of 0.19±0.13 mm ($p<0.001$). Greater axial elongation was observed among children aged 8–10 years than among those aged 11–14 years (0.24±0.14 vs. 0.16±0.11 mm, $p=0.004$), those with a positive family history of myopia than those without (0.22±0.13 vs. 0.15±0.11 mm, $p=0.017$), and those with poor than good lens compliance (0.33±0.14 vs. 0.16±0.11 mm, $p<0.001$). Children reporting ≥2 hours/day of outdoor activity had lower axial elongation than those reporting <2 hours/day (0.14±0.10 vs. 0.21±0.13 mm, $p=0.012$). In multivariable analysis, younger age, lower baseline myopia, positive family history, and poor lens compliance were independently associated with greater axial elongation, whereas ≥2 hours/day of outdoor activity was associated with lower elongation.

Conclusion: Axial length increased progressively over twelve months in children undergoing orthokeratology treatment, with greater elongation observed in younger children and those with a positive family history of myopia, lower baseline myopia, and poorer lens compliance. Greater outdoor activity was associated with less axial elongation. As this study had no untreated or conventional-correction control group, the observed axial elongation should be interpreted as change occurring during orthokeratology treatment and should not be used alone to infer the efficacy of orthokeratology in controlling axial elongation.

KEYWORDS: Orthokeratology; Myopia; Axial length; Axial elongation; Myopic children; Myopia management

INTRODUCTION

Myopia is one of the most common refractive errors worldwide and represents an increasing public health concern. Global estimates have projected that approximately half of the world's population may be myopic by 2050, with a substantial increase in the prevalence of high myopia. The clinical importance of progressive childhood myopia extends beyond refractive error because excessive axial elongation is associated with an increased lifetime risk of ocular complications, including myopic maculopathy, retinal detachment, cataract, and glaucoma [1,2]. Consequently, limiting excessive axial elongation has become an important objective of contemporary myopia management.

Orthokeratology (OK) is a non-surgical optical intervention that uses specially designed, highly oxygen-permeable rigid gas-permeable contact lenses, typically worn overnight, to temporarily and reversibly reshape the anterior corneal surface and provide reduced refractive error during the daytime after lens removal [3]. In addition to correcting refractive error, OK has been extensively investigated as a myopia-control intervention in children. Evidence from randomized controlled trials and systematic reviews indicates that children receiving OK generally demonstrate less axial elongation than those receiving conventional single-vision correction [4]. A systematic review and meta-analysis of randomized controlled trials reported significantly less axial elongation with OK than with control correction at 6, 12, 18, and 24 months, with pooled between-group differences of −0.11, −0.16, −0.23, and −0.28 mm, respectively [4].

Importantly, the myopia-control effect of OK should be understood as a reduction in the rate of axial elongation rather than complete prevention of ocular growth. Children undergoing OK may continue to experience axial elongation during treatment, and the magnitude of this residual elongation varies considerably among individuals. Therefore, longitudinal assessment of axial length provides an objective measure of ocular growth during myopia management and may help identify children who exhibit greater residual axial elongation despite treatment.

Several demographic and ocular factors have been associated with differences in axial elongation during OK treatment. In a study of 1,176 children aged 8–14 years, including 588 children treated with OK and 588 wearing single-vision spectacles, the OK group demonstrated 39% less axial elongation over one year than the spectacle group. Younger age was associated with greater axial elongation in both groups, while shorter baseline axial length was associated with greater axial elongation in younger children undergoing OK [5]. Other studies have also reported associations between age, baseline spherical equivalent, and baseline axial length and subsequent axial elongation during OK treatment [6,7,8].

Treatment-related optical factors may additionally influence the magnitude of axial elongation. The size and decentration of the corneal treatment zone have been associated with axial elongation in children undergoing OK, with treatment-zone characteristics potentially contributing to differences in treatment response [9]. These findings support the concept that individual responses to OK are multifactorial and may reflect a combination of age, baseline ocular characteristics, lens-related factors, and other behavioral or environmental influences.

Longitudinal observations have further demonstrated substantial inter-individual variability in axial elongation during OK treatment. In a retrospective study of 600 children receiving OK, the mean axial length increased by 0.19±0.15 mm during the first year of treatment. Axial elongation was greater during winter than summer, suggesting that environmental and seasonal factors may also influence ocular growth during OK treatment [10]. More recent long-term evidence has suggested that early axial-length changes may provide clinically useful information regarding subsequent axial growth in children undergoing OK, although such findings require confirmation in prospective studies [11].

Despite substantial evidence that OK reduces axial elongation compared with conventional correction, individual children may continue to exhibit measurable axial growth during treatment. Understanding the factors associated with greater residual axial elongation may therefore assist clinicians in identifying children who require closer monitoring and may contribute to more individualized approaches to myopia management. Accordingly, the present study longitudinally evaluated changes in axial length over 12 months among myopic children undergoing OK treatment and examined demographic, refractive, family-history, treatment-compliance, and outdoor-activity factors associated with greater axial elongation..

Objective

To longitudinally evaluate changes in axial length over 12 months in myopic children undergoing orthokeratology treatment and to identify demographic and clinical factors associated with greater axial elongation during treatment..

METHODOLOGY

Study Design and Participants

This prospective longitudinal observational study was conducted at Shifa Eye Care Clinic, Mardan, Pakistan, from July 2024 to June 2026. Participants were consecutively recruited from July 2024 to June 2025 and followed prospectively for 12 months from the date of orthokeratology lens fitting, with the final participant completing the 12-month follow-up in June 2026. A total of 120 children with myopia were enrolled using non-probability consecutive sampling. Children of either sex aged 8–14 years, with myopia ranging from −1.00 to −6.00 diopters (D), astigmatism ≤1.50 D, normal ocular health, and no previous history of orthokeratology treatment were eligible for inclusion. Participants were required to be clinically suitable for overnight orthokeratology lens wear.

Children were excluded if they had keratoconus or other corneal abnormalities, active ocular infection or inflammation, significant dry eye disease, amblyopia, strabismus, previous ocular surgery or ocular trauma, systemic disease likely to affect ocular development, or concurrent use of other myopia-control interventions, including atropine.

Data Collection

The study was conducted in accordance with the principles of the Declaration of Helsinki after obtaining approval from the relevant institutional ethics committee. Written informed consent was obtained from the

parents or legal guardians of all participants. Demographic and clinical information was recorded at baseline using a standardized data-collection proforma. The recorded variables included age, sex, family history of myopia, duration of myopia, daily screen time, and daily outdoor activity. Baseline ophthalmic assessment included unaided and best-corrected visual acuity, cycloplegic refraction, spherical equivalent (SE), slit-lamp examination, keratometry, corneal topography, and axial length measurement. Cycloplegic refraction was performed using 1% cyclopentolate hydrochloride eye drops. One drop was instilled in each eye twice at an interval of 5 minutes, and cycloplegic refraction was performed approximately 30 minutes after the second instillation following confirmation of adequate cycloplegia. Spherical equivalent was calculated as the spherical component plus half of the cylindrical component.

Axial length was measured using an IOLMaster 500 optical biometer (Carl Zeiss Meditec AG, Jena, Germany). Three consecutive measurements were obtained for each eye using the same standardized measurement technique, and the mean of the three measurements was recorded as the axial length for that visit. The same instrument and measurement protocol were used at all subsequent visits. All eligible participants were fitted with Paragon CRT orthokeratology lenses (Paragon Vision Sciences, a CooperVision Specialty EyeCare company), reverse-geometry rigid gas-permeable lenses manufactured from HDS 100 high-oxygen-permeable material. Lens parameters were selected individually according to baseline refractive error, keratometric measurements, and corneal topography, following the manufacturer's fitting guidelines. Participants and their parents or guardians were instructed regarding overnight lens wear, lens handling, cleaning, disinfection, storage, and scheduled follow-up visits. Participants were instructed to wear the orthokeratology lenses overnight for approximately 8 hours per night. Follow-up examinations were scheduled at 3, 6, and 12 months after initiation of orthokeratology treatment. At each follow-up visit, ocular health, lens centration and fit, treatment compliance, and any adverse events or complications were assessed. Treatment compliance was recorded based on the reported number of nights of lens wear. Compliance was calculated as the percentage of prescribed nights on which the lenses were worn and was classified as good when ≥80% of prescribed nights were completed and poor when <80%. Axial length was reassessed at 3, 6, and 12 months using the same optical biometer and standardized measurement protocol. For the statistical analysis, only the right eye of each participant was included, and the right eye was selected consistently for all participants. The primary outcome was the change in right-eye axial length from baseline to 12 months. Twelve-month axial elongation was calculated as:

12-month axial elongation (mm) = right-eye axial length at 12 months − right-eye baseline axial length.

Changes in right-eye axial length at 3 and 6 months were considered secondary longitudinal outcomes.

Statistical Analysis

Data were entered, cleaned, and analyzed using IBM SPSS Statistics version 26. Continuous variables were assessed for normality before statistical analysis. Normally distributed continuous variables were summarized as mean ± standard deviation (SD), whereas non-normally distributed variables were presented as median and interquartile range (IQR). Categorical variables were summarized as frequencies and percentages. Baseline demographic and clinical characteristics were summarized descriptively. Only the right eye of each participant was included in the statistical analysis, thereby ensuring that each participant contributed one independent ocular observation. Changes in right-eye axial length across the four assessment points (baseline, 3 months, 6 months, and 12 months) were evaluated using repeated-measures analysis of variance (ANOVA) when the assumptions of parametric analysis were satisfied. The assumption of sphericity was assessed using Mauchly's test, and appropriate corrections were applied when necessary. When the assumptions required for repeated-measures ANOVA were not satisfied, the Friedman test was used as the non-parametric alternative. Where appropriate, post-hoc pairwise comparisons were performed with adjustment for multiple comparisons. The association between 12-month right-eye axial elongation and potential explanatory variables, including age, sex, baseline spherical equivalent, baseline axial length, duration of myopia, family history of myopia, screen time, outdoor activity, and treatment compliance, was initially assessed using Pearson's or Spearman's correlation coefficient, as appropriate. Appropriate parametric or non-parametric tests were used for comparisons involving categorical variables. To identify factors independently associated with greater 12-month axial elongation, multivariable linear regression analysis was performed with right-eye 12-month axial elongation as the dependent variable. Candidate explanatory variables were selected based on clinical relevance and/or their association with axial elongation in univariable analyses. Adjusted regression coefficients (β), 95% confidence intervals (CIs), and corresponding p-values were reported. Multicollinearity among explanatory variables was assessed before construction of the final model. A two-sided p-value <0.05 was considered statistically significant.

RESULTS

A total of 120 myopic children were included in the analysis. The mean age was 10.8±1.9 years, with 55 (45.8%) males and 65 (54.2%) females. A family history of myopia was present in 72 (60.0%) participants. The mean duration of myopia was 2.4±1.1 years, mean spherical equivalent (SE) was −3.21±1.24 D, and mean baseline right-eye axial length was 24.63±0.82 mm. The mean baseline keratometry was 43.18±1.37 D. Mean daily screen time was 4.3±1.6 hours, whereas mean daily outdoor activity was 1.5±0.7 hours. Good orthokeratology lens compliance was observed in 101 (84.2%) participants.

Table 1. Baseline demographic and clinical characteristics of participants

Characteristic	Value
Number of participants	120
Age (years)	10.8±1.9
Sex	
Male	55 (45.8%)
Female	65 (54.2%)
Family history of myopia	72 (60.0%)
Duration of myopia (years)	2.4±1.1
Spherical Equivalent (D)	−3.21±1.24
Baseline right-eye axial length (mm)	24.63±0.82
Baseline keratometry (D)	43.18±1.37
Daily screen time (hours)	4.3±1.6
Daily outdoor activity (hours)	1.5±0.7
Good orthokeratology lens compliance	101 (84.2%)

Values are presented as mean±SD or n (%), as appropriate.

Mean right-eye axial length increased progressively during the 12-month follow-up, from 24.63±0.82 mm at baseline to 24.66±0.82 mm at 3 months, 24.70±0.83 mm at 6 months, and 24.82±0.85 mm at 12 months. The overall longitudinal change in axial length across the four assessment points was statistically significant ($p<0.001$). Compared with baseline, mean right-eye axial elongation was 0.03±0.05 mm at 3 months ($p=0.018$), 0.07±0.08 mm at 6 months ($p<0.001$), and 0.19±0.13 mm at 12 months ($p<0.001$).

Table 2. Longitudinal changes in right-eye axial length during orthokeratology

Follow-up	Right-eye axial length, mm	Change from baseline, mm	P value*
Baseline	24.63±0.82	—	—
3 months	24.66±0.82	0.03±0.05	0.018
6 months	24.70±0.83	0.07±0.08	<0.001
12 months	24.82±0.85	0.19±0.13	<0.001

*P values represent comparisons with baseline. The overall longitudinal time-effect was statistically significant ($p<0.001$).

At 12 months, mean right-eye axial elongation was greater among children aged 8–10 years than among those aged 11–14 years (0.24±0.14 vs. 0.16±0.11 mm, $p=0.004$). Axial elongation did not differ significantly between males and females (0.20±0.13 vs. 0.18±0.12 mm, respectively; $p=0.438$). Participants with baseline SE between −1.00 and −3.00 D had greater axial elongation than those with SE >−3.00 to −6.00 D (0.22±0.13 vs. 0.16±0.12 mm, $p=0.021$). Participants with a positive family history of myopia also had greater axial elongation than those without a family history (0.22±0.13 vs. 0.15±0.11 mm, $p=0.017$). Poor orthokeratology lens compliance was associated with greater axial elongation compared with good compliance (0.33±0.14 vs. 0.16±0.11 mm, $p<0.001$). Participants reporting ≥2 hours/day of outdoor activity had lower axial elongation than those reporting <2 hours/day (0.14±0.10 vs. 0.21±0.13 mm, $p=0.012$).

Table 3. Twelve-month right-eye axial elongation according to selected demographic, clinical, and behavioral factors

Factor	Category	n	Right-eye axial elongation, mm	P value
Age	8–10 years	49	0.24±0.14	0.004
	11–14 years	71	0.16±0.11	
Sex	Male	55	0.20±0.13	0.438
	Female	65	0.18±0.12	
Baseline SE	−1.00 to −3.00 D	58	0.22±0.13	0.021
	>−3.00 to −6.00 D	62	0.16±0.12	
Family history of myopia	Yes	72	0.22±0.13	0.017
	No	48	0.15±0.11	
Orthokeratology lens compliance	Good	101	0.16±0.11	<0.001
	Poor	19	0.33±0.14	
Outdoor activity	<2 hours/day	83	0.21±0.13	0.012
	≥2 hours/day	37	0.14±0.10	

Values are presented as mean±SD. SE, spherical equivalent.

Multivariable linear regression was performed to identify factors independently associated with 12-month right-eye axial elongation. Younger age, less baseline myopia, positive family history of myopia, and poor orthokeratology lens compliance were associated with greater axial elongation, whereas ≥2 hours/day of outdoor activity was associated with lower axial elongation. Baseline axial length was not independently associated with 12-month axial elongation. In the current model, the regression coefficients were β=0.028 (95% CI, 0.011–0.045; p=0.002) for younger age, β=0.021 (95% CI, 0.004–0.038; p=0.016) for less baseline myopia, β=0.049 (95% CI, 0.010–0.088; p=0.014) for positive family history, β=0.142 (95% CI, 0.087–0.197; p<0.001) for poor compliance, and β=−0.043 (95% CI, −0.080 to −0.006; p=0.023) for ≥2 hours/day of outdoor activity. Baseline axial length was not statistically significant (β=0.017; 95% CI, −0.006–0.040; p=0.145).

Table 4. Multivariable linear regression analysis of factors associated with twelve-month right-eye axial elongation

Predictor	β	95% CI	P value
Younger age, per 1-year decrease	0.028	0.011 to 0.045	0.002
Less baseline myopia, per 1-D decrease in myopia	0.021	0.004 to 0.038	0.016
Positive family history of myopia	0.049	0.010 to 0.088	0.014
Poor orthokeratology lens compliance	0.142	0.087 to 0.197	<0.001
Outdoor activity ≥2 hours/day	−0.043	−0.080 to −0.006	0.023
Baseline right-eye axial length, per 1 mm increase	0.017	−0.006 to 0.040	0.145

β, regression coefficient; CI, confidence interval.

DISCUSSION

The present prospective longitudinal study evaluated changes in axial length over 12 months in 120 myopic children aged 8–14 years undergoing overnight orthokeratology (OK) treatment and examined demographic and clinical factors associated with greater axial elongation. Mean right-eye axial length increased progressively from 24.63±0.82 mm at baseline to 24.82±0.85 mm at 12 months, corresponding to a mean axial elongation of 0.19±0.13 mm. Axial elongation was 0.03±0.05 mm at 3 months and 0.07±0.08 mm at 6 months, indicating a gradual increase throughout the follow-up period. The magnitude of 12-month elongation in our cohort is consistent with a recent study of 600 children receiving OK, in which mean axial elongation during the first year was also 0.19±0.15 mm [10]. This close similarity supports the observation that measurable axial growth may continue during the first year of OK treatment despite ongoing treatment.

The observed axial elongation should not be interpreted as evidence that OK is ineffective. Because our study did not include an untreated or alternative-treatment control group, the natural rate of axial elongation in these children cannot be determined. Randomized controlled trials have demonstrated that children receiving OK generally have less axial elongation than those receiving conventional correction, with a meta-analysis of randomized trials reporting approximately 0.16 mm less axial elongation at 12 months with OK compared with controls [4]. Therefore, our findings describe axial growth occurring during OK treatment rather than the treatment effect itself. The progressive increase in axial length observed at 3, 6, and 12 months also emphasizes the importance of serial axial-length monitoring rather than relying solely on refractive or visual outcomes.

Younger age was associated with greater axial elongation in our study. Children aged 8–10 years demonstrated greater mean elongation than those aged 11–14 years (0.24±0.14 vs. 0.16±0.11 mm), and younger age remained independently associated with greater elongation in the multivariable analysis. This finding is consistent with previous studies showing greater axial growth among younger children undergoing OK [5,12]. Younger children generally have greater residual ocular growth potential, which may contribute to the greater axial elongation observed during childhood. These findings support closer biometric monitoring of younger children receiving myopia-management treatment.

Less baseline myopia was also associated with greater axial elongation in the present study. Children with SE between −1.00 and −3.00 D had greater elongation than those with SE >−3.00 to −6.00 D, and this association remained significant after adjustment for other factors. Previous studies have reported variable relationships between baseline refractive error and axial elongation during OK [5,12]. Because baseline SE is related to age, axial length, and the stage of ocular development, this association may partly reflect differences in these underlying characteristics. Therefore, our finding should be interpreted as an association rather than evidence that lower baseline myopia directly causes greater axial growth.

A positive family history of myopia was associated with greater axial elongation, with mean elongation of 0.22±0.13 mm compared with 0.15±0.11 mm among children without a family history. This association remained significant in the multivariable analysis. Parental myopia is a well-established risk factor for childhood myopia, reflecting the contribution of familial susceptibility to myopic eye growth [13]. Although family history is not a modifiable factor, its association with greater axial elongation may help identify children who require closer longitudinal monitoring.

Poor OK lens compliance showed the strongest association with greater axial elongation in our study. Participants with poor compliance had mean elongation of 0.33±0.14 mm compared with 0.16±0.11 mm among those with good compliance, and poor compliance remained independently associated with greater elongation.

Regular overnight lens wear is important for maintaining the intended corneal reshaping and optical treatment effect of OK. Previous longitudinal evidence has also suggested greater axial elongation among children with lower OK compliance [14, 15]. Nevertheless, because compliance in our study was based on reported lens-wearing behavior and the study was observational, this finding should be interpreted as an association rather than a causal effect.

Greater outdoor activity was associated with lower axial elongation. Children reporting ≥2 hours/day of outdoor activity had mean elongation of 0.14±0.10 mm compared with 0.21±0.13 mm among those reporting <2 hours/day, and the association remained significant after adjustment for other factors. This finding is consistent with previous evidence linking greater outdoor exposure with slower axial elongation in children [16,17]. However, outdoor activity was self- or parent-reported and may be associated with other lifestyle factors; therefore, the present study cannot establish a causal relationship or determine whether 2 hours/day represents a specific therapeutic threshold.

No significant association was found between sex and axial elongation, and baseline axial length was not independently associated with 12-month elongation. These findings indicate that, within our cohort, age, baseline refractive status, family history, treatment compliance, and outdoor activity may be more relevant to variation in axial growth than sex or baseline axial length alone. Differences from previous studies may be related to variations in age, refractive status, sample size, follow-up duration, and statistical methodology [8,18,19,20].

The study has several strengths, including its prospective longitudinal design, standardized axial-length measurements using the same instrument, predefined follow-up intervals, and assessment of multiple potential explanatory factors. However, several limitations should be acknowledged. The single-arm observational design prevents direct estimation of the efficacy of OK relative to natural myopic progression or other myopia-control interventions. The sample size was relatively modest, particularly in the poor-compliance group, and behavioral variables such as outdoor activity and compliance were based on reported information. The follow-up period was limited to 12 months, and only the right eye was included to ensure statistical independence. Longer-term controlled studies with larger samples are needed to confirm these associations and determine their persistence over time.

CONCLUSION

Right-eye axial length increased progressively over 12 months among myopic children undergoing OK treatment, with a mean axial elongation of 0.19±0.13 mm. Greater axial elongation was associated with younger age, less baseline myopia, positive family history of myopia, and poor OK lens compliance, whereas greater outdoor activity was associated with lower axial elongation. These findings highlight the variability in axial growth during OK treatment and support regular axial-length monitoring, particularly among younger children and those with suboptimal treatment adherence..

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