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Posterior Rather Than Anterior Ocular Growth Characterizes Han–Uyghur Differences in Childhood Myopic Development: A Longitudinal Study

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Research Article

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Posterior Rather Than Anterior Ocular Growth Characterizes Han–Uyghur Differences in Childhood Myopic Development: A Longitudinal Study

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Key Points

1.Han schoolchildren showed faster axial elongation and greater myopic progression than Uyghur schoolchildren over approximately two years.

2.The between-group difference in axial elongation was concentrated predominantly in vitreous chamber growth, with comparatively similar anterior ocular development.

3.The longitudinal findings remained robust after adjustment for baseline refractive status and sensitivity analyses addressing extreme and influential observations.

Abstract

Purpose: To compare longitudinal refractive and ocular biometric trajectories between Han and Uyghur schoolchildren in Xinjiang and to determine whether between-group differences in axial elongation are concentrated in the posterior rather than anterior ocular compartment.

Methods: This longitudinal cohort included 638 children (316 Han and 322 Uyghur) examined annually in 2023, 2024, and 2025. Cycloplegic spherical equivalent (SE) and ocular biometric parameters were assessed. Longitudinal differences were evaluated using linear mixed-effects models. Ocular-component decomposition was performed using $\Delta AL = \Delta VCD + \Delta ACD + \Delta LT$, with $\Delta ACD + \Delta LT$ defined as the combined anterior ocular dimension. Between-group component differences were estimated using 5,000 ethnicity-stratified bootstrap resamples.

Results: Han children showed greater myopic progression than Uyghur children (ΔSE, −0.74 ± 0.83 vs −0.46 ± 1.02 D; $P < 0.001$) and greater axial elongation (ΔAL, 0.54 ± 0.32 vs 0.43 ± 0.27 mm; $P < 0.001$). Annual SE change (−0.376 vs −0.232 D/year) and AL elongation (0.270 vs 0.213 mm/year) were also greater in Han children (both $P < 0.001$). The Han–Uyghur difference in ΔAL was 0.113 mm (95% bootstrap CI, 0.069–0.159), closely matched by the difference in ΔVCD of 0.122 mm (95% CI, 0.073–0.170). In contrast, the combined anterior ocular dimension differed by only −0.008 mm (95% CI, −0.027 to 0.010), and its longitudinal trajectory did not differ

significantly between groups (P = 0.309). Adjustment for ΔAL reduced the ethnicity coefficient for ΔSE by 55.2%.
Conclusions: Han children demonstrated greater myopic progression and faster axial elongation than Uyghur children. The between-group difference in axial elongation was concentrated predominantly in vitreous chamber elongation, whereas anterior ocular development remained comparable. These findings identify differential posterior ocular growth as a principal biometric feature characterizing Han–Uyghur differences in childhood refractive development.

Keywords: Myopia; Axial length; Vitreous chamber depth; Ocular biometry; Ethnicity; Longitudinal study

Introduction

Myopia has become a major global public health concern, particularly among children and adolescents. Recent large-scale evidence indicates a continuing increase in childhood and adolescent myopia worldwide, with a particularly high burden in East Asia (1). Greater myopic severity and longer axial length are associated with substantially increased risks of myopic macular degeneration, retinal detachment, glaucoma, and visual impairment (2). Longitudinal studies in Chinese schoolchildren have further demonstrated substantial refractive progression and axial elongation during the primary-school years (3). Characterizing ocular growth during this critical developmental period is therefore important for understanding childhood myopic development.

Axial elongation is a central structural correlate of childhood myopic progression. Longitudinal studies have shown that changes in axial length (AL) closely accompany refractive progression and vary with age, refractive status, region, and ethnicity (4-6). Large longitudinal datasets such as the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) study have likewise demonstrated distinct age-related AL trajectories across racial and ethnic groups (7). These findings indicate that childhood ocular growth trajectories are not uniform across populations.

Xinjiang provides a particularly informative setting in which to investigate such variation. Han and Uyghur children live within the same broad geographic region yet have repeatedly shown marked differences in refractive status and ocular biometry. In a school-based study of 67,102 children from multiple ethnic groups in Xinjiang, Han children had a higher prevalence of myopia, longer AL, and higher axial length-to-corneal radius (AL/CR) ratios than Uyghur children (8). Another regional study involving more than 84,000 Han and Uyghur students similarly reported higher prevalences of both myopia and high myopia among Han participants (9). Additional work from Xinjiang has identified differences in familial and behavioral characteristics associated with myopia (10). However, most of this evidence is cross-sectional and therefore cannot determine whether these biometric differences reflect distinct longitudinal ocular growth trajectories.

The anatomical basis of such differential axial growth also remains incompletely understood. Total AL reflects the combined dimensions of the anterior chamber, crystalline lens, and vitreous chamber, which undergo coordinated developmental changes during childhood (11-13). During emmetropization, axial and vitreous chamber growth may be partly compensated by crystalline lens thinning and loss of lens power, whereas this balance changes around the onset of myopia (11, 12). Longitudinal studies have further shown that vitreous chamber depth (VCD) may increase in close parallel with total axial elongation, while changes in anterior chamber depth and lens thickness are comparatively smaller (13-15).

Whether the previously observed Han–Uyghur differences in ocular biometry reflect distinct longitudinal trajectories, and whether the between-group difference in axial elongation is concentrated predominantly in the posterior ocular compartment, remain unclear. Addressing these questions may help distinguish population differences in the magnitude and anatomical distribution of ocular growth.

Accordingly, the present longitudinal study compared refractive and ocular biometric trajectories in Han and Uyghur schoolchildren across three annual examinations from 2023 to 2025. We evaluated longitudinal changes in spherical equivalent (SE), AL, VCD, anterior chamber depth (ACD), lens thickness (LT), corneal radius (CR), and the AL/CR ratio. We further sought to anatomically localize the ocular component underlying the between-group difference in axial elongation by decomposing total axial change into vitreous chamber and anterior ocular components and examined the association between axial elongation and refractive progression.

We hypothesized that Han children would demonstrate greater myopic progression and axial elongation than Uyghur children, and that this between-group difference in axial elongation would be concentrated predominantly in the posterior rather than anterior ocular compartment.

2. Methods

2.1 Study Design and Participants

This longitudinal cohort study was conducted in three primary schools in Urumqi, Xinjiang Uygur Autonomous Region, China, between March 2023 and March 2025. Participants were recruited using a cluster-sampling approach. The parent cohort underwent a baseline examination in March 2023 and two annual follow-up examinations in March 2024 and March 2025.

For the present analysis, 638 children of Han or Uyghur ethnicity with longitudinal ocular biometric data were included, comprising 316 Han and 322 Uyghur participants.

Eligibility for the parent cohort was determined according to the original study protocol. For the present analysis, participants were required to have sufficient baseline and longitudinal ocular biometric data for inclusion. Children with major ocular or systemic conditions that could substantially affect refractive development or ocular biometric measurements were excluded.

Exclusion criteria included inability to cooperate with ocular examinations; a history of ocular trauma, refractive surgery, or intraocular surgery; amblyopia, strabismus, abnormal ocular motility, congenital cataract, or aphakia; uveitis or major retinal, macular, or optic fundus abnormalities; and ocular biometric abnormalities that precluded reliable measurement. Participants who could not complete follow-up examinations were considered lost to follow-up according to the parent study protocol.

The original cohort study was approved by the Ethics Committee of the Affiliated Hospital of Traditional Chinese Medicine of Xinjiang Medical University in 2019 (approval No. 2019XE0151-2). The present postgraduate research project subsequently received additional ethical approval from the same committee in 2025 (approval No. 2025XE-GS094). Written informed consent was obtained from participants and/or their legal guardians. The study was conducted in accordance with the principles of the Declaration of Helsinki.

2.2 Follow-up Schedule and Ophthalmic Examinations

Participants underwent three examinations: baseline in March 2023, the first follow-up approximately 12 months later in March 2024, and the second follow-up approximately 24 months after baseline in March 2025. A ±1-month window was permitted for each follow-up examination.

At each visit, the same standardized examination protocol was applied, including visual acuity, cycloplegic refraction, axial length (AL), anterior chamber depth (ACD), lens thickness (LT), corneal curvature, central corneal thickness (CCT), pupil diameter, intraocular pressure, slit-lamp examination, and fundus examination. Assessments were performed by trained ophthalmologists, technical staff, and nursing personnel using the same instruments and designated examiners whenever possible to maximize longitudinal comparability.

2.3 Cycloplegic Refraction

Cycloplegia was induced using 1% cyclopentolate hydrochloride eye drops (Cyclogyl; Novartis Manufacturing N.V., Puurs-Sint-Amands, Belgium). One drop was instilled every 10 minutes for a total of three instillations.

Cycloplegic refraction was measured using a tabletop autorefractor (Topcon RM800, Topcon Corporation, Japan) by a trained optometrist. Cycloplegic autorefraction is an

established method for refractive assessment in pediatric populations (16). The autorefractor was calibrated using a model eye before examinations each day.

Refraction was measured in both eyes, with the right eye examined first. Three consecutive measurements were obtained for each eye and averaged; measurements were repeated if any two differed by more than 0.50 D.

Spherical equivalent (SE) was calculated as spherical power plus one-half of the cylindrical power. A more negative change in SE during follow-up indicated greater myopic refractive progression.

2.4 Ocular Biometric Measurements and Eye Selection

Ocular biometric parameters were measured using the TOMEY OA-2000 optical biometer (Tomey Corporation, Nagoya, Japan). Previous studies have demonstrated high repeatability and reproducibility of the OA-2000 for measurements of axial length, anterior chamber depth, lens thickness, and keratometric parameters (17).

Axial length was measured three consecutive times and averaged; measurements were repeated if the difference between any two values exceeded 0.02 mm. Anterior chamber depth, flat keratometry (K1), steep keratometry (K2), lens thickness, central corneal thickness, and pupil diameter were likewise measured three times and averaged.

Mean keratometry was calculated from K1 and K2, and corneal radius (CR) was derived from the corresponding keratometric measurements. Vitreous chamber depth (VCD) was calculated as AL − ACD − LT. The axial length-to-corneal radius ratio (AL/CR) and anterior chamber depth-to-axial length ratio (ACD/AL) were calculated as dimensionless biometric indices.

Slit-lamp biomicroscopy and fundus examination were performed to identify anterior- and posterior-segment abnormalities that could affect ocular measurements or study eligibility.

Because measurements from fellow eyes are not statistically independent, one eye per participant was included in the analysis. The right eye was preferentially selected; when right-eye data were unavailable or incomplete for a given analysis, the left eye was used instead.

2.5 Outcomes and Longitudinal Changes

The primary outcomes were longitudinal changes in spherical equivalent (SE) and axial length (AL) and whether their trajectories differed between Han and Uyghur children.

Secondary ocular biometric outcomes included vitreous chamber depth (VCD), anterior chamber depth (ACD), lens thickness (LT), corneal radius (CR), and the AL/CR ratio.

For baseline-to-final analyses, longitudinal changes were calculated as the 2025 value minus the corresponding 2023 baseline value. Thus, ΔSE, ΔAL, ΔVCD, ΔACD, ΔLT, ΔCR, and changes in biometric ratios represented total change over the approximately 2-year observation period.

To characterize the anatomical distribution of axial elongation, the combined anterior ocular dimension was defined as ACD + LT, with longitudinal change calculated as ΔACD + ΔLT. Because VCD was derived as AL − ACD − LT, total axial change could be decomposed as ΔAL = ΔVCD + ΔACD + ΔLT.

For analyses incorporating all three examinations, time was coded continuously as 0, 1, and 2 years for the 2023, 2024, and 2025 visits, respectively.

2.6 Quality Control

All investigators underwent standardized training before data collection, and a pilot examination was conducted to ensure consistency in measurement procedures. Each ocular parameter was assigned to designated examiners whenever feasible.

Instruments were calibrated before daily examinations, and repeatability assessments were performed in a subset of children with different refractive states. Data collection forms were reviewed for missing or implausible values, and electronic data entry incorporated predefined logical and automatic validation procedures.

The same examination protocol, equipment, and measurement procedures were maintained across all three annual examinations to maximize longitudinal reliability and comparability.

2.7 Statistical Analysis

All analyses were performed using R software. Continuous variables were summarized as mean ± standard deviation or median (Q1, Q3), as appropriate, and categorical variables as number (%). Between-group comparisons were performed using Welch’s two-sample t-test, Pearson’s chi-squared test, or the Wilcoxon rank-sum test, as appropriate. Baseline-to-final changes were calculated as the 2025 value minus the corresponding 2023 baseline value.

Longitudinal differences in SE and ocular biometric parameters were assessed using linear mixed-effects models including time, ethnicity, time × ethnicity, baseline age, and sex as fixed effects, with a participant-specific random intercept. Time was modeled continuously as 0, 1, and 2 years, and model-estimated annual slopes and 95% confidence intervals were derived.

To anatomically localize the between-group difference in axial elongation, ocular-component decomposition was performed using ΔAL = ΔVCD + ΔACD + ΔLT, with the combined anterior ocular dimension defined as ΔACD + ΔLT. Between-group differences in these components were estimated with percentile 95% confidence intervals from 5,000 ethnicity-stratified bootstrap resample. The longitudinal trajectory of the combined anterior ocular dimension (ACD + LT) was additionally assessed using a mixed-effects model with the same fixed-effect structure and participant-specific random intercept.

Sequential multivariable linear regression models were used to evaluate ocular biometric changes associated with ΔSE. Model 1 included ethnicity, baseline age, and sex; Model 2 additionally included ΔAL; and Model 3 further included ΔACD, ΔLT, and ΔCR. The change in the ethnicity coefficient after inclusion of ΔAL was quantified descriptively; no formal mediation analysis was performed. A ΔAL × ethnicity interaction was tested, and ΔVCD was examined in a complementary model because VCD was mathematically derived from AL, ACD, and LT.

Multicollinearity was assessed using variance inflation factors. HC3 heteroscedasticity-consistent standard errors were applied to the fully adjusted model because residual diagnostics indicated mild heteroscedasticity. Analyses of ΔSE used complete cases, and participants with and without available ΔSE were compared by baseline age, sex, and ethnicity. A sensitivity analysis excluded participants with baseline SE > +0.75 D or missing baseline refractive data. Additional sensitivity analyses were conducted to assess the robustness of the primary findings. For axial length, the longitudinal mixed-effects model was further adjusted for baseline spherical equivalent (SE), and a model allowing participant-specific random intercepts and random slopes for time was fitted. A complementary baseline-to-final regression model assessed ethnic-group differences in axial elongation after adjustment for baseline age, sex, and baseline SE.

For refractive progression, additional regression models included baseline SE as a covariate. The influence of extreme refractive changes was evaluated by repeating the analyses after excluding participants with an absolute change in SE greater than 3.0 D. Influential observations were also identified using Cook's distance, with a threshold of 4/n, and the regression analyses were repeated after their exclusion. Changes in the ethnicity coefficient following adjustment for axial elongation were quantified descriptively. All tests were two-sided, with $P < 0.05$ considered statistically significant.

3. Results

3.1 Baseline Characteristics

Baseline characteristics stratified by ethnicity are shown in Table 1. A total of 638 children were included, comprising 316 Han and 322 Uyghur participants. Baseline age and sex distribution were comparable between the two groups (both $P > 0.05$).

Significant between-group differences were observed in several refractive and ocular biometric parameters. Uyghur children had a more hyperopic spherical equivalent than Han children [0.13 (−0.13, 0.38) D vs −0.13 (−0.25, 0.25) D; P < 0.001], as well as shorter axial length (23.11 ± 0.73 vs 23.25 ± 0.72 mm; P = 0.016), shorter vitreous chamber depth (16.04 ± 0.69 vs 16.17 ± 0.72 mm; P = 0.019), shallower anterior chamber depth (3.51 ± 0.22 vs 3.54 ± 0.20 mm; P = 0.032), and greater lens thickness (3.56 ± 0.15 vs 3.53 ± 0.15 mm; P = 0.015).

The AL/CR ratio was lower in Uyghur than Han children (2.94 ± 0.07 vs 2.96 ± 0.08; P = 0.003), whereas mean keratometry, corneal radius, ACD/AL ratio, central corneal thickness, and pupil diameter did not differ significantly between groups (all P > 0.05).

Table 1. Baseline demographic and ocular biometric characteristics of Han and Uyghur children

Characteristic	Overall N = 638	Han N = 316	Uyghur N = 322	P value
Age, years	8.51 ± 1.12	8.50 ± 1.08	8.52 ± 1.16	0.8
Sex				0.3
Male	346 (54%)	178 (56%)	168 (52%)	
Female	292 (46%)	138 (44%)	154 (48%)	
Spherical equivalent, D	0.00 (−0.25, 0.25)	−0.13 (−0.25, 0.25)	0.13 (−0.13, 0.38)	<0.001
Axial length, mm	23.18 ± 0.73	23.25 ± 0.72	23.11 ± 0.73	0.016
Vitreous chamber depth, mm	16.11 ± 0.71	16.17 ± 0.72	16.04 ± 0.69	0.019
Anterior chamber depth, mm	3.52 ± 0.21	3.54 ± 0.20	3.51 ± 0.22	0.032
Lens thickness, mm	3.55 ± 0.15	3.53 ± 0.15	3.56 ± 0.15	0.015
Mean keratometry, D	43.03 ± 1.44	43.03 ± 1.42	43.03 ± 1.46	>0.9
Corneal radius, mm	7.85 ± 0.26	7.85 ± 0.26	7.85 ± 0.27	>0.9
AL/CR ratio	2.95 ± 0.07	2.96 ± 0.08	2.94 ± 0.07	0.003
ACD/AL ratio	0.152 ± 0.008	0.152 ± 0.008	0.152 ± 0.008	0.3
Central corneal thickness,	530 ± 32	528 ± 33	532 ± 31	0.2

Characteristic	Overall N = 638	Han N = 316	Uyghur N = 322	P value
μm				
Pupil diameter, mm	6.30 ± 0.89	6.28 ± 0.87	6.32 ± 0.91	0.7

Values are presented as mean ± SD, n (%), or median (Q1, Q3), as appropriate. Between-group comparisons were performed using Welch's two-sample t-test, Pearson's chi-squared test, or the Wilcoxon rank-sum test, as appropriate.

3.2 Changes in Refractive and Ocular Biometric Parameters During Follow-up

During follow-up, Han children showed a significantly greater myopic shift in spherical equivalent than Uyghur children (−0.74 ± 0.83 D vs −0.46 ± 1.02 D; P < 0.001). Axial elongation was also greater in Han children (0.54 ± 0.32 mm vs 0.43 ± 0.27 mm; P < 0.001), as was vitreous chamber elongation (0.51 ± 0.33 mm vs 0.39 ± 0.30 mm; P < 0.001). The increase in the AL/CR ratio was likewise greater in Han children (0.06 ± 0.04 vs 0.05 ± 0.04; P = 0.001).

In contrast, changes in anterior chamber depth and lens thickness were comparable between the two groups (both P > 0.05). The combined anterior ocular dimension (ΔACD + ΔLT) also showed no significant between-group difference (0.029 ± 0.104 mm in Han children vs 0.037 ± 0.134 mm in Uyghur children; P = 0.387). Small but statistically significant between-group differences were observed in changes in mean keratometry (−0.14 ± 0.38 D vs −0.09 ± 0.22 D; P = 0.028) and corneal radius (0.026 ± 0.072 mm vs 0.016 ± 0.040 mm; P = 0.033), whereas the change in the ACD/AL ratio did not differ significantly between groups (P = 0.093).

These unadjusted longitudinal comparisons showed greater myopic progression, axial elongation, and vitreous chamber elongation in Han children, whereas anterior ocular changes were similar between groups.

Table 2. Changes in refractive and ocular biometric parameters during follow-up, stratified by ethnicity

Characteristic	Overall N = 638	Han N = 316	Uyghur N = 322	P value
ΔSE, D(n=625)	−0.60 ± 0.94	−0.74 ± 0.83	−0.46 ± 1.02	<0.001
ΔAL, mm	0.48 ± 0.30	0.54 ± 0.32	0.43 ± 0.27	<0.001
ΔVCD, mm	0.45 ± 0.32	0.51 ± 0.33	0.39 ± 0.30	< 0.001
ΔACD, mm	0.10 ± 0.13	0.10 ± 0.11	0.10 ± 0.15	>0.9

Characteristic	Overall N = 638	Han N = 316	Uyghur N = 322	P value
ΔLT, mm	−0.07 ± 0.10	−0.07 ± 0.11	−0.07 ± 0.10	0.3
ΔACD + ΔLT, mm	0.033 ± 0.120	0.029 ± 0.104	0.037 ± 0.134	0.387
ΔMeanK, D	−0.11 ± 0.31	−0.14 ± 0.38	−0.09 ± 0.22	0.028
ΔCR, mm	0.021 ± 0.058	0.026 ± 0.072	0.016 ± 0.040	0.033
ΔAL/CR	0.05 ± 0.04	0.06 ± 0.04	0.05 ± 0.04	0.001
ΔACD/AL	0.001 ± 0.006	0.001 ± 0.005	0.002 ± 0.007	0.093

Values are presented as mean ± standard deviation (SD). The total cohort comprised 638 children (316 Han and 322 Uyghur). Baseline-to-final spherical equivalent change (Δ SE) was available for 625 children (309 Han and 316 Uyghur); the remaining 13 children had incomplete refractive data. All other outcomes were analyzed using the available data for each variable. Between-group comparisons were performed using Welch's two-sample t-test. Δ indicates change from baseline to the final follow-up examination.

3.3 Ethnic Differences in Longitudinal Trajectories

Linear mixed-effects models were used to evaluate between-group differences in longitudinal refractive and ocular biometric trajectories, accounting for repeated measurements and adjusting for baseline age and sex (Table 3).

A significant time-by-ethnicity interaction was observed for spherical equivalent (SE; $P < 0.001$). The estimated annual change in SE was −0.376 D/year (95% CI, −0.435 to −0.318) in Han children and −0.232 D/year (95% CI, −0.290 to −0.174) in Uyghur children, corresponding to a faster myopic shift in Han children.

Axial length increased by 0.270 mm/year (95% CI, 0.258–0.283) in Han children and 0.213 mm/year (95% CI, 0.201–0.226) in Uyghur children. The time-by-ethnicity interaction was significant ($\beta = −0.0567$ mm/year; $P < 0.001$), corresponding to slower axial elongation in Uyghur children.

Vitreous chamber depth also increased progressively in both groups, with a greater rate of elongation in Han children. The adjusted annual increase in VCD was 0.256 mm/year (95% CI, 0.242–0.269) in Han children and 0.195 mm/year (95% CI, 0.182–0.208) in Uyghur children, corresponding to a Han–Uyghur difference of 0.061 mm/year ($P < 0.001$).

In contrast, anterior chamber depth increased at nearly identical rates in Han and Uyghur children (0.0517 vs 0.0515 mm/year; interaction $P = 0.967$), while lens

thickness decreased similarly in both groups (−0.0372 vs −0.0329 mm/year; interaction P = 0.248). Consistent with these individual anterior-segment measures, the combined anterior ocular dimension (ACD + LT) increased by 0.0144 mm/year (95% CI, 0.0088–0.0201) in Han children and 0.0186 mm/year (95% CI, 0.0130–0.0241) in Uyghur children, with no significant difference in longitudinal trajectory between groups (Uyghur–Han difference in slope, +0.00411 mm/year; 95% CI, −0.00382 to 0.0120; P = 0.309).

Corneal radius increased modestly in both groups, with a small but statistically significant difference in the rate of change (0.0132 vs 0.00818 mm/year; interaction P = 0.015). The AL/CR ratio increased more rapidly in Han children than in Uyghur children (0.0294 vs 0.0243 per year; interaction P < 0.001) (Figure 1).

Overall, Han children showed faster myopic progression and axial elongation, accompanied by greater vitreous chamber elongation, while anterior ocular growth trajectories were similar between groups.

Table 3. Linear mixed-effects models of longitudinal changes in refractive and ocular biometric parameters

Outcome	Han slope (95% CI)	Uyghur slope (95% CI)	Difference in slope	P value
SE, D/year	−0.376 (−0.435, −0.318)	−0.232 (−0.290, −0.174)	0.144 (0.062, 0.226)	<0.001
AL, mm/year	0.270 (0.258, 0.283)	0.213 (0.201, 0.226)	−0.0567 (−0.0740, −0.0393)	<0.001
VCD, mm/year	0.256 (0.242, 0.269)	0.195 (0.182, 0.208)	−0.0608 (−0.0796, −0.0419)	<0.001
ACD, mm/year	0.0517 (0.0454, 0.0580)	0.0515 (0.0453, 0.0577)	−0.00019 (−0.00904, 0.00866)	0.967
LT, mm/year	−0.0372 (−0.0424, −0.0321)	−0.0329 (−0.0381, −0.0278)	0.00430 (−0.00299, 0.0116)	0.248
ACD + LT, mm/year	0.0144 (0.0088, 0.0201)	0.0186 (0.0130, 0.0241)	0.00411 (−0.00382, 0.0120)	0.309
CR, mm/year	0.0132 (0.0103, 0.0160)	0.00818 (0.00535, 0.0110)	−0.00497 (−0.00899, −0.00095)	0.015
AL/CR per year	0.0294 (0.0277, 0.0311)	0.0243 (0.0226, 0.0260)	−0.00517 (−0.00758, −0.00276)	<0.001

Estimated annual changes are presented with 95% confidence intervals from linear mixed-effects models adjusted for baseline age and sex, with a random intercept for participant ID. Han was the reference ethnicity. The Time × Ethnicity coefficient represents the difference in annual slope for Uyghur relative to Han children. SE, spherical equivalent; AL, axial length; VCD, vitreous chamber depth; ACD + LT, combined anterior ocular dimension; ACD, anterior chamber depth; LT, lens thickness; CR, corneal radius.

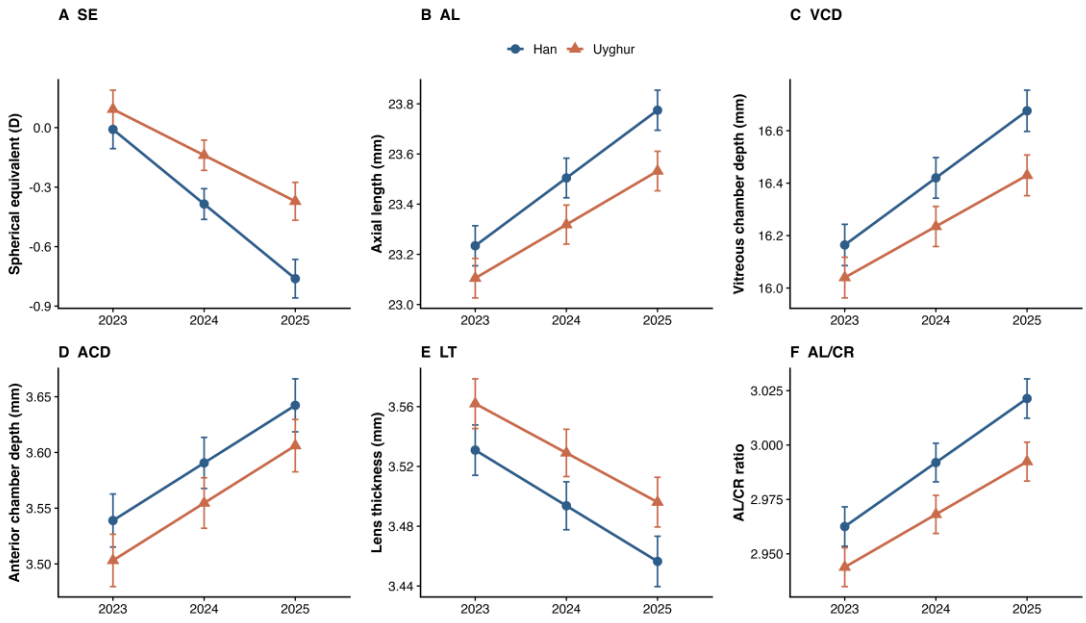


Figure 1. Adjusted longitudinal trajectories of refractive and ocular biometric parameters in Han and Uyghur children from 2023 to 2025. Points represent model-estimated marginal means, and error bars indicate 95% confidence intervals. Panels show spherical equivalent (SE), axial length (AL), vitreous chamber depth (VCD), anterior chamber depth (ACD), lens thickness (LT), and AL/CR ratio. Estimates were derived from linear mixed-effects models adjusted for baseline age and sex and therefore represent adjusted rather than raw observed means.

3.4 Ocular-Component Decomposition of Axial Elongation

Baseline-to-final axial growth was decomposed into changes in vitreous chamber depth (ΔVCD), anterior chamber depth (ΔACD), and lens thickness (ΔLT) to localize the anatomical distribution of the between-group difference in axial elongation (Table 4; Figure 2).

The mean increase in axial length was 0.540 mm in Han children and 0.427 mm in Uyghur children, corresponding to a Han–Uyghur difference of 0.113 mm (95% bootstrap CI, 0.069–0.159). The corresponding difference in vitreous chamber

elongation was 0.122 mm (Han, 0.511 mm; Uyghur, 0.390 mm; 95% bootstrap CI, 0.073–0.170), closely matching the magnitude of the total between-group difference in axial elongation.

In contrast, the between-group difference in anterior chamber depth change was negligible (+0.0004 mm; 95% bootstrap CI, −0.020 to 0.020), while the difference in lens thickness change was small and in the opposite direction (−0.0086 mm; 95% bootstrap CI, −0.024 to 0.007). Accordingly, the combined anterior ocular dimension (ΔACD + ΔLT) differed by only −0.0082 mm between Han and Uyghur children (95% bootstrap CI, −0.027 to 0.010).

The longitudinal mixed-effects analysis showed the same pattern, with no significant between-group difference in the trajectory of the combined anterior ocular dimension (P = 0.309).

The between-group difference in total axial elongation was therefore concentrated predominantly in vitreous chamber elongation, whereas anterior ocular growth was similar between groups (Figure 2).

Table 4. Ocular-component decomposition of baseline-to-final axial elongation in Han and Uyghur children

Component	Han mean change, mm	Uyghur mean change, mm	Han–Uyghur difference, mm	95% bootstrap CI
ΔAL	0.540	0.427	+0.113	0.069 to 0.159
ΔVCD	0.511	0.390	+0.122	0.073 to 0.170
ΔACD	0.103	0.103	+0.0004	−0.020 to 0.020
ΔLT	−0.074	−0.066	−0.0086	−0.024 to 0.007
ΔACD + ΔLT	0.029	0.037	−0.0082	−0.027 to 0.010

Values represent mean baseline-to-final changes from 2023 to 2025. Between-group differences are expressed as Han minus Uyghur. Confidence intervals were derived from 5,000 ethnicity-stratified bootstrap resamples. Because VCD was calculated as AL − ACD − LT, the decomposition satisfies ΔAL = ΔVCD + ΔACD + ΔLT. ACD + LT represents the combined anterior ocular dimension. AL, axial length; VCD, vitreous chamber depth; ACD, anterior chamber depth; LT, lens thickness.

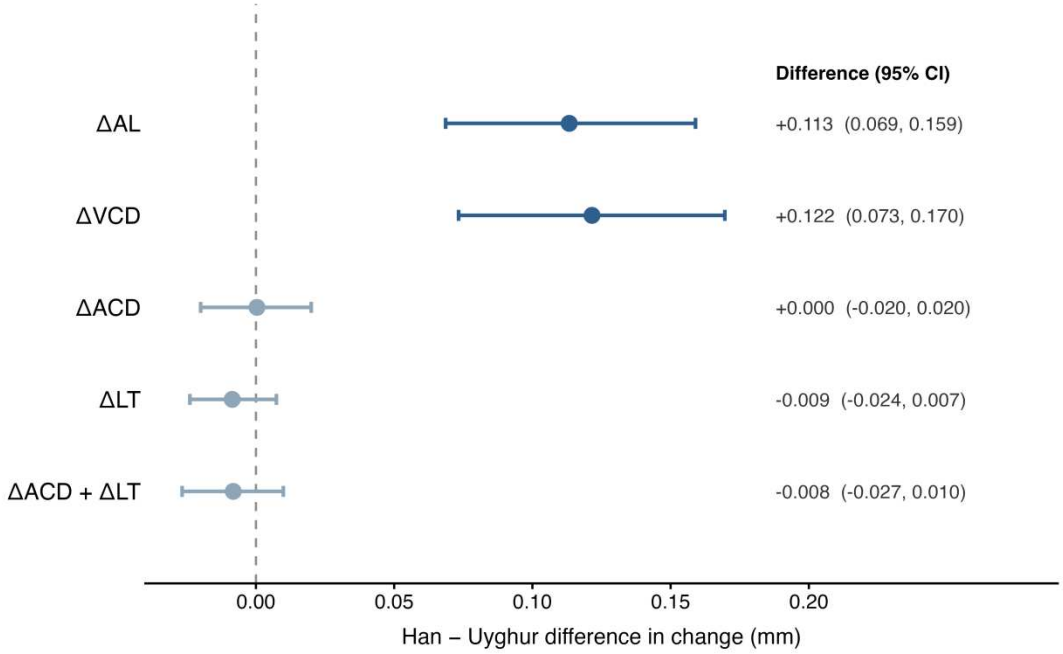


Figure 2. Ocular-component decomposition of the between-group difference in axial elongation from 2023 to 2025. Points represent mean Han–Uyghur differences in baseline-to-final change, and horizontal error bars represent 95% confidence intervals derived from 5,000 ethnicity-stratified bootstrap resamples. Positive values indicate greater change in Han children, and the vertical reference line at zero indicates no between-group difference. AL, axial length; VCD, vitreous chamber depth; ACD, anterior chamber depth; LT, lens thickness. Numerical values displayed in the figure are rounded to three decimal places; more precise estimates are provided in Table 4.

3.5 Ocular Biometric Changes Associated With Refractive Progression

Sequential multivariable linear regression models were used to evaluate ocular biometric changes associated with change in spherical equivalent (ΔSE) (Table 5).

In Model 1, after adjustment for baseline age and sex, Uyghur children showed 0.294 D less myopic progression than Han children (β = 0.294 D; 95% CI, 0.148–0.440; P < 0.001).

After axial elongation was added in Model 2, the ethnicity coefficient decreased to 0.132 D (95% CI, −0.005 to 0.268; P = 0.059), representing a 55.2% attenuation. Greater axial elongation was strongly associated with a more negative change in spherical equivalent (β = −1.338 D/mm; 95% CI, −1.573 to −1.102; P < 0.001).

In the fully adjusted model, axial elongation remained strongly associated with refractive progression (β = −1.586 D/mm; 95% CI, −1.867 to −1.306; P < 0.001), and change in corneal radius was also significantly associated with ΔSE (β = 2.643 D/mm; 95% CI, 1.237–4.048; P < 0.001). In contrast, changes in anterior chamber depth (β =

0.842; 95% CI, −0.033 to 1.718; P = 0.059) and lens thickness (β = −1.144; 95% CI, −2.444 to 0.156; P = 0.085) were not statistically significant. A small residual between-group difference remained after full adjustment (β = 0.141 D; 95% CI, 0.007–0.275; P = 0.039).

The ΔAL × ethnicity interaction was not significant (β = −0.201; P = 0.391), and the association between axial elongation and refractive change did not differ detectably between Han and Uyghur children. In a complementary model replacing ΔAL with ΔVCD, greater vitreous chamber elongation was associated with a more negative ΔSE (β = −1.199 D/mm; P < 0.001), while the ΔVCD × ethnicity interaction was not significant (P = 0.567).

Overall, adjustment for axial elongation substantially attenuated the between-group difference in refractive progression.

Table 5. Associations of ethnicity and ocular biometric changes with change in spherical equivalent

Predictor	Model 1 β (95% CI)	P value	Model 2 β (95% CI)	P value	Model 3 β (95% CI)*	P value*
Uyghur (vs Han)	0.294 (0.148, 0.440)	<0.001	0.132 (−0.005, 0.268)	0.059	0.141 (0.007, 0.275)	0.039
ΔAL, mm	—	—	−1.338 (−1.573, −1.102)	<0.001	−1.586 (−1.867, −1.306)	<0.001
ΔACD, mm	—	—	—	—	0.842 (−0.033, 1.718)	0.059
ΔLT, mm	—	—	—	—	−1.144 (−2.444, 0.156)	0.085
ΔCR, mm	—	—	—	—	2.643 (1.237, 4.048)	<0.001
Baseline age, years	−0.025 (−0.090, 0.040)	0.444	−0.100 (−0.161, −0.039)	0.001	−0.078 (−0.137, −0.019)	0.010
Female (vs Male)	−0.131 (−0.278, 0.016)	0.080	−0.002 (−0.138, 0.134)	0.974	−0.010 (−0.146, 0.126)	0.883
Adjusted R^2	0.024		0.186		0.238	

β coefficients are unstandardized linear regression coefficients. Model 1 included ethnicity, baseline age, and sex. Model 2 additionally included change in axial length (ΔAL). Model 3 additionally included changes in anterior chamber depth (ΔACD),

lens thickness (ΔLT), and corneal radius (ΔCR). Han ethnicity and male sex were the reference categories. *For Model 3, 95% confidence intervals and P values were calculated using heteroscedasticity-consistent HC3 robust standard errors because residual diagnostics indicated mild heteroscedasticity. The ethnicity coefficient decreased from 0.294 D in Model 1 to 0.132 D in Model 2, a 55.2% attenuation after inclusion of ΔAL. No formal mediation analysis was performed.

3.6 Sensitivity and Robustness Analyses

Multicollinearity was low in the fully adjusted regression model, with variance inflation factors ranging from 1.03 to 1.38. HC3 heteroscedasticity-consistent standard errors were used for the fully adjusted model because residual diagnostics indicated mild heteroscedasticity.

Additional adjustment for baseline SE did not materially alter the between-group difference in longitudinal axial elongation (time × ethnicity interaction, β = −0.0581 mm/year; 95% CI, −0.0754 to −0.0407; P < 0.001; n = 631). A random-slope mixed-effects model allowing individual variation in axial growth rates yielded a similar estimate (β = −0.0567 mm/year; 95% CI, −0.0796 to −0.0337; P < 0.001; n = 638). In a complementary baseline-to-final analysis, the difference in axial elongation remained significant after adjustment for baseline age, sex, and baseline SE (Uyghur vs Han: β = −0.0985 mm; 95% CI, −0.1419 to −0.0550; P < 0.001; n = 631).

Additional adjustment for baseline SE also yielded consistent results for refractive progression. The ethnicity coefficient was 0.297 D (95% CI, 0.150 – 0.445; P < 0.001) before inclusion of ΔAL and decreased to 0.153 D (95% CI, 0.017 – 0.289; P = 0.028) after adjustment for axial elongation, corresponding to a 48.6% attenuation. Axial elongation remained strongly associated with refractive change (β = −1.431 D/mm; 95% CI, −1.673 to −1.190; P < 0.001).

Exclusion of 14 participants with extreme refractive changes (|ΔSE| > 3.0 D) did not materially alter the findings. The ethnicity coefficient decreased from 0.293 D (95% CI, 0.186 – 0.399; P < 0.001) to 0.148 D (95% CI, 0.053 – 0.242; P = 0.002) after inclusion of ΔAL, representing a 49.5% attenuation. Similarly, exclusion of 22 influential observations identified using Cook's distance yielded an ethnicity coefficient of 0.293 D (95% CI, 0.189 – 0.397; P < 0.001), decreasing to 0.122 D (95% CI, 0.034 – 0.210; P = 0.007) after adjustment for axial elongation, corresponding to a 58.4% attenuation.

Participants with and without available ΔSE data were similar in baseline age (P = 0.762), sex (P = 1.000), and ethnicity (P = 0.973). In the previously specified sensitivity analysis excluding participants with baseline SE > +0.75 D or missing baseline refractive data (n = 620), the principal between-group differences in longitudinal SE and AL trajectories persisted, and the attenuation of the ethnicity coefficient after inclusion of ΔAL was approximately 58.3%.

4. Discussion

In this longitudinal school-based cohort, Han and Uyghur children demonstrated distinct refractive and ocular growth trajectories over three annual examinations. Han children experienced greater myopic progression and faster axial elongation than Uyghur children. Ocular-component decomposition showed that the between-group difference in total axial elongation was concentrated predominantly in vitreous chamber elongation, whereas changes in anterior chamber depth, lens thickness, and the combined anterior ocular dimension were similar between groups. Adjustment for axial elongation substantially attenuated the between-group difference in refractive progression, while the association between axial elongation and refractive change did not differ significantly by ethnicity. Together, these findings characterize the Han–Uyghur difference in childhood refractive development primarily by the magnitude and anatomical distribution of ocular elongation, particularly posterior ocular growth, rather than by divergent anterior segment development.

Previous studies have documented marked Han–Uyghur differences in childhood myopia within Xinjiang. Large school-based cross-sectional studies reported a higher prevalence of myopia, longer axial length, and higher AL/CR ratios among Han than Uyghur children (8, 9), while additional regional work identified differences in familial and behavioral factors associated with myopia (10). These studies were predominantly cross-sectional and therefore did not resolve whether the biometric differences reflected distinct ocular growth trajectories. The present study extends this evidence longitudinally, showing greater myopic progression and faster axial elongation in Han children over approximately two years.

The principal findings were consistent across additional sensitivity analyses. Adjustment for baseline refractive status produced little change in the longitudinal Han – Uyghur difference in axial elongation, and allowing individual variation in axial growth rates yielded a similar between-group estimate. The difference in baseline-to-final axial elongation also persisted after adjustment for baseline age, sex, and baseline SE. In the analyses of refractive progression, the attenuation of the ethnicity coefficient following inclusion of axial elongation remained consistent after adjustment for baseline SE and after exclusion of extreme or influential observations. These findings demonstrate that the observed associations were not driven solely by baseline refractive differences or a small number of influential observations.

The findings also align with broader longitudinal evidence showing substantial population variation in childhood axial elongation and refractive progression. Pooled and meta-analytic studies have shown that axial growth varies with age, refractive status, geographic region, and population background (5, 6). Large longitudinal datasets such as CLEERE have identified distinct age-related axial length trajectories across racial and ethnic groups (7), while longitudinal Chinese cohorts have documented substantial axial elongation and refractive progression during the primary-school years (3). More recent trajectory analyses show accelerated axial elongation around the transition to myopia, particularly at younger ages (18). Within

this context, Han and Uyghur children in the present cohort differed not only in baseline ocular biometry but also in longitudinal axial growth.

The most distinctive structural finding was the posterior concentration of the between-group difference in axial elongation. From baseline to final follow-up, the Han–Uyghur difference in total axial elongation was 0.113 mm, while the corresponding difference in vitreous chamber elongation was 0.122 mm. By contrast, the combined anterior ocular dimension (ΔACD + ΔLT) differed by only −0.008 mm between groups, with a confidence interval spanning zero. The mixed-effects analysis showed the same pattern: VCD increased more rapidly in Han children, whereas ACD, LT, and the combined anterior ocular dimension showed no meaningful between-group divergence. The excess axial elongation in Han children was therefore anatomically concentrated mainly within the vitreous chamber rather than the anterior ocular segment.

This anatomical pattern is consistent with longitudinal studies of ocular-component development in childhood. Normal ocular growth involves coordinated changes in axial length, vitreous chamber depth, anterior chamber depth, and crystalline lens dimensions (11, 12). During emmetropization and early myopic development, axial elongation is accompanied by vitreous chamber expansion, while anterior-segment changes are smaller and are partly offset by crystalline lens thinning and remodeling (11-13). In longitudinal studies of myopic schoolchildren, increases in VCD closely paralleled total axial elongation, whereas changes in ACD and LT were comparatively modest (13, 14). More recent pediatric biometric studies have also reported a strong relationship between VCD and AL (15). These observations provide external context for the posteriorly concentrated growth pattern in the present cohort.

VCD was mathematically derived as AL − ACD − LT and was therefore inherently dependent on total axial length. The component analysis was used to localize the anatomical distribution of axial growth rather than to estimate an independent effect of VCD. The Han–Uyghur difference in ΔVCD closely matched the difference in ΔAL, whereas the combined anterior ocular dimension showed little between-group difference. This pattern localizes the additional axial growth observed in Han children predominantly to the posterior ocular compartment.

Anterior ocular development was broadly comparable between Han and Uyghur children. Longitudinal studies of normal ocular growth have shown progressive anterior chamber deepening and crystalline lens thinning during childhood (11, 12). A recent two-year longitudinal study in Chinese children similarly reported anterior biometric changes accompanying refractive development, with relatively limited differences in ACD progression across groups with different rates of myopic shift (19). In the present cohort, ACD increased and LT decreased in both groups, but neither parameter showed a significant time-by-ethnicity interaction. The combined anterior ocular dimension (ACD + LT) also showed no significant between-group difference in baseline-to-final change or longitudinal trajectory. Anterior ocular remodeling

therefore accompanied childhood eye growth in both groups but did not distinguish their refractive and axial growth patterns.

The AL/CR ratio provided a complementary biometric perspective on these longitudinal differences. Previous studies have shown that AL/CR is strongly associated with childhood myopia and has good diagnostic performance for identifying myopic refractive status (20). Longitudinal evidence also links higher AL/CR values with a greater subsequent risk of myopia development and progression (21). In the present study, AL/CR increased more rapidly in Han than Uyghur children, consistent with greater axial elongation in the Han group. Corneal radius showed a small between-group difference in longitudinal change and remained associated with ΔSE in the fully adjusted regression model, but the larger and more consistent AL and VCD differences indicate that the divergence in AL/CR was driven predominantly by axial rather than corneal growth.

Ethnicity in this analysis represents a population grouping that may capture differences in genetic ancestry, familial characteristics, cultural practices, educational environments, socioeconomic conditions, and behavioral exposures. Contemporary genetic evidence indicates that refractive error and myopia are highly polygenic traits and that gene–environment interactions contribute to individual susceptibility (22). Familial influences are also well established. Recent longitudinal evidence links greater parental myopia with faster axial elongation and greater refractive change in children (23), consistent with earlier findings linking parental myopia with larger ocular dimensions and more rapid eye growth (24). The observed between-group differences may therefore reflect a combination of inherited susceptibility and family-level exposures not measured in the present study.

Environmental and behavioral exposures are additional plausible contributors to the observed Han–Uyghur differences in refractive development. Greater outdoor exposure is consistently associated with a lower risk of myopia onset, whereas its effect on progression in already myopic children is less uniform; intervention and longitudinal data nevertheless show favorable refractive or axial outcomes in some pediatric populations (25-28). Meta-analytic evidence also links greater near-work exposure with childhood myopia, while prospective data suggest that longer working distance and regular breaks during near tasks are associated with more favorable refractive outcomes (28, 29). Longitudinal studies in Chinese schoolchildren have further linked parental myopia and lower outdoor exposure with greater axial elongation and myopia development (30). Educational exposure may contribute as well: among children of the same age, those in higher school grades showed greater myopic progression and axial elongation (31), and more recent longitudinal data linked higher academic performance with slightly faster myopic shift and greater axial growth (32). Detailed longitudinal measures of these exposures were not comprehensively available in this cohort, leaving residual confounding from environmental and educational factors.

The observed differences also have clinical and epidemiological relevance because longitudinal axial length change is an informative marker of childhood ocular growth. Children transitioning toward myopia show distinct axial growth trajectories, with more rapid elongation around myopia onset, particularly at younger ages (18). Prospective cohort data further indicate that age, parental myopia, near-work behavior, and outdoor exposure are associated with patterns of rapid axial growth (33). School-based longitudinal studies suggest that baseline refractive status and axial length can help identify children at increased risk of subsequent myopia (34), while longer-term follow-up indicates that early axial elongation can improve estimation of future high-myopia risk (35). These findings support serial axial-length assessment in childhood. Ethnicity alone is insufficient for individual-level risk prediction; clinical assessment should integrate age, refractive status, longitudinal axial growth, family history, and relevant environmental exposures.

This study has several strengths. Three standardized annual examinations enabled direct assessment of within-child refractive and biometric trajectories rather than inference from cross-sectional age differences. Cycloplegic refraction and repeated optical biometry enhanced measurement validity and longitudinal comparability. Han and Uyghur participants were examined within the same geographic region using the same examination protocol and instrumentation, reducing geographic and methodological heterogeneity. The principal findings were supported by complementary analytical approaches, including linear mixed-effects models, sequential regression, interaction testing, heteroscedasticity-consistent inference, missing-data comparisons, and sensitivity analyses. Ocular-component decomposition provided anatomical localization of the between-group difference in axial elongation, and longitudinal analysis of the combined anterior ocular dimension provided a complementary assessment of anterior versus posterior growth.

Several limitations warrant consideration. First, participants were recruited from three primary schools in Urumqi, which limits the generalizability of the findings to other populations. School identifiers were unavailable in the analytical dataset, preventing explicit adjustment for school-level clustering. Second, detailed longitudinal information on parental myopia, outdoor activity, near work, educational intensity, and socioeconomic conditions was not comprehensively available. These unmeasured factors may contribute to the observed between-group differences.

Third, VCD was derived mathematically from AL, ACD, and LT rather than measured independently. The ocular-component decomposition therefore characterizes the anatomical distribution of axial growth but does not establish an independent causal role for VCD in refractive progression. Fourth, the observation period covered approximately two years, and longer follow-up is needed to characterize subsequent ocular growth trajectories. Finally, a small proportion of participants had missing refractive data, and several extreme refractive changes

required additional scrutiny. Sensitivity analyses addressing baseline refractive status, extreme changes, and influential observations yielded consistent principal findings, although verification against original examination records remains important.

5. Conclusion

In conclusion, Han and Uyghur children exhibited distinct longitudinal patterns of refractive development and ocular growth over approximately two years, with Han children demonstrating greater myopic progression and faster axial elongation. Ocular-component decomposition localized the between-group difference in total axial growth predominantly to vitreous chamber elongation, while anterior ocular development remained broadly comparable. Adjustment for axial elongation substantially attenuated the between-group difference in refractive progression, reinforcing the close relationship between axial growth and refractive change. These findings extend previous cross-sectional observations from Xinjiang by providing longitudinal evidence that differential posterior ocular elongation is a principal biometric feature characterizing Han–Uyghur differences in childhood refractive development. Future studies integrating environmental, behavioral, familial, and genetic factors can clarify the determinants of these divergent ocular growth trajectories.

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Author Contributions

Linhao Wang: Investigation, Data curation, Formal analysis, Visualization, Writing – original draft.

Liu Chen: Conceptualization, Methodology, Formal analysis, Validation, Writing – original draft, Writing – review & editing.

Yong Zhao: Investigation, Resources, Project administration, Writing – review & editing.

Yunxian Gao: Conceptualization, Supervision, Resources, Project administration, Funding acquisition, Writing – review & editing.

All authors reviewed and approved the final manuscript

Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The datasets generated and analyzed during the current study are not publicly available due to ethical and privacy considerations involving pediatric participants but may be made available from the corresponding author upon reasonable request, subject to institutional and ethical approval.

Ethics Approval and Consent to Participate

The original cohort study was approved by the Ethics Committee of the Affiliated Hospital of Traditional Chinese Medicine of Xinjiang Medical University (Approval No. 2019XE0151-2). Additional ethical approval for the present research project was obtained from the same committee (Approval No. 2025XE-GS094). Written informed consent was obtained from the participants' parents or legal guardians. The study was conducted in accordance with the Declaration of Helsinki.

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