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Increased axial elongation and myopia risk in non-myopic adolescents with convergence insufficiency

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Abstract

Background/Objectives:

To investigate the association between convergence insufficiency (CI) and ocular biometric changes indicative of future myopia development in a non-myopic adolescent population.

Subjects/Methods:

This one-year longitudinal study enrolled 244 non-myopic male adolescents (aged 14–17), comprising 50 with CI and 194 normal controls. Comprehensive visual function and ocular biometry assessments were conducted at baseline, 3, 9, and 12 months.

Results

At baseline, the CI group exhibited significantly poorer binocular function, including reduced negative relative accommodation (NRA) (p = 0.02), convergence amplitude (p = 0.00), and Accommodative Convergence / Accommodation (AC/A) ratio (p = 0.00), along with a deeper anterior chamber depth (ACD) (p = 0.01) and larger white-to-white (WTW) distance (p = 0.00) compared to normal controls. After 12 months, axial elongation was significantly greater in the CI group (0.16 ± 0.12 mm vs. 0.11 ± 0.16 mm, p = 0.02). A higher proportion of participants in the CI group experienced clinically significant axial elongation (≥ 0.2 mm) (34.0% vs. 19.1%, p = 0.02).

Conclusion

CI is associated with accelerated axial elongation and distinct ocular biometric profiles in non-myopic adolescents, suggesting it may be an early functional risk factor for myopia onset.

Introduction

Myopia has emerged as a significant global public health challenge, with its prevalence escalating rapidly worldwide, particularly in East Asia [1]. While the elongation of axial length (AL) is the primary anatomical hallmark of myopia, growing evidence suggests that visual function, especially binocular vision, plays a crucial role in its development and progression [2–5]. Among various binocular vision anomalies, CI is one of the most prevalent, affecting approximately 18% of school-aged children and often leading to symptoms such as asthenopia, blurred vision at near, and difficulty sustaining concentration [6, 7].

Substantial research conducted in myopic populations has a higher prevalence of CI, characterized by reduced convergence amplitude and more exophoric near phoria [8–10]. Furthermore, studies on near-

work activities, such as smartphone use, have demonstrated that prolonged near tasks can induce transient accommodative and vergence dysfunction, paralleling the features of CI [11–13]. Given the well-documented link between accommodative dysfunction and myopia risk and considering the intimate coupling of the accommodation and vergence systems, we hypothesize that CI may contribute to myopia development by disrupting ocular homeostasis during near vision.

However, a critical gap remains in the literature. Existing studies have primarily focused on the coexistence of CI and myopia, leaving it unclear whether CI is a consequence of myopic ocular growth or a potential predisposing factor [2, 4, 5]. There is a notable lack of longitudinal studies investigating the association between CI and the subsequent risk of myopia onset in initially non-myopic adolescents.

Therefore, this prospective longitudinal study aims to elucidate the relationship between CI and ocular biometric changes in a cohort of non-myopic adolescents. We seek to characterize their accommodative, binocular visual function, and biometric parameters profiles in adolescents with CI. Our findings are expected to provide new insights for the early identification of individuals at high risk for myopia.

Materials/Subjects and Methods

Ethics approval

The study protocol was approved by the Ethics Committee of the Air Force Medical Center (2023-162-S01) and adhered to the principles outlined in the Declaration of Helsinki. Written and verbal consent was obtained from all participants and their legal guardians prior to the initiation of any study procedures.

Participants

Total of 257 students were enrolled from 12 adolescent aviation schools across 10 provinces in China, based on the principle of voluntary participation. All participants underwent visual function assessments. Based on the results, 53 were diagnosed with CI. Among them, 3 students withdrew from the study during the 9m follow-up due to the annual physical examination. Additionally, 204 students were assigned to the normal group, of which 10 withdrew during the 9m follow-up for the same reason. Consequently, the final analysis included 50 participants in the CI group and 194 in the normal group (Fig. 1).

The enrolled participants who successfully passed both the Air Force recruitment selection physical examination and the national senior high school entrance examination were randomly selected and invited to participate in a comprehensive eye examination as part of this study. The inclusion criteria were as follows: (1) uncorrected distance visual acuity 20/20 or better in each eye. (2) spherical equivalent refraction (SER) ranging from 0 ~ + 2.00 D and cylindrical refraction not exceeding 0.50 D in

each eye. Students who had histories of refractive surgery, strabismus or ocular diseases that could potentially affect vision were excluded. All examinations were conducted between October and November 2023. CI was defined based on the following criteria: (1) exophoria at near ≥ 4△combined with exophoria at distance; (2) positive fusional vergence ≤ 15△ base-out (BO) or failure to meet Sheard`s criterion.

Visual acuity and refraction assessment

Visual acuity and refractive error assessment were performed according to our previous study [14]. In brief, visual acuity was measured using a Landolt C chart at a standard testing distance of 5m, with chart illumination maintained at approximately 500 lux. Refractive error was assessed by experienced optometrists following cycloplegia, achieved by administering 0.5% tropicamide- phenylephrine ophthalmic solution (Mydrin-P; Santen, Osaka, Japan). The eye drops were instilled every 5 minutes for a total of 20 minutes to ensure complete pupil dilation prior to examination. For analytical purposes, only data from each participant`s dominant eye was included. Ocular dominance was determined using the hole-in-the-card test.

Accommodative function evaluation

Accommodative function was comprehensively evaluated using a phoropter, with all near tests performed at 40cm using a 20/30 optotype as the fixation target: NRA: Binocular measurement using plus lenses in 0.25D increments until first sustained blur. Positive relative accommodation (PRA): Similarly measured with minus lenses and always performed after NRA testing. Amplitude of Accommodation (AMP): Determined via the negative lens method, adding minus lenses until sustained blur occurred. AC/A ratio: Calculated using the lens gradient method with + 3.0D lens at near. Binocular cross-cylinder (BCC): Assessed using a cross grid under dim illumination. Positive Fusional Vergence (PFV): Measured with a base-out prism bar during near fixation. Exophoria: Quantified via prism bar and cover test at both distance and near. Accommodative Facility (AF): Evaluated monocularly and binocularly using + 2.00 D/-2.00 D flipper lenses, with the participant reading 20/30 letters at 40cm.

Binocular vision analysis

Binocular functions including subjective/objective phoria in far, divergence and convergence were assessed using a synoptophore. The car and the door slides were used to measure subjective and objective phoria. When a car was seen in the middle of the door, the value of subjective phoria was obtained. The cover-uncover test was performed when observing the slides, the value of objective phoria was obtained when the eyes stilled. The butterfly and cat slides were used to measure motor fusion. To assess divergence and convergence amplitudes, the synoptophore was initially set at the subjective phoria position. The tubes were then gradually abducted or adducted until the point of fusion disruption was observed, which served as the measurement endpoint for both divergence and convergence ranges.

Binocular biometry examination

The ocular biometric data including AL, corneal curvature (K_1 andK_2), ACD, lens thickness (LT), central corneal thickness (CCT), and WTW was measured with an IOLMaster 700. The K value calculated by $K = (K_1 + K_2)/2$.

Statistical analysis

IBM SPSS V 25.0 software was used for data analysis. The *t*-test was used to evaluate differences between CI and normal group. The Spearman correlation was performed to analyze the correlation between CI and baseline parameters, visual function and biometric parameters. Categorical variables were analyzed using the chi-square test. All *P* values were two-sided and $p < 0.05$ was considered statistically significant.

Results

Clinical characteristics of participants in normal and CI group

A total of 244 male participants of ages from 14 to 17 years old were included in the final analysis, comprising 50 diagnosed with CI and 194 normal controls. No significant differences were observed between the two groups in age, SER, or LogMAR visual acuity at baseline ($p>0.05$) (Table 1).

Characteristics of the accommodative and binocular visual function in CI

To characterize the accommodation and binocular visual function of participants with CI, we compared with normal group and the results revealed that the CI group presents with reduced NRA ($p<0.05$), while PRA, AMP, AF and BCC showed no statistical difference with normal ($p>0.05$). Furthermore, the binocular visual function in CI group showed more negative deviation in far subjective/objective deviation angels, decreased convergence and a lower AC/A ratio ($p<0.05$) (Table 2).

Change of ocular biological features in CI

To characterize the ocular biological features of participants with CI, we conducted assessments of ocular biometry in all participants The results revealed that the CI students showed a deeper ACD (3.52 ± 0.19 vs 3.38±0.39) ($p<0.05$) and a larger WTW distance (12.23 ± 0.37 vs 11.96 ± 0.61) ($p<0.05$) (Table 3).

Furthermore, to investigate whether CI is associated with axial elongation, we conducted a one-year follow-up of all participants. By comparing the axial length between the two groups at baseline, 3 months, 9 months, and 12 months, it was found that the CI group had a longer axial length at baseline compared to the normal group, though the difference was not statistically significant (24.02 ± 0.70 vs 23.83 ± 0.68, $p>0.05$). However, at the 12-month follow-ups, the axial length in the CI group was longer

than that in the normal group, with statistically significant differences (24.18 ± 0.75 vs 23.93 ± 0.72, $p<0.05$) (Table 3).

Correlation between CI and baseline parameters, visual function, and biometric parameters revealed that CI exhibits a significant positive correlation with logMAR visual acuity, ACD, and WTW ($p<0.05$). Conversely, CI showed significant negative correlations with NRA, objective and subjective phoria in far, convergence, and the AC/A ($p<0.05$) (Table S1).

Changes in axial length and AL/CR in CI and normal group

Furthermore, we quantitatively analyzed the axial elongation and AL/CR changes at the three follow-up time points. The results demonstrated that the axial growth in the CI group was significantly faster than that in the normal group, with the difference in growth rate reaching statistical significance at the 12-month follow-up (0.16 ± 0.12 vs 0.11 ± 0.16, $p<0.05$). The changes in AL/CR within the CI group showed no statistically significant differences compared to the normal group at all three follow-up time points *(*$p>0.05$) (Table 4).

A correlation analysis between changes in axial length in 12-month follow-up and baseline parameters, visual function, and ocular biometric parameters found that the axial elongation was significantly negatively correlated with NRA, convergence, and AC/A ratio, and significantly positively correlated with ACD, WTW, and CI ($p<0.04$) (Table S2).

Proportion of individuals with axial elongation in CI

To further validate the distribution of axial elongation across the entire study population, we performed a chi-square analysis on the number of participants in different axial elongation groups at the 12-month follow-up. The results revealed that the proportion of individuals with axial elongation ≥0.2 mm was significantly higher in the CI group compared to the normal group (p0.05) (Table 5).

Discussion

This one-year longitudinal study provides novel evidence that CI is associated with accelerated axial elongation in non-myopic adolescents. Our findings position CI not merely as a distinct binocular vision disorder, but as a potential functional biomarker for identifying adolescents at risk of excessive ocular growth prior to the onset of myopia.

In our study, we confirmed that adolescents with CI exhibit characteristic binocular vision deficits, including reduced NRA, diminished convergence amplitude, and a lower AC/A ratio. The novelty of our study lies in identifying these functional anomalies in a cohort without myopia. Previous studies have indicated that the cause of CI lies in the disruption of reflexive fusional vergence responses, leading to a decline in the adaptability of binocular convergence [15]. More importantly, from a structural perspective, we observed that the CI group had a deeper ACD and a larger WTW distance at baseline. ACD dynamics are influenced by near visual activity and convergence effort, while WTW may reflect adaptations in

anterior segment anatomy [16–18]. The significant positive correlations of CI with ACD and WTW provide statistical evidence for a link between CI and this distinct anterior segment biometric profile. Given the established correlation between ciliary muscle morphology and AL, we hypothesize that a larger WTW could be indicative of morphological adaptations in the ciliary body, potentially contributing to a deeper ACD. This structural predisposition might represent an underlying mechanism linking the functional deficit in CI to accelerated axial elongation.

The central finding of our study is that adolescents with CI experienced a significantly faster axial elongation over 12 months compared to the normal, with a higher proportion exhibiting clinically significant AL growth. Moreover, the axial elongation showed significantly negatively correlated with NRA, convergence amplitude, and the AC/A ratio, and significantly positively correlated with ACD, WTW, and the presence of CI. Previous study reported that myopes exhibit reduced velocity of disaccommodation [4]. Additionally, a study has shown that convergence ranges gradually decrease with increasing exophoria in myopic children.[9] Myopia is associated with accommodative dysfunction [19]. Our study provides the first evidence that CI may influence axial elongation even in non-myopic populations.

Previous studies have shown that myopic shift is associated with visual fatigue and an increased CISS score [20]. We propose that the inherent vergence dysfunction in CI disrupts the precise coordination of the accommodation-convergence system during near work. This chronic disruption may lead to anomalous visual signals that interfere with the homeostatic control of eye growth, potentially mediated through mechanisms involving retinal defocus, choroidal thinning, or dopaminergic signaling. Our study thus identifies CI as a significant environmental factor potentially disrupting the homeostasis of "functional ocular growth" during a critical developmental period.

Several limitations should be considered. First, the absence of cycloplegic refraction at the study endpoint prevents us from correlating axial elongation with actual changes in SER. Our findings establish an important association between CI and biometric risk factors for myopia, but do not confirm that CI directly causes myopic onset. Second, the observational design of our study cannot definitively establish causality. Future long-term studies incorporating endpoint refraction and mechanistic investigations are needed to elucidate the precise role of CI in myopigenesis.

In summary, this study demonstrates that CI in non-myopic adolescents is associated with a distinct profile of binocular vision dysfunction, anterior segment biometric features, and, most critically, an accelerated rate of axial elongation. These findings suggest that assessment of binocular vision function could be a valuable component of myopia risk screening protocols. Whether vision therapy targeted at correcting CI can modify the trajectory of axial elongation presents a compelling question for future randomized controlled trials.

Declarations

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Tables

Tables 1 to 5 are available in the Supplementary Files section.

Figures

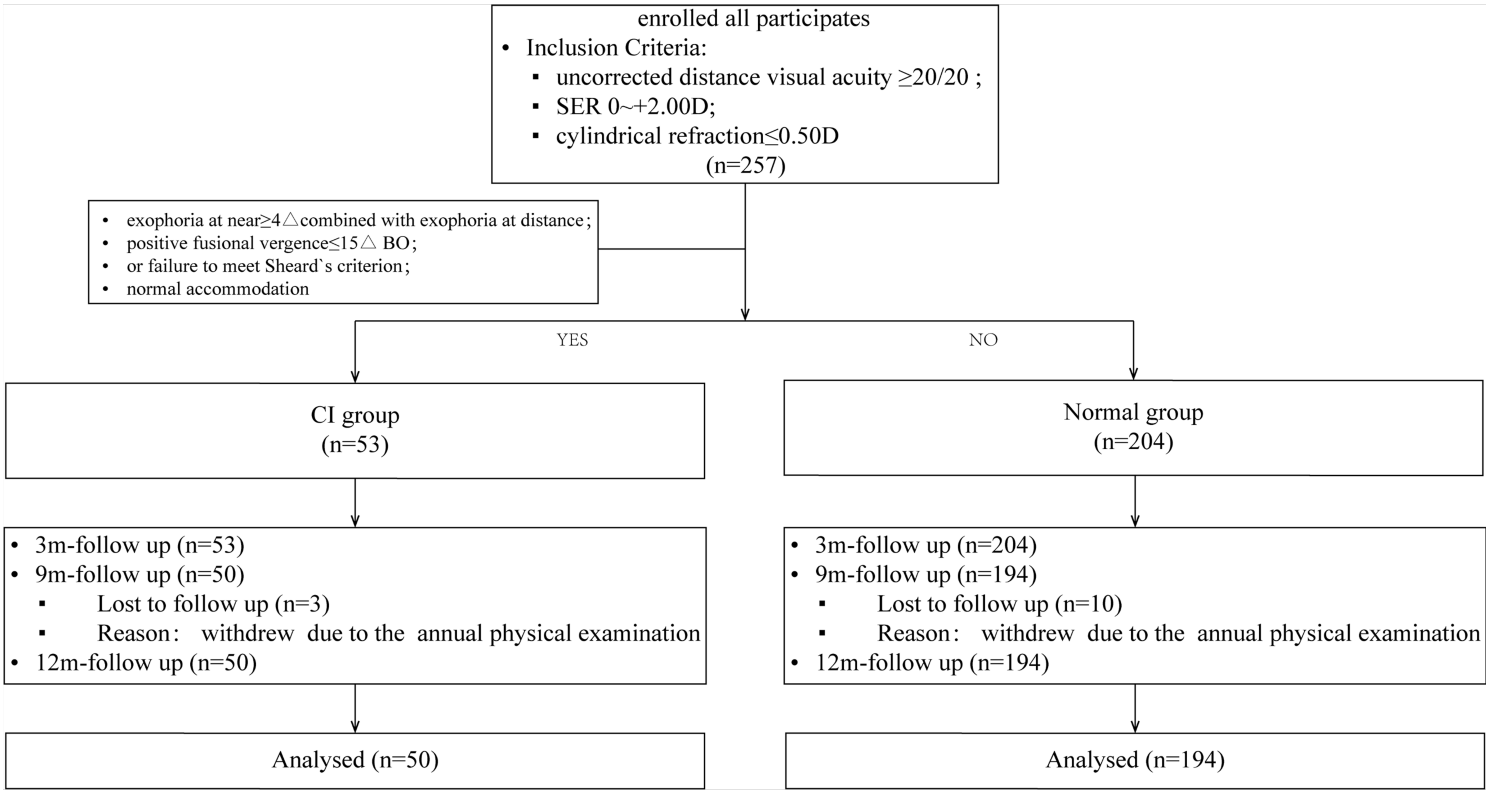

Figure 1

flow diagram of the study.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx
- Table2.docx
- Table3.docx
- table4.docx
- table5.docx
- Supplementaldata.docx