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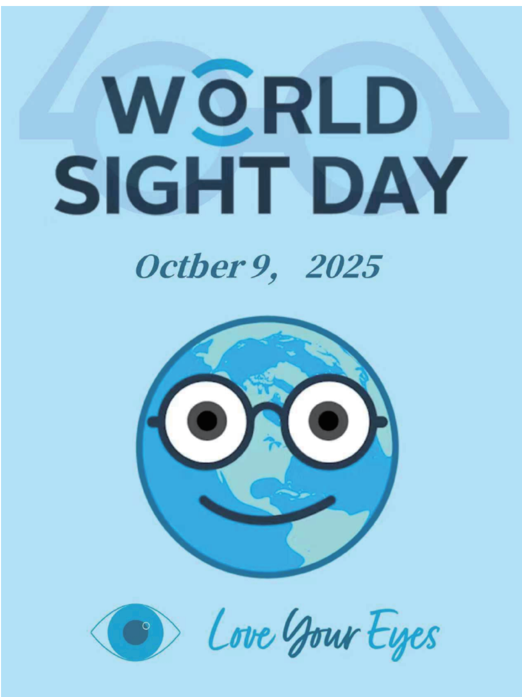

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This week's issue was organized by Guest Editor Xin Guo.

Foreword

The Significance of Hyperopic Reserve Monitoring and Its Value for Myopia Prevention and Control

Xin Guo[1,2,#]

Myopia represents a critical public health challenge with far-reaching implications for future development, as global prevalence is projected to reach 49.8% by 2050 (*1*–*2*). The Chinese government has implemented comprehensive policies and proactive measures (*3*–*6*) to accelerate prevention efforts through systematic interventions. Traditional monitoring approaches have focused primarily on vision screening and diopter examination following myopia onset, thereby lacking early warning systems for tracking hyperopic reserve depletion. Commissioned by the National Disease Control and Prevention Bureau, our team has spearheaded a landmark large-scale monitoring project on hyperopic reserves among children and adolescents since 2020, encompassing ten provincial-level administrative divisions (PLADs; including Beijing, Liaoning, Zhejiang, Henan, Chongqing, Shaanxi, Guangdong, Shanxi, Hunan, and Shandong). Through a multistage cluster sampling design at each site, students from senior kindergarten through high school were systematically selected, with 67,260 individuals initially surveyed. This initiative represents a transformative measure that emerged in direct response to the developmental requirements of the new era. The hyperopic reserve monitoring framework comprises two integrated components: comprehensive questionnaire surveys and detailed ophthalmic examinations. Emphasis is strategically placed on hyperopic reserve assessment rather than conventional diopter examination alone, with cycloplegic refraction methods employed to determine visual acuity status, yielding substantially more accurate results. This advancement signifies that China's myopia prevention and control efforts are transitioning toward a more scientific, precise, and forward-looking paradigm.

This special issue presents five pivotal studies that collectively advance our understanding of hyperopic reserve monitoring. Gao et al. comprehensively investigated axial length (AL), corneal radius (CR), and AL/CR ratios in children and adolescents from ten provinces and municipalities, analyzing the distribution patterns of each refractive parameter and their relationships with refractive status while evaluating the monitoring effectiveness of each parameter for refractive development (*7*). Luo et al. characterized different percentiles of spherical equivalent (SE) following cycloplegic refraction across children and adolescents aged 5–18 years throughout ten provinces and cities in China (*8*). Zhang et al. examined the association between screen exposure and insufficient hyperopic reserve in Chinese children aged 6–12 years, highlighting significant regional heterogeneity (*9*). Liu et al. explored the application of machine learning models to predict cycloplegic spherical equivalent in children and adolescents using non-cycloplegic measurements and ocular biometric parameters (*10*). These investigations collectively illuminate the critical importance of hyperopic reserve for myopia prevention and control while underscoring the substantial value of the hyperopic reserve detection initiative across ten provinces and municipalities. Specifically, this monitoring program demonstrates several prominent contributions to the field.

Addressing Critical Gaps: A Strategic Transformation from "Reactive Treatment" to "Proactive Prevention"

Hyperopic reserve represents the physiological hyperopia (*11*) naturally present during ocular development in children and adolescents — functioning as a protective "buffer zone" that mitigates myopia risk. This reserve undergoes gradual depletion as the eye matures (*12*). When hyperopic reserve is consumed too rapidly before achieving emmetropia, myopia onset becomes imminent or has already occurred (*13*). Traditional, myopia monitoring has predominantly been implemented following vision deterioration or myopia development, resulting in delayed intervention opportunities. For the first time, this groundbreaking initiative has established a comprehensive, large-scale monitoring system for hyperopic reserves in preschool and school-aged children across ten PLADs in China, addressing a fundamental gap in preventive eye care. This achievement marks a paradigm shift in myopia prevention and control, advancing beyond outcome-based indicators such as "myopia presence" and "myopia severity" toward predictive early warning metrics, including "myopia occurrence probability." By repositioning the prevention and control checkpoint earlier in the developmental timeline, this approach fundamentally transforms myopia management from passive response strategies to proactive prevention methodologies.

Establishing Evidence-Based Standards: Constructing the Foundation for Scientific Assessment and Precision Intervention

One of the fundamental contributions of this monitoring initiative, which encompasses ten provinces and municipalities with substantial sample sizes and robust regional representation, lies in its capacity to establish the first comprehensive "reference range" for hyperopic reserve among Chinese children and adolescents. The hyperopic reserve reference range enables identification of early changes preceding myopia onset, facilitating early detection and warning systems while enabling precise prevention and control with advanced checkpoint positioning. These values demonstrate variation according to age, geographic region, and environmental factors. Previously, the absence of authoritative national baseline data created significant challenges for physicians, educational institutions, and parents in accurately determining whether an individual child's hyperopic reserve values were within normal parameters or depleting at concerning rates. The subsequent phase of this research will provide scientifically validated evaluation standards based on the growth and developmental characteristics of Chinese children for nationwide implementation. The establishment of these standards encompasses several key components:

Scientific assessment foundation: Enables primary medical institutions and school health professionals to accurately evaluate myopia risk levels using standardized benchmarks.

Precision intervention support: High-risk children — those demonstrating hyperopic reserve significantly below age-appropriate standards or experiencing rapid depletion — can be identified early, enabling targeted interventions including increased outdoor activities, visual habit modifications, and optical strategies to prevent or delay myopia onset.

Policy development guidance: Provides essential data to support the standardization of myopia risk screening processes and the evaluation of prevention effectiveness. Assists national and local authorities in formulating more refined prevention and control policies.

Empowering Grassroots Implementation: Strengthening Early Myopia Risk Identification Capabilities

The analysis of large-scale hyperopic reserve monitoring data and the establishment of evidence-based standards must ultimately serve grassroots clinical practice. This study significantly enhances early warning capabilities for myopia prevention and control at the community level. Following standard implementation, several key improvements will be realized:

Community hospitals and school clinics: By incorporating hyperopic reserve assessments into routine physical examinations — using standardized values preliminarily calculated through non-mydriatic computerized refraction — these facilities can identify high-risk children early and promptly notify parents of concerning findings.

Parents and teachers: Armed with standardized hyperopic reserve reference values, they can proactively monitor children's visual development, emphasizing outdoor activities and limiting excessive near-work activities, rather than waiting for vision deterioration to occur.

Coordinated prevention efforts: Risk identification based on unified standards facilitates more effective communication and collaboration among families, schools, and medical institutions, creating a comprehensive network to safeguard children's visual health.

Highlighting Transformation: Advancing the National Myopia Prevention Strategy

The launch and advancement of hyperopic reserve monitoring across ten provinces and municipalities represents a transformative milestone in China's national commitment to myopia prevention. This groundbreaking initiative demonstrates:

Enhanced investment: Unprecedented funding and comprehensive project support for foundational research and critical monitoring efforts in myopia prevention.

Strategic advancement: The prevention and control paradigm has evolved from merely "managing myopia severity" to "preventing myopia onset," emphasizing early intervention and proactive source management.

Evidence-based leadership: Leveraging specialized institutions within the disease control system to conduct large-scale epidemiological investigations and drive policy decisions through rigorous scientific data ensures a standardized, evidence-based framework for myopia prevention and control in the contemporary era.

The hyperopic reserve monitoring initiative among children and adolescents across ten provinces and municipalities represents pioneering work in China's myopia prevention and control field. This comprehensive effort not only addresses critical data gaps but also substantially advances the prevention and control timeline. The next phase will establish China's indigenous hyperopic reserve assessment standards, with reference ranges stratified by age (6–18 years, with discrete age groups) and region (province/city) to accommodate developmental variations among children across different geographical areas. This framework will provide a robust foundation for early myopia risk identification, precise intervention strategies, and evidence-based prevention and control measures nationwide. This work exemplifies the accelerating transformation of pediatric and adolescent myopia prevention and control toward more scientific, precise, and efficient methodologies. Beyond representing a technological breakthrough, this initiative serves as a pivotal milestone in the comprehensive implementation of the national myopia prevention and control strategy, facilitating the paradigm shift from "treating existing conditions" to "preventing disease onset." It will undoubtedly strengthen frontline defenses, securing improved visual health outcomes for millions of children and adolescents throughout the country.

Conflicts of interest: No conflicts of interest.

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Preplanned Studies

Association Between Refractive Status and Ocular Biometric Parameters Among Children and Adolescents — 10 PLADs, China, 2020–2024

Ruoyi Gao[1,2]; Huijuan Luo[2]; Yaqing Meng[3]; Liru Wang[4]; Suyun Li[5]; Bingjie Sun[2]; Xin Guo[1,6,#]

Summary

What is Already Known About This Topic?

Myopia prevalence among Chinese students remains persistently high, with axial length and the axial length-to-corneal radius ratio demonstrating significant associations with refractive status in children and adolescents.

What Is Added by This Report?

This investigation employed cycloplegic optometry to assess refractive errors across children and adolescents in 10 provincial-level administrative divisions, utilizing axial length (AL) and axial length-to-corneal radius ratio (AL/CR) as predictive indicators of refractive status.

What Are The Implications For Public Health Practice?

The AL/CR ratio demonstrates superior predictive accuracy for myopia compared to AL alone and can effectively identify at-risk children during early developmental stages. Incorporating routine monitoring of AL and AL/CR into school health programs can enhance early detection capabilities and support targeted myopia management strategies.

ABSTRACT

Introduction: Myopia prevalence among Chinese children and adolescents remains persistently high, with an alarming trend toward earlier onset. Understanding the correlation between ocular biometric parameters and myopia development provides essential insights into underlying mechanisms. This study evaluated the associations between axial length (AL), axial length-to-corneal radius ratio (AL/CR), and spherical equivalent refraction (SER) across different age groups to inform early detection strategies and myopia management protocols.

Methods: Students aged 5–18 years were recruited from 10 provincial-level administrative divisions across China between November 2020 and July 2024 using hierarchical clustering and probability proportionate to size (PPS) sampling methods. The final analytical sample comprised 60,270 participants. Trained professionals conducted cycloplegic optometry and measured ocular biometric parameters. Data underwent weighted analysis using nonparametric tests and receiver operating characteristic (ROC) curve analysis to establish predictive thresholds for myopia detection.

Results: Overall myopia prevalence reached 29.24%, demonstrating a progressive increase across school grades. Median SER values exhibited increasingly negative trends with advancing educational levels. Correlation analysis revealed that AL/CR demonstrated stronger associations with SER (R=−0.750, P<0.001) compared to AL alone (R=−0.657, P<0.001). ROC analysis confirmed superior predictive accuracy for AL/CR over AL across all age groups, with area under the curve values approaching or exceeding 0.88 among upper-grade students.

Conclusions: Both AL/CR and AL serve as effective indicators for identifying children at elevated myopia risk during early childhood. Routine monitoring of AL and AL/CR within school health programs can facilitate early intervention strategies and myopia control measures, particularly in regions with limited access to cycloplegic optometry services.

In 2018, China elevated myopia prevention and control to a national strategic priority; however, myopia prevalence among Chinese children and adolescents has remained persistently high, with overall rates reaching 52.7% by 2020 (*1*) and demonstrating a concerning trend toward younger age of onset. Axial myopia represents the predominant form of myopia in Chinese youth (*2*), and accumulating evidence indicates that the axial length-to-corneal radius ratio

(AL/CR) correlates more strongly with refractive status than axial length (AL) alone (*3*–*5*). Investigating the relationships between ocular biometric parameters and myopia development provides fundamental insights into myopia pathogenesis. Compared to automated refractometers that measure only refractive error, biometric parameter assessment offers the distinct advantage of identifying high-risk populations earlier, enabling early intervention before visual acuity deteriorates. Although previous studies have examined correlations between ocular biometric parameters and myopia in Chinese students, most have focused on specific regions, with national-scale investigations remaining limited. Therefore, leveraging the comprehensive monitoring system for hyperopic reserves among children and adolescents established across 10 provincial-leveladministrative divisions (PLADs) in China beginning in 2020, this study examined AL, corneal radius (CR), and AL/CR in students from these ten regions. We analyzed the distribution of refractive parameters and their associations with refractive status to further elucidate ocular growth patterns and refractive development in students, while evaluating the monitoring effectiveness of ocular biometric parameters for refractive development to inform myopia prevention and control strategies.

The National Disease Control and Prevention Administration of China coordinated a cross-sectional survey of hyperopic reserves across 10 PLADs from November 2020 to July 2024. These included Liaoning Province, Beijing Municipality, Zhejiang Province, Guangdong Province, Henan Province, Hunan Province, Shanxi Province, Shaanxi Province, Shandong Province, and Chongqing Municipality. Students from senior kindergarten through high school were selected using multistage cluster sampling at each site. Initially, 67,260 participants were surveyed. Exclusions included 22 individuals with diseases affecting visual development or interfering with ophthalmic examinations, 6,030 with missing spherical equivalent data or abnormal post-mydriasis values, 171 outside the 5–18 year age range, and 767 with missing or abnormal right eye AL or corneal radius (CR) values. The final sample comprised 60,270 participants: 14,475 kindergarten students, 28,482 lower-grade primary school students (grades 1–3), 11,317 upper-grade primary school students (grades 4–6), 3,496 junior high school students, and 2,500 senior high school students. All participants provided informed consent, and the study received institutional ethics committee approval (batch number: 2022 [24]). Myopia was defined as spherical equivalent refraction (SER) ≤−0.50 D in either eye under cycloplegia (*6*). Classifications included non-myopia (SER>−0.50 D), mild myopia (−3.00 D≤SER≤−0.50 D), and moderate myopia (−6.00 D≤SER<−3.00 D). Cycloplegic refraction employed 0.5% compound tropicamide eye drops administered four times at 5-minute intervals, with refraction performed 30 minutes after the final instillation. Intraocular pressure measurement was conducted when clinically indicated. All regions selected ocular biometric measurement instruments based on local resources, with standardized equipment brands and models used whenever possible.

Statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Since SER, AL, and AL/CR did not follow normal distributions, we reported data as median values with interquartile ranges and used non-parametric tests for comparisons. The Mann–Whitney U test was employed for two-group comparisons, while the Kruskal–Wallis test was used for multiple-group analyses. Correlations between variables were assessed using Spearman's rank correlation coefficient. To determine optimal cut-off points for AL and AL/CR in predicting myopia onset, we calculated the Youden index and constructed receiver operating characteristic (ROC) curves with corresponding areas under the curve and 95% confidence intervals. When Youden indices were equivalent, we prioritized sensitivity over specificity. Statistical significance was established at $P<0.05$.

This study examined the visual status of 60,270 students aged 5–18 years across 10 PLADs in China, comprising 31,070 boys and 29,200 girls. The overall myopia prevalence was 29.24%. Myopia prevalence among kindergarten, lower-grade primary school, upper-grade primary school, junior high school, and senior high school students was 5.20%, 19.76%, 56.49%, 79.12%, and 83.28%, respectively. Student myopia prevalence demonstrated a significant increasing trend with advancing grade levels (χ^2=15,989.103, $P<0.001$), with statistically significant differences between each grade after Bonferroni adjustment. The overall myopia prevalence was lower in boys (28.04%) than in girls (30.51%) (Table 1).

Correlation analysis demonstrated that SER values between left and right eyes, as well as biometric parameters between eyes, exhibited strong correlations ($R>0.9$). Consequently, only right eye data were

TABLE 1. Myopia prevalence among students by gender and grade level (%).

Grade	Male	Female	Total
Kindergarten	5.50	4.85	5.20
Lower grades of primary school	19.64	19.88	19.76
Upper grades of primary school	52.80	60.55	56.49
Junior high school	76.02	82.08	79.12
Senior high school	80.66	85.91	83.28
Total	28.04	30.51	29.24

included in subsequent analyses. The median SER values [M (Q25, Q75)] for kindergarten, lower-grade primary school, upper-grade primary school, junior high school, and senior high school students were 1.00 (0.63, 1.38) D, 0.63 (0.00, 1.00) D, −0.50 (−1.88, 0.38) D, −1.88 (−3.38, −0.38) D, and −2.38 (−3.75, −0.75) D, respectively. SER values progressively decreased with advancing grade levels, with statistically significant differences between all grade comparisons (P<0.001). Median AL values [M (Q25, Q75)] across grade levels were 22.56 (22.06, 23.02) mm, 23.00 (22.46, 23.53) mm, 23.81 (23.16, 24.45) mm, 24.34 (23.67, 25.01) mm, and 24.59 (23.82, 25.36) mm, respectively. AL demonstrated a consistent increase with grade progression, with significant differences between all grade levels (P<0.001). Corneal radius (CR) values [M (Q25, Q75)] remained relatively stable across grades: 7.77 (7.60, 7.94) mm, 7.77 (7.60, 7.95) mm, 7.79 (7.62, 7.96) mm, 7.79 (7.61, 7.97) mm, and 7.80 (7.64, 7.98) mm. The AL/CR ratio [M (Q25, Q75)] increased progressively across grade levels: 2.90 (2.86, 2.95), 2.95 (2.90, 3.01), 3.05 (2.98, 3.13), 3.13 (3.04, 3.21), and 3.15 (3.06, 3.24), with significant differences between all grade comparisons (P<0.001) (Table 2).

Female students consistently demonstrated SER values equal to or lower than their male counterparts across all grade levels. Male students exhibited greater AL and CR measurements compared to females in all grades. The AL/CR ratio was higher in male students across all grades except senior high school, with all differences reaching statistical significance (P<0.05) (Table 2).

Spearman correlation analysis revealed strong associations between ocular biometric parameters and refractive status. AL demonstrated a high negative correlation with SER (R=−0.657, P<0.001), while AL/CR showed an even stronger negative correlation (R=−0.750, P<0.001). Regardless of the student's refractive classification, the correlation between AL/CR and SER consistently exceeded that observed between AL, CR, and SER (Table 3).

ROC curve analysis established optimal cut-off values for myopia prediction across all school grades. For AL, the cut-off points were 23.10 mm (kindergarten), 23.24 mm (lower-grade primary school), 23.72 mm (upper-grade primary school), 24.00 mm (junior high school), and 24.12 mm (senior high school). The corresponding areas under the ROC curve were 0.724 (95% *CI*: 0.704, 0.744), 0.784 (95% *CI*: 0.777, 0.791), 0.801 (95% *CI*: 0.793, 0.809), 0.824 (95% *CI*: 0.809, 0.840), and 0.858 (95% *CI*: 0.840, 0.876), respectively. For AL/CR, the optimal cut-off values were 2.97 (kindergarten), 2.99 (lower-grade primary school), 3.04 (upper-grade primary school), 3.07 (junior high school), and 3.10 (senior high school). The AL/CR parameter demonstrated superior predictive accuracy with areas under the ROC curve of 0.825 (95% *CI*: 0.808, 0.843), 0.854 (95% *CI*: 0.848, 0.860), 0.881 (95% *CI*: 0.875, 0.887), 0.885 (95% *CI*: 0.872, 0.897), and 0.882 (95% *CI*: 0.865, 0.899) for the respective grade levels.

DISCUSSION

Cycloplegic mydriatic optometry represents the internationally recognized gold standard for myopia diagnosis. This study employed post-mydriasis SER measurements to determine myopia status, ensuring reliable diagnostic accuracy. Additionally, our findings provide comprehensive baseline data on SE, AL, CR, and AL/CR ratios for children aged 5–18 years across 10 Chinese PLADs, addressing the limited availability of ocular biometric parameter data for East Asian pediatric populations.

Research demonstrates that the AL/CR ratio may serve as the optimal myopia indicator (*7*–*8*). Our analysis confirmed that AL/CR exhibited stronger correlations with SER compared to AL alone across all refractive error categories. Consequently, we employed the Youden index to establish optimal sensitivity-specificity combinations for AL and AL/CR myopia

TABLE 2. Effects of grade level and sex on spherical equivalent refraction and ocular biometric parameters among children [M (Q25, Q75)].

Parameter	Kindergarten	Lower grades of primary school	Upper grades of primary school	Junior high school	Senior high school	H	*P*
SER (D)							
Total	1.00 (0.63, 1.38)	0.63 (0.00, 1.00)	−0.50 (−1.88, 0.38)	−1.88 (−3.38, −0.38)	−2.38 (−3.75, −0.75)	18,308.070	<0.001*
Male	1.00 (0.50, 1.38)	0.63 (0.00, 1.00)	−0.38 (−1.75, 0.50)	−1.75 (−3.25, −0.25)	−2.00 (−3.63, −0.50)	8,529.575	<0.001*
Female	1.00 (0.63, 1.50)	0.63 (0.00, 1.13)	−0.63 (−2.00, 0.38)	−2.00 (−3.38, −0.59)	−2.50 (−3.88, −1.00)	9,789.880	<0.001*
Z	−9.131	−3.899	−6.967	−3.265	−4.104		
P	<0.001*	0.002*	<0.001*	0.001*	0.001*		
AL (mm)							
Total	22.56 (22.06, 23.02)	23.00 (22.46, 23.53)	23.81 (23.16, 24.45)	24.34 (23.67, 25.01)	24.59 (23.82, 25.36)	17,839.505	<0.001*
Male	22.83 (22.37, 23.25)	23.22 (22.76, 23.76)	24.00 (23.38, 24.67)	24.60 (23.97, 25.32)	24.78 (23.98, 25.57)	9,170.277	<0.001*
Female	22.25 (21.86, 22.70)	22.72 (22.22, 23.22)	23.60 (22.98, 24.20)	24.08 (23.44, 24.81)	24.40 (23.69, 25.06)	9,842.362	<0.001*
Z	−46.824	−54.150	−22.987	−14.139	−7.929		
P	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*		
CR (mm)							
Total	7.77 (7.60, 7.94)	7.77 (7.60, 7.95)	7.79 (7.62, 7.96)	7.79 (7.61, 7.97)	7.80 (7.64, 7.98)	81.673	<0.001*
Male	7.83 (7.67, 8.00)	7.84 (7.67, 8.01)	7.85 (7.68, 8.03)	7.85 (7.68, 8.03)	7.84 (7.69, 8.02)	22.471	0.009*
Female	7.69 (7.54, 7.87)	7.71 (7.55, 7.88)	7.73 (7.58, 7.90)	7.73 (7.55, 7.91)	7.76 (7.58, 7.92)	86.936	<0.001*
Z	−30.661	−40.687	−23.493	−13.521	−9.884		
P	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*		
AL/CR							
Total	2.90 (2.86, 2.95)	2.95 (2.90, 3.01)	3.05 (2.98, 3.13)	3.13 (3.04, 3.21)	3.15 (3.06, 3.24)	20,161.492	<0.001*
Male	2.91 (2.87, 2.96)	2.96 (2.91, 3.02)	3.05 (2.98, 3.14)	3.14 (3.04, 3.23)	3.15 (3.06, 3.25)	10,026.251	<0.001*
Female	2.89 (2.85, 2.93)	2.94 (2.89, 3.00)	3.04 (2.97, 3.13)	3.12 (3.04, 3.20)	3.15 (3.07, 3.24)	10,273.051	<0.001*
Z	−18.051	−18.548	−4.942	−3.660	−0.840		
P	<0.001*	<0.001*	<0.001*	0.001*	0.401		

Note: M represents the median, Q25 represents the 25th percentile, Q75 represents the 75th percentile, H represents the Kruskal–Wallis test statistic for ocular biometric parameters across different school grades, and Z represents the Mann–Whitney U test statistic for comparing ocular biometric parameters between sexes within each grade.
Abbreviation: SER=spherical equivalent refraction; AL=axial length; CR=corneal radius; AL/CR=axial length-to-corneal radius ratio.
* *P*<0.05 indicates statistically significant differences.

TABLE 3. Correlation analysis between spherical equivalent refraction and ocular biometric parameters across different refractive status groups [M (Q25, Q75)].

Group	SER (D)	AL		CR		AL/CR	
		R	*P*	R	*P*	R	*P*
Non−myopia	0.75 (0.38, 1.25)	−0.42	<0.001*	−0.004	0.358	−0.531	<0.001*
Mild myopia	−1.38 (−2.00, −0.88)	−0.414	<0.001*	−0.001	0.882	−0.546	<0.001*
Moderate myopia	−4.00 (−4.63, −3.50)	−0.299	<0.001*	0.008	0.630	−0.424	<0.001*
Total	0.50 (−0.50, 1.00)	−0.657	<0.001*	−0.001	0.001*	−0.750	<0.001*

Note: Data are presented as medians with 25th and 75th percentiles (Q25 and Q75).
Abbreviation: SER=spherical equivalent refraction; AL=axial length; CR=corneal radius; AL/CR=axial length-to-corneal radius ratio.
* *P*<0.05 indicates statistical significance.

prediction thresholds. Both AL and AL/CR demonstrated robust predictive accuracy across all grade levels, with ROC curve areas exceeding 0.7. However, AL/CR consistently outperformed AL in myopia prediction across every grade level, as evidenced by larger ROC curve areas. These findings suggest that when AL or AL/CR values — particularly AL/CR — exceed corresponding grade-specific thresholds, clinical vigilance is warranted.

This research's primary strength lies in its large-scale population survey encompassing ten Chinese PLADs, utilizing post-cycloplegia spherical equivalent refractive error as the diagnostic foundation. Compared to previous studies employing non-cycloplegic refraction results, our approach provides a more accurate pediatric vision status assessment. However, several limitations warrant consideration. The cross-sectional design permits statistical association identification but precludes causal inference establishment. Furthermore, the ocular biometric parameter thresholds derived from this study enable current myopia status prediction rather than future myopia development forecasting.

In conclusion, myopia prevalence among children and adolescents in East Asia remains consistently elevated, with China demonstrating particularly concerning rates. Both AL and AL/CR exhibit strong correlations with myopia development, establishing them as valuable indicators for myopia detection. Screening protocols utilizing established AL and AL/CR threshold values represent a non-invasive, rapid, and accurate public health strategy that enables early myopia detection and population-based prevention, effectively reducing both incidence and severity.

Conflicts of interest: No conflicts of interest.

Ethical statements: Received ethics approval from the institutional review board of Beijing Centers for Disease Prevention and Control (2022 No.24).

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Preplanned Studies

Current Status of Hyperopic Reserve Among Children and Adolescents — 10 PLADs, China, 2020–2024

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Summary

What is already known about this topic?

China exhibits a high prevalence of myopia; however, comprehensive national data based on cycloplegic refraction to assess the current status of hyperopic reserve in children and adolescents remains unavailable.

What is added by this report?

This study describes different percentiles of spherical equivalent (SE) after cycloplegic refraction for children and adolescents aged 5–18 years across 10 provincial-level administrative divisions (PLADs) and cities in China. SE values declined progressively with age in both males and females, with females demonstrating significantly lower median SE values than males beginning at age 10.

What are the implications for public health practice?

Hyperopic reserve requires systematic monitoring, particularly among females approaching puberty and younger children. Early surveillance by relevant departments is strongly recommended to support comprehensive myopia prevention and control strategies.

ABSTRACT

Introduction: To investigate the distribution characteristics of hyperopic reserve across 10 PLADs in China and determine the levels and patterns of change in spherical equivalent after cycloplegic refraction among children and adolescents aged 5–18 years by sex.

Methods: The National Disease Control and Prevention Administration of China conducted a comprehensive study between 2020 and 2024, involving 61,076 students from kindergarten through high school across 10 provincial-level administrative divisions (PLADs) in China. Median [first quartile (Q1), third quartile (Q3)] values were used to describe SE distribution, and the Mann–Whitney U test was employed to compare SE between males and females within the same age group.

Results: The median SE decreased progressively with age in both sexes, with females demonstrating a more rapid decline than males. The median SE reached ≤ −0.5 D at age 12 for males and age 11 for females. Among non-myopic participants, both sexes exhibited a consistent decline in median SE from ages 5–12, followed by relatively stable fluctuations from ages 13–18. However, the magnitude of both decline and fluctuations was greater in females than in males.

Conclusion: Hyperopic reserve among Chinese children and adolescents aged 5–18 years is substantially insufficient, with myopia onset occurring at increasingly younger ages, particularly among females approaching puberty and younger children. Early initiation of myopia prevention and control measures is essential, with timely monitoring of hyperopic reserve to prevent premature depletion.

During refractive development, children and adolescents experience a gradual transition from hyperopia to emmetropia, with continued development beyond emmetropia resulting in myopia. In 2022, the overall prevalence of myopia among students from senior kindergarten through high school in China reached 51.9% (*1*), highlighting the concerning depletion of hyperopic reserve in this population. Cycloplegic refraction represents the internationally recognized gold standard for myopia diagnosis (*2*). However, previous population-based investigations examining hyperopic reserve status in children and adolescents have been constrained by limited sample sizes (*3*). Furthermore, comprehensive national studies providing different percentile reference values of spherical equivalent (SE) following cycloplegic refraction in individuals aged 5–18 years remain insufficient, thereby limiting accurate evaluation of hyperopic reserve in this demographic. This study characterizes the distribution patterns of hyperopic reserve across 10 PLADs in China, elucidates the levels and developmental trajectories of spherical equivalent after cycloplegic refraction in children and adolescents aged 5–18 years by sex, addresses the existing data gap in this field, and provides essential evidence to support myopia prevention and control initiatives.

This study utilized data from a national cross-sectional survey examining ocular development in children and adolescents, conducted between 2020 and 2024 under the auspices of the National Disease Control and Prevention Administration of China. The survey encompassed 10 provincial-level administrative divisions (PLADs): Beijing, Shanxi, Liaoning, Zhejiang, Shandong, Henan, Hunan, Guangdong, Chongqing, and Shaanxi. From each PLAD, 1–2 cities were selected through direct sampling based on economic development levels, while municipalities contributed one district each from urban and suburban areas using identical selection criteria. Within each selected city or district, schools were sampled by grade level using multistage cluster sampling, encompassing kindergarten, primary, junior high, and senior high schools. After identifying target schools and classes, all students within selected classes were enrolled as study participants. Inclusion criteria required participants aged 5–18 years who underwent computerized refraction under ciliary muscle paralysis, provided voluntary participation, and had parental informed consent. Exclusion criteria comprised any diseases affecting visual development or interfering with eye examinations.

Participants completed a self-administered electronic questionnaire to collect demographic information, including sex, age, educational level, and geographic area. All participants underwent slit-lamp examination to exclude contraindications to pupil dilation, followed by computerized refraction under ciliary muscle paralysis. Equipment was calibrated before use, and examinations were performed by personnel with certified ophthalmology-related professional qualifications. To ensure data quality, we randomly selected 5% of participants for retesting of visual acuity parameters, including spherical and cylindrical power, before cycloplegic refraction. When differences between any two measurements exceeded 0.5 D, readings were discarded and the eye was re-examined. We used a desktop autorefractor (KR8800; Topcon) to measure refraction under cycloplegia, which was induced by administering 0.5% tropicamide every 5 minutes for four applications. After 30 minutes, we assessed pupil dilation and cycloplegia. SE was calculated as the sum of spherical power plus half the cylindrical power. Myopia was defined as SE ≤−0.5 D.

We performed data analysis using SPSS (version 26.0; IBM Corp., NY, USA). The Kolmogorov–Smirnov normality test indicated that SE data were not normally distributed; therefore, we presented results as M (Q1, Q3). Since SE values in the right and left eyes were significantly correlated (r=0.897, P<0.01), we analyzed only the right eye. We presented count data as frequencies and percentages. The Mann–Whitney U test was used to compare SE between males and females within the same age group. A two-sided P<0.05 was considered statistically significant.

A total of 67,260 students participated in the study. Of these, 22 were excluded due to diseases affecting visual development or interfering with eye examinations, 4,968 were excluded for missing cycloplegic SE (right eye) data, and 1,023 outliers (<Q1−3×IQR or >Q3+3×IQR) were removed. Additionally, 171 participants outside the 5–18-year age range were excluded. The final analysis included 61,076 students, with the data collection procedure detailed in Supplementary Figure S1 (available at https://weekly.chinacdc.cn/). The cohort comprised 31,519 (51.61%) males and 29,557 (48.39%) females. Among all participants, 15,962 (26.13%) were classified as myopic (mean age, 11.15±3.09 years; median SE, −1.75 D), while 45,114 (73.87%) were non-myopic (mean age, 7.77±2.07 years; median SE, 0.75 D).

Among all participants, the median SE for children and adolescents aged 5–18 years was 0.50 D. The median SE demonstrated a progressive decline with increasing age, with females exhibiting a more pronounced decline than males. Males reached a median SE≤−0.5 D beginning at age 12, while females reached this threshold at age 11. Statistically significant differences in median SE between males and females were observed at ages 5–7, 10–12, 14, and 17–18 (Z=−2.30, −7.86, −5.34, −5.86, −4.00, −4.22, −3.37, −2.10, −3.10, all P<0.05). Notably, females aged 5–7 years demonstrated higher median SE values than males. These comprehensive findings are detailed in Table 1 and Figure 1.

Among non-myopic participants, the median SE for children and adolescents aged 5–18 years was 0.75 D (0.75 D for males and 0.88 D for females). Both sexes demonstrated a decline in median SE from ages 5 to 12, followed by relatively stable fluctuations from ages 13 to 18. The magnitude of decline and subsequent fluctuations was greater in females than in males. Statistically significant differences in median SE between sexes were observed at ages 5–8 and 10–11 (Z=−2.32, −8.21, −4.52, −2.17, −2.86, −2.40, all P<0.05), with females exhibiting higher median SE values than males

TABLE 1. Distribution of hyperopic reserve among children and adolescents across 10 PLADs in China, 2020–2024.

Age (years)	Males		Females		All	
	n (%)	M (Q1, Q3)	*n* (%)	M (Q1, Q3)	*n* (%)	M (Q1, Q3)
5	583 (1.85)	1.00 (0.63, 1.50)	551 (1.86)	1.13 (0.63, 1.63)	1,134 (1.86)	1.13 (0.63, 1.50)
6	6,808 (21.60)	1.00 (0.50, 1.38)	6,215 (21.03)	1.00 (0.63, 1.50)	13,023 (21.32)	1.00 (0.63, 1.38)
7	7,077 (22.45)	0.75 (0.25, 1.13)	6,671 (22.57)	0.75 (0.38, 1.25)	13,748 (22.51)	0.75 (0.25, 1.13)
8	4,552 (14.44)	0.50 (−0.13, 1.00)	4,285 (14.50)	0.50 (−0.13, 1.00)	8,837 (14.47)	0.50 (−0.13, 1.00)
9	3,334 (10.58)	0.25 (−0.75, 0.75)	3,215 (10.88)	0.13 (−0.88, 0.75)	6,549 (10.72)	0.25 (−0.75, 0.75)
10	2,531 (8.03)	0.00 (−1.25, 0.63)	2,247 (7.60)	−0.38 (−1.50, 0.38)	4,778 (7.82)	−0.13 (−1.38, 0.50)
11	1,985 (6.30)	−0.38 (−1.75, 0.50)	1,910 (6.46)	−0.63 (−2.00, 0.25)	3,895 (6.38)	−0.50 (−1.88, 0.38)
12	1,576 (5.00)	−0.75 (−2.25, 0.38)	1,380 (4.67)	−1.13 (−2.49, 0)	2,956 (4.84)	−1.00 (−2.38, 0.25)
13	780 (2.47)	−1.25 (−3.00, 0)	744 (2.52)	−1.63 (−2.88, −0.25)	1,524 (2.50)	−2.13 (−3.00, −0.13)
14	595 (1.89)	−1.75 (−3.25, −0.25)	642 (2.17)	−2.13 (−3.50, −0.88)	1,237 (2.03)	−2.00 (−3.38, −0.50)
15	455 (1.44)	−2.13 (−3.63, −0.50)	488 (1.65)	−2.25 (−3.63, −1.00)	943 (1.54)	−2.13 (−3.63, −0.75)
16	475 (1.51)	−2.13 (−3.63, −0.63)	486 (1.64)	−2.38 (−3.75, −0.88)	961 (1.57)	−2.38 (−3.63, −0.75)
17	411 (1.30)	−2.13 (−3.63, −0.75)	449 (1.52)	−2.63 (−4.00, −1.13)	860 (1.41)	−2.38 (−3.75, −0.88)
18	357 (1.13)	−2.00 (−3.50, −0.25)	274 (0.93)	−2.50 (−4.00, −1.00)	631 (1.03)	−2.13 (−3.63, −0.50)

Abbreviation: PLADs=provincial-level administrative divisions; M=median; Q1=first quartile; Q3=third quartile.

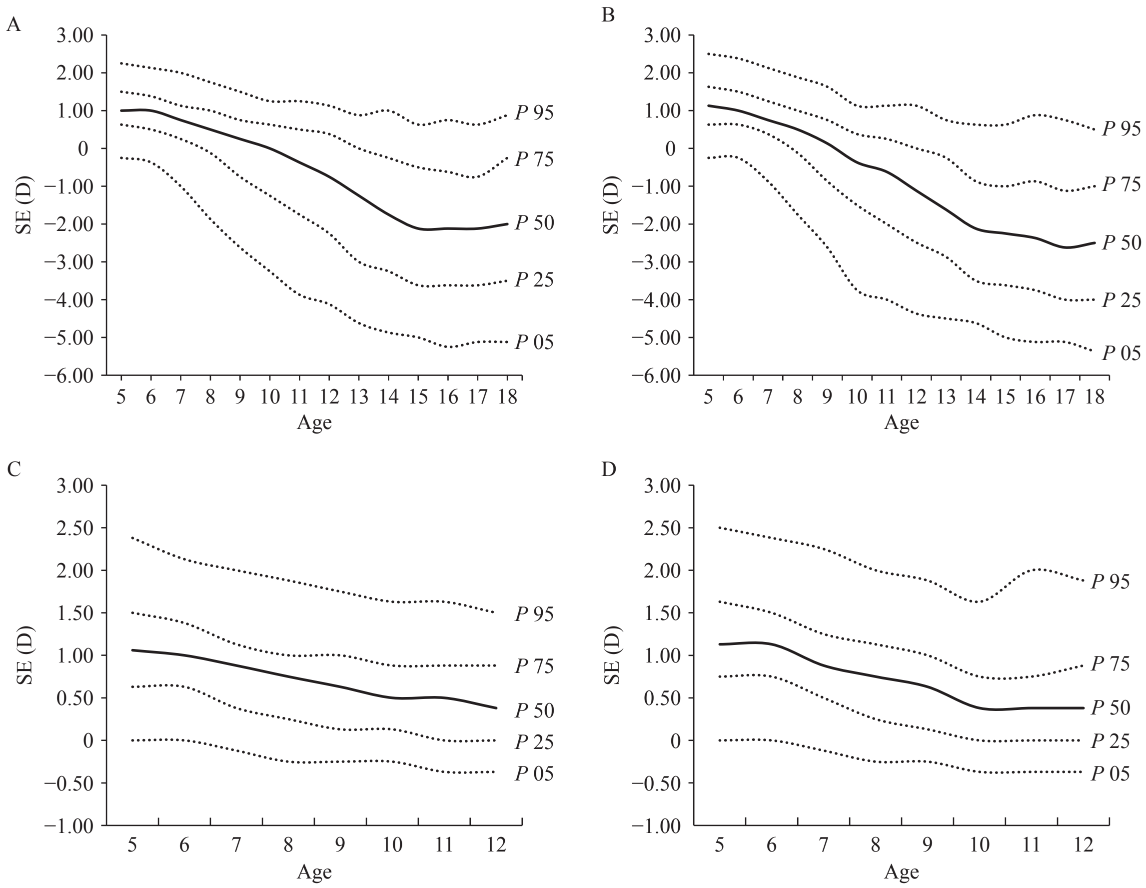

FIGURE 1. Distribution of hyperopic reserve among children and adolescents across 10 PLADs and cities in China. (A) All males; (B) All females; (C) Non-myopic males; (D) Non-myopic females.
Abbreviation: PLADs=provincial-level administrative divisions; SE=spherical equivalent; D=diopters.

at ages 5–8. Given the stability of the sample size, the distribution of hyperopic reserve among participants aged 5–12 years without myopia across different sexes is presented in Table 2 and Figure 1.

DISCUSSION

Among all participants, the median SE was 1.00 to 1.13 D for preschoolers (5–6 years), −1.00 to 0.75 D for primary school students (7–12 years), −2.13 to −1.44 D for junior high students (13–15 years), and −2.13 to −2.38 D for senior high students (16–18 years). In contrast, a prior Chinese expert consensus using data from Henan, Shandong, and Gansu provinces reported median SE of 1.38 D for 6-year-olds, 0.50 to 1.38 D for 7–12-year-olds, and 0.31 to 0.50 D for 13–15-year-olds (*3*). Overall, SE values in this study were slightly lower, possibly because participants were from ten PLADs nationwide, and the sample size was nearly 5.4 times larger than it, making the current study more representative.

This study found a myopia rate of 26.13%, versus the national rate of 51.9% (*1*). This difference arises as all participants in this study underwent cycloplegic refraction, which detects lower myopia prevalence than non-cycloplegic methods. Parents should take children for regular cycloplegic refraction (instead of relying on school annual vision screenings) to prevent early myopia onset.

Among countries using cycloplegic refraction, Armenia's 5–19-year-old myopia rate was 18.13%, and Poland's 6–18-year-old rate was 13.30% (*4*). This may relate to earlier school enrollment and greater academic pressure on students in China.

This cross-sectional study revealed that median SE values decreased progressively with age in both males and females. Among all participants and non-myopic children aged 5–12 years, females exhibited lower median SE values than males beginning at age 10, which aligns with findings from previous cross-sectional studies conducted in Shandong Province (*5*). The accelerated SE decline observed in females likely stems from multiple interconnected factors: females typically spend more time engaged in indoor academic activities and less time outdoors, while exposure to natural light stimulates dopamine release, which inhibits axial elongation of the eye (*6*). Furthermore, earlier myopia onset correlates with an earlier peak in height growth velocity, potentially due to surging growth hormone levels during this developmental phase (*7*); experimental studies in rats demonstrate that growth hormone induces ocular axial elongation and accelerates myopia progression (*8*). Since females enter puberty and reach their height growth peak earlier than males (*9*), they experience more rapid myopia progression. These findings support implementing targeted myopia prevention strategies specifically for females approaching puberty. The results also demonstrated that both sexes

TABLE 2. Distribution of hyperopic reserve among non−myopic children and adolescents in 10 PLADs of China, 2020–2024.

Age (years)	Males		Females		All	
	n (%)	M (Q1, Q3)	*n* (%)	M (Q1, Q3)	*n* (%)	M (Q1, Q3)
5	562 (2.38)	1.06 (0.63, 1.50)	533 (2.48)	1.13 (0.75, 1.63)	1,095 (2.43)	1.13 (0.75, 1.63)
6	6,517 (27.59)	1.00 (0.63, 1.38)	5,960 (27.73)	1.13 (0.75, 1.50)	12,477 (27.66)	1.00 (0.63, 1.50)
7	6,403 (27.11)	0.88 (0.38, 1.13)	6,127 (28.51)	0.88 (0.50, 1.25)	12,530 (27.77)	0.88 (0.50, 1.25)
8	3,735 (15.81)	0.75 (0.25, 1.00)	3,524 (16.40)	0.75 (0.25, 1.13)	7,259 (16.09)	0.75 (0.25, 1.13)
9	2,337 (9.89)	0.63 (0.13, 1.00)	2,181 (10.15)	0.63 (0.13, 1.00)	4,518 (10.01)	0.63 (0.13, 1.00)
10	1,528 (6.47)	0.50 (0.13, 0.88)	1,183 (5.50)	0.38 (0, 0.75)	2,711 (6.01)	0.50 (0, 0.88)
11	1,013 (4.29)	0.50 (0, 0.88)	857 (3.99)	0.38 (0, 0.75)	1,870 (4.15)	0.50 (0, 0.88)
12	698 (2.95)	0.38 (0, 0.88)	482 (2.24)	0.38 (0, 0.88)	1,180 (2.62)	0.38 (0, 0.88)
13	261 (1.10)	0.25 (0, 0.63)	205 (0.95)	0.13 (−0.13, 0.63)	466 (1.03)	0.13 (0, 0.63)
14	168 (0.71)	0.25 (0, 0.75)	130 (0.60)	0.25 (−0.13, 0.63)	298 (0.66)	0.25 (−0.13, 0.63)
15	107 (0.45)	0.38 (0, 0.63)	86 (0.40)	0.25 (0, 0.75)	193 (0.43)	0.25 (0, 0.63)
16	103 (0.44)	0.38 (0, 0.75)	96 (0.45)	0.50 (0, 0.88)	199 (0.44)	0.38 (0, 0.75)
17	92 (0.39)	0.25 (−0.13, 0.56)	81 (0.38)	0.25 (−0.13, 0.75)	173 (0.38)	0.25 (−0.13, 0.63)
18	97 (0.41)	0.38 (0, 0.63)	48 (0.22)	0 (−0.13, 0.69)	145 (0.32)	0.25 (−0.13, 0.63)

Abbreviation: PLADs=provincial-level administrative divisions; M=median; Q1=first quartile; Q3=third quartile.

developed myopia during primary school years, emphasizing the critical need for early vision screening programs and promoting cycloplegic refraction to guide timely interventions before hyperopic reserves are completely depleted.

A major strength of this investigation lies in the accurate estimation of refractive data through cycloplegia combined with computerized recording, ensuring high reliability and precision. This represents China's most extensive cycloplegic refraction survey to date, encompassing children and adolescents aged 5–18 years across ten PLADs.

This study presents two notable limitations: its cross-sectional design precludes long-term follow-up, restricting our analysis to describing current hyperopic reserve status without evaluating refractive progression trajectories. Additionally, certain age subgroups contained relatively small sample sizes. Future investigations incorporating larger, more balanced samples are essential for establishing more representative hyperopic reserve reference values.

In summary, Chinese children and adolescents aged 5–18 years demonstrate insufficient hyperopic reserves accompanied by earlier myopia onset. Urgent interventions should include establishing nationwide longitudinal surveillance programs with representative samples to develop scientific hyperopic reserve reference standards, facilitating systematic classification and management of children and adolescents. Additionally, enhancing public awareness campaigns targeting parents and educational institutions remains crucial for transforming myopia prevention from reactive to proactive approaches.

Conflicts of interest: No conflicts of interest.

Ethical statements: Approved by the Ethics Committee of the Beijing Center for Disease Prevention and Control (2022 No.24), and written informed consent was obtained from all parents of participants.

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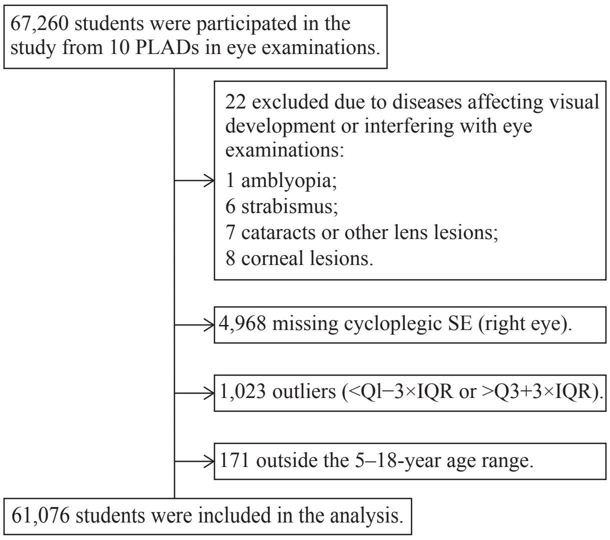
SUPPLEMENTARY MATERIALS



SUPPLEMENTARY FIGURE S1. Flowchart depicting the participant inclusion and exclusion process.

Note: To minimize the influence of extreme outliers on our analyses, we excluded values that fell below Q1–3×IQR or exceeded Q3+3×IQR, where Q1 and Q3 represent the first and third quartiles of the grade-specific sample data, respectively, and IQR represents the interquartile range (Q3–Q1). This exclusion criterion resulted in the removal of 1.5% of all observations from the final dataset.

Abbreviation: PLADs=provincial-level administrative divisions; SE=spherical equivalent; Q1=first quartile; IQR=interquartile range; Q3=third quartile.

Preplanned Studies

Regional Heterogeneity in Screen Time and Usage Habits Associated with Insufficient Hyperopic Reserve in Schoolchildren — 9 PLADs, China, 2020–2024

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Summary

What is already known about this topic?

Insufficient hyperopic reserve serves as a preclinical indicator of myopia development and is influenced by socioeconomic factors and behavioral patterns. However, region-specific risk profiles remain inadequately characterized.

What is added by this report?

This nationwide investigation demonstrates substantial regional heterogeneity in myopia risk factors. Children residing in low-gross domestic product (GDP) regions exhibit significantly stronger associations between screen time usage and poor screen habits with insufficient hyperopic reserve. This relationship is most pronounced among girls in low-GDP areas.

What are the implications for public health practice?

Public health interventions should prioritize targeted screen use guidance for children, particularly girls in socioeconomically disadvantaged regions, to effectively protect visual health and prevent myopia progression.

ABSTRACT

Introduction: Premature depletion of hyperopic reserve has been demonstrated to associate with subsequent myopia development. However, the relationship between screen use and insufficient hyperopic reserve (defined as spherical equivalent refraction below age-specific thresholds) remains unclear, and regional heterogeneity in this association warrants investigation.

Methods: This cross-sectional study (2020–2024) included 28,993 children from 9 provincial-level administrative divisions (PLADs). We assessed associations between screen exposure (time and habits) and hyperopic reserve status. Multivariable logistic regression analyses were conducted with stratified analyses based on regional gross domestic product (GDP) levels.

Results: Among screened children, 49.0% exhibited insufficient hyperopic reserve. High screen time [odds ratio (*OR*)=1.21, 95% confidence interval (95% *CI*): 1.14, 1.29] and poor screen habits (*OR*=1.19, 95% *CI*: 1.12, 1.27) were independently associated with insufficient hyperopic reserve. Low-GDP regions demonstrated significantly higher detection rates among children aged 6–9 years, whereas high-GDP regions showed accelerated increases in detection rates after age 11. Low-GDP regions exhibited heightened risks for both high screen time and poor screen habits, with this association most pronounced among girls in low-GDP areas.

Conclusions: Screen exposure associates with insufficient hyperopic reserve, exhibiting notable regional and gender differences. High screen time and poor screen habits represent key risk factors for insufficient hyperopic reserve, particularly among girls residing in low-GDP areas.

The high prevalence of myopia and its associated irreversible ocular complications underscore the urgent need for early prevention and control measures (*1*). As a core indicator of refractive development, premature depletion of hyperopic reserve has been demonstrated to associate with subsequent myopia development, highlighting its critical role in early refractive management (*2*). Epidemiological studies suggest that factors including prolonged electronic screen exposure and sustained near-work patterns may accelerate hyperopic reserve depletion through mechanisms such as light bio-regulation and retinal defocus (*3*). However, this association exhibits significant regional variation. Research indicates that these differences may relate to economic development levels (*4*). This study systematically analyzes regional heterogeneity in screen use and insufficient hyperopic reserve among school-aged children aged 6–12 years, using nationwide multi-center epidemiological data to provide evidence-based support for developing targeted myopia prevention and control strategies across different regions.

The National Disease Control and Prevention Administration of China coordinated a cross-sectional survey of nationwide hyperopic reserves across 10 provincial-level administrative divisions (PLADs) between November 2020 and July 2024. Students from senior kindergarten through high school were selected using multistage cluster sampling at each site. This study analyzed data from 9 PLADs (Liaoning, Beijing, Zhejiang, Guangdong, Henan, Hunan, Shanxi, Shaanxi, and Chongqing) after excluding Shandong Province due to insufficient sample size. The Beijing Center for Disease Control and Prevention developed a standardized questionnaire to collect demographic characteristics, genetic factors, environmental exposures, and visual behaviors. Of 67,260 questionnaires distributed to students from senior kindergarten through high school, 28,993 valid responses were obtained from primary school students aged 6–12 years. Professional institutions conducted comprehensive ophthalmic examinations including cycloplegic refraction, axial length, and corneal curvature measurements. All participants underwent slit-lamp examination to rule out contraindications before testing, and certified optometrists performed all subsequent measurements (*5*).

Hyperopic reserve was defined as spherical equivalent refraction relative to age-specific normative ranges, with values below the lower limit classified as insufficient hyperopic reserve (*6*). Daily screen time was calculated by summing average hours spent on computers, television, and mobile devices. Screen habits were assessed through questionnaire responses regarding use in direct sunlight, dim surroundings, lying or prone posture, and while walking or riding. A composite screen habits score was constructed by summing frequency ratings for these behaviors, with higher scores indicating more frequent high-risk screen use. Both screen time and screen habits scores were categorized into low, medium, and high tertiles based on sample distribution.

To compare groups with and without insufficient hyperopic reserve, we used the Wilcoxon rank-sum test for continuous variables and Pearson's chi-squared test for categorical variables. We employed multivariable logistic regression models to assess associations between screen time and screen habits with insufficient hyperopic reserve, adjusting for key covariates including age, sex, ethnicity, body mass index (BMI), region, grade level, parental education level, and parental myopia status. Statistical significance was set at a two-sided $P<0.05$. All analyses were performed using R Statistical Software (version 4.3.1; R Core Team, R Foundation for Statistical Computing, Vienna, Austria).

This study analyzed data from 28,993 participants, of whom 14,507 exhibited insufficient hyperopic reserve. As demonstrated in Table 1, participants with insufficient hyperopic reserve were significantly more likely to display several key characteristics: enrollment in upper primary grades, female gender, obesity, residence in low-GDP regions, and parental myopia history.

The findings revealed that insufficient hyperopic reserve detection rates increased progressively with age, demonstrating a rapid escalation among students aged 6–8 years. Following a plateau phase between ages 8–11 years, the rates surged dramatically after age 11 (Figure 1A). Notably, substantial disparities in insufficient hyperopic reserve detection rates emerged across regions with varying levels of economic development. Using the 2023 national per capita GDP as the reference standard, participating regions were stratified into high-GDP and low-GDP categories. Specifically, before age 8 years, detection rates in low-GDP regions consistently exceeded those in high-GDP regions. This disparity gradually diminished with advancing age, achieving parity in prevalence by age 9 years. No significant GDP-based regional differences were observed during the 9–11 year period. However, after age 12 years, children in high-GDP regions demonstrated significantly higher prevalence of insufficient hyperopic reserve compared to their counterparts in low-GDP regions (Figure 1B).

After adjusting for all relevant confounding factors in Model 3, both medium screen time [odds ratio (*OR*)=1.09, 95% confidence interval (95% *CI*): 1.03, 1.15] and high screen time (*OR*=1.21, 95% *CI*: 1.14, 1.29) demonstrated significantly stronger associations with insufficient hyperopic reserve compared to the low screen time group. Similarly, for screen habits score, the medium screen habits score group (*OR*=1.07, 95% *CI*: 1.01, 1.13) and high screen habits score group (*OR*=1.19, 95% *CI*: 1.12, 1.27) showed increased odds of insufficient hyperopic reserve relative to the low screen habits score group (Figure 2A). GDP-stratified analysis revealed that the associations

TABLE 1. Characteristics of participants by insufficient hyperopic reserve status among schoolchildren aged 6–12 years, 2020–2024 (*n*=28,993).

Characteristic	Overall (*n*=28,993)	Insufficient hyperopic reserve		
		No (*n*=14,458)	Yes (*n*=14,535)	*P**
Age [median (IQR)]	8.00 (7.00, 9.00)	7.00 (6.00, 9.00)	8.00 (7.00, 9.00)	<0.001
Gender [*n* (%)]				0.005
Male	14,886 (51.34)	7,544 (52.18)	7,342 (50.51)	
Female	14,107 (48.66)	6,914 (47.82)	7,193 (49.49)	
Ethnicity [*n* (%)]				0.694
Han	27,466 (94.73)	13,704 (94.78)	13,762 (94.68)	
Other	1,527 (5.27)	754 (5.22)	773 (5.32)	
BMI [*n* (%)]				<0.001
Normal	19,360 (66.77)	9,873 (68.29)	9,487 (65.27)	
Overweight	4,529 (15.62)	2,255 (15.60)	2,274 (15.64)	
Obesity	5,104 (17.60)	2,330 (16.12)	2,774 (19.08)	
Grade [*n* (%)]				<0.001
Elementary school lower grades (1–3)	21,390 (73.78)	11,640 (80.51)	9,750 (67.08)	
Elementary school upper grades (4–6)	7,603 (26.22)	2,818 (19.49)	4,785 (32.92)	
GDP region [*n* (%)]				<0.001
Low GDP	16,016 (55.24)	7,660 (52.98)	8,356 (57.49)	
High GDP	12,977 (44.76)	6,798 (47.02)	6,179 (42.51)	
Father's education level [*n* (%)]				0.010
Junior high school and below	6,149 (21.21)	3,161 (21.86)	2,988 (20.56)	
High school or vocational school	9,217 (31.79)	4,508 (31.18)	4,709 (32.40)	
College and above	13,627 (47.00)	6,789 (46.96)	6,838 (47.05)	
Mother's education level [*n* (%)]				0.036
Junior high school and below	5,824 (20.09)	2,983 (20.63)	2,841 (19.55)	
High school or vocational school	8,794 (30.33)	4,313 (29.83)	4,481 (30.83)	
College and above	14,375 (49.58)	7,162 (49.54)	7,213 (49.63)	
Parental myopia status [*n* (%)]				<0.001
Neither parent myopic	12,982 (44.78)	7,240 (50.08)	5,742 (39.50)	
Only the father is myopic	4,288 (14.79)	2,079 (14.38)	2,209 (15.20)	
Only the mother is myopic	6,537 (22.55)	3,089 (21.37)	3,448 (23.72)	
Both parents are myopic	5,186 (17.89)	2,050 (14.18)	3,136 (21.58)	
Screen time [*n* (%)]				<0.001
Low	9,240 (31.87)	4,907 (33.94)	4,333 (29.81)	
Medium	12,299 (42.42)	6,154 (42.56)	6,145 (42.28)	
High	7,454 (25.71)	3,397 (23.50)	4,057 (27.91)	
Screen habits score [*n* (%)]				<0.001
Low	7,418 (25.59)	3,951 (27.33)	3,467 (23.85)	
Medium	11,973 (41.30)	6,090 (42.12)	5,883 (40.47)	
High	9,602 (33.12)	4,417 (30.55)	5,185 (35.67)	

Note: Screen time represents the sum of average daily hours spent on computers, television, and mobile devices; Screen habits score represents the sum of frequency ratings for use in direct sunlight, dim surroundings, lying/prone posture, and while walking or riding; higher scores indicate more frequent high-risk usage patterns; both variables were categorized into sample-based low/medium/high tertiles.
Abbreviation: BMI=body mass index; GDP=gross domestic product; IQR=interquartile range; *n* (%)=number (percentage).
* To compare groups with and without insufficient hyperopic reserve, the Wilcoxon rank-sum test was applied for continuous variables, and Pearson's chi-squared test was used for categorical variables.

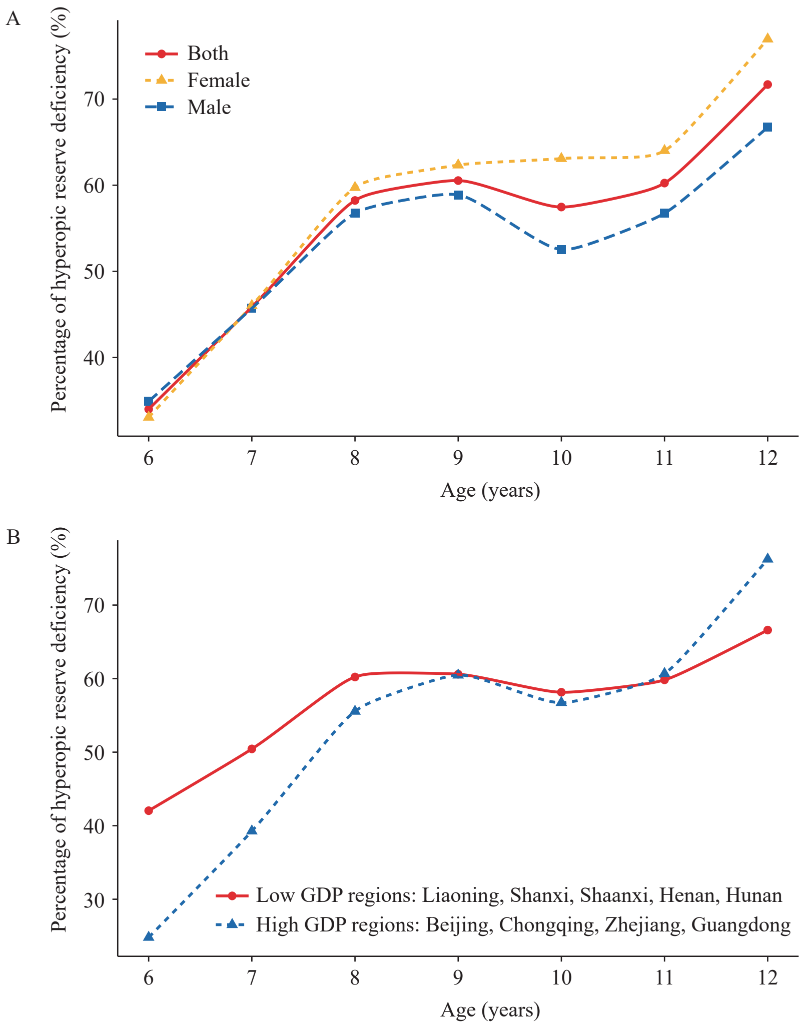

FIGURE 1. Age-related patterns in insufficient hyperopic reserve prevalence. (A) Gender-stratified age trends in insufficient hyperopic reserve detection rates; (B) Regional GDP-based differences in age-related insufficient hyperopic reserve patterns.

Note: GDP regional classifications are based on national per capita GDP levels in 2023.

Abbreviation: GDP=gross domestic product.

between both screen time and screen habits score with insufficient hyperopic reserve were markedly more pronounced in low-GDP regions (Figure 2B). Further subgroup analysis demonstrated distinct gender-based patterns: insufficient hyperopic reserve among girls in low-GDP regions exhibited stronger associations with both screen time and screen habits score, while the association with direct sunlight exposure was more pronounced among boys in low-GDP regions (Figure 2C).

DISCUSSION

This nationwide study of 28,993 students aged 6–12 years revealed that insufficient hyperopic reserve risk follows distinct age-related patterns, affecting approximately 70% of students by age 12. Our findings demonstrate significant positive associations between both screen time and poor screen habits with insufficient hyperopic reserve, with these relationships displaying marked heterogeneity across regions stratified by GDP levels. Even after controlling for potential confounders, both screen exposure duration and suboptimal viewing habits remained independently associated with insufficient hyperopic reserve.

Our results demonstrate that the relationship between screen exposure and insufficient hyperopic reserve exhibits pronounced regional heterogeneity, with low-GDP areas consistently showing stronger correlations. The elevated prevalence of insufficient hyperopic reserve among children aged 6–8 years in

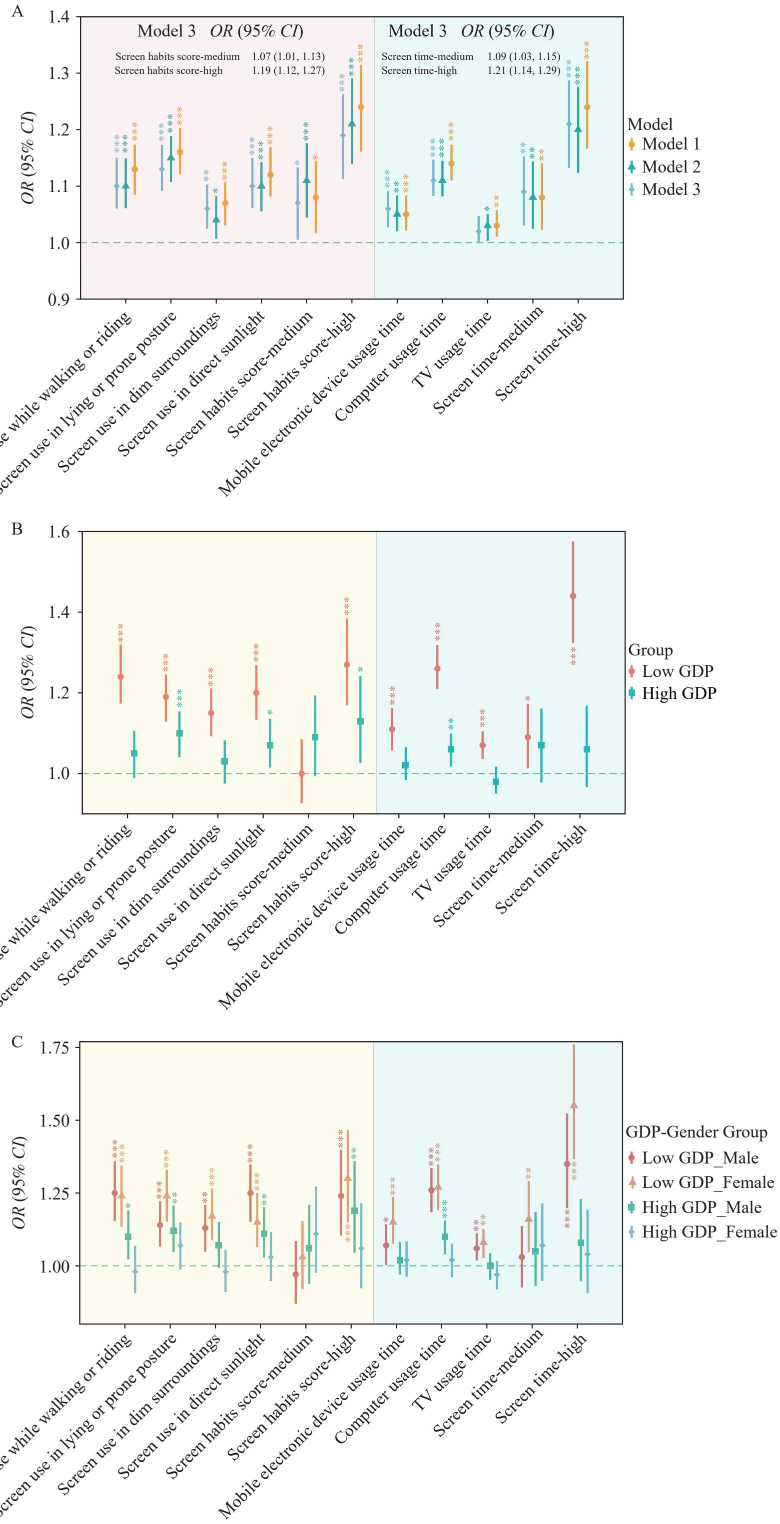

FIGURE 2. Regional GDP and gender-stratified associations between screen exposure and insufficient hyperopic reserve. (A) Overall associations of screen time and screen habits with insufficient hyperopic reserve; (B) GDP-stratified regional variations in screen exposure associations; (C) Combined GDP-gender stratified differences in screen exposure relationships.

Note: Model 1 adjusts for age and gender; Model 2 additionally includes BMI, grade level, GDP region, and ethnicity; Model 3 further incorporates paternal education level, maternal education level, and parental myopia status.

Abbreviation: GDP=gross domestic product; BMI=body mass index; *OR*=odds ratio; *CI*=confidence interval.

* *P*<0.05; ** *P*<0.01; *** *P*<0.001.

economically disadvantaged regions likely stems from multiple interconnected factors: limited family awareness regarding ocular health, premature and poorly regulated electronic device usage, and inadequate outdoor recreational spaces. These conditions create a problematic combination of excessive accommodative demands and insufficient hyperopic stimulation during critical visual development periods, thereby accelerating the depletion of hyperopic reserves. As technological advancement accompanies economic growth, intensifying educational pressures may drive students toward prolonged screen-based learning through online courses, supplemental tutoring, and practice sessions, consequently elevating myopia incidence (*7*). The competitive academic environment fuels increased reliance on electronic educational devices, while concurrent adolescent axial elongation means that sustained near-work demands frequently exceed the eye's homeostatic regulatory capacity (*8*).

Our findings also revealed that girls from low-GDP regions demonstrate a stronger association between screen time, screen habits score, and insufficient hyperopic reserve. Research indicates that girls in low-income communities may experience greater screen exposure compared to their peers in high-income areas, primarily due to limited access to extracurricular activities and recreational facilities in these regions (*9–10*). Previous studies have also demonstrated that girls in low-socioeconomic-status regions exhibit significantly higher overall screen time and weekly hours spent watching television/movies than those in high-GDP regions — a gender-specific pattern not observed among boys (*10*). Excessive electronic screen use reduces outdoor activity time, while natural outdoor light stimulates retinal dopamine secretion, inhibits axial elongation, and prevents myopia development.

This study encompasses nine PLADs and municipalities across China, providing extensive geographic coverage, substantial sample size, and strong representativeness. However, several limitations warrant acknowledgment. The cross-sectional design precludes causal inference between screen use and insufficient hyperopic reserve. Although we adjusted for key confounders, residual confounding from unmeasured factors such as detailed outdoor activity patterns or other near-work tasks cannot be eliminated. Reliance on questionnaires for screen time assessment may introduce recall bias. Additionally, the study did not comprehensively examine other potential influences including dietary habits or detailed family history. Future longitudinal studies incorporating objective measures and broader risk factor assessments are warranted.

In summary, this study reveals a high prevalence of insufficient hyperopic reserve among Chinese primary school students. The findings demonstrate positive associations between screen time, screen habits score, and insufficient hyperopic reserve. These associations were particularly pronounced in low-GDP areas, especially among girls. The research suggests that parents should implement strict limitations on children's screen time and correct poor screen habits. Government agencies should intensify educational outreach efforts in low-GDP areas.

Ethical statements: Approval by the institutional review board of Beijing Centers for Disease Prevention and Control (2022 No.24).

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Methods and Applications

Predicting Cycloplegic Spherical Equivalent Refraction Among Children and Adolescents Using Non-cycloplegic Data and Machine Learning — China, 2020–2024

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ABSTRACT

Introduction: Cycloplegic refraction is the gold standard for assessing refractive error in children. However, logistical constraints hinder its implementation in large-scale surveys.

Methods: Data obtained from a nationwide ocular health survey conducted in ten provincial-level administrative divisions in China were analyzed (2020–2024). Participants aged 5–18 years underwent standardized non-cycloplegic and cycloplegic autorefraction, axial length (AL), corneal radius (CR), and AL/CR measurements. Random forest and XGBoost models were trained to predict the cycloplegic spherical equivalent (SE) using non-cycloplegic SE, uncorrected visual acuity (UCVA), and biometric parameters. Performance was evaluated using R^2, root mean square error (RMSE), and Bland–Altman analysis.

Results: Both models exhibited strong predictive performance. In the test set, random forest achieved R^2=0.88 and RMSE=0.55 diopter (D), whereas XGBoost achieved R^2=0.89 and RMSE=0.54 D. Non-cycloplegic SE, AL/CR ratio, AL, and UCVA were consistently the top predictors. The predicted SE exhibited strong agreement with the cycloplegic SE, with minimal residual bias.

Conclusion: Machine learning models incorporating noncycloplegic SE and ocular biometrics accurately estimate cycloplegic SE in children and adolescents, providing a practical alternative for large-scale refractive-error surveillance when cycloplegia is impractical.

Refractive error screening in children is a major public health challenge in China. A Chinese study projects that by 2050, urban myopia rates will be 27.1% [95% confidence interval (95% *CI*): 10.0%–44.4%) for 7–9 year olds and 81.5% (95% *CI*: 74.7%–88.3%) for 16–18 year olds, with rural rates at 20.1% (95% *CI*: 8.6%–31.7%) and 74.1% (95% *CI*: 63.2%–84.8%), respectively. High myopia in 16–18 year olds is expected to increase from 7.3% in 2001 to 22.1% by 2050 (*1*). Despite its status as the gold standard for accurate measurements (*2*), the implementation of cycloplegic refraction in large-scale school screenings is often impractical because of logistical constraints and potential side effects (*3*). Current reliance on non-cycloplegic refraction introduces substantial variability, with studies reporting mean differences in the range of 0.60–1.23 diopters (D) compared with cycloplegic measurements (*4*), particularly in younger children with strong accommodative responses. Recent advances in machine learning (ML) have shown promise in the prediction of ophthalmic parameters. However, their application in bridging cycloplegic and non-cycloplegic measurements remains underexplored in population-based settings. Ocular biometric parameters are important indicators for assessing far-vision reserve in children and for objectively evaluating the development of refraction (*5*). This study aimed to develop and validate ML-based models to predict cycloplegic spherical equivalent (SE) in children aged 5–18 years using non-cycloplegic refraction, axial length (AL), corneal radius (CR), AL/CR ratio, and uncorrected visual acuity (UCVA). These models may offer practical alternatives to cycloplegic refraction for the surveillance of myopia in large populations.

This study used data from a national cross-sectional survey of ocular development in children and adolescents organized by the National Disease Control and Prevention Administration of China between 2020 and 2024. The survey was conducted in 10 provincial-level administrative divisions (PLADs): Beijing, Shanxi, Liaoning, Zhejiang, Shandong, Henan, Hunan, Guangdong, Chongqing, and Shaanxi. In most PLADs, two cities were selected on the basis of their levels of economic development. A multistage cluster sampling method was used to recruit students from kindergarten to high school. The detailed survey protocol has been previously described (*5*). A flowchart of the data collection procedure is presented in Supplementary Figure S1 (available at https://weekly.chinacdc.cn/).

All participants underwent standardized eye examinations, including noncycloplegic and cycloplegic autorefraction, using the same desktop autorefractor model at all sites. For cycloplegia, 0.5% tropicamide was applied four times at 5-min intervals. Trained personnel performed all assessments using a unified protocol. Owing to the high inter-eye correlation, only the right-eye data were analyzed. SE was calculated as the spherical power plus half the cylindrical power. For variable selection, univariate analyses were performed to assess the associations between each potential predictor and refractive error. Additionally, we calculated the variance inflation factors (VIFs) to evaluate multicollinearity and applied the least absolute shrinkage and selection operator (LASSO) regression to refine the variable set. Variables with significant univariate *P*-values, acceptable VIFs (<5), and retention in the LASSO model were included in the final analyses. These included AL, CR, AL/CR ratio, UCVA, and patient age. Gender and region, despite their theoretical importance, were not retained in the LASSO model and were thus excluded from the final analysis. UCVA was recorded on a Chinese 5-point scale, where 5.0 corresponded to 0 logarithm of the minimum angle of resolution (logMAR) (Snellen 20/20).

The dataset was randomly divided into training (80%) and test (20%) datasets. At the baseline, a multivariate linear regression model was fitted using all the non-cycloplegic variables. On the test set, this model achieved an R-squared (R^2) value of 0.79, root mean square error (RMSE) of 0.73 D, and mean absolute error (MAE) of 0.54 D, suggesting the need for more flexible ML algorithms. Random forest regression and eXtreme Gradient Boosting (XGBoost) regression were used to develop predictive models, and model performance was evaluated using R^2, RMSE, actual-predicted SE plots, and Bland–Altman plots. All analyses were performed using R software (version 4.5.1, R Foundation for Statistical Computing, Vienna, Austria, 2024).

This study included 58,252 participants: 46,603 (80.0%) in the training set and 11,649 (20.0%) in the test set. As summarized in Table 1, the baseline characteristics were well balanced between the two groups: The mean ages were 8.25±2.82 years in the training set and 8.27±2.86 years in the test set, gender distributions were similar (51.7% *vs.* 51.8% male), and urban–rural residence patterns were comparable (76.6% *vs.* 76.1% urban residents). Ocular measurements exhibited similar refractive profiles between groups, including non-cycloplegic SE (−0.63±1.44 D *vs.* −0.64±1.46 D), cycloplegic SE (both 0.09±1.57 D), AL (23.20±1.04 mm *vs.* 23.21±1.05 mm), CR (7.78±0.26 mm *vs.* 7.79±0.26

TABLE 1. Baseline characteristics of the participants (*n*=58,252).

Variable	Test set (*n*=11,649) Mean±SD / *n* (%)	Train set (*n*=46,603) Mean±SD / *n* (%)
Age (years)	8.27±2.86	8.25±2.82
Sex		
Male	6,036 (51.8)	24,073 (51.7)
Female	5,613 (48.2)	22,530 (48.3)
Region		
City	8,867 (76.1)	35,686 (76.6)
Country	2,782 (23.9)	10,917 (23.4)
Non-cycloplegic spherical equivalent (D)	−0.64±1.46	−0.63±1.44
Cycloplegic spherical equivalent (D)	0.09±1.59	0.09±1.57
Axial length (mm)	23.21±1.05	23.20±1.04
corneal radius (mm)	7.79±0.26	7.78±0.26
AL/CR ratio	2.98±0.12	2.98±0.12
Uncorrected visual acuity (logMAR)	4.85±0.28	4.85±0.28

Abbreviation: D=diopter; AL=axial length; CR=corneal radius; logMAR=Logarithm of the Minimum Angle of Resolution.

mm), AL/CR ratio (both 2.98±0.12), and UCVA (both 4.85±0.28 logMAR). Descriptive characteristics of the study population are summarized in Table 1.

Both the random forest and XGBoost models exhibited strong performance in predicting cycloplegic SE using non-cycloplegic refraction and ocular biometric parameters. In the test set, random forest achieved an R^2 of 0.88 with an RMSE of 0.55 D and MAE of 0.40 D, whereas XGBoost exhibited comparable performance (R^2=0.89, RMSE=0.54 D, and MAE=0.39 D). The performance of the training set was superior (random forest: R^2=0.94, RMSE=0.39 D; XGBoost: R^2=0.90, RMSE=0.51 D) (Table 2). The importance of the features of each ML model in the training and test sets is shown in Figure 1. Non-cycloplegic SE, the AL/CR ratio, AL, and UCVA were consistently among the four most important features for predicting cycloplegic SE in these models. Scatter plots of the predicted versus actual cycloplegic SE demonstrated satisfactory alignment along the identity line for both models (Figure 2). Bland–Altman plots showed that 95% of prediction errors were within ±2.0 D for both models, indicating acceptable agreement (Figure 3).

TABLE 2. Performance of machine-learning models for predicting cycloplegic spherical equivalent in the train and test set.

Model	Test set (*n*=11,649)	Train set (*n*=46,603)
Random Forest		
R^2	0.88	0.94
RMSE (D)	0.55	0.39
MAE (D)	0.40	0.29
XGBoost		
R^2	0.89	0.90
RMSE (D)	0.54	0.51
MAE (D)	0.39	0.37

Abbreviation: D=diopter; XGBoost=eXtreme Gradient Boosting.

DISCUSSION

In this large population-based study involving more than 58,252 Chinese children and adolescents, we developed and validated ML models to predict cycloplegic SE refraction using non-cycloplegic SE and ocular biometric parameters. Both the random forest and XGBoost models demonstrated excellent predictive performance, with R^2 values approaching 0.90 and RMSEs below 0.55 D in the test dataset. These findings suggest that ML algorithms can provide accurate estimates of cycloplegic refractive error in large-scale field settings without pharmacological cycloplegia.

Our findings are consistent with and extend those of previous studies that explored the use of non-cycloplegic data to estimate refractive status. Similar studies conducted on Chinese school-aged populations have reported R^2 values between 0.80 and 0.94 using models such as LASSO, support vector regression, and ensemble approaches (*4*,*6*). However, most previous studies have relied on smaller sample sizes or fewer

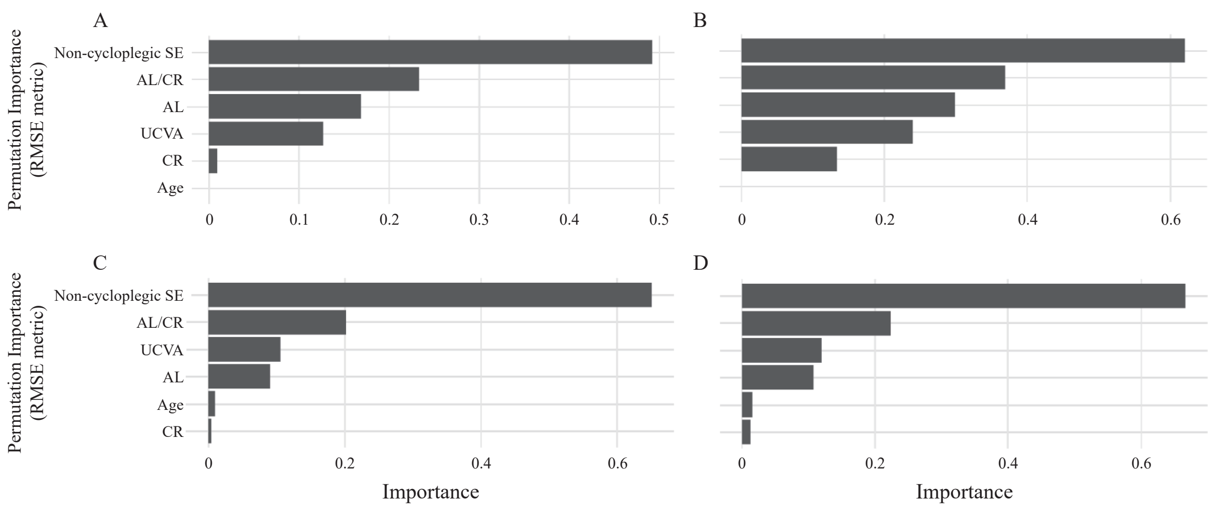

FIGURE 1. Permutation feature importance for predicting cycloplegic spherical equivalent (RMSE metric). (A) Random Forest, test set; (B) Random Forest, training set; (C) XGBoost, test set; (D) XGBoost, training set.
Abbreviation: SE=spherical equivalent; AL/CR=axial length/corneal radius ratio; AL=axial length; UCVA=uncorrected visual acuity; CR=corneal radius; XGBoost=eXtreme Gradient Boosting.

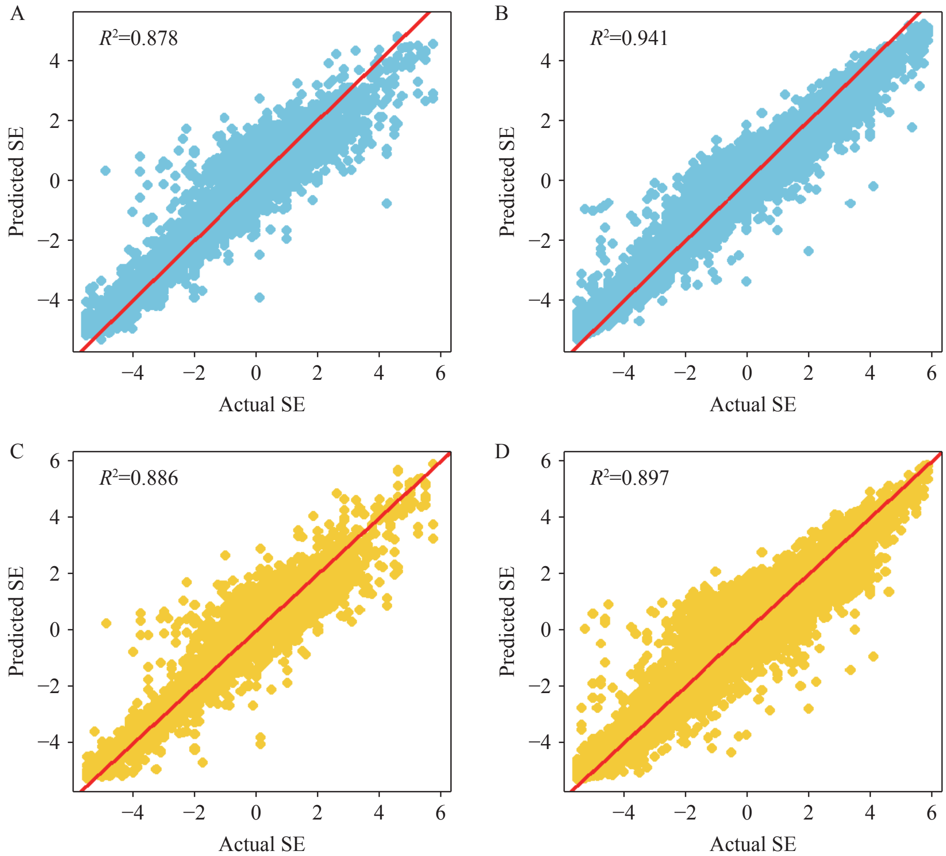

FIGURE 2. Actual *vs*. predicted cycloplegic SE by ML models. (A) Random Forest, test set (R^2=0.878); (B) Random Forest, training set (R^2=0.941); (C) XGBoost, test set (R^2=0.886); (D) XGBoost, training set (R^2=0.897).
Note: Dashed line represents perfect agreement; solid line represents the fitted linear regression.
Abbreviation: XGBoost=eXtreme Gradient Boosting; SE=spherical equivalent; ML=machine learning.

input variables. By incorporating a broad set of ocular biometric parameters, including AL, CR, AL/CR ratio, and UCVA, the proposed models captured more of the physiological variations underlying refractive error, leading to higher predictive accuracy.

The feature-importance rankings further underscore the value of integrating multiple ocular measures. In both the Random Forest and XGBoost models, noncycloplegic SE, AL/CR ratio, AL, and UCVA consistently emerged as the top contributors. This aligns with the known roles of axial elongation and optical geometry in the development of myopia, and supports their inclusion in prediction tools when available. These measures are associated with cycloplegic refractive error and have been used to predict the cycloplegic refractive error in previous studies (*7*–*9*).

From a public health implementation perspective, our study demonstrated that ML models trained on noncycloplegic refraction and ocular biometry can serve as effective alternatives for estimating cycloplegic SE in large-scale pediatric eye health surveillance. The strong predictive performance, along with minimal residual bias and tight limits of agreement, suggests that these models are sufficiently robust for estimating refractive status where cycloplegia is infeasible. This approach can complement existing screening programs, support a more efficient allocation of clinical resources, and enhance the accuracy of population-level myopia monitoring without increasing procedural burden.

This study has several limitations. First, the cross-sectional design limits causal inference and prevents the tracking of refractive changes over time. Unmeasured confounders may also have biased model estimates. Second, although the overall model performance was robust, prediction errors exceeding ±2.0 D occurred in some cases, which may be clinically relevant. Third, although our sample covered 10 PLADs with diverse geographic and socioeconomic profiles, external validation in other countries or ethnic groups is required to assess generalizability. Finally, we focused on continuous SE prediction instead of the categorical

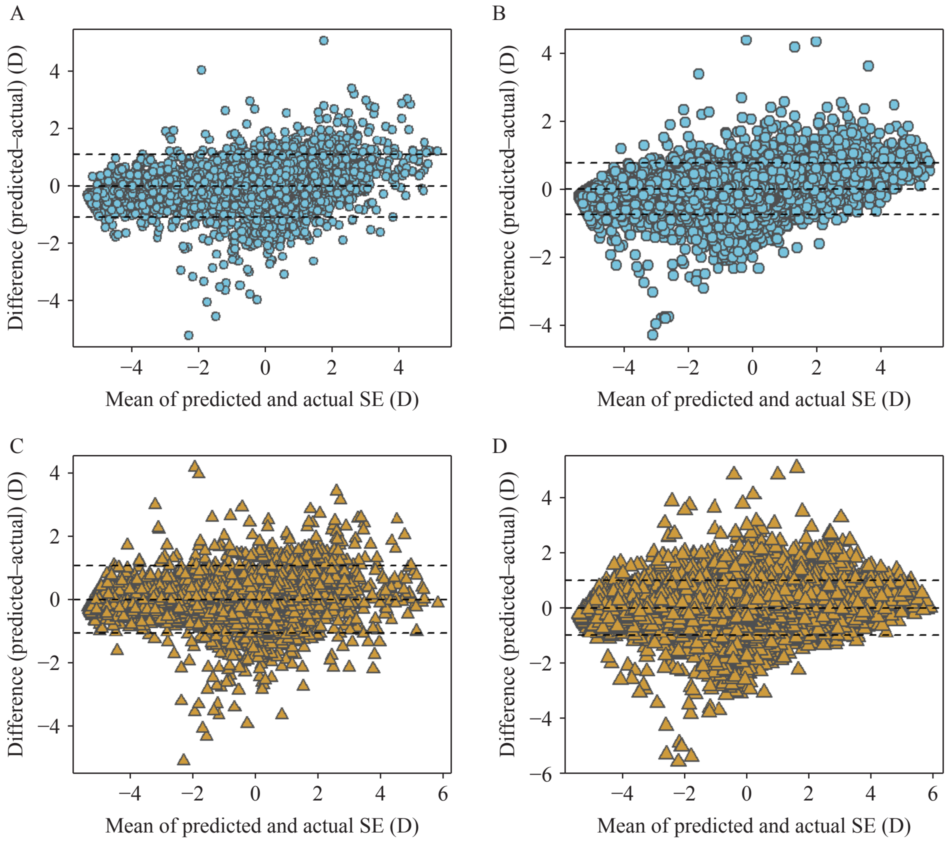

FIGURE 3. Bland–Altman analysis of ML model performance in predicting cycloplegic spherical equivalent. (A) Random Forest, test set; (B) Random Forest, training set; (C) XGBoost, test set; (D) XGBoost, training set.
Note: Plots display the differences between predicted and actual cycloplegic spherical equivalent (SE) values (in diopters, D) against their means. Solid horizontal lines represent mean differences, whereas dashed lines indicate 95% limits of agreement (±1.96 SD). The training sets (B and D) demonstrate narrower limits of agreement than those of test sets (A and C), reflecting expected performance variations between training and validation datasets.
Abbreviation: XGBoost=eXtreme Gradient Boosting.

classification of myopia. Although classification may offer direct clinical utility, continuous prediction allows a more nuanced interpretation and avoids threshold bias.

In conclusion, this study demonstrated that ML models incorporating non-cycloplegic refraction and ocular biometric parameters can accurately estimate cycloplegic SE in children. Such models hold promise for enhancing refractive error surveillance in large-scale community-based settings, where cycloplegia is infeasible.

Conflicts of interest: No conflicts of interest.

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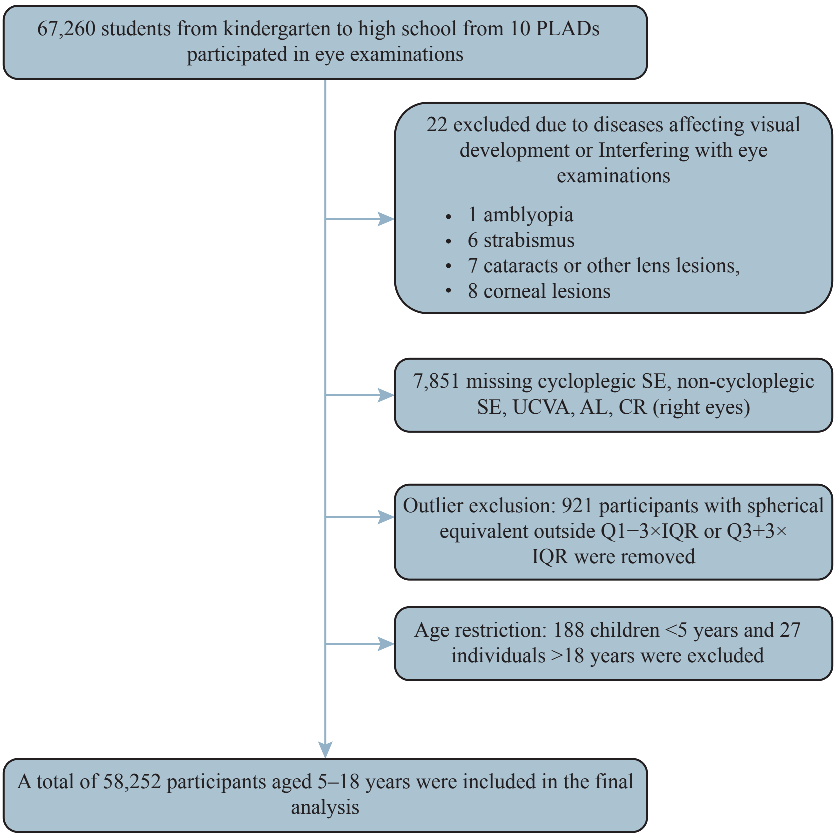
SUPPLEMENTARY MATERIAL



SUPPLEMENTARY FIGURE S1. Flow diagram of study population.

Abbreviation: PLADs=provincial-level administrative divisions; SE=spherical equivalent; AL/CR=axial length/corneal radius ratio; AL=axial length; UCVA=uncorrected visual acuity; Q1=first quartile; IQR=interquartile range; Q3=third quartile.

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