Mingming et al. BMC Ophthalmology (2025) 25:195
https://doi.org/10.1186/s12886-025-04017-8

BMC Ophthalmology

RESEARCH

Open Access

Research on the predictive performance of using ROC curve to evaluate axial length for myopia in children and adolescents

Cui Mingming[1,2†], Zhu Zhongxin[3†], Gao Yuting[3†], Zong Xinnan[4], Li Shaoli[5,6], Liu Junting[5,6], Chen Fangfang[7], Yang Zhou[8], Yin Tao[9], Lyu Yanyu[10] and Zhang Hao[8*]

Abstract

Background Assessing myopia risk can help clinicians intervene as early as possible. There is still a lack of reference values for predicting myopia based on the axial length (AL) of children. The study aims to explore the relationship between AL and myopia, and to predict the risk thresholds of AL in children of different age and sex groups.

Method Visual acuity examination, refractive screening and ocular axis examination of 2388 children aged 7–18 (4776 eyes) from 8 schools in a certain area of Beijing were used as the data source, we evaluated the predictive ability of AL for myopia in children using Receiver Operating Characteristic (ROC) curves, and constructed Logistic Regression to analyze the reference value of AL threshold for children of different age and sex groups.

Results The myopia rate among children and adolescents was 51.47%. The AL and SE were significantly correlated by Spearman correlation coefficient($P<0.01$). Predicting myopia in children based on their AL has a good reference value(AUC = 0.73). Children with AL ≥ 23.92 mm have a significantly higher myopia rate than those with AL < 23.92 mm (χ^2=661.14, $P<0.01$). The difference in AL among children of different age groups is statistically significant, and the AL shows an increasing trend with age. Among them, the AL threshold for children aged 7–12 is 23.67 mm, while that for children aged 13–15 is 23.92 mm, and children aged 16–18 is 24.42 mm. Children with an AL ≥ the threshold have a 4.41-fold higher risk of myopia than those with an AL < the threshold (OR = 4.41, 95% CI = 3.88–5.01). There is a statistically significant difference in AL between children of different sex groups. The male group has a higher AL(24.27 mm) than the females (23.71 mm), and children with AL ≥ threshold have a 5.58-fold higher risk of myopia than those with AL < threshold (OR = 5.58, 95% CI = 4.93–6.33).

Conclusion The correlation between SE and AL was strong in school children. Age-specific and sex-specific AL threshold for myopia might provide reference data as a useful indicator, aid in identifying and monitoring individuals at risk of myopia and have utility in population-based screening for myopia in children and adolescents.

Keywords Children, Myopia, Axial length(AL), ROC curve, Logistic regression

†Cui Mingming, Zhu Zhongxin and Gao Yuting contributed equally to this work and share first authorship.

*Correspondence:
Zhang Hao
40785840@qq.com

Full list of author information is available at the end of the article

Introduction

At present, myopia has become a global public health problem, especially with the rapidly increasing prevalence of myopia in children and adolescents [1, 2]. During the period of 2020–2023, the myopia rate among children and adolescents reached as high as 54%. In 2022, the general myopia rate among children and adolescents in China was 51.9%, which shows a trend of early onset and high incidence [3]. Myopia not only affects daily life and studies, but also affects issues such as education and employment. In particular, high myopia increases the risk of retinal detachment, myopic macular degeneration, and may be accompanied by irreversible vision loss, and even blindness [4–6].

It is generally believed that myopia is multifactorial. There are many factors that can affect myopia in children, and most of the current research is based on genetic factors, environmental factors, and behavioral habits [7]. Assessing myopia risk can help clinicians intervene as early as possible. However, few studies have evaluated the effects of various factors to accurately determine the risk of onset and progression on myopia. And the myopia risk predictive models that have been constructed to date are overly complicated for quantifying myopia risk reliably, limiting their application in population-based epidemiological survey [8, 9].

Cycloplegic refractive error is the gold standard for the detection of myopia [10]. However, it sometimes can be challenging to administer cycloplegic eyedrops to children, particularly in large-scale studies and routine vision screening for children. Noncycloplegic refractive error is still commonly used for determining the presence or severity of myopia in some population-based epidemiological studies of pediatric myopia [11]. When the refractive error assessment does not involve cycloplegia, errors due to overaccommodation are very common [12]. Many previous studies reported the there is high correlation between ocular biometric measures and the refractive error [13–15]. Axial length (AL) is a critical biometric parameter in the management and control of myopia [10]. At present, modern technology for AL measurements using partial coherence interferometry and swept-source techniques is more accurate, measurement errors and variability between instruments are limited to few microns [16]. In addition, techniques to measure AL are rapid, noninvasive and can be easy for both the practitioner and children. Thus, utilising AL measures either alone or in combination with other ocular measurements to differentiate normal from excessive ocular growth to identify at risk children for clinicians as soon as possible. Multi-predictor models included incorporate additional predictors such as corneal curvature, anterior chamber depth, age, and other biometric or demographic factors [12–15]. Although AL/corneal radius of curvature (AL/CR) is a more robust measure of the refractive than AL [12–14]. However, the measurement technology of CR needs to be more precise and accurately interpret the results and less data-efficient, which may be difficult to large-scale vision screening for children. They also generally outperform AL-based models in terms of sensitivity and specificity. AL values obtained using modern biometers are rapid, objective, require less time and resources and are less prone to errors compared with spherical equivalent [17].

Current studies suggest that visual impairment is more strongly associated with AL than refractive error [12, 14], and excessive AL growth gives precipitate vision threatening complications [18]. Additionally, as an increase in myopia is primarily due to axial elongation, estimating and monitoring AL change is advantageous [12]. Compared to refractive error measurement, AL is less susceptible to the influence of eye accommodation ability, and has strong stability and shows regular growth with age, especially in children. Refractive error does not reflect the structural changes in the eye and fully capture the risk of myopia-related complications. Therefore, the AL can be used as an objective and convenient biological parameter indicator for observing and evaluating the development of children's eyeballs, as well as predicting the risk of myopia in children [17, 18]. At present, there is still a lack of reference values for predicting myopia based on the AL of children and adolescents of different age groups in China. Previous study has predicted the annual growth rate of the physiological AL in Chinese preschool children aged 4–6 years old in Beijing [9]. Currently, there is a lack of similar results on school children in Beijing. To this end, we collected data on visual acuity examination, refractive screening, and AL examination of children from 8 schools in a certain area of Beijing, and explored the relationship between AL and myopia in school children. Receiver operating characteristic (ROC) curves were applied to determine the risk threshold of AL that affects the occurrence of myopia, and its predictive value was evaluated, which is expected to provide a reference for comprehensive prevention and control of myopia in children and adolescents.

Methods

Study design and participants

This study was to identify an objective and convenient indicator for predicting the risk of myopia through secondary data analysis of Beijing Children and Adolescents Health Cohort (BCHC) [19]. All procedures were approved by the Institutional Review Board at the Capital Institute of Pediatrics prior to study commencement. In 2022, 2742 aged 4–18 years old children in a certain district of Beijing were using random cluster sampling method. Considering the stability of the sample, representative and stable schools in primary and junior high schools are preferred. Selected students are measured using computer optometry under noncycloplegic refraction, binocular naked eye vision examination, and AL measurement. After excluding children who did not cooperate and did not meet the age requirements, information on 2388 children aged 7–18 years old from 8 schools was obtained, with an effective examination rate of 87.1%.

Inclusion criteria: (1) Permanent population of Beijing. (2) Except for refractive errors, there is no history of ophthalmic diseases, eye trauma, or surgery. (3) Physical and mental health, no congenital developmental abnormalities, and no related diseases affecting vision and refractive examination. (4) Not wearing corneal reshaping lenses within one month. (5) Students and parents who are willing to cooperate. This study was approved by the Medical Ethics Committee of the Capital Institute of Pediatrics (SHERLL2022043). The guardian and/or their children provided informed consent and were willing to participate, and the investigation was approved by the local education bureau and school. To express our gratitude for their contributions, participants were given a Health check-up report which was promptly emailed to them following their interview.

Eye examination

Vision examination light boxes that comply with the national standard (GB11533 logarithmic visual acuity chart) were used for distance vision screening. A desktop automatic computer optometry instrument (KR–800, Topcon company) that complies with the ISO10342 ophthalmic instrument optometry standard was used to detect refractive status under non ciliary muscle paralysis. The AL of the eye was measured using a biometric instrument (IOL Master, Germany). All instruments and equipment have been tested and approved by relevant departments. Both computer optometry and biometric instruments undergo simulated human eye calibration before use. Children with myopia screening undergo according to the updated version of the "Guidelines for the Prevention and Control of Myopia in Children and Adolescents" released by the National Health Commission [11].

Variable definitions

According to the International Myopia Institute(IMI) [20] and the National Health Commission's "Guidelines for Appropriate Techniques for Prevention and Control of Myopia in Children and Adolescents (Updated Edition)" [11], The criteria for determining myopia eye the standard logarithmic visual acuity of the naked eye < 5.0 and spherical equivalent (SE) < –0.50D.

Questionnaire survey

The questionnaire was developed by the Capital Institute of Pediatrics and and students or their parents filled out questionnaires. Before completing the questionnaire, the survey or explained the significance of the survey, emphasized the confidentiality of the questionnaire, and any questions that were not understood would be explained by the investigator until the students could understand the questions correctly in order to guarantee the credibility of the results. The survey content was mainly included several aspects such as sex, age, parents' myopia, etc.

Quality control

On site investigation had been conducted by trained and qualified medical personnel using a unified vision examination method. Organizing and collecting raw materials was done by a school basis, and a dedicated person will verify and input the data to create a health record for follow-up visit and notification of examination results. The vision examination light box and examination method have complied with national standards, and the testing space environment and distance also met relevant requirements. In a semi dark room, refractive testing on children was performed in their natural state (noncycloplegic refraction) to ensure that the system error was within a reasonable range. The environment was fixed and the lighting was appropriate. It was required that the child's seat fixed within a radius of 50 cm, with the head in a straight position, ensuring that both eyes were level with the instrument, and the distance between the right and left eyes was 35 cm. The average value of at least 3 consecutive readings with a computerized refractometer was considered the examination result, while the average value of at least 5 consecutive readings with an ocular axis biometric instrument was considered the examination result.

Statistical analysis

Using Excel 2021 to access the dataset, the Shapiro Wilk test was used to determine the normality of the data. Pearson or Spearman correlation coefficients were used for correlation analysis based on the normality results. Continuous variables with normal distribution were represented by mean ± standard deviation ($\mu \pm \sigma$), and *t*–test is used for comparison between two samples. Non normally distributed continuous variables were represented by median and interquartile range [M (P25, P75)]. Generalized estimating equation (GEE) including age, sex, and the AL of both eyes. The results showed that AL of the right eye was 0.084 mm longer than that of the left eye on average, and there was a significant difference in AL ($P < 0.01$) after controlling for age and sex. Kruskal Wallis H test was used for multiple sample comparisons,

Table 1 The characteristics of myopia in children with different age and sex groups

Variables	Myopia N(%)	Non-Myopia N(%)	Total eyes N(%)	χ^2	P
Age(years)					
7~	887(41.33)	1259(58.67)	2146(44.93)	160.69	< 0.01
13 ~ 15	1162(60.14)	770(39.86)	1932(40.45)		
16 ~ 18	409(58.60)	289(41.40)	698(14.62)		
Sex					
Male	1130(48.09)	1220(51.91)	2350(49.20)	20.90	< 0.01
Female	1328(54.74)	1098(45.26)	2426(50.80)		
Total	2458(51.47)	2318(48.53)	4776(100)		

*$P<0.05$, **$P<0.01$

Nemenyi test was used for pairwise comparisons, and Mann Whitney U test (Wilcoxon rank sum test) was used for two sample comparisons. Use number of cases and percentages (n and %) for counting data, and chi square test was used for comparation between groups. We have drawn ROC curve and calculate the area under the Area Under Curve (AUC) to determine the optimal threshold for AL, and construct logistic regression analysis to determine the reference value of AL threshold for children of different age groups and sex. The statistical significance was determined by the test level $\alpha = 0.05$, and the above analysis was conducted using Python 3.12 software.

The statistical measures of ROC curve include sensitivity (SE), specificity (specificity, SP), area under the curve (AUC), and Youden index (Youden index) under the ROC curve index [21]. This study used AL as the predictive indicator and myopia as the outcome indicator. The value corresponding to the maximum Jordan index was the optimal AL threshold.

Results

Demographic characteristics of children with myopia

All 2388 children aged 7-18-year-old (4776 eyes) had a myopia rate of 51.47%; 1175 males (2350 eyes) had a myopia rate of 48.09%, while 1213 females (2426 eyes) had a myopia rate of 54.74%. There was a statistically significant difference in myopia rates between children of different sex (χ^2=20.90, $P<0.01$). 1073 children (2146 eyes) aged 7–12 years had a myopia rate of 41.33%, 966 children (1932 eyes) aged 13–15 years had a myopia rate of 60.14%, and 349 children (698 eyes) aged 16–18 years had a myopia rate of 58.60%. There was a statistically significant difference in myopia rates among children of different age groups (χ^2=160.69, $P<0.01$), as shown in Table 1.

Characteristics of children's AL

The AL of all children was 24.20(23.40,25.11)mm, children aged 7–12 years was 23.83(23.14,24.63)mm, children aged 13–15 years was 24.49(23.68,25.36)mm, children aged 16–18 years was 24.93 ± 1.15 mm. The AL of male children was 24.42(23.65,25.37)mm and females was 23.95(23.18,24.89)mm (Table 2).

Shapiro Wilk normality test was conducted on the axial data of children's eyes, and the data did not conform to bivariate normal distribution. Spearman correlation coefficient was used, and AL and SE were significantly correlated ($P<0.01$)in all children(r=-0.68)(Fig. 1), in the 7–12 year age group (r=-0.58), 13–15 year age group (r=-0.69), 16–18 year age group (r=-0.65), in the male group (r=-0.70) and female group (r=-0.72).(Figures 2 and 3).

The Kruskal Wallis H test was applied to evaluate the differences in AL data distribution between different age groups. Nemenyi test was used for pairwise comparisons between groups, and the differences between different age groups were statistically significant ($P<0.01$). The 7–12 years group vs. 13–15 years group (χ^2=372.00, $P<0.01$), 7–12 yeas group vs. 16–18 years group (χ^2=443.55, $P<0.01$), and 13–15 years group vs. 16–18 years group (χ^2=50.17, $P<0.01$) all showed statistically significant differences. The Mann Whitney U test (Wilcoxon rank sum test) was used to evaluate the differences in AL between sex, and the difference between males and females (Z = 13.00, $P<0.01$) was statistically significant(Table 3).

The differences in AL between myopic and non-myopic children in each age group and sex group were examined separately. There was a statistically significant difference (Z = 27.68, $P<0.01$) in the AL between myopic children (24.69 (23.96, 25.48)) and non-myopic children (23.65 (22.99, 24.48)). The differences in AL between myopic

Table 2 Comparison of AL between myopic and non-myopic children of different age and sex groups

Variables		AL of Myopia (mm)	AL of Non-Myopia (mm)	Total AL (mm)	t/Z	P
Age(years)	7~	24.32(23.68,25.01)	23.27(22.78,24.01)	23.83(23.14,24.63)	19.06	< 0.01
	13~	24.85(24.11,25.68)	23.89(23.24,24.74)	24.49(23.68,25.36)	16.19	< 0.01
	16 ~ 18	25.13 ± 1.04	24.65 ± 1.24	24.93 ± 1.15	5.35	< 0.01
Sex	Male	24.98(24.27,25.77)	23.89(23.27,24.70)	24.42(23.65,25.37)	20.45	< 0.01
	Female	24.44(23.73,25.20)	23.33(22.77,24.18)	23.95(23.18,24.89)	21.02	< 0.01
Total		24.69(23.96,25.48)	23.65(22.99,24.48)	24.20(23.40,25.11)	27.68	< 0.01

*$P<0.05$, **$P<0.01$

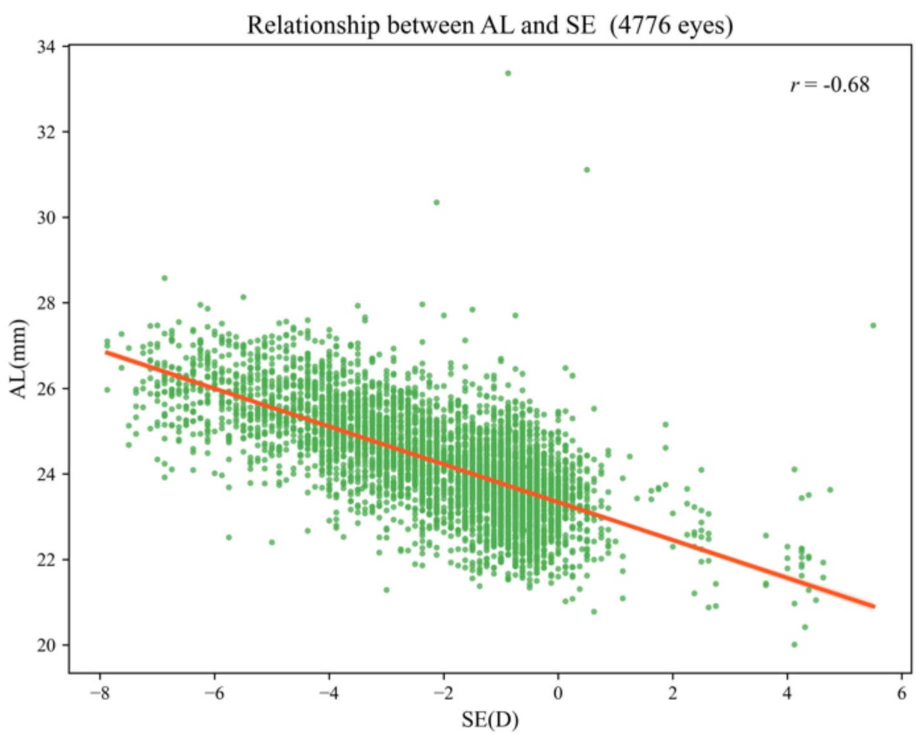

Fig. 1 Correlation between AL and SE for children

and non-myopic children in the 7–12 year age group (Z = 19.06, $P < 0.01$), 13–15 year age group (Z = 16.19, $P < 0.01$), 16–18 year age group (t = 5.35, $P < 0.01$), male group (Z = 20.45, $P < 0.01$), and female group (Z = 21.02, $P < 0.01$) were statistically significant, as shown in Table 2.

ROC curve evaluation of AL's predictive ability and optimal threshold analysis for myopia in children

AL is an important factor affecting the vision of children and adolescents. Not only there is a significant correlation between AL and SE, but there is also a significant difference in AL between myopic and non-myopic children. In order to further explore the critical value of the influence of AL on the myopia of children and adolescents, this study plotted a ROC curve (Fig. 4) showing the relationship between AL and myopia. The area AUC under the ROC curve was 0.73 ($P < 0.01$), and the optimal threshold for AL was 23.92 mm. At this threshold, children were classified into group greater than and less than the threshold. The myopia rate of children with AL ≥ 23.92 mm (67.13%) was much higher than that of children with AL < 23.92 mm (29.34%) (χ^2=661.14, $P < 0.01$). (Tables 4 and 5).

To further investigate the effect of AL on myopia in children of different ages, ROC curves were plotted to evaluate the predictive ability of AL for myopia in children. The ROC curve was used to evaluate the predictive ability of AL for myopia in children of different age groups. The results are shown in Fig. 5, where the axis of 7–12-year-old group (AUC = 0.74), 13–15-year-old group (AUC = 0.72), and 16-18- year-old group (AUC = 0.62) all showed good predictive ability for myopia. The optimal threshold for AL indicators in the 7–12 years age group is 23.67 mm, while that in the 13–15 years age group is 23.92 mm, 24.42 mm in 16–18 years age group. The detailed parameters of the optimal thresholds for each group are shown in Table 3. Using the optimal threshold of each group as a classification reference for their AL, the myopia rate of children with AL ≥ threshold is much higher than that of children with AL < threshold in age groups of 7–12,13–15 and 16–18-year-old, as shown in Table 5.

To further investigate the effect of AL on myopia in children of different sex, ROC curves were plotted to evaluate the predictive ability of AL for myopia in children. The ROC curve was used to evaluate the predictive ability of AL for myopia in children of different sex. The results are shown in Fig. 6. Both the male group (AUC = 0.74) and the female group (AUC = 0.75) had good predictive ability for myopia in children. The optimal threshold for AL index in the male group is 24.27 mm, and the optimal threshold for AL index in the female group is 23.71 mm. The detailed parameters of the optimal thresholds for each group are shown in Table 3. Using the optimal threshold of each group as the classification reference for their AL, the myopia rate of children

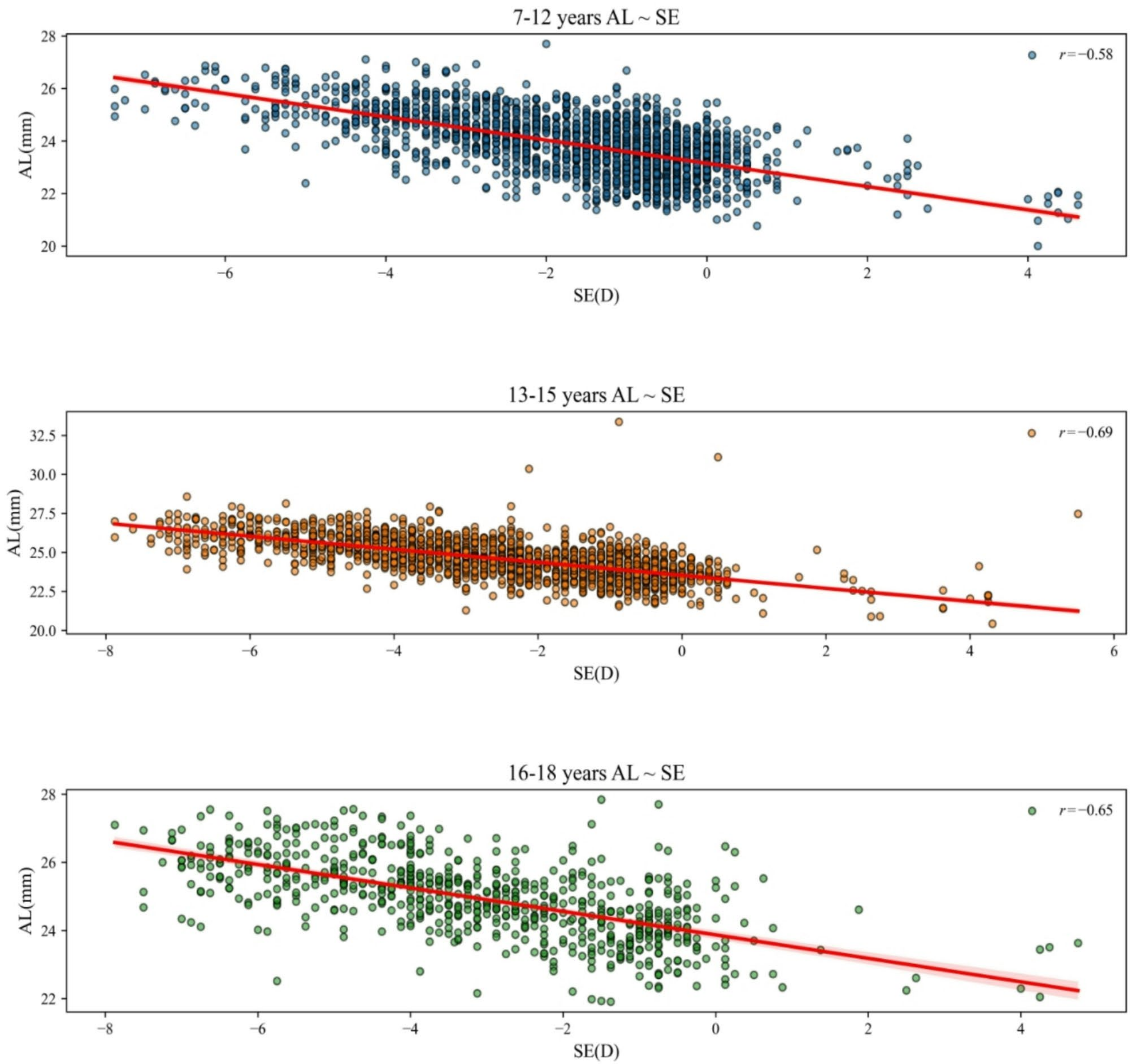

Fig. 2 Correlation between AL and SE for different age groups

with AL ≥ threshold in both male and female groups is much higher than that of children with AL < threshold, as shown in Table 5.

Correlation analysis between AL threshold and myopia

In order to verify the reliability of the axial threshold for different age groups, logistic regression analysis was used. The results showed that children with AL ≥ threshold had a 4.41-fold higher risk of myopia than those with AL < threshold (OR = 4.41, 95% CI = 3.88–5.01). Compared with children aged 7–12 years, the risk of myopia in children aged 13–15 years is 1.85 times higher (OR = 1.85, 95% CI = 1.62–2.11), and that of 16–18 years is 1.73 times higher (OR = 1.73, 95% CI = 1.44–2.08), as shown in Table 6.

In order to verify the reliability of the axial thresholds for each sex, logistic regression analysis was used, and the results showed that children with AL values ≥ the threshold had a 5.58-fold higher risk of myopia than those with AL values < the threshold (OR = 5.58, 95% CI = 4.93–6.33). Compared with males, the risk of myopia in females is 1.30 times higher (OR = 1.30, 95% CI = 1.15–1.47), as shown in Table 6.

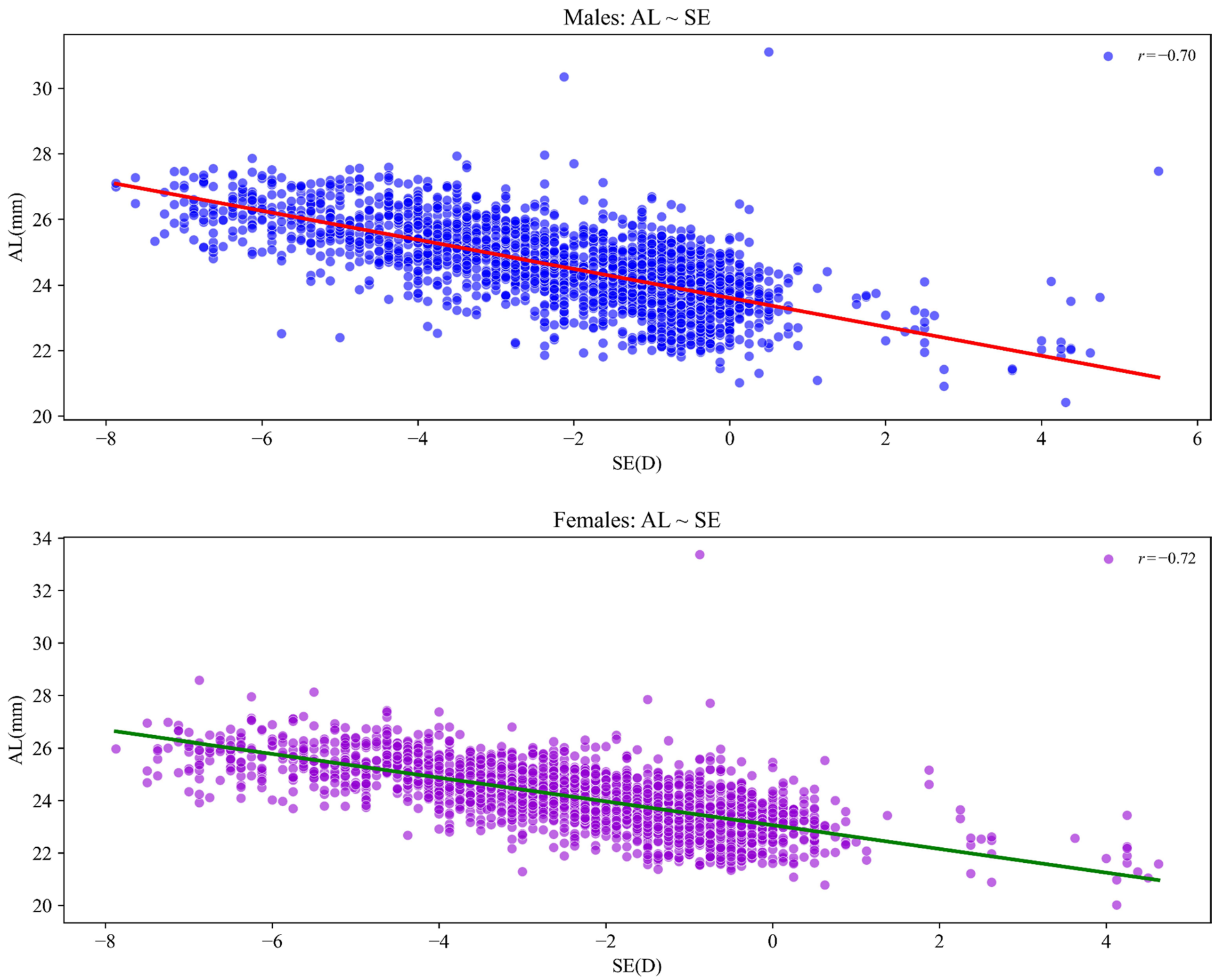

Fig. 3 Correlation between AL and SE for different sex groups

Table 3 Statistical analysis of differences in AL between different age and sex groups

Pairwise comparison groups		χ^2/Z	*P*
7 ~ years	13 ~ years	372.00†	< 0.01*
7 ~ years	16 ~ 18 years	443.55†	< 0.01*
13 ~ years	16 ~ 18 years	50.17†	< 0.01*
Male	Female	13.00	< 0.01

*P < 0.05, **P < 0.01

Note † Nemenyi test for further pairwise comparison after Kruskal Wallis H test

Discussion

In this cross-sectional school-based study, we found that the correlation between SE and AL in children. The accuracy of the AL for myopia assessment has a good predictive ability for the risk of myopia in children and adolescents. The results from this study of AL for Chinese children aged 7–18 years indicate age and sex dependency.

In recent years, the myopia rate of children and adolescents has not significantly decreased. This study found that the myopia rate in children and adolescents was 51.47%, which is similar to the national myopia survey results [3]. It is generally believed that the main cause of myopia in school-age children is excessive axial elongation [14]. There is a significant correlation between SE and AL in children of all age groups, and the AL of myopic children in each age group is significantly greater than that AL of non-myopic children, which is similar to the conclusion of other studies [14, 22]. Many previous studies reported the high correlation of ocular biometric measures with the refractive error [14, 22, 23].

Refractive parameters of 7–18-year-old children such as AL and SE in different age and sex groups were measured and analyzed in this study. AL increased with the increase of age in this study, which is consistent with study in shanghai [14]. We found that the average AL of all children and adolescents was 24.28 mm, the AL of the

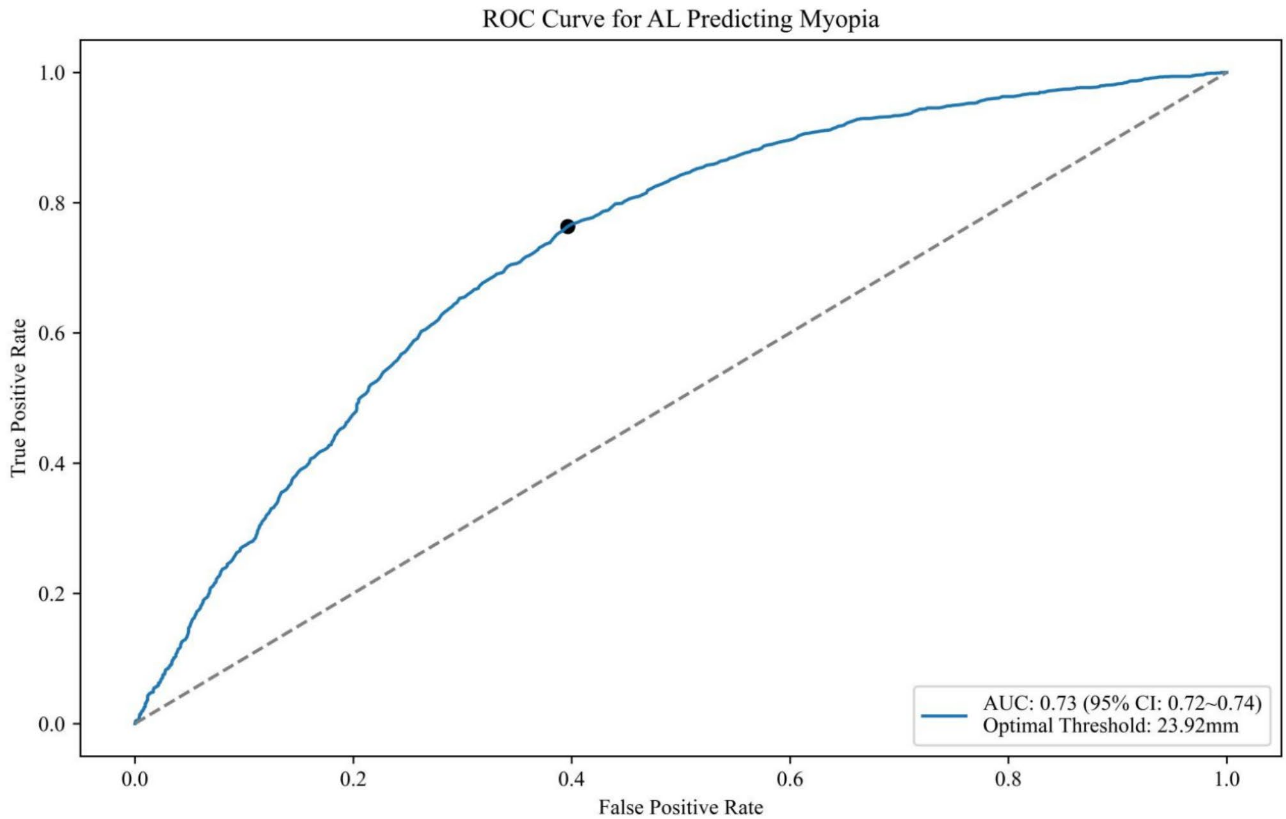

Fig. 4 ROC curve of AL and myopia assessment

Table 4 Detailed indicators of ROC curve

Variables		AUC(95%CI)	AL Threshold(mm)	TPR
Age(years)	7~	0.74(0.72 ~ 0.75)	23.67	0.75
	13~	0.72(0.70 ~ 0.74)	23.92	0.81
	16 ~ 18	0.62(0.58 ~ 0.66)	24.42	0.75
Sex	Male	0.74(0.73 ~ 0.76)	24.27	0.75
	Female	0.75(0.73 ~ 0.76)	23.71	0.76
Total		0.73(0.72 ~ 0.74)	23.92	0.76

Table 5 Analysis of differences in myopia rates of children classified by AL threshold

Variables		Classification by AL threshold (mm)	Myopia *N*(%)	χ^2	*P*
	7~	≥ 23.67	668(58.85)	303.50	< 0.01
		< 23.67	219(21.66)		
Age(years)	13~	≥ 23.92	944(71.46)	221.65	< 0.01
		< 23.92	218(35.68)		
	16 ~ 18	≥ 24.42	312(65.82)	30.87	< 0.01
		< 24.42	97(43.30)		
Sex	Male	≥ 24.27	852(66.41)	378.36	< 0.01
		< 24.27	278(26.05)		
	Female	≥ 23.71	1003(71.90)	388.48	< 0.01
		< 23.71	325(31.52)		
Total		≥ 23.92	1877(67.13)	661.14	< 0.01
		< 23.92	581(29.34)		

*$P < 0.05$, **$P < 0.01$

children with myopia(24.69 mm) in this study was larger than that in Spanish [24], China [14, 22].

The AL of children gradually increased as the age growth of the younger age group towards the older age group in this study, which was longer than that in previous study [12]. The AL of non-myopic children conforms to the reference value reported by the National Health Commission, which states that the AL of children is about 16 mm at birth and an average of about 22.5 mm at the age of 6, the growth rate of AL in developing children generally does not exceed 0.2 mm per year, and If it exceeds 0.2 mm, high attention should be paid to the "AL reference value" [25]. But the AL of myopic children is greater than this reference value, which may be due to the average annual growth rate of children's AL exceeding 0.2 mm. At the same time, the Expert Consensus on the Application of Axial Length in Myopia Prevention, Control and Management (2023) discussed the predictive value of AL for myopia [17]. The expert consensus indicates that the refractive change corresponding to every 1 mm increase in AL increases with age, and the refractive power change of myopic individuals is greater than that of non-myopic individuals; it further recommends to use an annual increase of less than 0.20 mm/year as

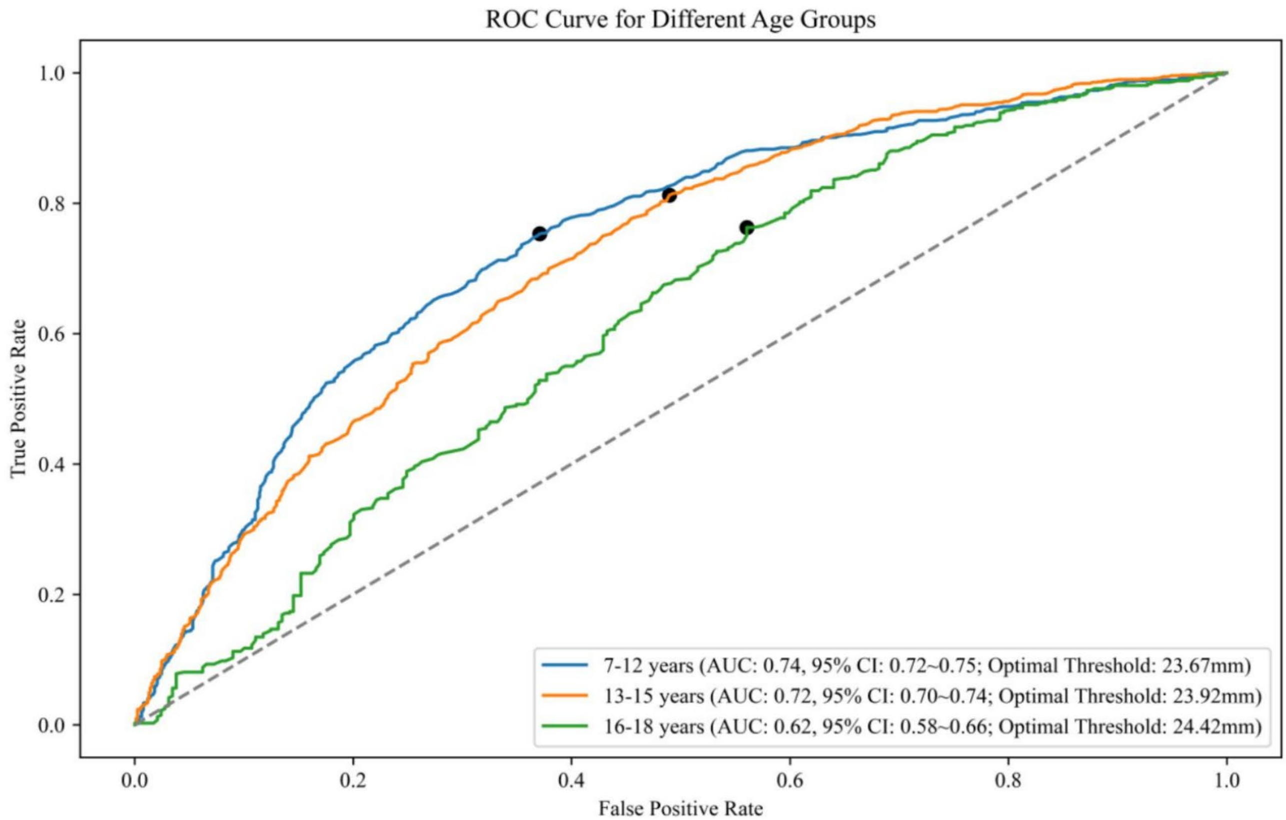

Fig. 5 ROC curves of AL and myopia risk assessment for different age groups

the threshold for safe AL growth in children aged 6–10 year old [17].There are significant differences in myopia rates and AL among children of different age groups, and as age increases, the AL of older children is significantly higher than that of younger children. The results of this study are similar to previous studies which have found that the reference value of children's AL increases with age [17, 26, 27].

Compared with males, females have a shorter AL(23.95(23.18, 24.89)mm vs. (24.42(23.65, 25.37)mm), and a slightly more myopic refractive error(54.74% vs. 48.09%). The data are strikingly similar to reported data for school children from Wuhan, China [28]. Comparing AL to European and other ethnic counterparts, longer AL was observed in Chinese children at all ages [23]. Methodological differences between the studies may account for some of this variation; however, it is more likely to be reflective of varying environmental influences across the different ethnic groups [7]. The study by Mu J et al. [29] also found that the AL of male eyes is greater than that of female eyes. Interestingly, female eyes tended to have more myopia than their male counterparts with the difference manifesting especially at the onset of myopia [30]. Based on the results of previous studies, this study infers that sex is an important influencing factor on an individual's static lifestyle [31], and the more lively and active social personality of males compared to females is the reason for the sex differences in myopia [32]. The fact that males are generally taller than females may be due to sex differences in AL [33, 34], which is similar to the conclusion of Mu J [29]. Although the relatively steeper corneas in females result in a more myopic refractive error, the smaller AL would in theory compensate for this myopic shift. There are reports of higher crystalline lens power in females than males [35].Therefore, the more myopic error may be indicative of an AL that has elongated past the length required for emmetropia or other optical components such as the crystalline lens might be playing a role [12].

This study found that the AL of myopic children of all ages and sex was significantly higher than that of children with normal vision. Previous studies have found a correlation between AL and myopia [17, 26, 36]. As shown in this study, the area under ROC of the AL for myopia assessment has a predictive value (AUC > 0.70), which is lower than other studies [15, 29]. The myopia rate (67.13%) of children with an AL ≥ 23.92 mm is much higher than non-myopia(29.34%) of children with an AL < 23.92 mm, indicating that AL has a high predictive value for myopia in children and adolescents. It is consistent with study in Spanish [24].The differences in sensitivity and specificity could be due to the differences

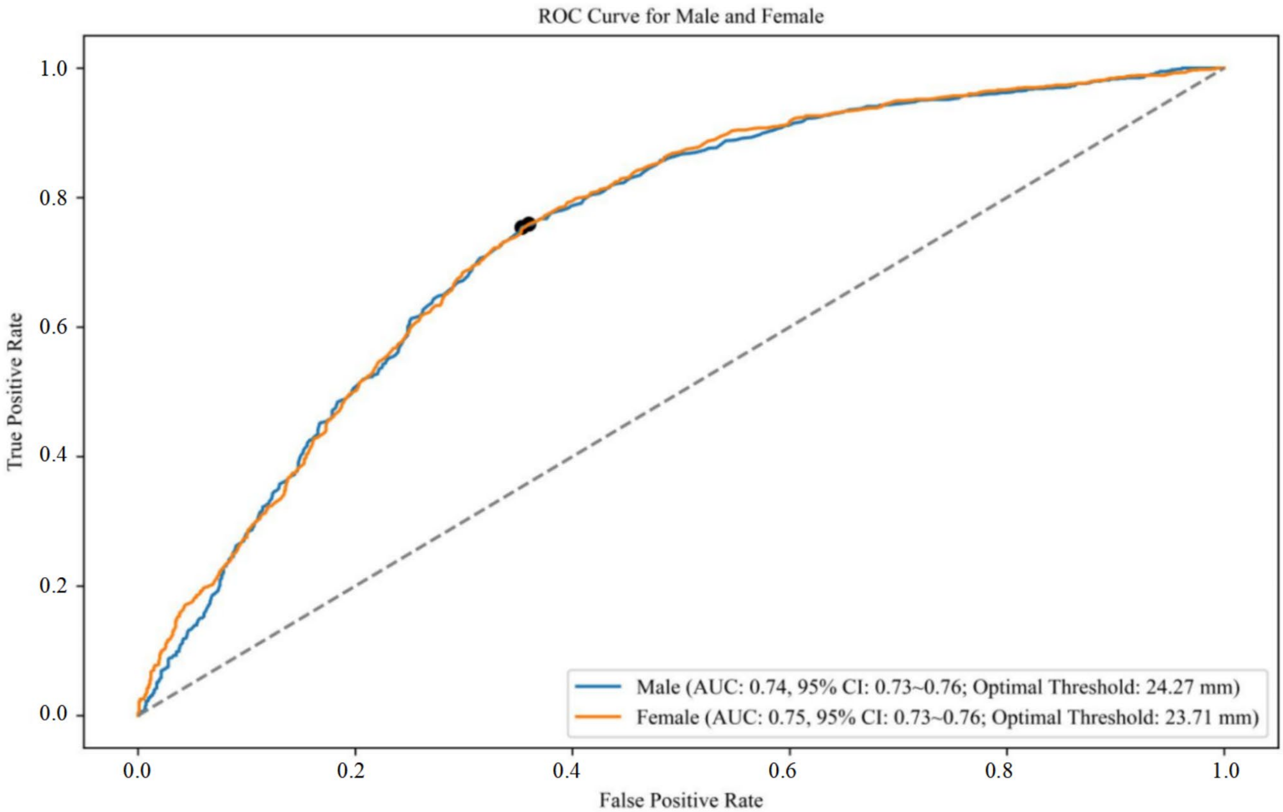

Fig. 6 ROC curves of AL and myopia risk assessment for different sex groups

Table 6 Logistic regression analysis of AL reference values and myopia by age and sex groups

Model		Comparison group	Control group	β	SE	Wald χ^2	*P*	OR	95% CI
Model1	Age group	13 ~ years	7 ~ years	0.61	0.07	81.58	< 0.01	1.85	1.62 ~ 2.11
		16 ~ 18 years		0.55	0.09	34.13	< 0.01	1.73	1.44 ~ 2.08
	Threshold AL	≥	<	1.48	0.07	518.40	< 0.01	4.41	3.88 ~ 5.01
Model2	Sex	Female	Male	0.26	0.06	17.09	< 0.01	1.30	1.15 ~ 1.47
	Threshold AL	≥	<	1.72	0.06	721.76	< 0.01	5.58	4.93 ~ 6.33

*$P < 0.05$, **$P < 0.01$

Note Model 1 and Model 2 represent two different Logistic Regression models. Model 1 includes the Age group and the corresponding Threshold AL Model 2 includes Sex and the corresponding Threshold AL

in the cutoff value of AL, the study characteristics of school children such as age, refractive error status and the device for biometric measures. Based on some study, the accuracy of the AL to corneal curvature radius (AL/CR) ratio (especially the combination of AL/CR ratio and parental myopia) for myopia assessment was higher than that of AL [13, 14, 37]. However, calculating AL/CR requires measuring AL and CR, which increases complexity, demands high quality of data, and high technical and equipment requirements. Generally, it is difficult to a large-scale population-based research.

In this study, AL was measured using biometry because it is a gold-standard measurement method. Draw ROC curves for different age and sex groups to evaluate the predictive ability of AL for myopia in children, the results show that as age increases, the AL increases, with males having a higher AL than females. The results are not consistent with previous trends found in study, which found that sex differences were not associated with AL changes in normal eye development [14, 38]. Using the optimal threshold of each group as a classification reference for their AL, the myopia rate of children with AL ≥ threshold in all age groups and sex is much higher than that of children with AL < threshold, specifically: the AL threshold of the 7–12-year-old children was 23.67 mm, which increased to 23.92 mm in the 13–15-year-old group and 24.42 mm in the 16–18-year-old group in this study, which was 24.27 mm in males and 23.71 mm in females in the study. Our results showed that AL in children who had just developed myopia or had persistent myopia showed a faster elongation than in emmetropic children. These results had also been obtained previously in Singaporean [39] and Spanish [24].

Currently, work to prevent and control myopia in China is viewed as important but remains challenging. Asian countries including China has been linked to an intensive education system with limited time outdoors [40]. This suggests that excessive AL may be useful for evaluating myopia risk. If the AL exceeds the critical threshold, sufficient attention should be paid to prevent the occurrence and development of myopia. This is consistent with previous studies [17, 26]. It is recommended to strictly monitor and control the excessive growth of children's AL, which is of great significance for myopia prevention and control. Due to individual differences, other individual characteristics such as age and sex should also be combined to comprehensively evaluate the growth of the AL in order to predict the risk of myopia when applying the eye axis to dynamic management [9]. From a public health perspective, these results hold a vital significance in school children.

The large data set with a wide age range and stratification by sex are some of the key strengths of this analysis, however, the non-homogeneity of the sample across specific ages was a limitation. The sample of this study is limited in a certain district of Beijing. Other limitations are the cross-sectional data with a single assessment per individual. The lack of longitudinal data is difficult to underly future risk of myopia. The study did not include other biological parameters of the eye and socio-economic factors, et al. This study only used naked eye vision to screen for myopic and non-myopic populations. Additionally, although the AUC > 0.70, the predictive value of AL for myopia was needed in-depth study. The reasons are not entirely clear but may be related to measurement variability or the use of cross-sectional data in the development of the ROC curves. Another potential limitation of the AL predictive model derived from urban Chinese children is that they are unable to be used across other groups that are not similar in distribution. Therefore, the predictive value of AL for myopia demonstrated in this study is somewhat limited. Later, multi-center, large sample studies were conducted by expanding the regional scope to further investigate and validate the conclusions. We will perform mydriatic refraction, which may result in more accurate results in future. Further conduct prospective cohort studies to investigate whether AL changes can be as an useful proxy for evaluating the progression of myopia.

Conclusion

In this study, we evaluated the performance of using AL for detecting myopia and found that AL might be a key indicator for myopia assessment in school-age children. Age-specific and sex-specific AL threshold might be useful indicators for monitoring and estimating the probability of myopia. Importantly, myopia probability estimates using AL, sex and age are comparable to screening techniques. This study might provide a useful tool for population-based screening myopia or estimating myopia prevalence in epidemiological studies.

Abbreviations

AL	Axial Length
SE	Spherical Equivalent
D	Diopter
SP	Specificity
ROC	Receiver Operating Characteristic
AUC	Area Under Curve
TPR	True Positive Rate
95% CI	95% Confidence interval
OR	Odds ratios
mm	Millimeter
BCHC	Beijing Children and Adolescents Health Cohort
GB	Guobiao (National Standards of the People's Republic of China)
ISO	International Organization for Standardization
IMI	International Myopia Institute

Acknowledgements
We would like to thank all the parents, children and data collectors who participated in this study. We also would like to thank the following individuals for their contribution and all of the medical workers and teachers involved in the study, for their enthusiasm, hard work and enduring support.

Author contributions
MMC and XNZ had full access to all the data, formulated the research question and made a design for the study; MMC, ZZX and YTG had participated in manuscript drafting and editing. ZY, LSL, JTL, FFC, XNZ collected the data; MMC and ZZX have made substantial contributions to the interpretation and statistical analysis of the data; MMC and ZH participated in the discussion and drafted the manuscript; TY, LYY and YTG participated in the discussion. MC and ZH have made substantial contributions to the interpretation of data and substantively revised the manuscript. All authors reviewed the manuscript.

Funding
This project was supported by Public service development and reform pilot project of Beijing Medical Research Institute (BMR2021-3) and Capital Health Research and Development of Special (Ying Jie 2022-1-1081). The funding body had no role in the design, analysis or writing of this article.

Data availability
The data that support the findings of this study are available on request from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The research was performed in accordance with the Declaration of Helsinki. This study was approved by the Ethics Committee of Capital Institute of Pediatrics under the code (NO.SHERLL2022043). Informed consent was obtained from children's parents or guardians.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Capital Institute of Pediatrics, 2 YaBao Rd, Beijing 100020, China
[2]Beijing Municipal Key Laboratory of Child Development and Nutriomics, Beijing, China

[3]Department of Environmental and Occupational Health, School of Public Health, Guangdong Medical University, Dongguan, China
[4]Department of Growth and Development, Capital Institute of Pediatrics, Beijing, China
[5]Child Health Big Data Research Center, Capital Institute of Pediatrics, Beijing, China
[6]Child Healthcare Center, Capital Center for Children's Health, Capital Medical University, Beijing, China
[7]Department of Epidemiology, Capital Institute of Pediatrics, Beijing, China
[8]Department of Ophthalmology, Capital Center for Children's Health, Capital Medical University, Beijing 100020, China
[9]Department of Science and Technology, Capital Institute of Pediatrics, Beijing, China
[10]Experiment Center, Capital Institute of Pediatrics, Beijing, China

Received: 24 January 2025 / Accepted: 25 March 2025
Published online: 10 April 2025

References

1. Liang J, Pu Y, Chen J et al. Global prevalence, trend and projection of myopia in children and adolescents from 1990 to 2050: a comprehensive systematic review and meta-analysis. Br J Ophthalmol. 2025;109(3):362–371.
2. Xu T, Wang B, Liu H, et al. Prevalence and causes of vision loss in China from 1990 to 2019: findings from the global burden of disease study 2019. Lancet Public Health. 2020;5(12):e682–91.
3. Central People's Government of the People's Republic of China. It actively promotes the prevention and control of myopia in children and adolescents, and the myopia rate is showing a downward trend by National Bureau of Disease Control and Prevention.[2024-03-13]. https://www.gov.cn/lianbo/bumen/202403/content_6939270.htm
4. Liang J, Pu Y, Chen J, et al. Global prevalence, trend and projection of myopia in children and adolescents from 1990 to 2050: a comprehensive systematic review and meta-analysis. Br J Ophthalmol. 2025;109(3):362–71.
5. Tahhan N, Wolffsohn JS, Sankaridurg P et al. Editorial: International Myopia Institute White Paper Series 2023 [published correction appears in Invest Ophthalmol Vis Sci. 2023;64(10):33. https://doi.org/10.1167/iovs.64.10.33.]. Invest Ophthalmol Vis Sci. 2023;64(6):1.
6. Lu L, Zheng Y, Xu Y, Feng J, Li S. Effects of myopia on health-related quality of life in adolescents: a population-based cross-sectional causal empirical survey. BMJ Open Ophthalmol. 2024;9(1):e001730.
7. Morgan IG, Wu P-C, Ostrin LA, et al. Imi risk factors for myopia. Invest Ophthalmol Vis Sci. 2021;62:3.
8. Zhang WJ, Feng XL. [Research progress on the development of myopia prediction models and their predictive performance]. [Zhonghua Yan Ke Za Zhi] Chin J Ophthalmol. 2024;60(11):937–42. https://doi.org/10.3760/cma.j.cn112142-20231128-00248.
9. Liu D, Zhao H, Tang T, et al. Ocular biometric parameters in Chinese preschool children and physiological axial length growth prediction using machine learning algorithms: a retrospective cross-sectional study. BMJ Open. 2024;14(12):e084891.
10. Flitcroft DI, He M, Jonas JB et al. IMI - Defining and Classifying Myopia: A Proposed Set of Standards for Clinical and Epidemiologic Studies [published correction appears in Invest Ophthalmol Vis Sci. 2024;65(13):19. https://doi.org/10.1167/iovs.65.13.19.]. Invest Ophthalmol Vis Sci. 2019;60(3):M20-M30.
11. National Health Commission of the PRC. Notice from the General Office of the National Health Commission on Issuing. Guidelines for prevention and control of myopia in children and adolescents(2024 version). [accessed 2024-05-31]. http://www.nhc.gov.cn/yzygj/s7653/202405/b6edbd0bf3a64ecc8cef30d72f80ed9e.shtml
12. He X, Sankaridurg P, Naduvilath T, et al. Normative data and percentile curves for axial length and axial length/corneal curvature in Chinese children and adolescents aged 4–18 years. Br J Ophthalmol. 2023;107(2):167–75.
13. Mu J, Zeng D, Fan J, et al. The accuracy of the axial length and axial length/corneal radius ratio for myopia assessment among Chinese children. Front Pediatr. 2022;10:859944.
14. Chen J, Liu S, Zhu Z, et al. Axial length changes in progressive and non-progressive myopic children in China. Graefes Arch Clin Exp Ophthalmol. 2023;261(5):1493–501.
15. Li SM, Ren MY, Zhang SG, et al. Effectiveness of myopia prediction model in screening children and teenager myopia[J]. Chin J Exp Ophthalmol. 2019;37(4):269–73.
16. Song JS, Yoon DY, Hyon JY, et al. Comparison of ocular biometry and refractive outcomes using IOL master 500, IOL master 700, and lenstar LS900. Korean J Ophthalmol. 2020;34:126–32.
17. Expert consensus on the application of axial length in myopia prevention and control. management(2023)Expert group.expert consensus on the application of axial length in myopia prevention and control management(2023). Chin J Ophthalmol. 2024;42(1):1–11.
18. Wolffsohn JS, Whayeb Y, Logan NS, Weng R, International Myopia Institute Ambassador Group*. IMI-Global trends in myopia management attitudes and strategies in clinical Practice-2022 update. Invest Ophthalmol Vis Sci. 2023;64(6):6.
19. Liu Junting L, Shaoli C, Fangfang Z, Xinnan H, Chunlei Z, Tong T, Jun. Gu Qinglong Baseline characteristics analysis of the Beijing Children and Adolescents Natural Population Cohort[J]. Chinese Journal of Child Health Care, 2024,32(11):1212–1218 + 1231 URL: https://link.cnki.net/urlid/61.1346.R.20241018.1414.016
20. Erratum in. IMI - Defining and classifying myopia: A proposed set of standards for clinical and epidemiologic studies. Invest Ophthalmol Vis Sci. 2024;65(13):19.
21. Zhang W, Huang G, Zheng K, Lin J, Hu S, Zheng S, Du G, Zhang G, Bruni C, Matucci-Cerinic M, Furst DE, Wang Y. Application of logistic regression and machine learning methods for idiopathic inflammatory myopathies malignancy prediction. Clin Exp Rheumatol. 2023;41(2):330–9.
22. Maruyama T, Yotsukura E, Torii H, et al. Children in Tokyo have a long sustained axial length from age 3 years: the Tokyo myopia study. J Clin Med. 2022;11(15):4413.
23. Rauscher FG, Francke M, Hiemisch A, Kiess W, Michael R. Ocular biometry in children and adolescents from 4 to 17 years: A cross-sectional study in central Germany. Ophthalmic Physiol Opt. 2021;41:496–511.
24. Güemes-Villahoz N, Gómez de Liano R, Porras Ángel P, et al. Lifestyle factors in myopic Spanish children. Child (Basel). 2024;11(2):139.
25. Public Health Ophthalmology Branch of Chinese Preventive Medicine Association. Chinese expert consensus on the reference interval of ocular hyperopia reserve, axial length, corneal curvature and genetic factors in school-age children (2022). Zhonghua Yan Ke Za Zhi. 2022;58(2):96–102. Chinese.
26. Dang RM, Watt K, Kang P. Impact of age on measurement variability for axial length in myopic children. Clin Exp Optom. 2024;107(4):428–33.
27. Tang T, Chen ST, Zhao H, Wang K, Zhao MW. Age-specific distribution of oculometric parameters and myopia in children aged 8-12y. Int J Ophthalmol. 2024;17(10):1887–97.
28. Sanz Diez P, Yang L-H, Lu M-X, et al. Growth curves of myopia-related parameters to clinically monitor the refractive development in Chinese school children. Graefes Arch Clin Exp Ophthalmol. 2019;257:1045–53.
29. Mu J, Zhang Z, Wu X, Chen S, Geng H, Duan J. Refraction and ocular biometric parameters in 3-to 6-year-old preschool children: a large-scale population-based study in Chengdu, China. BMC Ophthalmol. 2024;24(1):207.
30. He X, Zou H, Lu L, et al. Axial length/corneal radius ratio: association with refractive state and role on myopia detection combined with visual acuity in Chinese schoolchildren. PLoS ONE. 2015;10:e0111766.
31. Mackintosh KA, McNarry MA, Berntsen S, Steele J, Sejersted E, Westergren T. Physical activity and sedentary time in children and adolescents with asthma: A systematic review and meta-analysis. Scand J Med Sci Sports. 2021;31(6):1183–95.
32. Xu R, Zhong P, Jan C, Song Y, Xiong X, Luo D, Dong Y, Ma J, Stafford RS. Sex disparity in myopia explained by puberty among Chinese adolescents from 1995 to 2014: A nationwide Cross-Sectional study. Front Public Health. 2022;10:833960.
33. Chinese Student Physical Fitness and Health Research Group. Chinese student physical fitness and health research report. 2022-07. Higher Education Press; 2019.
34. Kearney S, Strang NC, Cagnolati B, Gray LS. Change in body height, axial length and refractive status over a four-year period in Caucasian children and young adults. J Optom. 2020;13(2):128–36.
35. Momeni-Moghaddam H, Hashemi H, Zarei-Ghanavati S, et al. Four-Year change in ocular biometric components and refraction in schoolchildren: a cohort study. J Curr Ophthalmol. 2019;31:206–13.
36. Zhang Y, Su M, Liang L, et al. The guiding significance of ocular biometry in evaluating the refractive status of preschool children. Ophthalmic Res. 2023;66(1):1213–21.

37. Zhao E, Wang X, Zhang H et al. Ocular biometrics and uncorrected visual acuity for detecting myopia in Chinese school students [published correction appears in Sci Rep. 2022;12(1):21184. https://doi.org/10.1038/s41598-022-25893-w.]. Sci Rep. 2022;12(1):18644.
38. Truckenbrod C, Meigen C, Brandt M, et al. Longitudinal analysis of axial length growth in a German cohort of healthy children and adolescents. Ophthalmic Physiol Opt. 2021;41(3):532–40.
39. Jos R, Sebastian D, Iribarren R, Lanca C, Saw SM. Axial growth and lens power loss at myopia onset in Singaporean children. Investig Ophthalmol Vis Sci. 2019;60:3091–9.
40. Morgan IG, French AN, Ashby RS, et al. The epidemics of myopia: aetiology and prevention. Prog Retin Eye Res. 2018;62:134–49.