Clinical and Epidemiologic Research

Annual Incidences and Progressions of Myopia and High Myopia in Chinese Schoolchildren Based on a 5-Year Cohort Study

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Purpose. To determine the annual incidences and rates of progression of myopia and high myopia in Chinese schoolchildren from grade 1 to grade 6 and explore the possible cause-specific risk factors for myopia.

Methods. From 11 randomly selected primary schools in Anyang city, central China, 2835 grade 1 students were examined with annual follow ups for 5 years. Students were invited to undergo a comprehensive examination, including cycloplegic autorefraction, ocular biometry, and standardized questionnaires.

Results. The mean spherical equivalent refraction decreased substantially from +0.94 ± 1.03 diopter (D) in grade 1 to −1.37 ± 2.08 D in grade 6, with rapid annual myopic shifts, especially for students in grades 3 through 6 (−0.51 to −0.59 D). The prevalence of myopia increased substantially, with the yearly incidence of myopia increasing from 7.8% in grade 1 and 2 to 25.3% in grades 5 and 6, and the incidence of high myopia increased from 0.1% to 1.0%. The 5-year incidence of myopia was lowest among children who has a baseline spherical equivalent refraction of greater than +2.00 D (4.4%), and increased to nearly 92.0% among children whose baseline spherical equivalent refraction was 0.00 to −0.50 D. The incidence of myopia was higher in children who had less hyperopic baseline refraction, two myopic parents, longer axial length, deeper anterior chamber, higher axial length–corneal radius of curvature ratio, and thinner lenses.

Conclusions. Both the annual incidence and progression rates of myopia and high myopia were high in Chinese schoolchildren, especially after grade 3. Hyperopic refraction of children should be monitored before primary school as hyperopia reserve to prevent the onset of myopia and high myopia.

Keywords: incidence of myopia, hyperopia reserve, schoolchildren

With the rapid increase in its prevalence over the past few decades, myopia has become a major global public health problem worldwide.[1,2] Although myopia can be corrected by spectacles or contact lens, high or pathologic myopia can lead to permanent visual impairment and even blindness.[3,4] High or pathologic myopia is associated with an increased risk of irreversible blinding conditions,[5,6] leading to a heavy cost burden on individuals and communities.

The prevalence of myopia has been reported to be high among East and Southeast Asian schoolchildren and young adults.[2] As reported in our previous studies, myopia affects 67.3% of grade 7 children and 83.2% of university students in central China.[7,8] In South Korea, an even higher prevalence of 96.5% was found in 19-year-old male conscripts.[9] There have been several cross-sectional studies of prevalence of myopia in school-aged children,[10–15] but few longitudinal studies on the incidence and progression of myopia in China. Wang et al.[16] reported annual incidence of myopia to be 20% from grade 1 to grade 6 and to be 30% from grade 7 to grade 9. However, this study did not perform cycloplegic refraction, which decreased the accuracy in evaluating the refractive status of children.[17] A 6-year follow-up of the Sydney Myopia Study revealed a mean annual incidence of myopia of 2.2% in the younger cohort among 1765 children with a mean age of 6.7 years at baseline.[18] The Northern Ireland Childhood Errors of Refraction (NICER) reported that the 6-year cumulative median change in spherical equivalent refraction (SER) was –1.38 diopter (D) in 6- to 7-year-old children.[19] However, neither of these studies performed annual follow-up testing, resulting in a lack of annual refraction changes for primary school students.

Longitudinal studies can assess the progression of myopia, its risk factors and impacts, and the likelihood of myopia and high myopia. These findings would be helpful to target the appropriate period for the prevention and treatment of myopia.[20] Consistent with the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) study, Jones-Jordan et al.[21] found that the risk for myopia onset was associated with parental myopia. In the Singapore Cohort Study of the Risk Factors of Myopia (SCORM), Saw et al.[22] found that children with greater axial lengths (ALs) and vitreous chamber depths and thinner lenses had higher incidence rates of myopia. As several studies have reported that myopic children with younger age show significantly faster myopic progression and are more likely to progress to high or pathologic myopia,[23–25] it is important to conduct a large-scale study of refractive errors to predict the onset of myopia in school-aged Chinese children.

Accordingly, the purpose of this study was to investigate the annual incidence and progression rates of myopia and to explore the possible cause-specific risk factors of myopia in a large-scale school-based cohort in central China. Students were examined and followed annually for 5 years from grade 1 until grade 6.

Methods

Study Design and Sample

The Anyang Childhood Eye Study (ACES) was a school-based cohort study aiming to determine the annual rate of incidence, progression, and risk factors for myopia among Chinese children in urban areas of Anyang city, central China. The study methodologies have been reported in detail previously.[7] In brief, we recruited 3112 grade 1 students from 11 randomly selected primary schools from February to May 2012; 2893 (93%) students were examined. They were followed annually for 5 years in February to May.

All children gave their written informed consent form signed by their parents or guardians, as well as verbal assent from each child. The study adhered to the tenets of the Declaration of Helsinki. Ethics committee approval was obtained from the Institutional Review Board of Beijing Tongren Hospital, Capital Medical University.

Procedures

Students who enrolled in the ACES underwent a comprehensive, standardized examination at both baseline and follow-up. After corneal anesthesia with 1 drop of topical anesthetic agent (Alcaine; Alcon, Fort Worth, TX), cycloplegia was induced by two drops of 1% cyclopentolate (Alcon) and 1 drop of tropicamide (Mydrin P; Santen, Osaka, Japan) with an interval of 5 minutes between drops. Thirty minutes after tropicamide, cycloplegia was considered adequate if the pupillary light reflex was absent or pupil size was more than 6.0 mm. Otherwise, a third drop of cyclopentolate was administered. Cycloplegic refraction was measured for three repeated measurements by an autorefractor (HRK7000 A, Huvitz, Gunpo, South Korea). Ocular biometric components, including AL, lens thickness, and anterior chamber depth (ACD), were measured by the Lenstar LS900 (Haag-Streit, Koeniz, Switzerland) for five repeated measurements with average data used for analysis.[26]

An interviewer-administered questionnaire was filled by parents. Information requested included parental myopia, age of myopia onset (if applicable), and time outdoors and near work activities (hours per day) of children after school hours.[27–29]

Definitions

SER was defined as the sum of spherical power and half of the cylinder. Myopia was defined as a SER of –0.5 D or less, hyperopia as a SER of +0.5 D or greater, and emmetropia as a SER between –0.5 D and 0.5 D. High myopia was defined as a SER of –6.00 D or less. The annual incidence rate of myopia was defined as the proportion of subjects who were not myopic in the preceding year and who subsequently developed myopia during the follow-up.[16] The annual progression of myopia was defined as the change in cycloplegic SER between the measurements acquired in the previous year and the measurements taken during the annual follow-up period. The anterior corneal radius of curvature (CR, in mm) was defined as the average of the greatest and least anterior corneal radii of curvature. The AL/CR ratio was defined as the AL divided by the CR.

Statistical Methods

All examination data were entered independently twice into a database using Epidata software 3.1 (The Epidata Association, Odense, Denmark) by two trained data entry clerks. All analyses were conducted using SPSS software (Version 20.0; SPSS, Inc., Chicago, IL). All data were presented as mean ± standard deviation or percentages. Only right eyes were included for data analyses, because the cycloplegic SER for the right and left eyes were highly correlated at baseline (Spearman correlation coefficient = 0.838). Independent t-tests and analyses of variance were used to compare normally continuous data as appropriate and the χ^2 test was used for the categorized data. Multivariate logistic regression models were performed to explore factors associated with incident myopia, using individual incident myopia as the dependent variable and various baseline characteristics as covariates and adjusting for age and gender where appropriate. To investigate the predictive ability of risk factors for incident myopia, receiver-operating characteristic curves were plotted to calculate area under the curve. The hazard ratios of having myopia for children with different hyperopic refractions were analyzed by taking those with a baseline SER of more than +2.00 D as a reference group. A two-sided P value of less than 0.05 was considered statistically significant.

Results

At baseline, 3112 students in grade 1 in school year 2012 were eligible to participate in the ACES, of whom 2835 (91.1%) had complete cycloplegic refraction measurement. Baseline demographic and ocular biometry parameters are included in Table 1. The mean age of the 2835 children was 7.2 ± 0.3 years, with 57.9% boys. Students were followed annually for 5 years (until 2017), at which time graduation of all children occurred. A total of 2553 children (90.1%) were reexamined in the first follow-up visit, 2533 (89.3%) in the second follow-up visit, 2479 (87.4%) in the third follow-up visit, 2362 (83.3%) in the fourth follow-up visit, and 2048

Table 1. Baseline Characteristics of the 2835 Participants

Variable	All (n = 2835)	Boys (n = 1641)	Girls (n = 1194)	P Value
Age, mean (SD), y	7.15 (0.28)	7.17 (0.41)	7.13 (0.38)	.003
SE, mean (SD), D	0.94 (1.03)	0.91 (0.99)	0.98 (1.09)	.094
AL, mean (SD), mm	22.72 (0.76)	22.95 (0.70)	22.39 (0.71)	<.001
ACD, mean (SD), mm	2.89 (0.24)	2.94 (0.23)	2.83 (0.24)	<.001
LT, mean (SD), mm	3.61 (0.19)	3.60 (0.18)	3.64 (0.20)	<.001
CR, mean (SD), mm	7.79 (0.25)	7.86 (0.25)	7.71 (0.24)	<.001
AL/CR, mean (SD),	2.92 (0.07)	2.92 (0.07)	2.91 (0.08)	<.001
Height, mean (SD), cm	123.54 (5.30)	124.20 (5.12)	122.64 (5.41)	<.001
Weight, mean (SD), kg	24.64 (4.81)	25.27 (4.90)	23.78 (4.54)	<.001
Parental Myopia n (%)				.062
None	1874 (66.1)	1106 (67.4)	768 (64.3)	
One	754 (26.6)	430 (26.2)	324 (27.1)	
Both	207 (7.3)	105 (6.4)	102 (8.5)	

LT, lens thickness; SD, standard deviation; SE, spherical equivalent.
P value shows the comparisons between boys and girls.

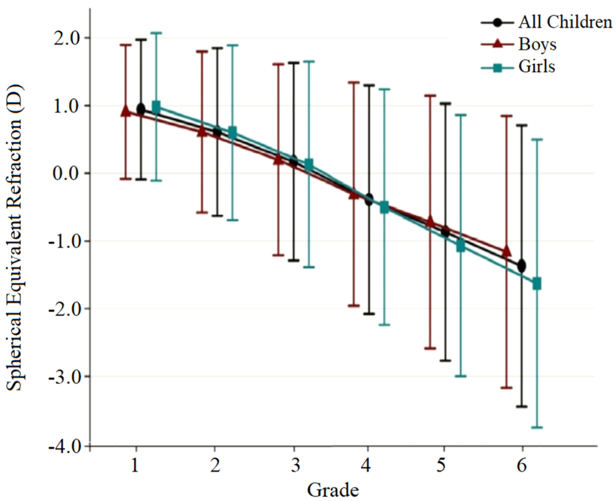

Figure 1. SER during primary school grades 1 through 6. Error bars indicate standard deviations. The data for boys and girls have been shifted horizontally to improve legibility.

(72.2%) in the fifth follow-up visit. There were no significant differences for all these demographic parameters between the follow-up subjects who had completed 6 years follow-up, and the dropout subjects who had not completed 6 years of follow-up.

Figure 1 shows mean SERs for each school year. The mean SER decreased substantially from 0.94 ± 1.03 D in grade 1 to –1.37 ± 2.08 D in grade 6, with considerable annual myopic shifts for grades 3 and 4 (−0.59 D), grades 4 and 5 (−0.51 D), and grades 5 and 6 (−0.56 D) (Table 2). Girls had greater annual myopic shifts than boys (P < 0.001) for the third and succeeding follow-up visits. Myopes had greater annual myopic shifts than nonmyopes (P < 0.001) for the follow-up visits (Table 2).

From 2012 to 2017, the prevalence of myopia increased from 6.6% (95% CI, 5.6%–7.5%) in grade 1 to 61.5% (59.4%–63.6%) in grade 6 (Table 3). The prevalence of myopia among boys and girls increased from 6.9% (5.7%–8.2%) and 6.0% (4.7%–7.4%), respectively, in grade 1, to 56.1% (53.2%–59.0%) and 67.9% (64.9%–70.9%), respectively, in grade 6. Girls had higher prevalence than boys of hyperopia in grade 1, but higher prevalence than boys of myopia in grades 2 through 6.

Table 4 shows the annual incidence of myopia and high myopia by gender. These increased with higher grade: from 7.8% (95% confidence interval [CI], 6.8%–8.9%) in grades 1 and 2 to 13.9 (12.4%–15.3%) in grades 2 and 3, 18.6 (16.9%–20.4%) in grades 3 and 4, 20.6 (18.5%–22.7%) in grades 4 and 5, and 25.3% (22.7%–27.9%) in grades 5 and 6. The annual incidence for high myopia was no more than 1% for the primary school students.

Figure 2 shows the 5-year cumulative incidence of myopia. The more hyperopic at baseline, that is, a greater "hyperopia reserve," the less likely myopia was to develop. Incidence rate of myopia was lowest among children whose had a baseline SER of more than +2.00 D (4.4%; 95% CI, 0.9%–7.9%), and increased to nearly 50% among children whose baseline SER was +1.50 to greater than +1.00 D (49.3%, 44.9%–53.7%). Of those children with a baseline SER of 0.00 to –0.50 D, 92.0% (86.3%–97.8%) progressed to myopia.

Figure 3 shows survival probability curves by baseline SER as a function of risk group. As refraction became less hyoperopic, the survival functions became increasingly steep. Taking children with a baseline SER of greater than +2.00 D as a reference group, children with different baseline SERs had increased hazard ratios for becoming myopia by the end of the cohort as follows: +2.00 to greater than +1.50 D, 6.2 (95% CI, 1.9–20.5; P = 0.003); +1.50 to greater than +1.00 D, 16.8 (5.4–52.7; P < 0.001); +1.00 to greater than +0.50 D, 37.5 (12.1–117.2; P < 0.001); +0.50 to greater than +0.00 D, 77.4 (24.7–242.9; P < 0.001); and +0.00 to greater than −0.50 D, 175.7 (54.7–564.5; P < 0.001).

Table 5 shows the 5-year cumulative incidence rates of myopia varied according to different baseline demographic and ocular biometry parameters in nonmyopic students. Girls had significantly greater odds for cumulative incidence of myopia (odds ratio [OR], 1.7; 95% CI, 1.4–2.1) than boys (P < 0.001). Compared with children without a myopic parent, the ORs for cumulative incidences of myopia were 1.6 (95% CI, 1.3–2.0; P < 0.001) for children with one myopic parent and 2.9 (95% CI, 1.8–4.6; P < 0.001) with two myopic parents. In our multivariate logistic regression analysis controlling for age, gender, myopic parents, time outdoors, near work, higher AL/CRs, longer ALs, deeper anterior chambers, lens thickness, and corneal curvature of radius, the following were associated with higher risk of cumulative incidence of myopia: female gender (OR, 3.1; 95% CI, 2.3–4.3; P < 0.001), more myopic parents (OR, 1.4;

Table 2. Annual Change of SER in Primary School Students

Variable	Annual Change of SER (D), Mean (Standard Deviation)		
	All	Myopes	Nonmyopes
All			
1–2 y	−0.33 (−0.35, −0.30)	−0.69 (−0.85, −0.53)	−0.30 (−0.32, −0.28)
2–3 y	−0.45 (−0.47, −0.43)	−0.90 (−0.98, −0.83)	−0.38 (−0.40, −0.36)
3–4 y	−0.59 (−0.61, −0.57)	−0.97 (−1.00, −0.93)	−0.47 (−0.50, −0.45)
4–5 y	−0.51 (−0.54, −0.49)	−0.76 (−0.80, −0.73)	−0.37 (−0.39, −0.34)
5–6 y	−0.56 (−0.59, −0.54)	−0.73 (−0.77, −0.70)	−0.41 (−0.44, −0.38)
Boys			
1–2 y	−0.29 (−0.32, −0.26)	−0.60 (−0.82, −0.39)	−0.27 (−0.30, −0.24)
2–3 y	−0.43 (−0.46, −0.40)	−0.86 (−0.98, −0.74)	−0.37 (−0.39, −0.34)
3–4 y	−0.54 (−0.57, −0.52)	−0.92 (−0.97, −0.87)	−0.43 (−0.45, −0.40)
4–5 y	−0.45 (−0.48, −0.42)	−0.73 (−0.78, −0.68)	−0.30 (−0.33, −0.27)
5–6 y	−0.50 (−0.53, −0.47)	−0.70 (−0.75, −0.66)	−0.34 (−0.38, −0.29)
Girls			
1–2 y	−0.37 (−0.41, −0.33)	−0.83 (−1.07, −0.59)	−0.35 (−0.38, −0.31)
2–3 y	−0.48 (−0.51, −0.44)	−0.96 (−1.05, −0.86)	−0.40 (−0.44, −0.36)
3–4 y	−0.66 (−0.69, −0.62)	−1.02 (−1.07, −0.96)	−0.54 (−0.57, −0.50)
4–5 y	−0.60 (−0.63, −0.57)	−0.80 (−0.85, −0.75)	−0.47 (−0.50, −0.43)
5–6 y	−0.64 (−0.68, −0.61)	−0.76 (−0.82, −0.71)	−0.51 (−0.57, −0.46)

Table 3. Prevalence of Myopia in Primary School Students

Variable	Prevalence, % (95% CI)			*P* Value
	All	Boys	Girls	
Year level				
1 y	6.6 (5.6–7.5)	6.9 (5.7–8.2)	6.0 (4.7–7.4)	.596
2 y	13.7 (12.4–15.0)	13.4 (11.7–15.1)	14.1 (12.1–16.1)	.827
3 y	25.2 (23.6–26.8)	24.2 (22.0–26.3)	26.5 (24.0–29.0)	.073
4 y	38.2 (36.4–40.1)	35.7 (33.3–38.1)	41.5 (38.6–44.3)	.003
5 y	50.2 (48.2–52.1)	46.2 (43.6–48.8)	55.3 (52.4–58.3)	<.001
6 y	61.5 (59.4–63.6)	56.1 (53.2–59.0)	67.9 (64.9–70.9)	<.001

P values were used to compare the prevalence of myopia for boys and girls.

95% CI, 1.1–1.8; $P = 0.004$), higher AL/CRs (OR, 2.3; 95% CI, 1.8–2.9; $P < 0.001$), longer ALs (OR, 1.7; 95% CI, 1.3–2.4; $P = 0.001$), and deeper anterior chambers (OR, 1.3; 95% CI, 1.02–1.5; $P = 0.035$). The following were not associated with cumulative incidence of myopia: age ($P = 0.57$), time outdoors ($P = 0.56$), near work ($P = 0.48$), lens thickness ($P = 0.27$), or CR ($P = 0.23$).

Figure 4 shows the receiver operating curve from univariate logistic regressions. The strongest single predictor of incident myopia was baseline SER with an area under the curve of 0.82 (95% CI, 0.80–0.84), followed by AL/CR (0.72; 0.70–0.75) and ACD (0.64; 0.61–0.67). The single factors of gender, parental myopia, AL, CR, and lens thickness had an area under the curve of less than 0.60. Slight improvements in prediction were provided by the model combining baseline SER, gender, and parental myopia (0.84; 0.82–0.85); the addition of AL/CR and ACD made no improvement.

Discussion

The mean SER decreased from 0.94 ± 1.03 D among students in grade 1 to –1.37 ± 2.08 D in grade 6, with rapid annual myopic shifts in grades 3 and 4 (−0.59 D), in grades 4 and 5 (−0.51 D), and in grades 5 and 6 (−0.56 D). The yearly incidence rates of myopia increased from 7.8% in the first year (grades 1–2) to 25.3% in the fifth year (grades 5–6). The incidence rates were higher in children who had less baseline refractions, two myopic parents, longer AL, deeper anterior chambers, higher AL/CR ratios, and thinner lenses.

Epidemiological studies reporting similar issues among primary school students with annual changes are lacking, with the exception of one in Guangzhou, China.[16] As acknowledged by its authors, that study overestimated myopia owing to the use of noncycloplegic autorefraction.[16] Our study demonstrated the mean annual rates of change in SER were more than −0.50 D per year after grade 3, with the fastest change of −0.59 D in the third year (grades 3–4). Consistent with the CLEERE,[30] we found that annual progression was faster than for boys. Therefore, it is highly important to implement interventions on preventing the development of myopia among primary school students, especially for students before grade 3. The low development of myopia in the first 2 to 3 years of primary schools indicates that there is a 3-year window to apply school-based measures to slow the onset of myopia before large numbers of children become myopic.

In another follow-up study conducted in Western China, the mean progression of myopia was −2.21 D over 5 years with an annual myopia progression rate of −0.43 D,[31] which was similar to the mean progression of −0.46 D in our study. In Shanghai children, the average 2-year myopia progression rates were much higher at −0.91 D for grade 1, −0.91 D for grade 2, and −1.11 D for grade 3.[32] Two studies from about 20 years ago found lower annual myopia progression rate than ours: a study in Shunyi District (−0.17 D per year in children aged 5–13 years)[33] and a Hong Kong study (−0.32 D per year in children aged 7–12 years).[34] The higher myopia progression rate in the recent studies may be associated with the development of intensive mass education systems and exposure to rapid urbanization.[35,36]

The mean myopia progression rates in Chinese children were higher than for studies in Australian primary school children (−0.16 D),[18] white Northern Irish schoolchildren (−0.38 D),[37] and children from the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error Study (−0.38 D),[38] but lower than reported in the Singapore Cohort Study of the Risk Factors for Myopia Singapore (−0.80 D in 7-year-olds, −0.66 D in 8-yearolds, and −0.57 D in 9-year-olds).[22]

Table 4. Annual Incidence Rates of Myopia and High Myopia in Primary School Students

Period	All		Boys		Girls		P Value
	N	% (95% CI)	N	% (95% CI)	N	% (95% CI)	
Incidence of myopia							
1–2 y	187/2385	7.8 (6.8–8.9)	98/1373	7.1 (5.8–8.5)	89/1012	8.8 (7.0–10.5)	.137
2–3 y	305/2196	13.9 (12.4–15.3)	169/1264	13.3 (11.4–15.2)	136/932	14.6 (12.3–16.9)	.383
3–4 y	351/1884	18.6 (16.9–20.4)	180/1091	16.5 (14.3–18.7)	171/793	21.6 (18.7–24.4)	.002
4–5 y	306/1485	20.6 (18.5–22.7)	153/862	17.7 (15.2–20.3)	153/623	24.6 (21.1–27.9)	.001
5–6 y	268/1059	25.3 (22.7–27.9)	127/623	20.4 (17.2–23.6)	141/436	32.3 (27.9–36.7)	<.001
Incidence of High Myopia							
1–2 y	3/2551	0.1 (0.0–0.3)	0	0.0 (0.0–0.0)	3/1076	0.3 (0.0–0.6)	–
2–3 y	3/2529	0.1 (0.0–0.3)	2/1449	0.1 (0.0–0.3)	1/1080	0.1 (0.0–0.3)	.999
3–4 y	9/2473	0.4 (0.1–0.6)	5/1421	0.4 (0.1–0.7)	4/1052	0.4 (0.0–0.8)	.999
4–5 y	16/2349	0.7 (0.3–1.0)	6/1314	0.5 (0.1–0.8)	10/1035	1.0 (0.4–1.6)	.136
5–6 y	20/2028	1.0 (0.6–1.4)	11/1122	1.0 (0.4–1.6)	9/906	1.0 (0.3–1.6)	.977

P Values were used to compare annual incidence of myopia and high myopia between boys and girls.

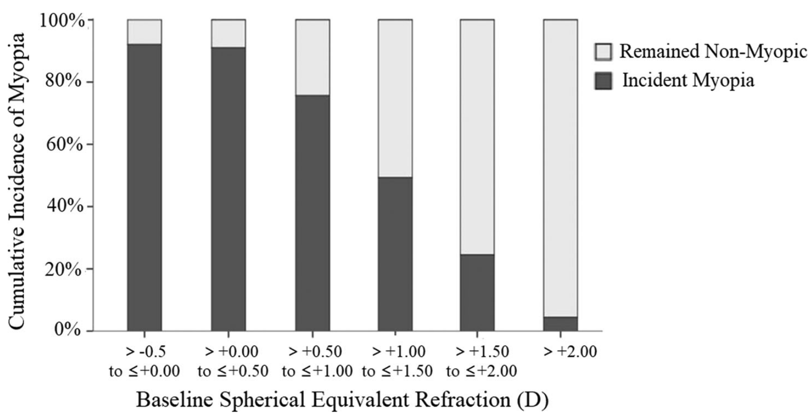

Figure 2. The 5-year cumulative incidence of myopia relative to baseline SER.

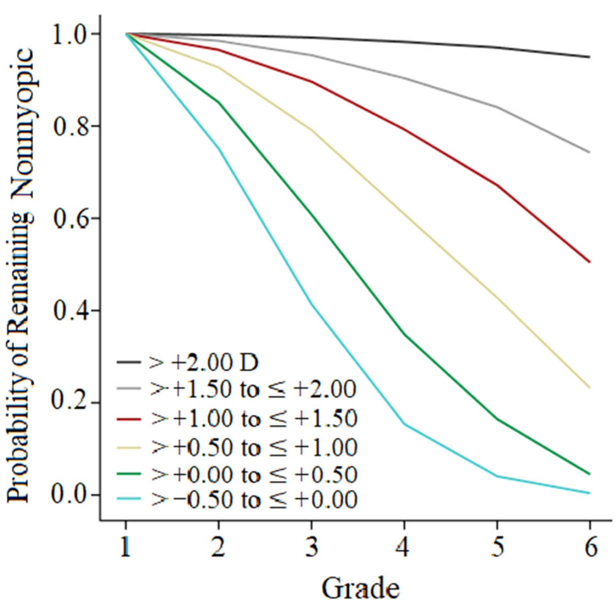

Figure 3. Survival probabilities for remaining nonmyopic by baseline SER. The ratio of the greater than +2.00 D probability to that of any other baseline SER group gives the mean hazard ratio.

Progression rates are higher in East Asia than elsewhere, which is consistent with the higher prevalence of myopia reported in East Asians.

The Guangzhou study reported a high annual myopia incidence of 20.0% to 30.0% throughout primary school.[16] However, in our study, the incidence rate of myopia was only 7.8% in the first year (grades 1–2), and increased to more than 20% in the fourth and fifth years (grades 4–6). Noncycloplegic refraction was used in the Guangzhou study; as mentioned elsewhere in this article, noncycloplegic refraction overestimates the myopic status and hence the rates of myopia. At present, to obtain the prevalence of myopia among children, the China's National Health Commission have carried out the strategy of school screening. However, although the prevalence of myopia will be overestimated, the use of noncycloplegic refraction for school screening is quite appropriate, because it has the desirable property of identifying all myopes. In addition, the survey was conducted in metropolitan Guangzhou, compared with our study in Anyang, where the socioeconomic status is similar to the national average. Studies have suggested that myopia prevalence is associated with socioeconomic status.[36,39] In the present study, the annual incidence of myopia was similar to those conducted in Chongqing City,[31] Hong Kong,[40] and Singapore,[22] but higher than in Australia[18] and Northern Ireland.[19] Annual incidence of myopia was 10.6% among Chongqing school-aged children aged 6 to 15 years,[31] was

Table 5. Associations between 5-Year Cumulative Incidence of Myopia and Baseline Demographic and Ocular Biometry Parameters

Baseline Characteristics	5-Year Cumulative Incidence, *n*, % (95% CI)	OR (95% CI)	*P* Value
Sex			
Boys	530 54.2 (51.1–57.4)	Reference	
Girls	510 66.7 (63.3–70.0)	1.69 (1.39, 2.06)	**<.001**
Parental myopia			
0 parents	681 55.8 (53.0–58.6)	Reference	
1 parent	277 66.6 (62.0–71.1)	1.58 (1.25, 2.00)	**<.001**
2 parents	82 78.1 (70.1–86.1)	2.85 (1.76, 4.62)	**<.001**
SER (D)			
> +1.50	55 16.4 (12.4–20.3)	Reference	
> +1.00 to ≤ +1.50	247 49.3 (44.9–53.7)	5.49 (3.87, 7.73)	**<.001**
> +0.50 to ≤ +1.00	425 75.6 (72.1–79.2)	18.99 (13.23, 27.25)	**<.001**
> –0.50 to ≤ +0.50	313 91.3 (88.2–94.3)	65.79 (40.45, 107.01)	**<.001**
AL (mm)			
First tertile (<22.36)	285 50.6 (46.5–54.8)	Reference	
Second tertile (22.36–22.97)	347 59.4 (55.4–63.4)	1.83 (1.42, 2.34)	**<.001**
Third tertile (>22.97)	383 68.3 (64.4–72.1)	3.27 (2.49, 4.31)	**<.001**
CR (mm)			
First tertile (<7.69)	371 65.2 (61.3–69.1)	Reference	
Second tertile (7.69–7.90)	331 58.1 (54.0–62.1)	0.80 (0.63, 1.02)	.076
Third tertile (>7.90)	256 55.0 (50.9–59.1)	0.75 (0.59, 0.96)	**.024**
Lens thickness (mm)			
First tertile (<3.54)	366 68.2 (64.2–72.1)	Reference	
Second tertile (3.54–3.69)	346 60.4 (56.4–64.4)	0.71 (0.56, 0.92)	**.008**
Third tertile (>3.69)	268 50.0 (45.8–54.2)	0.44 (0.34, 0.56)	**<.001**
ACD (mm)			
First tertile (<2.78)	251 45.1 (40.9–49.2)	Reference	
Second tertile (2.78–2.97)	358 61.1 (57.1–65.1)	2.32 (1.81, 2.97)	**<.001**
Third tertile (>2.97)	393 72.2 (68.5–76.0)	4.16 (3.18, 5.45)	**<.001**
AL/CR ratio			
First tertile (<2.88)	206 36.6 (32.6–40.6)	Reference	
Second tertile (2.88–2.93)	343 62.7 (58.6–66.8)	3.24 (2.52, 4.17)	**<.001**
Third tertile (>\2.93)	466 77.9 (74.6–81.3)	7.52 (5.73, 9.88)	**<.001**

Boldface indicates statistical significance ($P < 0.05$).
ORs for each group were adjusted for potential confounding effects of age and gender.

14.4% among Hong Kong children aged 5 to 16 years,[40] and was 14.2% among Singaporean children aged 7 to 9 years.[22] However, the annual incidence of myopia was as low as 2.2% for both Australian children with a mean age of 6.7 ± 0.4 years and for Northern Ireland children aged 6 to 7 years.[18,19]

As with previous cohort studies, our findings showed that children who had more hyperopic baseline refractions, described by the term "hyperopia reserve," were less likely to become myopic.[41–43] Ma et al.[32] found that approximately 9% of grade 1 students in Shanghai with more than 1.0 D hyperopia progressed to myopia after 2 years, whereas we found 36.1% progression in this grade. In addition, we found that 81.5% of children with a baseline SER of +1.00 D to greater than –0.5 D progressed to myopia after 5 years. Our study suggested that school-based health education and prevention programs could be targeted at the grade 1 students with baseline SER less than +1.00 D, aiming to prevent the development of myopia. Our cut-point of +1.00 D is slightly higher than the +0.75D determined in the CLEERE study in the United States.[42]

Consistent with previous cohort studies,[31,22] we found that girls had a higher cumulative incidence of myopia than boys. This finding may be because of more time spend on near work and less time on outdoor activities, as reported by other studies.[11,44] Consistent with the CLEERE study[21] and the Orinda Longitudinal Study of Myopia,[45] we found also that the risk for myopia onset was associated with parental

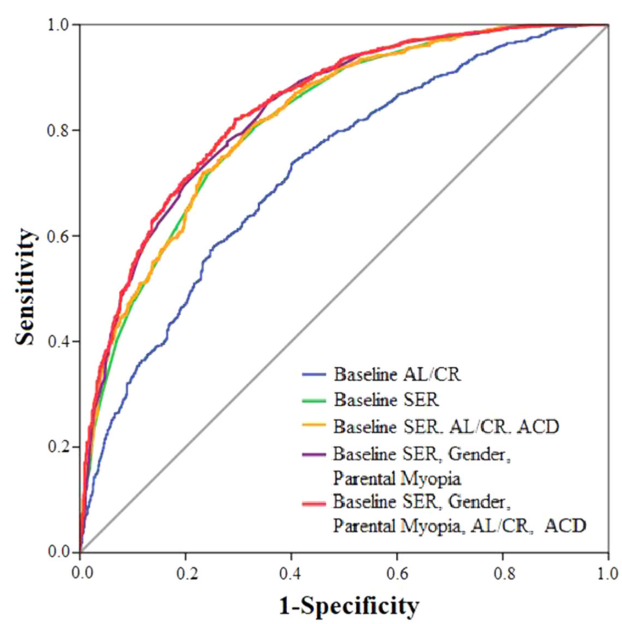

Figure 4. The receiver operating characteristic curves for predicting five-year cumulative incidence myopia with different predictor combinations. Individual predictors are baseline SER, baseline AL/CR, baseline ACD, gender, and parental myopia.

myopia. In SCORM, Saw et al.[22] found that children with greater ALs and vitreous chamber depths and thinner lenses had higher incidence rates of myopia. In Chinese children, Wang et al.[16] reported that an AL/CR ratio higher than the 75th percentile at baseline was the second strongest factor associated with incidence of myopia. However, some studies[46,47] reported a lower sensitivity for AL/CR ratio than Wang et al. Thus, these relationships may be inconsistent between different ethnic groups and populations. These findings are largely consistent with our study. Therefore, some premyopic biometry parameters are risk factors for myopia onset in children. As with previous cohort studies, our findings showed that baseline SER is the single best predictive factor for myopia onset.[42] Adding gender and parental myopia improve the prediction. The further addition of AL/CR and ACD make little difference.

The strengths of our study included the standardized measurement of refractive errors using cycloplegia, a large sample size, and a 5-year longitudinal cohort. However, there are limitations in present study. The main limitation is that, despite efforts to maintain high follow-up rates, there were 27.8% missing data by the fifth, final follow-up visit. Students in grade 6 had intensive mass education pressure due to the unified junior high schools entrance examination soon, leading to lower level of participation. In addition, it might be considered that the overall incidence rates of myopia may be biased because this was a school-based investigation rather than a population-based cohort, but as the attendance rates of grade 1 students were greater than 99%,[7] the children in our study are a fair representation of the Anyang population.

Conclusions

For children in Anyang city in Central China, we found an increasing incidence of myopia from 7.8% in grades 1 and 2 to 25.3% in grades 5 and 6. Mean SER decreased substantially from grade 1 to grade 6, with considerable annual myopic shifts for grades 3 and 4 (−0.59 D), grades 4 and 5 (−0.51 D), and grades 5 and 6 (−0.56 D). Yearly incidence of myopia and changes in SER were higher for girls than boys. We suggest implementing interventions to prevent myopia development throughout primary school, especially before grade 3. Hyperopic refraction of children should be monitored before primary school as hyperopia reserve to prevent the onset of myopia and high myopia, and thus reducing the potential for sight-threatening pathological changes later in life.

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