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Progression and incidence of myopia among schoolchildren in the post-COVID-19 pandemic period: a prospective cohort study in Shantou, China

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ABSTRACT

Objectives To determine the progression and incidence of myopia in Chinese schoolchildren in the post-COVID-19 pandemic period in Shantou, China.

Design Prospective cohort study.

Setting Shantou Myopia Study, China.

Participants 1-year follow-up data were available for 621 881 schoolchildren (301 999 females). Data on spherical equivalent refraction (SER) were collected.

Primary and secondary outcome measures The primary outcomes were myopia progression and incidence. Myopia progression is defined as a change of SER towards the negative direction in the follow-up visit. Incidence is defined as the proportion of schoolchildren who were not myopic but developed myopia in the follow-up study. Age, sex and SER at baseline were evaluated as associated factors for myopia burden, which were defined as the secondary outcomes.

Results Mean progression of SER was −0.35±0.97 D for the population (ranging from −0.06 D at 18 years of age to −0.46 D at 11 years of age), with a rapid myopic progression for students at the age of 10–12 years (−0.50 D in girls and −0.44 D in boys). A myopic shift greater than −0.50 D/year occurred in 256 299 eyes (41.21%). Myopic progression in refraction was associated with the 10–12 years age groups (OR 1.42; 95% CI 1.39 to 1.45, p<0.001), female sex (OR 1.09; 95% CI 1.08 to 1.10, p<0.001) and higher refractive errors at baseline (OR>1.00, p<0.001). The annual incidence of myopia among schoolchildren was 24.85%, with an incidence of 26.69% in girls and 23.02% in boys.

Conclusions Our study revealed an annual myopia progression of −0.35 D and an incidence of 24.85% among schoolchildren in the post-COVID-19 pandemic period. Myopia progressed rapidly at 10–12 years of age, with −0.50 D in girls and −0.44 D in boys. The incidence was higher for children aged 10–11 years and for girls.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ An advantage of this study was the city-wide, population-based design, with a large sample size of over 620 000 children and teenagers.
- ⇒ The study had a relatively high response rate of 86.25%.
- ⇒ Devices used in the study supported real-time and automatic data upload and management, which showed a significant advantage in saving time and avoiding data entry errors.
- ⇒ Due to the non-cycloplegic refraction data used, the progression rate and incidence of myopia among schoolchildren might be underestimated.
- ⇒ The rate of myopia progression was calculated based on only 1-year follow-up observation, thus limiting our knowledge of how myopia changes with time.

INTRODUCTION

Myopia is one of the most common causes of visual impairment, affecting millions of schoolchildren and imposing a heavy economic burden on countries and individuals.[1] At the end of 2019, there was a global outbreak of the COVID-19. To prevent the spreading of the virus infection, the Chinese government started an emergency pandemic prevention measure of closing schools from the end of January to May 2020.[2] More than 220 million schoolchildren were restricted to their homes and had to learn through the internet because of the lockdown measures to control the pandemic in China, which could potentially worsen the burden of myopia.[3 4] Conditions, such as prolonged time exposure of electronic devices, intensive online teaching and learning and non-sufficient time for outdoor activities, posed a great challenge to the prevention and intervention of myopia during the home confinement.[5 6] Due to those restrictions, Wang *et al*[7] found that the prevalence of myopia among schoolchildren aged 6–8 years was significantly greater in the year after home confinement than the year before.

Previous studies have explored the impact of home confinement on myopia changes in schoolchildren during school closures and found that some behaviours, such as intensive screen time, insufficient outdoor activity, and unhealthy lifestyles and eyesight habits, increased the risk of myopia in schoolchildren.[3–8] However, these studies only provide evidence of changes in the distribution of refraction during the COVID-19 lockdown, so more research is needed on whether the lifestyles and eyesight habits developed during the COVID-19 lockdown still have an impact on the burden of myopia after the COVID-19 pandemic. To our knowledge, there are only three studies on myopia progression among Chinese schoolchildren in the post-COVID-19 pandemic period in Chengdu, Hangzhou and Wuhan, respectively.[9–11] As there is a high variation across the regions of China, more longitudinal studies of myopia are still in urgent need.

In September 2020, during the period of school reopens, a long-term programme Shantou Myopia Study was conducted in Shantou City, southern China. As reported in the study, myopia affects 51.8% of schoolchildren, with girls suffering a higher myopia burden than boys (55.2% vs 48.7%).[12] Since the prevalence of myopia in Shantou is much higher than the national average (35.6%), it is necessary to further explore the annual progression and incidence of myopia among those children. The vision screening in Shantou Myopia Study is designed to conduct once a year. Since September 2021, the school-based vision screening of 1-year longitudinal follow-up study has been completed. Based on the baseline and follow-up information, this study aimed to determine the progression and incidence of myopia in Chinese schoolchildren in the post-COVID-19 pandemic period.

METHODS

Study design and population

The Shantou Myopia Study is a prospective cohort study where schoolchildren aged 6–18 years were enrolled from rural and urban areas in Shantou city. The study methodology of the baseline observation has been reported in detail previously.[12] The baseline information was obtained from the first-year vision screening from September 2020 to July 2021. At baseline, schoolchildren were excluded if they had information errors, missing data, correction by the contact lens, orthokeratology or refractive surgery, and if they were uncooperative with examinations. A total of 721 032 schoolchildren were included at baseline. Schoolchildren who attended both the baseline and the 1-year follow-up visit (from September 2021 to July 2022) with available information on age, sex and spherical equivalent refraction (SER) were analysed in this study.

Patient and public involvement

Schoolchildren were involved in the conduct and dissemination plans of this research. All schoolchildren and their parents or legal guardians were given an explanation of the nature of the study and were willing to participate. The final results will be disseminated to study participants by the internet or smartphone.

Examination procedures

Identical ophthalmic examination under the same settings as the baseline was repeated at the follow-up visit among these children. The fast vision screening tests, including the non-cycloplegic autorefraction (NCAR) test, were mainly carried out by the technicians from the JSIEC. Refraction measurement was performed by our screening teams including one manager, two ophthalmic nurses, one optometrist and two ophthalmologists. Twelve full-time screening teams took measurements in various districts throughout Shantou city. All the technicians were trained and passed the examination before they performed operations on-site. The examination procedure was shown as follows: (1) recording personal information of each subject, such as age and sex; (2) taking autorefraction measurement (RM-800; Topcon, Tokyo, Japan) at least third times in one eye without cycloplegic dilation, and the average value was obtained. The measurement had to be repeated if the difference between the minimum and maximum value of these readings from one eye was more than 0.50 D. All examination data were automatically uploaded into our data management system (Bo'aite, Beijing, China), which was created for data transmission, storage and management.

Definitions

SER is defined as the sum of the spherical dioptres and half of the cylindrical dioptres. In the present setting, myopia is defined as a non-cycloplegic SER ≤−0.50 D in one or both eyes, and hyperopia is defined as a non-cycloplegic SER ≥ +0.50 D in at least one eye. Emmetropia is defined as −0.50<SER < +0.50 D in both eyes. Myopia progression rate is defined as a progression of SER towards the negative direction over the 1-year period (the follow-up measurement minus the original baseline measurement/interval). Incidence of myopia is defined as the proportion of schoolchildren who were not myopic but developed myopia in the follow-up study. A myopia progression rate greater than −0.50 D is considered to be clinically significant. The primary outcomes were myopia progression and incidence. Age, sex and SER at baseline were evaluated as associated factors for myopia burden, which were defined as the secondary outcomes. The subjects were further divided into subgroups according to their SER at baseline (emmetropia: > −0.50 D to < +0.50 D, mild myopia: ≤ −0.50 D to> −3.00 D, moderate to high myopia: ≤ −3.00 D, mild hyperopia: ≥ +0.50 D to < +3.00 D, moderate to high hyperopia: ≥ +3.00 D).

Statistical analysis

Logistic regression models were performed to explore risk factors associated with myopia progression, using individual myopia progression (whether it was greater than 0.50 D or not) as the binary outcome variable and various baseline information as covariates (age, sex and SER at baseline). Restricted cubic spline was used to evaluate the relationship between myopia progression and age.

Statistical analyses were performed using the available software R and R Studio (R V.4.0.2, R Foundation; Boston, Massachusetts, USA). The 'ggplot2' package of R software was used for data visualisation. All data were presented as mean±SD or percentages. A two-tailed $p<0.05$ was considered to be statistically significant. Only the right eye of each student was included for data analyses.

RESULTS

Participant demographics

At baseline, a total of 721 032 schoolchildren were eligible for further analysis in the Shantou Myopia Study, of whom 621 881 had complete refraction and visual acuity measurements at the follow-up study. The response rate was 86.25%. A total of 87 843 (12.18%) schoolchildren originally examined were no longer residing in the district. In general, those mainly were senior children who had completed their schooling and had left the area for further education. A total of 11 044 (1.53%) children were excluded due to information error or missing data, 255 (0.04%) children were due to the current use of contact lens or orthokeratology lens, and 9 children were due to a history of ocular surgery over the 1-year follow-up period. The mean age of those 621 881 children was 12.5±3.8 years, with 301 999 females (48.56%) and 319 882 males (51.44%).

Myopia progression and incidence

The mean (SD) SER at baseline, SER at the 1-year follow-up visit and SER progression for each age group and school year are presented in table 1. The percentages of myopia progression for each age group and school year are also demonstrated. At the 1-year follow-up visit, the mean (SD) SER was −1.78±2.21 D, ranging from −0.38 D to −3.58 D. The average rate of myopic progression was −0.35±0.97 D (ranging from −0.06 D at the 18 years or more of age to −0.46 D at the 11 years of age) during the follow-up interval. The mean (SD) change in SER was −0.33±0.96 D (ranging from −0.10 D to −0.44 D) in males and −0.36±0.97 D (ranging from 0.00 D to −0.50 D) in females. A myopic shift of greater than −0.50 D occurred in 256 299 eyes (41.21%).

Of the 246 912 schoolchildren who were not myopic at baseline, 60 941 had developed myopia during the 1-year follow-up, resulting in an incidence of 24.85% (26.69% for females and 23.02% for males, respectively). The incidences of myopia stratified by age and sex are presented in table 2. The highest incidence was detected in the 10-year-old girls (34.20%) and the 11-year-old boys (28.16%). The incidence of myopia was lower among schoolchildren who were less than 7 years of age at baseline (20.19% for females and 18.21% for males, respectively).

Table 1 Spherical equivalent refraction (SER) and its annual change

Variable	N	Initial SER (mean±SD)	1-year follow-up SER (mean±SD)	SER progression (mean±SD)	Myopia progression, N (%)		
					≤−0.5 D	−0.5 to −1.0 D	>−1.0 D
Total	621 881	−1.44±2.10	−1.78±2.21	−0.35±0.97	365 582 (58.8%)	160 755 (25.8%)	95 544 (15.4%)
Sex							
Female	301 999	−1.55±2.14	−1.90±2.23	−0.36±0.97	173 434 (57.4%)	79 515 (26.3%)	49 050 (16.2%)
Male	319 882	−1.34±2.06	−1.66±2.18	−0.33±0.96	192 148 (60.1%)	81 240 (25.4%)	46 494 (14.5%)
Age at baseline							
≤7	100 431	−0.11±1.26	−0.38±1.35	−0.28±1.10	63 749 (63.5%)	21 282 (21.2%)	15 400 (15.3%)
8	77 196	−0.41±1.35	−0.75±1.50	−0.35±1.07	44 634 (57.8%)	18 857 (24.4%)	13 705 (17.8%)
9	73 098	−0.73±1.47	−1.13±1.66	−0.40±1.00	39 609 (54.2%)	19 402 (26.5%)	14 087 (19.3%)
10	67 268	−1.10±1.64	−1.54±1.85	−0.45±0.92	34 075 (50.7%)	19 984 (29.7%)	13 209 (19.6%)
11	68 215	−1.54±1.83	−2.00±2.02	−0.46±0.88	33 923 (49.7%)	21 285 (31.2%)	13 007 (19.1%)
12	64 952	−1.97±1.99	−2.36±2.15	−0.40±0.89	35 311 (54.4%)	19 601 (30.2%)	10 040 (15.5%)
13	56 199	−2.38±2.17	−2.72±2.29	−0.36±0.82	33 500 (59.6%)	15 988 (28.4%)	6711 (11.9%)
14	41 852	−2.79±2.28	−3.07±2.38	−0.29±0.82	26 974 (64.5%)	10 757 (25.7%)	4121 (9.8%)
15	29 857	−3.22±2.38	−3.40±2.45	−0.19±0.88	21 496 (72.0%)	6047 (20.3%)	2314 (7.8%)
16	27 569	−3.39±2.46	−3.52±2.52	−0.13±0.91	20 850 (75.6%)	4915 (17.8%)	1804 (6.5%)
17	13 207	−3.45±2.52	−3.58±2.59	−0.14±1.06	9893 (74.9%)	2309 (17.5%)	1005 (7.6%)
18	2037	−3.32±2.56	−3.40±2.60	−0.06±1.36	1568 (77.0%)	328 (16.1%)	141 (6.9%)

Table 2 Annual incidence of myopia

Age at baseline	N	New case of myopia	Incidence
Female	111 850	29 853	26.69%
≤7	36 696	7410	20.19%
8	23 303	6252	26.83%
9	17 218	5412	31.43%
10	11 554	3952	34.20%
11	8278	2787	33.67%
12	5793	1757	30.33%
13	3889	1094	28.13%
14	2174	566	26.03%
15	1268	271	21.37%
16	1137	242	21.28%
17	476	96	20.17%
18	64	14	21.88%
Male	135 062	31 088	23.02%
≤7	38 742	7054	18.21%
8	25 873	5821	22.50%
9	20 494	5073	24.75%
10	15 155	4125	27.22%
11	11 830	3331	28.16%
12	8851	2389	26.99%
13	6177	1595	25.82%
14	3573	843	23.59%
15	1785	376	21.06%
16	1638	303	18.50%
17	809	149	18.42%
18	135	29	21.48%

Factors associated with myopia progression

Table 3 shows the OR and p value of myopia progression in a multivariate logistic regression model among all children stratified by sex, age groups and SER at baseline. In multivariate analysis, the mean rate of SER progression was significantly associated with sex and baseline age (both p<0.001). Girls had greater and earlier myopic SER progression than boys over the 1-year period (−0.50±0.86 D in girls vs −0.44±0.89 D in boys; OR 1.09, 95% CI 1.08 to 1.10, p<0.001). And a higher proportion of myopia progression among schoolchildren aged 10–12 years than in other groups could be seen in this study, with the highest in the 11-year-old age group (OR 1.42, 95% CI 1.39 to 1.45, p<0.001). In boys, the mean rate of SER progression increased from −0.27 D at the age of less than 7 years to −0.44 D at the age of 11–12 (11.6) years, and then fell to −0.13 D at the age of 17 years; as for girls, the mean rate increased from −0.29 D at the age of less than 7 years to −0.50 D at the age of 10–11 (10.6) years, and then fell to −0.15 D at the age of 17 years (table 4). Myopia progression was significantly associated with baseline SER categories in the multivariate model (p<0.001, table 3). Compared with schoolchildren without refractive errors at baseline, children with myopia or hyperopia were more likely to have myopia progression, especially those with higher myopic baseline SER (OR 2.05, 95% CI 2.01 to 2.08; OR 1.67, 95% CI 1.65 to 1.69; OR 1.35, 95% CI 1.25 to 1.45 and OR 1.27, 95% CI 1.24 to 1.30 in children with moderate to high myopia, mild myopia, moderate to high hyperopia and mild hyperopia, respectively, all p<0.001).

Relationship between age and myopia progression

Regardless of baseline refractive status, the progression rate was lower for younger and older age children, with the highest rate in the 10–11 (10.6) years of age among female children. Restricted cubic spline showed the pattern of myopia progression followed a U shape across different age groups, revealing a non-linear increasing trend from age under 7 years to age over 18 years. And the most rapid increase was found in the 10–12 years of age, the primary school stage (figure 1).

DISCUSSION

Our schoolchildren were of different socioeconomic and academic backgrounds. The highlight of this study is that we investigated the burden of myopia among Chinese schoolchildren 1 year after the COVID-19 pandemic. Over the 1-year follow-up period in the post-COVID-19 pandemic period, the mean SER has an overall myopic shift in refraction among schoolchildren, with an average rate of myopia progression of −0.35±0.97 D and an incidence of 24.85%. The highest incidence and progression rates were found in the 10-year-old girls and the 11-year-old boys, respectively.

Due to the COVID-19 pandemic in 2020, a nationwide school closure was conducted in China. This study is one of the few to investigate the progression and incidence of myopia among Chinese schoolchildren after school reopens in the post-COVID-19 pandemic period. Consistent with recently published studies, our results showed a high risk of myopia among Chinese schoolchildren in the post-COVID-19 pandemic period, which might be associated with the failure to change unhealthy lifestyles and eyesight habits developed during the pandemic.[9–11] Several recent studies have also presented a significant decrease in mean SER among schoolchildren during the COVID-19 pandemic. Mohan *et al*[13] found that the mean annual myopia progression among Indian schoolchildren was significantly higher during COVID-19 as compared with pre-COVID-19 (0.90 vs 0.25 D, p<0.00001). Ma *et al*[14] and Wang *et al*[15] reported that myopia progression in Chinese children during the COVID-19 pandemic home confinement was accelerated, and increased digital screen times and decreased outdoor activity times were risk factors. Less myopic development was expected after students returned to schools in 2020, however, the refractive error of schoolchildren remained progressing in 2021, indicating that myopia-prone lifestyles might persist

Table 3 Factors associated with myopia progression over a 1-year period

Variable	Myopia progression N (<0.50 D)	N (≥0.50 D)	Univariate OR (95% CI)	Multivariate OR (95% CI)
Sex				
Female	173 434 (47.4%)	128 565 (50.2%)	Reference	Reference
Male	192 148 (52.6%)	127 734 (49.8%)	0.90 (0.89 to 0.91, p<0.001)	0.92 (0.91 to 0.93, p<0.001)
Age at baseline				
≤7	63 749 (17.4%)	36 682 (14.3%)	Reference	Reference
8	44 634 (12.2%)	32 562 (12.7%)	1.27 (1.24 to 1.29, p<0.001)	1.22 (1.20 to 1.25, p<0.001)
9	39 609 (10.8%)	33 489 (13.1%)	1.47 (1.44 to 1.50, p<0.001)	1.35 (1.32 to 1.37, p<0.001)
10	34 075 (9.3%)	33 193 (13%)	1.69 (1.66 to 1.73, p<0.001)	1.46 (1.43 to 1.49, p<0.001)
11	33 923 (9.3%)	34 292 (13.4%)	1.76 (1.72 to 1.79, p<0.001)	1.42 (1.39 to 1.45, p<0.001)
12	35 311 (9.7%)	29 641 (11.6%)	1.46 (1.43 to 1.49, p<0.001)	1.11 (1.09 to 1.14, p<0.001)
13	33 500 (9.2%)	22 699 (8.9%)	1.18 (1.15 to 1.20, p<0.001)	0.86 (0.84 to 0.88, p<0.001)
14	26 974 (7.4%)	14 878 (5.8%)	0.96 (0.94 to 0.98, p<0.001)	0.67 (0.66 to 0.69, p<0.001)
15	21 496 (5.9%)	8361 (3.3%)	0.68 (0.66 to 0.70, p<0.001)	0.45 (0.44 to 0.47, p<0.001)
16	20 850 (5.7%)	6719 (2.6%)	0.56 (0.54 to 0.58, p<0.001)	0.37 (0.36 to 0.39, p<0.001)
17	9893 (2.7%)	3314 (1.3%)	0.58 (0.56 to 0.61, p<0.001)	0.39 (0.37 to 0.41, p<0.001)
18	1568 (0.4%)	469 (0.2%)	0.52 (0.47 to 0.58, p<0.001)	0.35 (0.32 to 0.39, p<0.001)
SER at baseline				
−0.50 D<SER <+0.50 D	140 531 (38.4%)	77 639 (30.3%)	Reference	Reference
+0.50 D≤SER <+3.00 D	27 704 (7.6%)	18 807 (7.3%)	1.23 (1.20 to 1.25, p<0.001)	1.27 (1.24 to 1.30, p<0.001)
−3.00 D<SER ≤−0.50 D	128 693 (35.2%)	107 078 (41.8%)	1.51 (1.49 to 1.52, p<0.001)	1.67 (1.65 to 1.69, p<0.001)
+3.00 D≤SER	1761 (0.5%)	1244 (0.5%)	1.28 (1.19 to 1.38, p<0.001)	1.35 (1.25 to 1.45, p<0.001)
SER≤−3.00 D	66 893 (18.3%)	51 531 (20.1%)	1.39 (1.37 to 1.41, p<0.001)	2.05 (2.01 to 2.08, p<0.001)

Data are ORsand 95% CI of the univariate and multivariate logistic model, respectively.
SER, spherical equivalent refraction.

for a long time. Thus, in the post-COVID-19 pandemic period, myopia prevention strategy should be based on the integrating participation of schools and families, such as controlling screen time and increasing eye break time as much as possible.

Before the COVID-19 outbreak, several longitudinal studies explored annual myopia progression in different regions of China. Compared with longitudinal studies with a 1-year follow-up period, the annual myopic progression rate in our study was −0.35 D measured without cycloplegia, which was lower than that of schoolchildren from grades 1 to 5 in Xining (−0.52 D with cycloplegia),[16] that of schoolchildren in Mojiang (−0.97 D in grade 1,–1.02 D in grade 7 with cycloplegia, respectively),[17] that of children at grade 2 in Taipei (−0.98 D with cycloplegia),[18] and that of schoolchildren residing in Hong Kong (−0.40 D with cycloplegia).[19] Compared with longitudinal studies with periods of 2 years or more, the annual rate of myopic progression in our study was also lower than that of a 5-year study recruiting children aged 6–15 years in Chongqing (−0.43 D with cycloplegia),[20] that of a 5-year study in children at grade 1 in Anyang city (−0.46 D with cycloplegia),[21] that of a 2-year study in children from grades 1 to 3 in Shanghai (−0.91/2 D in grade 1, −0.91/2 D in grade 2 and −1.11/2 D in grade 3 with cycloplegia, respectively),[22] and that of a 2-year study in Wenzhou (−0.44 D without cycloplegia).[23] As the differences in the follow-up period, cycloplegia using and age range of schoolchildren, direct comparison of those findings should be cautioned. The lower annual progression rate in our study could be due to an overestimation of myopia students owing to NCAR, which might account for the slower progression rate among all children. Another reason might be associated with an accommodative spasm during the COVID-19 lockdown.

The annual incidence of myopia across all ages and both sexes was 24.85% in our population, which was similar to that in Guangzhou.[24] The Guangzhou study reported an annual incidence of 20%–30% among their grades 1–9 schoolchildren, with the highest incidence found in grade 5 students (30.2%). An annual incidence of myopia of 37.1% in Taipei,[18] of 10.6% in Chongqing,[20] of 14.4% in Hong Kong,[19] and 14.2% in Singapore[25] was also reported previously, suggesting the variations in myopia incidence could be associated with geography or urbanisation. Given that this study was conducted after

Table 4 Spherical equivalent refraction and its annual change, stratified by sex

Age at baseline	N	Initial SER (mean±SD)	1-year follow-up SER (mean±SD)	SER progression (mean±SD)	Myopia progression, N (%)		
					≤–0.5 D	–0.5 to –1.0 D	>–1.0 D
Female	301 999	–1.55±2.14	–1.90±2.23	–0.36±0.97	173 434 (57.4%)	79 515 (26.3%)	49 050 (16.2%)
≤7	49 008	–0.12±1.28	–0.40±1.35	–0.29±1.10	30 489 (62.2%)	10 624 (21.7%)	7895 (16.1%)
8	37 372	–0.43±1.36	–0.80±1.50	–0.37±1.06	20 837 (55.8%)	9373 (25.1%)	7162 (19.2%)
9	35 308	–0.79±1.47	–1.23±1.67	–0.45±0.97	17 913 (50.7%)	9629 (27.3%)	7766 (22.0%)
10	32 466	–1.21±1.66	–1.69±1.88	–0.49±0.91	15 363 (47.3%)	9945 (30.6%)	7158 (22%)
11	32 978	–1.69±1.84	–2.16±2.03	–0.50±0.86	15 732 (47.7%)	10 600 (32.1%)	6646 (20.2%)
12	31 229	–2.14±2.02	–2.53±2.15	–0.40±0.89	17 032 (54.5%)	9515 (30.5%)	4682 (15%)
13	26 970	–2.57±2.18	–2.90±2.29	–0.34±0.83	16 276 (60.3%)	7616 (28.2%)	3078 (11.4%)
14	20 408	–2.97±2.27	–3.25±2.36	–0.29±0.83	13 237 (64.9%)	5221 (25.6%)	1950 (9.6%)
15	15 248	–3.36±2.35	–3.54±2.43	–0.19±0.93	10 933 (71.7%)	3102 (20.3%)	1213 (8.0%)
16	13 720	–3.52±2.42	–3.65±2.47	–0.13±1.02	10 217 (74.5%)	2571 (18.7%)	932 (6.8%)
17	6416	–3.65±2.49	–3.79±2.55	–0.15±1.13	4722 (73.6%)	1176 (18.3%)	518 (8.1%)
18	876	–3.59±2.51	–3.63±2.53	0.00±1.29	683 (78.0%)	143 (16.3%)	50 (5.7%)
Male	319 882	–1.34±2.06	–1.66±2.18	–0.33±0.96	192 148 (60.1%)	81 240 (25.4%)	46 494 (14.5%)
≤7	51 423	–0.10±1.25	–0.37±1.35	–0.27±1.10	33 260 (64.7%)	10 658 (20.7%)	7505 (14.6%)
8	39 824	–0.38±1.34	–0.70±1.50	–0.33±1.08	23 797 (59.8%)	9484 (23.8%)	6543 (16.4%)
9	37 790	–0.67±1.47	–1.03±1.65	–0.36±1.02	21 696 (57.4%)	9773 (25.9%)	6321 (16.7%)
10	34 802	–1.01±1.62	–1.41±1.81	–0.40±0.93	18 712 (53.8%)	10 039 (28.8%)	6051 (17.4%)
11	35 237	–1.41±1.81	–1.84±2.01	–0.44±0.89	18 191 (51.6%)	10 685 (30.3%)	6361 (18.1%)
12	33 723	–1.81±1.96	–2.21±2.14	–0.41±0.90	18 279 (54.2%)	10 086 (29.9%)	5358 (15.9%)
13	29 229	–2.20±2.15	–2.56±2.28	–0.37±0.81	17 224 (58.9%)	8372 (28.6%)	3633 (12.4%)
14	21 444	–2.62±2.28	–2.90±2.40	–0.30±0.80	13 737 (64.1%)	5536 (25.8%)	2171 (10.1%)
15	14 609	–3.08±2.40	–3.26±2.47	–0.19±0.82	10 563 (72.3%)	2945 (20.2%)	1101 (7.5%)
16	13 849	–3.27±2.50	–3.39±2.56	–0.13±0.80	10 633 (76.8%)	2344 (16.9%)	872 (6.3%)
17	6791	–3.26±2.54	–3.38±2.62	–0.13±0.99	5171 (76.1%)	1133 (16.7%)	487 (7.2%)
18	1161	–3.11±2.58	–3.22±2.64	–0.10±1.40	885 (76.2%)	185 (15.9%)	91 (7.8%)

SER, spherical equivalent refraction.

the COVID-19 pandemic, the high incidence of myopia in our study possibly indicated that the impact of the COVID-19 lockdown would remain for at least 1 year. In addition, annual myopia incidence was much higher in East Asian ethnicity (10% to 30%) compared with children the same age in Europe and Australia (1%–7%).[26–28]

Consistent with previous longitudinal studies, our findings showed that children who had higher refractive errors at baseline were more likely to have rapid myopic shifts in refraction.[20 21 29 30] The mean annual rate of myopic change for schoolchildren with myopia at baseline was significantly higher for those who were not myopic at baseline in a Hong Kong study (–0.63 D vs –0.29 D, p<0.001).[19] Prior cohort studies have shown that SER at baseline could be a simple predictor for myopia onset and progression, such as that schoolchildren with more hyperopic baseline refraction are less likely to become myopic, so the baseline refractive status also deserves attention, especially for children with baseline SER less than +1.00 D before 7 years.[21 27] We recommend that school-based eye health education programmes could be targeted at those population, and then monitoring their actual refraction regularly to prevent the development of myopia. Besides, higher proportions of progressors were observed within the 10–12 years age groups in our study, which was similar to a Hong Kong study of 10–11 years age groups.[19] It is noteworthy that females aged 10–11 years of age in this study had the highest rate of progression of –0.50 D. The difference among myopia levels of more than 0.50 D is clinically meaningful, as this is a proposed criterion for the implementation of treatments to prevent myopia progression.[31]

As anticipated, this study confirmed previous research, finding that girls had a higher mean rate of myopic progression than boys.[19–21 29 30] Hyman *et al*[32] also found that myopic girls had a faster progression

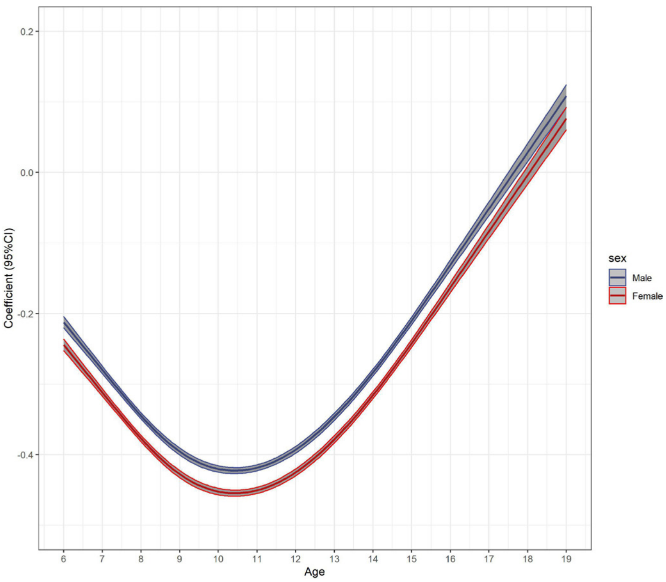

Figure 1 Restricted cubic spline for male and female, respectively, showing the pattern of myopia progression followed a U shape across age groups, thus revealing a non-linear relationship between myopia progression and age.

of 0.16 D than myopic boys over 3 years (p<0.05). Fan *et al*[19] and Lin *et al*[33] reported a lower prevalence and slower myopic progression among boys in Hong Kong and Taiwan, respectively. This difference has also been indicated in recent longitudinal studies of North American children,[34] Indian Children[35] and Chinese children,[20] which further indicate the reliability of the current study. Maybe more near-work activities and limited outdoor exercise among girls predispose them to a faster myopia development.[5 6] However, two critical myopia biomarker data, axial length (AL) and choroidal thickness, were unavailable in our datasets, thus maybe we have missed some of the important biological evidence on the development and progression of myopia.[36 37] Whether we should implement earlier myopia interventions for girls than boys needs to be further explored in future studies.

The strengths of our study included the large sample size of over 620 000 children and teenagers, the full-time professional screening teams, and real-time screening results transmission and storage. The main limitation of this study was that we did not have cycloplegia before autorefraction, which may result in the phenomenon of child pseudomyopia and then accounting for the slower progression rate among these children. However, non-cycloplegic refraction is cost-effective and acceptable in such a large-scale vision screening.[38] Second, the rate of myopia progression was calculated based on only 1-year follow-up observation, thus limiting our knowledge of how myopia changes with time. A longer follow-up study provided better knowledge is needed in the future. Third, the lack of ocular biological parameters data, such as AL or choroid data, limited our understanding and explanation of the change in SER.

Our study revealed an overall myopic shift in refraction among Chinese schoolchildren, with an annual myopia progression of −0.35 D and an annual incidence of 24.85%. Myopia progressed rapidly at 10–12 years of age, with −0.50 D in girls and −0.44 D in boys. The incidence was higher for children aged 10–11 years and for girls. We recommend myopia monitoring and earlier intervention in schoolchildren. The annual myopic progression rate of Chinese schoolchildren in the post-COVID-19 pandemic period was similar to that before the pandemic, but the annual incidence was higher in the postperiod than before, suggesting that the impact of the COVID-19 lockdown would remain for at least 1 year.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval The study protocol was approved by Human Medical Ethics Committee of the Joint Shantou International Eye Center of Shantou University and the Chinese University of Hong Kong (approval number: EC20200120(1)-P15), which is in accordance with the tenets of the Declaration of Helsinki. Participants gave informed consent to participate in the study before taking part.

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