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REVIEW

The Current and Future Landscape of the Childhood Myopia Epidemic in China—A Review

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ABSTRACT

Over the last two decades, the prevalence of myopia has gradually increased in China. Numerous epidemiological studies suggest that education and inadequate time spent outdoors are the major causes of the current myopia epidemic. China is one of the few countries that has begun to address the myopia epidemic with a national-level strategy, implementing nationwide education reform, cost-reduction measurements, and dissemination of information on myopia prevention and control. These "natural experiments" will provide insights into areas that may face similar or potential myopia problems.

Keywords: Myopia; Childhood; China; Awareness; Education; Outdoor

Key Summary Points

The prevalence of myopia in China has gradually increased over the last few decades due to a change in lifestyle over time.

The lockdown measures during the Coronavirus Disease 2019 (COVID-19) pandemic resulted in more time spent indoors and less time outdoors, which has further aggravated the development and progression of myopia among children and teenagers.

The Chinese government has undertaken a series of measures at the national level, including education reforms, programs aimed improving parents' awareness, and application-approved interventions to combat the myopia epidemic.

Other countries should be aware of the outcomes of these efforts, irrespective of success.

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INTRODUCTION

China is one of the few countries in the world that has begun to address the myopia epidemic by implementing national-level strategies. The collective efforts of the government, educational institutions, families, healthcare professionals, and researchers are focused on combating this epidemic through innovative interventions and social measures. Consequently, China has become a central hub for conducting "natural experiments" aimed at managing and preventing myopia. Given the potential increase in myopia cases in other countries, the outcomes and strategies—successful or not—tested in China may offer valuable lessons for the global community.

Childhood myopia may lead to serious eye diseases, potentially causing irreversible blindness later in life [1]. Low, moderate, and high myopia are all associated with serious eye diseases, such as myopic macular degeneration (MMD), retinal detachment (RD), cataract, and open angle glaucoma (OAG) [1]. The likelihood of developing complications related to myopia increases with the severity of myopia. According to Haarman et al., the odds of those with high myopia developing MMD, RD, cataract, and OAG are 845.1-, 12.6-, 2.9–4.6-, and 2.9-fold higher, respectively, than those without myopia [1].

Children who develop myopia at an early age are particularly vulnerable because they are exposed to the condition for a longer duration, experience rapid myopia progression more quickly, and face an increased risk of developing severe myopia. Despite various education and healthcare reforms and other initiatives that China has introduced in recent years, the effectiveness of these strategies may require some time to become evident. Therefore, the objective of this study is to comprehensively examine the epidemiology of childhood myopia in China, and to discuss the challenges and strategies for the prevention and control of myopia among Chinese children.

ASPECTS OF THE CURRENT TREND OF CHILDHOOD MYOPIA EPIDEMIC IN CHINA

In this review, myopia is defined as the spherical equivalent of ≤ −0.50 D. The gold standard for detecting myopia requires cycloplegia, which involves relaxing the accommodation of the eyes. While non-cycloplegic measurements may lead to an overestimation of myopia prevalence [2], such measurements have been commonly used in school-based myopia screening. In a study conducted in Shandong, Hu and colleagues identified a difference in refractive error, reported by these authors as a mean difference of 0.78 D, between the results obtained through cycloplegic and non-cycloplegic autorefraction, in a sample of 5999 children aged 4–18 years [3].

In the present review, in order to draw conclusions from different studies, we used primarily the results of age-specific and cycloplegic measurements; non-cycloplegia results were noted otherwise.

This article is based on previously conducted studies and does not contain any studies with human participants or animals performed by any of the authors.

Change in Prevalence Over Time

Over the last two decades, there has been a gradual increase in the prevalence of childhood myopia in China. Figure 1 shows a comparison of age-specific myopia prevalence over time for children aged 6–12 years. In the Chinese education system, children typically begin primary school around the age of 6 or 7 years and complete it around the age of 11 or 12 years. Figure 1 shows that for 6-year-olds, the myopia prevalence has remained relatively stable, with rates of 5.9% in Guangzhou in 2002 [4], 3.9% in Anyang in 2012 [5], and 5.6% in Shanghai in 2013 [6]. In contrast, the prevalence of myopia among 12-year-olds in Guangzhou was 49.7% in 2002, as reported by He et al. [4]; by 2014, it had reportedly reached 65.8% [7]. In 2012, Li et al. found a notable increase in myopia prevalence in Anyang, a second-tier city

situated in Northern China, resulting in its alignment with the prevalence of myopia in other major cities; among 12-year-olds, the prevalence had surged to 67.3% in 2012 [5].

The prevalence of high myopia has remained low in children over the years. In 1012, Li et al. found that the prevalence of high myopia in Anyang was only 0.1% in 6-year-olds and 2.7% in 12-year-olds [5]. Similarly, Guo et al. reported that in Guangzhou in 2015, only 1.8% of primary and middle school students had high myopia [7]. A meta-analysis of studies from 1998 to 2016 indicated that high myopia affected 3.1% of Chinese children [8]. Tang et al. reported a comparable prevalence of 2.8% [9]. A contributing factor to the low prevalence of high myopia in childhood is the definition of high myopia itself, which requires a refractive error of ≥ −6.00 D, a level that may take several years for a myopic child to reach. Therefore, monitoring the progression of myopia in children, particularly those who exhibit rapid deterioration, is crucial.

Impact of COVID-19

In December 2019, the Coronavirus Disease 2019 (COVID-19) outbreak necessitated nationwide closure of schools, which persisted until May 2020 but subsequently re-introduced temporarily until December 2022. During the lockdown period, students were placed under strict stay-at-home measures. Table 1 provides a concise overview of various studies that have examined the effects of the COVID-19 lockdown on the development and progression of myopia in Chinese children. These studies, which include both cycloplegic and non-cycloplegic assessments, consistently indicate a significant increase in myopia rates during the lockdown, which the authors attribute to abrupt environmental changes [10–15]. Research conducted by Wang's team in Feicheng (non-cycloplegic) and Zhang's team in Hong Kong (cycloplegic) extended their analysis beyond the lockdown period, as depicted in Fig. 2 [16, 17]. Wang et al. observed a return to pre-pandemic myopia levels, in contrast to the findings of Zhang et al. [16, 17]. For a more thorough understanding of the long-term impacts, future research should consider including more cycloplegic data, as these measurements provide more precise and consistent information on the trends in myopia over time.

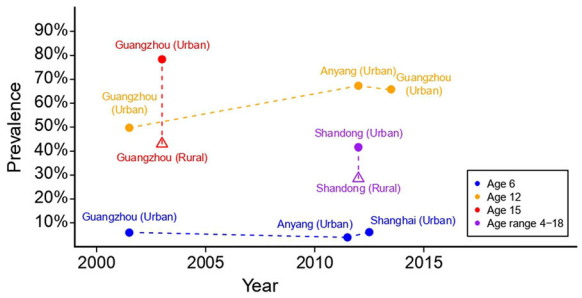

Fig. 1 Reported prevalence of childhood myopia based on cycloplegic refraction over time in China. Solid circles indicate prevalence of myopia in urban area; open triangles indicate myopia prevalence in rural areas. Prevalence of myopia in 6-year-olds (in blue) is stable over time, and prevalence of myopia in 12-year-olds (in orange) increases gradually over time. Myopia prevalence differs among urban and rural areas (in red and purple, respectively)

Myopia Prevalence in Hong Kong and Taiwan Areas

Hong Kong and Taiwan experienced an outbreak of childhood myopia earlier than mainland China. As early as 2004, the prevalence of myopia (cycloplegic) among 5- and 6-year-old primary school students in Hong Kong was already 17% [18]. The Hong Kong Children Eye Study revealed that myopia rates among Hong Kong's children remained consistently high over time, as depicted in Fig. 2 [17, 19]. A similar trend was observed in Taiwan, where a review by Tsai et al. examined population-based myopia surveys (cycloplegic) from 1983 to 2017 [20]. These authors noted a rapid increase in myopia prevalence, with the weighted prevalence in 7-year-olds increasing from 5.37% in 1983 to 25.4% in 2017 [20].

Table 1 Published results of research on the impact of Coronavirus Disease 2019 (COVID-19) lockdown on myopia in students

Author	Sample size (*n*)	Age	Cycloplegia	Time interval	Prevalence before lockdown	Prevalence during lockdown	Conclusions
Chang et al. [10]	29,719	10-year-old students	No	09/2019–05/2020	53.2% overall	73.7% overall	Accelerated myopic progression during the COVID-19 pandemic lockdown in children and teenagers
Xu el at. [11]	1,001,749	7- to 18-year-old students	No	12/2019–06/2020	34.4% in elementary school students	42.8% in elementary school students	COVID-19 quarantine was a risk factor for the progression and incidence of myopia
Hu et al. [12]	1472	Grade 3 primary school students	Yes	11/2019–12/2020	13.3%	20.8%	Development of myopia increased during the COVID-19 outbreak period in young schoolchildren in China
Wang et al. [13]	1728	Primary school students	No	10/2019–06/2020	28%	39%	Increased digital screen exposure contributes to myopic progression in children and adolescents of Chongqing during the COVID-19 pandemic
Ma et al. [14]	208	8- to 10-year-old students	Yes	01/2020–08/2020	58.7%	85.6%	Children were at risk of myopia progression during the COVID-19 pandemic study at home than 7 months before the outbreak
Zhang et al. [15]	1084	6- to 8-year-old students	Yes	12/2019–08/2020	19.0%	35.3%	Increase in myopia incidence, significant decrease in outdoor time and increase in screen time among schoolchildren in Hong Kong during the COVID-19 pandemic

COVID-19 Coronavirus Disease 2019

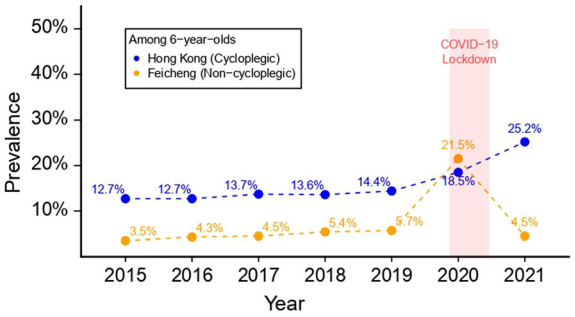

Fig. 2 Prevalence of myopia among 6-year-olds before, during, and after the Coronavirus Disease 2019 (COVID-19) outbreak: Feicheng (in orange), without cycloplegia, showed a huge spike of myopia prevalence during the COVID-19 lockdown, but returned to pre-pandemic levels in 2021. Hong Kong (in blue), with cycloplegia, also showed a significant increase in prevalence during the lockdown; however, the trend continued in 2021

LESSONS FROM EPIDEMIOLOGICAL STUDIES

Myopia occurs when the image of a distant object cannot be properly focused on the photoreceptors of the eyes, but rather focuses in front of them [21]. In the 1960s, it was widely believed that myopia was primarily caused by genetic factors, with only minor environmental influences [21]. At that time, the overall prevalence of myopia in the Chinese population was estimated to be between 10% and 20% [22].

However, genetic factors alone cannot account for the dramatic increase in myopia prevalence within several decades. The myopia prevalence was > 80% among 18-year-olds in Shandong in 2012 [3]. Over the years, numerous epidemiological studies have suggested that environmental factors may be the primary driver of the escalating myopia epidemic [23, 24]. Notably, there are distinct differences in the prevalence of myopia between rural and urban areas in China (Fig. 1). For example, in 2002, the myopia prevalence among 15-year-old urban students in Guangzhou was remarkably high, at 78.4% [4], while the prevalence among their rural counterparts in Guangzhou stood at 43.0% in that same year [25]. Similarly, among students aged 4–18 years in Shandong in 2012, the prevalence of myopia was 41.6% for urban students and 28.6% for their rural counterparts [3]. These disparities in myopia rates between urban and rural areas emphasize the significant role that environmental factors play in the development of myopia.

Environmental Risk Factors

Morgan et al. extensively discussed the role and significance of various environmental factors associated with myopia [24]. Among these factors, education and inadequate time spent outdoors are the two major risk factors for school-related myopia, with a causal relationship between these factors and the development of myopia [24].

An interesting historical perspective is that the prevalence of myopia was relatively low during the "Cultural Revolution" in the 1960s, when there was minimal formal education. However, after the resumption of the education system and the introduction of the college entrance exam (*Gaokao*) in 1977, the prevalence of myopia quickly caught up with that of more developed regions in East Asia [23, 24, 26, 27]. In epidemiological studies on myopia, it is frequently observed that at a specific location and time, the prevalence of myopia among students tends to increase with the number of years of education they receive [3, 28]. While the age and grade level of students are highly correlated, it is the duration of exposure to education that appears to determine the myopic shift. In a study conducted by Ding et al. in which they compared the cycloplegic refraction of students in the same grade but with different ages, no statistically significant differences were found in the spherical equivalent or myopia prevalence [28]. Additionally, regions with greater and earlier educational pressures on children tend to have a higher prevalence of myopia and an earlier age of onset, as exemplified by Hong Kong [29]. Mountjoy et al. also proved that more years spent in education is a causal risk factor for myopia using Mendelian randomization method [30]. These findings highlight the significant impact of educational intensity and duration on the development and prevalence of myopia.

Time spent outdoors is indicated to prevent myopia in multiple previous epidemiological studies [31, 32]. For example, in a randomized clinical trial conducted by He et al., students in grade 1 who engaged in an additional 40 min of outdoor activities after school showed a significantly lower 3-year cumulative incidence of myopia compared to those who did not (30.4% vs. 39.5%) [31]. Further, the Shanghai Time Outside to Reduce Myopia trial (STORM) study also corroborated these findings by revealing that students with more outdoor exposure had a lower onset of myopia [32]. However, the protective effect of spending time outdoors in terms of slowing down the progression of refractive error among students who were already myopic is somewhat mixed. A randomized trial conducted in Taiwan from 2013 to 2015 revealed a significant reduction in myopia progression among myopic students who spent more time outdoors [33]. Conversely, the results from the STORM study suggested a null effect on myopic students [32]. A plausible explanation might be that the dose effect of outdoor time is weaker among those who are already myopic compared with those who are on the verge of becoming myopic.

Further, since there has been a notable increase in the use of digital devices in the last decade [34], there has been another speculation that digital devices might be a contributing risk factor for myopia. However, it should be pointed out that myopia was already on the rise in China before the widespread adoption of computers and smartphones. It appears that the increase near-work time induced by using digital devices might be the underlying factor. A supporting finding is that during the COVID-19 lockdown, young students experienced a significant increase in screen time, with a few reports indicating an increase of 2- to 10-fold compared to pre-pandemic levels [14, 35, 36]. However, the impact of screen time on myopia was mixed. Lanca et al. reviewed 15 studies, among which approximately half (7 out of 15) found an association between screen time and myopia [34]. It is worthwhile to note that factors such as education and screen time often compete with outdoor time. When children spend more time on homework or digital screens, they have less time available for outdoor activities. Further research is still required to comprehensively understand the relative dose effect between near-work and outdoor time.

CHALLENGES AND STRATEGIES RELATED TO MYOPIA PREVENTION AND CONTROL

In 2018, the Chinese government took a significant step by announcing a comprehensive implementation plan for the prevention and control of myopia in children and adolescents. This plan included directives for schools to reduce homework loads and ensure that students engage in at least 90 min of outdoor activities each day [37]. In 2021, the government made further attempts to alleviate students' educational burdens by implementing the "Double Reduction" policy, which aimed to reduce homework and after-school tutoring [26]. However, despite these government efforts, there remain numerous challenges in the area of myopia prevention and control. These challenges may include issues related to the effective implementation of policies, the persistence of cultural and societal factors that contribute to myopia, and the need for ongoing research to develop and refine strategies for myopia management. Addressing these challenges requires a multifaceted approach and continued commitment to finding effective solutions to the growing myopia problem among children and adolescents.

Nationwide Myopia Screenings

In the myopia comprehensive implementation plan, schools are mandated to perform myopia screenings twice annually [37]. This approach, outlined in the "Children and Adolescents Myopia Survey" (CAMS) by Xu et al. and known as the Wenzhou screening method, has gained widespread adoption in China [38]. The process typically involves qualified nurses, optometrists, and ophthalmologists from local hospitals conducting on-site visual acuity and non-

cycloplegic refractive error assessments at schools. Given that the primary responsible parties are the government's education bureau and the schools themselves, student participation rates are remarkably high, with Wenzhou city reporting a 99.37% participation rate [38]. While non-cycloplegic refractive error measurements may overestimate myopia prevalence, they are effective for screening purposes, successfully identifying most myopic students. However, areas such as information systems, cost management, and the referral process still require improvements [26].

Education

China's history includes an imperial examination system during Imperial China dynasties, which lasted over a millennium and was the primary means for individuals to become bureaucrats through written examinations, without consideration of their social status at birth [39]. The contemporary equivalent of this system is the university entrance examination, known as *Gaokao*. Among China's vast general population, *Gaokao* is widely viewed as the fairest pathway to achieving social and economic success for an individual [40]. Consequently, the pressure for any individual to succeed in their educational endeavors is felt from the high school level through to middle school, primary school, and even at the preschool levels

In order to secure a spot in a prestigious college, students often need to attend high-quality high schools; the same applies to middle schools, primary schools, and even preschools. Stereotypical Chinese parents, influenced by these expectations, often have high aspirations for their children's academic achievements and frequently enroll them in cram schools, typically held after regular school hours and on weekends [41, 42].

With the implementation of the "Double Reduction" policy, private tutoring companies are prohibited from providing primary, middle, and high school curriculum-related subjects (except physical education) for profit [26]. However, the demand for tutoring services from parents may not decrease significantly. It will take time to assess whether this policy has had the intended effects and whether it has alleviated the education-related pressures on students and families as intended.

Increasing Time Spent Outdoors

The effectiveness of mainland China's "Double Reduction" policy is yet to be confirmed. One expectation of mainland China's "Double Reduction" policy is potentially allowing more outdoor time for children. After years of an increasing trend of myopia in Taiwan, the "Tian-Tian 120" initiative, introduced in 2010, has significantly reduced myopia prevalence by promoting 120 min of daily outdoor activity at school and home [43]. This led to a decline in myopia prevalence among primary school students from 50.0% in 2010 to 46.1% in 2015 [43]. Similarly, the Yilan Myopia Prevention and Vision Improvement Program (YMVIP), which extended this approach to preschoolers, saw a decrease in myopia prevalence from 15.5% in 2014 to a stable range of 8.5% to 10.3% between 2016 and 2020 [44].

Despite the political systems of Taiwan and mainland China being distinctly different, the "Double Reduction" policy may slow the trend in increasing myopia prevalence or even reduce myopia prevalence, similar to the results of the "Tian-Tian 120" initiative and "YMVIP" program. Taiwan and mainland China share a strong cultural connection and similar attitudes towards education, characterized by high expectations for educational outcomes and extensive use of tutorials [20, 29]. According to Tsai et al., Taiwan faced a similar challenge in childhood myopia epidemic due to increased time spent in near-work [20]. Thus, full implementation of the "Double Reduction" policy may free students from long time near-work and allow them more time outdoors.

Awareness

Parents are crucial in fostering success in the initiative to promote outdoor activities and reduce near-work, as they significantly

influence the their children's behaviors. According to Xu et al., children's physical activity levels and sedentary behaviors are critically shaped by parents' role modeling, particularly in their early years of life [45]. In other words, parents' awareness to take children for outdoor activities or to study at home may greatly impact children's myopic status. Understanding parents' awareness is crucial for the development and progression of myopia in children. However, it is concerning that many parents are likely not familiar with the potential consequences of myopia. A cross-sectional survey conducted in 2021 that involved 2500 parents nationwide found that 70% of respondents were not aware of pathological changes related to myopia [46]. Interestingly, those who believed myopia could be prevented or controlled were more likely to take preventive measures [46].

A common phenomenon in rural areas of China is "left-behind children," i.e., children left in the care of grandparents or other relatives when their parents leave the area to work in cities as migrant workers. In 2016, it was estimated that there were 61 million left-behind children, approximately 22% of the country's child population [47]. This number had increased to 69.7 million in 2018 [48]. A review published in 2020 highlighted that left-behind children are more susceptible to parental neglect [49]. While research on the effects of parental migration on myopia among left-behind children is limited, Du et al. reported that the myopia correction rate was lower in the left-behind children [48], suggesting a potential neglect or lack of awareness of their myopia condition. Further, in a randomized clinical trial conducted in 2018, Li et al. demonstrated that sending school-based myopia health education messages to parents on a weekly basis through social media could effectively improve the latter's awareness [50]. This approach may serve as a valuable method for enhancing parents' awareness and attitudes toward their children's myopia status, including left-behind children, and finally may lead to the effective prevention and control of myopia.

Cost of Interventions

Despite numerous studies that have demonstrated the effectiveness of various interventions, such as orthokeratology lenses, peripheral defocus modifying spectacles, and low-dose atropine, in controlling myopia more effectively than single-vision spectacles [51], the most commonly prescribed intervention for myopia in China at the present time remains single-vision spectacles. Research conducted on children's myopia correction patterns on the east coast of China revealed that a significant majority of children, specifically 88% of the sampled children, were using single-vision spectacles as their primary correction method [52].

Cost considerations appear to be a significant factor influencing the choice of myopia control interventions in China. For example, in China, the mean annual cost of orthokeratology can be considerably higher, ranging from 19- to 24-fold higher, than the mean annual cost of single-vision spectacles [53]. Additionally, low-dose atropine is currently not yet approved for myopia control by the China Food and Drug Administration (CFDA), which leads many parents to seek it from sources outside of mainland China or through the off-label "hospital's internal medicine" channel [54]. The cost of 0.01% atropine from Sinqi Pharmaceutical Co., Ltd. can reach ¥3600 annually (a Chinese pharmaceutical company branded atropine as "hospital's internal medicine") [55].

It is noteworthy that even though single-vision spectacles may appear to be the more affordable option upfront, a simulation of the lifetime cost of different myopia control approaches suggests that single-vision spectacles may not necessarily be the cheapest option in the long run. According to research by Fricke et al., when potential myopia progression, pathological consequences, and other costs are taken into consideration, both low-dose atropine and peripheral defocus modifying spectacles are cheaper than single-vision spectacles in China [56].

It is encouraging to see efforts being made to reduce the cost and improve the accessibility of effective myopia control interventions in

China. In May 2023, the CFDA took the step of moving the clinical trial for 0.01% atropine to a priority evaluation and approval process, which could potentially lead to its availability and, thereafter, reduce its overall cost [57]. In June 2023, the Hebei Provincial Ministry of Health initiated the measure to place a price ceiling on the orthokeratology sold in public hospitals through "centralized purchasing" [58]. Thereafter, 15 other provinces joined the initiative [59]. Consequently, a few orthokeratology products are now available at prices as low as 50% of the original price, which can significantly reduce the financial burden on families seeking to use orthokeratology as a myopia control method [59]. These actions demonstrate a commitment to making effective myopia control interventions more affordable and accessible to a wider population.

The World Health Organization (WHO) launched the SPECS 2030 initiative, which aims to reduce the uncorrected refractive error in children and adults globally [60]. The specific strategies include "improve access to refractive services," "build capacity of personnel to provide refractive services," "improve population education," "reduce the cost of refractive services," and "strengthen surveillance and research [60]. The strategies outlined in this article and China's comprehensive implementation plan for the prevention and control of myopia comply with the WHO SPECS 2030 initiative.

CONCLUSION

In summary, China faces an ongoing incremental and severe childhood myopia epidemic. The major risk factors include near-work and outdoor time. China's government and the general population are endeavoring to cope with these challenges through education reforms, improving parents' awareness and lowering the cost of approved interventions. These measurements may take time to show their effects and, irrespective of whether they are successful or unsuccessful, the results will certainly pave the way for myopia prevention and control at a global level.

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Declarations

Conflict of Interest. Wei Pan and Weizhong Lan have nothing to disclose.

Ethical Approval. This article is based on previously conducted studies and does not contain any studies with human participants or animals performed by any of the authors.

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