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Epidemiological Status of Myopia: A Global Public Health Challenge

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Abstract. Myopia has emerged as a critical global public health challenge in the 21st century, with its prevalence escalating and exhibiting significant regional heterogeneity. By 2050, it is projected to affect half of the world's population. Pathological complications of high myopia—such as retinal detachment and choroidal neovascularization—substantially increase the risk of blindness, exacerbating socioeconomic burdens. The development of myopia results from complex interactions among genetic, environmental, and behavioral factors. Genome-wide association studies (GWAS) have identified over 200 associated genetic loci, while environmental drivers—including digital lifestyles, intensive education, and insufficient outdoor activity—have fueled a dramatic surge in myopia prevalence over the past three decades. Current interventions, such as low-concentration atropine eye drops, orthokeratology lenses, and outdoor light exposure, partially slow progression but face limitations like poor adherence and rebound effects. Emerging technologies like VR show promise in simulating defocus states and regulating axial elongation, though their safety and efficacy require further validation. Moreover, large-scale epidemiological surveys have demonstrated that the burden of myopia extends beyond ophthalmology, significantly impacting education systems, workforce readiness, and national healthcare expenditures. For instance, the United States spends approximately 7.5 billion USD annually on direct medical costs related to myopia, while in several Asian countries, corrective interventions for school-aged children account for 12–18% of household healthcare expenditure. Future strategies must integrate multimodal approaches, leveraging artificial intelligence, biometric monitoring, and personalized interventions to establish a comprehensive system for scientific prevention, precise correction, and dynamic monitoring. This is essential to counter the trends of early-onset and high myopia in youth and ultimately achieve universal vision health.

Keywords: tmyopia, epidemiology, genetic factors, environmental factors, prevention technology

1. Introduction

Myopia has increasingly shifted from being a refractive disorder to a multidimensional public health crisis. According to the World Health Organization, the global prevalence of myopia rose from 22.9% in 2000 to 33.6% in 2020, with projections suggesting that nearly 49.8% of the global

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population will be affected by 2050, including 9.8% with high myopia. The geographical distribution is highly uneven: East Asian countries report prevalence exceeding 80% among adolescents, with Singaporean data showing 82.2% prevalence in 15-year-olds, while Western populations still show lower baseline levels (30–40%) but have exhibited an annual growth rate of 1.4–2.5%. Particularly alarming is the trend toward earlier onset, with the detection rate of myopia in Chinese children aged 6 rising from 5.7% in 2019 to 14.3% in 2021.

The socioeconomic burden is equally concerning. High myopia not only elevates the risk of retinal detachment and macular degeneration by 10–20 times but also undermines talent selection in critical industries. For example, the proportion of South Korean military flight cadet candidates disqualified for visual reasons increased from 25.3% in 2001 to 42.1% in 2019. This indicates that the impact of myopia extends into national security, workforce competitiveness, and social productivity.

Modern lifestyles exacerbate the problem. Genome-wide association studies (GWAS) have identified over 200 susceptibility loci, such as GJD2 and RASGRF1, explaining 12–18% of refractive variance. However, dramatic increases in near-work exposure, digital device use, and intensive educational pressures over the past three decades are considered the principal drivers of the global surge in prevalence. In East Asian countries, students devote 15.2 more study hours per week compared to the OECD average, correlating significantly with higher regional myopia prevalence ($r = 0.78$, $p < 0.01$).

Thus, understanding the interplay between genetic, environmental, and behavioral factors is crucial for developing effective prevention and control strategies. This review provides a comprehensive analysis of the epidemiological status, pathogenesis, current prevention technologies, research challenges, and future perspectives in myopia research, aiming to offer a holistic framework for public health action.

2. Epidemiological status of myopia

2.1. Global prevalence and trends

The global myopic population is projected to increase from 1.406 billion in 2000 to 4.758 billion (49.8% of the world population) by 2050, affecting individuals aged 10–79 years [1]. Among these, the number of high myopia cases will reach approximately 938 million (9.8% of the global population) [2]. This indicates a significant upward trend, establishing myopia as a widespread public health issue [3]. The magnitude of this growth underscores a “myopia epidemic” that is expanding beyond traditional high-risk regions into parts of Africa and South America, where prevalence was historically low but is now steadily climbing due to urbanization and lifestyle transitions.

Regional disparities are pronounced, with prevalence rates in Asian countries ranging between 70%–90%, compared to 30%–40% in the United States and Europe [4]. East Asia reports the highest rates among children and adolescents, with China projected to reach 84% by 2050, while the global average for this demographic will approach 50% [5].Alarmingly, studies have confirmed that myopia onset is occurring at younger ages, with children developing myopia as early as 5–6 years old. Earlier onset is strongly correlated with higher risk of progression to pathological myopia, highlighting the urgency of early interventions.

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2.2. Influencing factors of myopia epidemic

2.2.1. Genetic factors

Genetic factors play a pivotal role in myopia development [6]. Children with two myopic parents face significantly elevated risks. Environmental influences on refractive development are also modulated by genetic background [4]. High myopia follows monogenic inheritance patterns, predominantly autosomal recessive. Multiple genes associated with myopia (e.g., GJD2, RASGRF1) and high myopia (e.g., TNFRSF21, CTSH, CCDC111, NDUFAF7) have been identified, explaining 12–18% of refractive variance [3]. Recent advances in next-generation sequencing have further revealed novel genetic variants that regulate scleral extracellular matrix remodeling and retinal signaling, providing new mechanistic insights. However, genetics alone cannot explain the rapid rise in prevalence over recent decades, underscoring the decisive role of environmental and lifestyle factors.

2.2.2. Near work activities

Prolonged near work (e.g., reading, digital device use, writing) accelerates myopia progression [5]. For example, university students exhibit accelerated myopia due to extensive reading and screen time [7]. Cumulative near-work duration in childhood correlates positively with adult high myopia incidence [2,5], likely due to axial elongation induced by sustained ocular strain [6]. In particular, studies have shown that each additional hour of daily near work during childhood is associated with a 2% increase in the risk of developing high myopia in adulthood. Furthermore, shorter rest intervals between near tasks amplify accommodative stress, exacerbating axial elongation.

2.2.3. Outdoor activity

Urbanized regions show higher myopia rates than rural areas, partly attributed to reduced outdoor exposure. Increased outdoor time significantly inhibits myopia onset and axial elongation in children [5], with each additional hour per week reducing incidence by 2% [7]. Natural light stimulates dopamine release [4], promoting retinal development and inducing myopic defocus. However, outdoor activity primarily relieves eye strain in adults without curbing progression [3]. Emerging evidence suggests that spectral quality of light, particularly violet light (360–400 nm), may play a crucial role in regulating ocular growth. Clinical trials have also shown that structured outdoor programs in schools can reduce the incidence of myopia by up to 50%.

2.2.4. Dietary structure and habits

Diet significantly influences myopia. Myopic individuals consume higher daily amounts of carbohydrates, folate, sugar, and copper, while non-myopic groups intake more iron and calcium [8]. Low consumption of liver and carrots (rich in retinol) and high sugar intake correlate with higher myopia incidence. Deficiencies in trace elements (e.g., selenium, zinc, chromium) are also implicated [9]. Nutritional studies further suggest that omega-3 fatty acids and antioxidants may have protective effects on retinal function, while high glycemic index diets may accelerate axial elongation. These findings highlight diet as a modifiable risk factor that could complement behavioral interventions.

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3. Pathogenesis of myopia

3.1. Biological basis

3.1.1. Axial elongation

Axial elongation is a key biological basis for myopia. Compensatory eye growth occurs when light fails to focus precisely on the retina [9]. In adults ≥25 years, every 0.24 mm increase in axial length corresponds to a −0.77 D refractive shift. Axial growth remains a critical factor for myopia progression even in adulthood [7]. This relationship is consistent across diverse populations, indicating a universal biological mechanism. Moreover, longitudinal studies among medical students and young professionals have shown continuous axial elongation well into adulthood, suggesting that myopia progression is not limited to childhood but extends across the lifespan.

3.1.2. Scleral pathological changes

Scleral thinning and biomechanical weakening drive myopia. Hypoxia triggers collagen reduction and extracellular matrix (ECM) remodeling [3]. Single-cell RNA sequencing implicates the HIF-1α signaling pathway in regulating scleral ECM reorganization. Choroidal thinning in high myopia reduces blood perfusion, exacerbating scleral hypoxia and collagen degradation [5]. These changes create a vicious cycle: hypoxia weakens scleral resistance, leading to further elongation, which in turn exacerbates hypoxic stress. Animal studies have confirmed that inhibiting HIF-1α signaling can mitigate scleral remodeling, offering potential therapeutic targets.

3.2. Gene-environment interactions

Myopia arises from interactions between genetic susceptibility and environmental triggers [4]. The scleral HIF-1α pathway may mediate these interactions by modulating ECM remodeling and oxygen homeostasis. While genetics are nonmodifiable, environmental interventions—controlled near work, balanced nutrition, >2 hours/day outdoors, and adequate sleep—effectively delay onset and progression [5]. This paradigm emphasizes that myopia should not be regarded solely as a hereditary disease, but as a complex phenotype shaped by modifiable exposures. Preventive strategies that target these exposures have the potential to delay onset, reduce progression, and ultimately decrease the burden of high myopia in later life.

4. Current prevention technologies and advances

4.1. Clinical interventions

4.1.1. Atropine eye drops

Low-concentration atropine (0.01%) demonstrates optimal efficacy in slowing myopia progression while minimizing side effects like pupil dilation (average 0.8 mm) and accommodative loss (2–3 D) [2]. Combined with orthokeratology, it enhances axial length control but faces challenges such as photophobia (15% incidence) and rebound effects post-discontinuation [6,9]. Recent randomized controlled trials have shown that combination therapy of low-dose atropine with optical interventions provides additive benefits. However, compliance and long-term safety remain major barriers, with concerns about allergic conjunctivitis and systemic anticholinergic effects.

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4.1.2. Spectacle lenses

Peripheral defocus spectacles create asymmetric optical zones to reduce retinal hyperopic defocus. Progressive addition lenses (PALs) show modest efficacy but are limited to controlling progression rather than treating myopia [6,9]. Recent advances include novel multifocal lenses that redistribute peripheral light more effectively, leading to greater reductions in axial elongation compared to traditional PALs. Clinical adoption is growing, though accessibility and cost remain limiting factors in low-resource settings.

4.2. Outdoor activity

Daily ≥2 hours of outdoor exposure reduces childhood myopia incidence by 33% via dopamine-mediated mechanisms. The protective effect is dose-dependent, with each additional 40 minutes lowering risk by 9.1% [3,5,6]. Longitudinal school-based trials in China and Australia have provided strong evidence for the efficacy of outdoor programs, with observed reductions in both incidence and progression rates. Importantly, such programs are low-cost, culturally adaptable, and sustainable, making them one of the most promising large-scale preventive strategies.

4.3. Surgical interventions

4.3.1. Corneal refractive surgery

SMILE and FS-LASIK are mainstream but unsuitable for high myopia with thin corneas due to risks of ectasia and dry eye [3]. Comparative studies indicate that SMILE may preserve corneal biomechanics better than LASIK, reducing the risk of postoperative complications. However, both procedures are refractive corrections rather than preventive measures, and neither halts axial elongation.

4.3.2. Phakic IOL implantation

Posterior-chamber IOLs correct up to −30.00 D but lack astigmatism correction [3]. They remain an essential option for patients with ultra-high myopia ineligible for corneal surgery, although long-term safety profiles require ongoing surveillance.

4.3.3. Posterior scleral reinforcement

This is the only method to mechanically restrain axial elongation, showing promise in pediatric pathological myopia [3]. Modified surgical techniques using allogenic or xenogenic grafts have demonstrated improved outcomes with reduced complication rates, offering a valuable approach for progressive pathological myopia.

5. Research challenges and limitations

Adult myopia risk factors and intervention outcomes remain understudied due to recruitment difficulties [7]. Existing methods primarily slow progression rather than reduce incidence, highlighting the need for innovative solutions [6]. Moreover, adherence to behavioral interventions such as reduced screen time or increased outdoor exposure is limited by sociocultural and

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educational pressures, particularly in East Asia where academic intensity is exceptionally high. This suggests that preventive strategies must be integrated into broader educational and social reforms.

6. Future perspectives

Myopia, as the most common ocular disorder, typically begins to manifest in children aged 6 to 12 years. In recent years, based on the peripheral defocus hypothesis and the light exposure hypothesis, experts have proposed that virtual reality (VR) technology may serve as a novel approach for myopia prevention and control [10]. Studies have shown that VR can effectively simulate a near-peripheral defocus state, thereby regulating axial elongation. At the same time, VR-based ciliary muscle training helps alleviate accommodative spasm, relieve visual fatigue, and consequently slow the progression of myopia. Notably, a significant increase in choroidal thickness has been observed after wearing VR devices—a finding of great importance, as the choroid, serving as the intermediary tissue between the retina and sclera, directly reflects changes in ocular growth signaling pathways. This thickening phenomenon, occurring after myopic defocus, suggests reduced ocular growth and indicates a degree of control over myopia progression. In addition, research has found that blue light stimulation delivered by VR devices may exert certain beneficial effects on myopia improvement.

Despite its theoretical potential in myopia prevention, VR technology still faces evident limitations. Current VR devices generally suffer from low resolution and restricted visual fields, and excessive use may even accelerate myopia progression in adolescents. Experimental data indicate that after 30 minutes of VR use, children with myopia exhibit impaired stereopsis and a marked deterioration in binocular balance. Therefore, before VR can be applied in practical myopia prevention, further research is required to assess its impact on visual function in children and to establish scientific guidelines for safe usage.

In the therapeutic domain, VR-based visual training demonstrates multiple advantages: it not only promotes visual neuroplasticity, improves binocular stereopsis and visual acuity, and repairs functional deficits, but also delays myopia progression through ciliary muscle training and choroidal thickening, thus opening new avenues for the treatment of ocular diseases. In terms of surgical simulation, current VR simulators are mainly focused on cataract surgery training, whereas simulations for glaucoma, retinal surgery, and other ophthalmic procedures remain underdeveloped. There is an urgent need to expand simulator types to meet the growing demands of clinical education.

Nevertheless, the development of VR technology continues to face challenges. The display quality and computational power of head-mounted displays (HMDs) limit the precision of virtual-to-real environment simulation, which hinders widespread clinical application. Future directions require large-scale, high-quality, and multicenter studies to drive continuous innovation in VR technology, thereby fully harnessing its potential in both myopia prevention and ophthalmic healthcare.

7. Conclusion

As a global public health concern, myopia has become a vision-threatening disease that cannot be ignored. Although its etiology and pathogenesis have not yet been fully elucidated, it is widely recognized that the interaction between genetic predisposition and environmental factors constitutes the primary basis of its development. Against an immutable genetic background, environmental interventions remain the cornerstone of prevention: establishing proper visual habits, ensuring more than two hours of outdoor light exposure daily, maintaining balanced nutrition, and optimizing sleep

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quality can all effectively prevent or delay the onset of myopia. In clinical practice, it is recommended to establish refractive development records for children, implement regular follow-up examinations, and strengthen school–family collaboration in eye health education, thereby creating an integrated prevention system emphasizing early screening and timely intervention.

At present, most preventive strategies focus on slowing the progression of myopia, such as the application of low-dose atropine eye drops and optical correction methods, but there is still a lack of core approaches that can significantly reduce incidence rates. It is important to note that myopia is influenced by multidimensional risk factors. Beyond the well-established ones, emerging contributors such as prolonged electronic device use, disrupted sleep rhythms, and imbalanced dietary patterns warrant clarification through large-scale epidemiological studies. Special attention should also be given to the impact of parental refractive errors on offspring and the potential link between childhood obesity and myopia development.

In China, myopia prevention and control among children and adolescents continues to face severe challenges. While existing measures can slow progression, they have not effectively curbed the rise in new cases. This underscores the need for ongoing innovative research to integrate biometric monitoring technologies, artificial intelligence–based predictive models, and personalized intervention strategies. Ultimately, the establishment of a comprehensive system encompassing scientific prevention, precise correction, and dynamic monitoring will provide a reliable foundation for achieving universal vision health.

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