



## Contemporary Strategies for Myopia Control in the Pediatric Population: A Narrative Review of Lifestyle, Pharmacological, and Optical Interventions

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### ABSTRACT

Myopia, or near-sightedness, is a prevalent refractive error characterized by the convergence of parallel light rays anterior to the retina, leading to blurred distance vision. The refractive error development involves a complex interplay between optical components and eyeball anatomy, with both genetic predisposition and environmental influences contributing to its onset and progression. The global prevalence of myopia in children and adolescents has risen markedly in recent decades, driven by reduced outdoor activity, prolonged near work, and increased screen exposure. This trend poses a growing public health concern, given the associated risk of sight-threatening complications. This narrative review synthesizes current evidence on lifestyle, pharmacological, and optical interventions for controlling myopia progression in the pediatric population. Lifestyle modifications, particularly increased outdoor exposure, have demonstrated protective effects. Pharmacological approaches, most notably low-dose atropine, have shown dose-dependent efficacy in slowing myopia progression, with an acceptable safety profile. Optical strategies, such as orthokeratology, repeated low-level red-light therapy, and diffusion optics technology lenses, target peripheral defocus and choroidal changes to mitigate axial elongation in subjects with myopia. The myopia control and prevention strategies are economically viable interventions that are both safe and effective, as demonstrated in the existing medical literature. Overall, a multimodal, individualized strategy combining behavioral, pharmacological, and optical measures offers the most promise in reducing the burden of myopia in children. Future research should prioritize long-term safety, optimal treatment combinations, and strategies to enhance adherence to the suggested myopia control interventions.

### 1. INTRODUCTION

Myopia, also referred to as near-sightedness, is a prevalent refractive error. In myopia, the parallel lights pass through the optic lens in the eye and converge at a focal point within the vitreous body,

in front of the retina. (1) The image formation of a distant object anterior to the retina results in the blurring of vision. (2) The origin of myopia lies in the impaired homeostasis between the focusing

elements (cornea, optical lens, and vitreous humor) and the length and shape of the eyeball. However, the exact etiological mechanisms of myopia remain elusive. (3)

Myopia is a significant public health concern, with the incidence and prevalence increasing considerably across the globe. (4) This can be attributed to a decline in outdoor activities, greater time spent using screens, and longer duration of near-vision work. (5) A recent meta-analysis evaluating the global prevalence of myopia in the pediatric and adolescent population across six continents concluded that the prevalence increased from 24.32% in 1990 to 35.81% in 2023, with a higher proportion of affected individuals living in East Asia. (6) A recent cross-sectional study conducted in Pakistan demonstrated that more than half of the adolescents who participated in the study were diagnosed with myopia. (7) A meta-analysis on the prevalence of myopia in school-going children in India suggested that myopia was reported in 8% of the analyzed population, and was the most common refractive error reported in the population. (8) Additionally, the prevalence of myopia in school-age children residing in the Eastern Mediterranean Region was 5.23% during 2000–2022. (9)

The increasing prevalence of myopia in the pediatric population not only contributes to the growing public health burden but is also associated with a heightened risk of vision-threatening complications. (10) This emphasizes the need for timely and effective interventions, particularly during childhood. Recent research has focused on pharmacological, optical, and behavioral strategies to slow myopia progression. However, there remains a lack of comprehensive synthesis of evidence to guide clinicians in selecting appropriate interventions for the pediatric population. This review aimed to provide an evidence-based overview of current strategies for controlling myopia progression in the pediatric population.

## 2. Pathophysiology and Risk Factors

The development of myopia coincides with the correction of hyperopia. (5) Animal and experimental studies have provided insights into the remodeling of the extracellular matrix and the response of the sclera to the visual stimuli, retino-scleral signaling cascade, and the closed feedback

loop, and the quality of the peripheral retinal images. (3) Moreover, there is substantial evidence suggesting the relationship between the release of retinal dopamine and axial growth. (11) Axial myopia constitutes the most common form of myopia and is characterized by an increase in the axial length. (4) High myopia is diagnosed on the basis of axial length > 26.0–26.5 mm, whereas pathologic myopia is characterized by high myopia plus degenerative macular changes. (12)

Previous studies, including genome-wide association analyses, have indicated an increase in the prevalence of myopia among children with two myopic parents compared to those with one myopic parent. The heritability of myopia is further suggested by similar refractive error in monozygotic twins. (13) The gene-gene and gene-environment interactions may further influence the onset of myopia. For instance, myopia susceptibility gene *APLP2* variants interact with the duration of reading, in relation to refractor error changes. (14) While environmental risk factors play a significant role in the development and progression, myopia is predominantly driven by genetic mechanisms. (15)

The strong correlation between a higher academic level and near-sightedness is explained by the intensive near work. (16) In addition to a longer duration of intensive work, shorter distances are associated with an elevated risk of myopia. Notably, regions with higher education enrolment and greater academic performance attainment have shown a higher prevalence of myopia, compared to relatively lower prevalence in regions with lower academic enrolment. (13,17) Another behavioral factor linked to high myopia prevalence is shorter outdoor activity, suggested by the relation between spending more time doing outdoor activities and reduced risk of myopia. (18) Certain dietary elements may influence the onset and progression of myopia in the pediatric population. High sodium intake has been demonstrated to increase the risk of the onset of myopia. (19) Dietary and metabolic factors that protect against the development of myopia include caffeine, 7-methylxanthine, and insulin. (20,21) The ethnic variations in the prevalence of myopia can be attributed to the differences in the axial length across different populations. South Asian children demonstrated longer axial length and higher myopia prevalence compared to British

children exposed to a similar environment and with similar healthcare-seeking behaviors (22).

### 3. INTERVENTIONS FOR MYOPIA CONTROL

#### 3.1. Lifestyle and Behavioral Interventions

Current evidence, including a survey conducted among Indian health practitioners, demonstrates a shift towards early management and the utilization of evidence-based approaches for myopia control in the pediatric population. (23) Behavioral interventions are focused on the modification of behavioral factors. These include spending more time outdoors, with increased duration and frequency of outdoor activities. Natural light exposure is responsible for stimulating the release of dopamine from the retina, suppressing the elongation of the eyeball. (24) While there is a lack of robust evidence linking circadian rhythm with the development of myopia, studies have demonstrated a delay in the onset of sleep, reduced sleep quality, and the absence of circadian rhythm cues in myopic children compared to children without myopia. (25)

Randomized controlled trials conducted in East Asian regions have yielded strong clinical evidence pertaining to the role of higher intensities of ambient light and increased time spent on outdoor activities in myopia control among children. (26–28) Furthermore, higher levels of vitamin D and the reduction in accommodative requirements associated with increased outdoor activities are also associated with slower axial elongation. (29) The public health measures focused on reducing screen time by limiting the use of mobile phones at school further complement myopia control strategies in school-age children. (30) Despite the proven advantages of lifestyle and behavioral interventions in myopia control in children, healthcare practitioners may not be confident and competent in providing lifestyle change counseling in the United Kingdom. (31).

#### 3.2. Pharmacological Approaches

Atropine has been used across various ophthalmological applications since the mid-1800s, and Donders was the first to suggest its use in myopia treatment. (32) Atropine has been demonstrated to mitigate the progression of myopia in Asian children. (33) In a multicentric retrospective study conducted in India, low-dose atropine of 0.01% concentration was associated

with an effective reduction in the progression of myopia in the pediatric population over a long-term period. (34) A single-arm clinical trial conducted in India further demonstrated the safety and effectiveness of atropine 0.05% in the management of rapidly progressing myopia during childhood. (35) Notably, the administration of atropine 0.05% has demonstrated efficacy in lowering myopia severity and may play a role in slowing its progression among school-aged children in a Pakistan-based quasi-experimental study. (36) Atropine drops are also frequently prescribed in Saudi Arabia for the prevention of myopia. (37).

Daily topical administration of low-dose atropine mitigates the progression of cycloplegic refraction and myopia in a dose-dependent fashion, by approximately 60–75%. The protective effect of atropine against myopia is mediated by its reversible antagonistic effect on the acetylcholine muscarinic receptors. (38) The inhibition of these receptors results in the suppression of myopic eye growth. Additionally, atropine also acts on non-muscarinic receptors, including serotonergic, adrenergic, and nicotinic receptors, yielding anti-myopia effects. (39) The inhibition of acetylcholine release prevents the contraction of the circular pupillary sphincter and ciliary muscles, resulting in mydriasis and cycloplegia, respectively. In addition to myopia control, atropine also relieves pain and aids in the management of malignant glaucoma. (40) In individuals with myopia, atropine is known to suppress choroidal thinning, increasing choroidal thickness. (41) A network meta-analysis conducted by Ha *et al.* suggested that the efficacy of atropine was not directly proportional to atropine dose; however, atropine had dose-related effects on the size of the pupil and the amplitude of accommodation. (42).

While the adverse effects are not different across different ethnic or racial groups, low-dose atropine is considered safer compared to moderate- and high-dose atropine in a meta-analysis conducted by Sun *et al.* (43) On the contrary, a pilot retrospective study by Joachimsen *et al.* demonstrated that the adverse effects of the topical application of 0.05% atropine were more prominent in Caucasian compared to those reported in Asian pediatric populations. (44) The use of atropine can be associated with photophobia, allergic reactions to the topical

application of atropine, and blurred vision. (45). Pirenzepine is a selective muscarinic receptor antagonist that has been demonstrated to inhibit both negative lens- and deprivation-induced myopia in both animal models and in the pediatric population. (46) Unlike atropine, this pharmaceutical formulation is not associated with mydriasis. The daily application of 2% pirenzepine gel has been demonstrated to reduce the progression of refractive errors in children; however, pirenzepine is not associated with changes in the axial length of the eye. While pirenzepine is safe and well-tolerated in human subjects, the hydrophilic nature of the drug has a negative effect on the corneal permeability and bioavailability of pirenzepine. (47) Apomorphine is a non-selective dopamine receptor agonist that has been demonstrated to suppress form deprivation myopia in different experimental models. Notably, apomorphine has shown greater effectiveness in the inhibition of defocus-induced myopia in combination with atropine, as demonstrated in animal models. (48)

### 3.3. Optical Interventions

Repeated low-level red-light therapy (RLRL) is characterized by the utilization of 650 nm visible red light that slows the progression of axial length elongation and an increase in the spherical equivalent. RLRL yields a greater extent of axial length shortening, which is achieved in a span of 1–3 months of treatment. The treatment is also associated with an improvement in choroidal blood perfusion and resultant choroidal thickening, with greater improvement in subjects with high myopia. (49) The safety standards and exposure limits in children, however, are yet to be investigated. (50) Diffusion Optics Technology (DOT) constitutes newer spectacle lenses that work by modulating the retinal contrast and reducing the progression of myopia. (51) The reduction in the retinal contrast signals reduces both the growth of the equivalent spherical lens and the axial length, slowing the progression of myopia in children. (47) The role of orthokeratology in slowing myopia progression is explained by the peripheral refraction theory. Orthokeratology wear decreases peripheral hyperopic defocus and increases the myopic focus, mitigating axial length elongation stimuli. (52) Orthokeratology results in reversible flattening of the central cornea, altering the

peripheral refraction in the direction of myopic defocus. (53,54) Orthokeratology lenses have been demonstrated to be effective in reducing axial elongation among Asian children with low and moderate myopia (55).

### 4. Safety, Compliance, and Cost-Effectiveness

The implementation of behavioral, optical, and pharmaceutical interventions for myopia control in childhood represents a cost-effective approach that can lower the risk of ocular complications and visual impairment while increasing quality-adjusted life years over the lifespan. (56) Another cost-effectiveness analysis suggested that 0.05% atropine and increased outdoor activity are cost-effective strategies for managing myopia progression in children. Although comparatively more costly, interventions such as RLRL may also provide cost-effective benefits, and the employment of these approaches could support effective and economically viable myopia control. (57) RLRL and low-dose atropine eye drops are considered safe and tolerable strategies for the prevention of myopia progression in pediatric subjects who are at risk of developing myopia. Additionally, the compliance with outdoor activities remains a challenge in urban regions, which can be countered by encouraging outdoor views. Lifestyle modifications and the integration of awareness programs regarding the use of myopia prevention strategies also enhance compliance to these strategies, maximizing the benefits. (58)

### 5. FUTURE DIRECTIONS

Notwithstanding the available evidence, future studies should focus on developing predictive models that integrate genetic, biometric, and lifestyle data to create individualized intervention plans. The precision-based approaches may optimize efficacy and prevent adverse events in the vulnerable population. Next, the identification of novel molecular pathways involved in scleral remodeling, choroidal blood flow, and retinal neurotransmission may yield innovative drug classes for myopia control, which can be further evaluated in clinical trials. Further advancements in optical device technology involve next-generation spectacle and contact lens designs that dynamically adapt to changing visual demands. This is a promising approach to enhance treatment

adherence and clinical outcomes.

Additionally, the integration of wearable technology and smartphone applications could provide real-time monitoring of outdoor activity, near-work duration, and lighting conditions. In addition to improving compliance, these digital health and behavioral modification tools further support early detection of rapid myopia progression. Lastly, international longitudinal studies are required to establish standardized myopia control guidelines adaptable to diverse healthcare settings. Collaboration between policymakers, educators, and ophthalmic experts could further drive school-based vision screening and structured preventive programs across the globe.

## 6. CONCLUSION

In summary, the escalating prevalence of myopia in the pediatric population poses a significant global public health challenge, with potential lifelong implications for vision and ocular health. The current evidence underscores the importance of early detection and timely intervention to slow disease progression and reduce the risk of sight-threatening complications in myopic children. Lifestyle modifications, pharmacological agents such as low-dose atropine, and optical interventions including orthokeratology and emerging technologies have demonstrated varying degrees of effectiveness. Nonetheless, the treatment should be tailored to the myopia risk profile of the children and the baseline refractive status. Furthermore, continued research into novel therapeutic targets, individualized intervention models, and strategies to enhance long-term adherence is of increased clinical significance. More importantly, a coordinated approach involving clinicians, researchers, policymakers, and educators is critical in implementing sustainable, evidence-based myopia control programs for addressing the rising burden among children worldwide.

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