Review Article

Controlling Childhood Myopia Progression: A Systematic Review of Interventions

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Abstract

Purpose: To synthesize evidence on risk factors and interventions for slowing myopia progression in children and adolescents.

Materials and Methods: PubMed, Scopus, Embase, and Web of Science were searched through December 2023. Eligible studies included randomized and observational designs evaluating environmental factors, specialized spectacle lenses (defocus incorporated multiple segments [DIMS], highly aspherical lens [HAL], slightly aspherical lens [SAL]), multifocal or dual-focus soft contact lenses, orthokeratology, low-dose atropine, and repeated low-level red-light therapy. Two reviewers independently screened and extracted data. Risk of bias was assessed with Cochrane RoB 2 for randomized trials and the Newcastle–Ottawa Scale for observational studies. Outcomes were annual change in spherical equivalent refraction (diopters/year) and axial length (millimeters/year).

Results: Increased outdoor time was consistently associated with reduced incidence and slower progression. Specialized spectacle lenses (DIMS, HAL, SAL) and dual-focus/multifocal soft contact lenses slowed refractive change and axial elongation compared with single-vision controls. Orthokeratology effectively reduced axial elongation in appropriately selected eyes. Low-dose atropine produced dose-dependent benefits, with 0.05 % generally more effective than 0.01 %; rebound varied with dose, treatment duration, and tapering. Emerging evidence for red-light therapy suggested short-term efficacy, but long-term safety and rebound remain uncertain. Combination strategies, such as atropine plus optical interventions, showed additive effects, though data are limited.

Conclusions: The strongest evidence supports outdoor exposure, DIMS/HAL/SAL spectacle lenses, dual-focus/multifocal soft contact lenses, orthokeratology, and low-dose atropine (≈0.05 %). Combination therapy may enhance outcomes. Red-light therapy is promising but remains investigational. Further trials should address long-term effectiveness, optimal dosing, and strategies to minimize rebound.

Keywords: Myopia; Disease Progression; Child; Adolescent; Orthokeratologic Procedures; Atropine/Therapeutic Use.

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Introduction

Myopia is a common refractive error resulting from excessive elongation of the axial length (AL) of the eye, leading to significant visual impairment [1]. The World Health Organization (WHO) projects that by 2050 nearly half of the global population will be affected [2]. The consequences are not limited to refractive blur: high myopia markedly increases the risk of irreversible vision loss due to complications such as myopic maculopathy, retinal detachment, glaucoma, and optic atrophy. As high myopia is a modifiable risk factor for pathologic sequelae, strategies that can slow progression are of urgent clinical importance [3]. The burden is most pronounced in East Asia, where prevalence among 17-year-olds already exceeds 70 %, accompanied by a growing incidence of high myopia [4,5]. In China, projections suggest that up to 84 % of the population could develop myopia in the coming decades, underscoring the public health urgency of effective prevention and control measures [6].

Progression is influenced by multiple determinants. Large-scale studies indicate that girls experience faster progression than boys [7]. Although genetic susceptibility contributes to risk, the dramatic increase in prevalence cannot be explained by heritability alone. Environmental and behavioral factors, including reduced time outdoors, limited physical activity, socioeconomic pressures, and intensive near-work tasks such as reading, studying, and digital device use, are now recognized as major drivers of onset and progression [8,9].

Experimental evidence supports these observations. Animal models have shown that hyperopic defocus accelerates ocular elongation, whereas myopic defocus inhibits it. Studies in chicks, guinea pigs, marmosets, and rhesus monkeys demonstrated that imposing myopic defocus with dual-power or multifocal lenses can slow or even reverse eye growth [10-13]. More recent investigations confirm that retinal signaling mechanisms respond asymmetrically to defocus, promoting elongation under hyperopic conditions and suppressing it with myopic defocus [14].

Epidemiologic studies further highlight the protective effect of outdoor activity, with declines in time spent outdoors and increases in indoor near-work associated with myopia progression. The COVID-19 pandemic provided a natural experiment, during which increased digital learning and home confinement were linked to accelerated myopia onset and progression, possibly exacerbated by accommodative spasm. Collectively, factors influencing progression include outdoor exposure, near-work intensity, genetic predisposition, sex, ethnicity, and the pattern of retinal defocus.

In response, diverse strategies have been developed to control progression. These include optical methods such as defocus-incorporated multiple segments (DIMS), highly aspherical lens designs (HAL), and defocus-incorporated soft contact lenses (DISC), as well as multifocal or dual-focus contact lenses, orthokeratology, bifocal or progressive addition spectacles, and careful adjustment of full versus under-correction. Pharmacological approaches, most notably low-dose atropine, have demonstrated robust efficacy, while lifestyle modification through increased outdoor time remains a non-invasive cornerstone. Surgical methods such as LASIK or LASEK correct refractive error but do not address progression and are not recommended for children. Although all of these strategies show promise, their effectiveness varies [15-18].

A recent network meta-analysis by Downie

et al., [19] systematically compared optical, pharmacological, and environmental interventions for slowing myopia progression in children. Their analysis confirmed that multiple strategies can significantly reduce refractive change and axial elongation. However, evidence regarding the potential synergistic benefits of combining modalities remains limited, highlighting the need for further investigation.

The objective of this systematic review is to evaluate risk factors associated with myopia progression and to compare the effectiveness and safety of current interventions, including optical devices (spectacle lenses, multifocal or dual-focus contact lenses, orthokeratology), pharmacologic therapy (low-dose atropine), and emerging approaches (repeated low-level red-light therapy), against standard or single-vision controls in children and adolescents, with outcomes measured as changes in spherical equivalent refraction and axial length.

Materials and Methods

Eligibility criteria were defined according to the PICOS (Population, Intervention, Comparison, Outcome, and Study design) framework. Studies were eligible if they involved individuals of any age diagnosed with myopia. Interventions of interest included factors associated with myopia progression, interventions for myopia control, or related treatments. Studies with or without control groups, as well as observational designs comparing different risk factors, were considered. Eligible outcomes included myopia progression measured by changes in refractive error, axial length, or other relevant ocular parameters. Study designs such as randomized controlled trials, cohort studies, case-control studies, cross-sectional studies, and systematic reviews were included.

A comprehensive literature search was conducted in PubMed, Scopus, Embase, and Web of Science from inception through December 2023. The search strategy combined controlled vocabulary and free-text terms including “myopia progression,” “myopia control,” “risk factors,” and “treatment.” Detailed search strategies for each database are presented in Supplement 1.

Two reviewers independently screened the titles and abstracts of all retrieved records. Full-text articles were obtained for potentially eligible studies and assessed against the inclusion criteria. Discrepancies were resolved through discussion, and when necessary, consultation with a third reviewer.

Data were extracted using a standardized form that captured study characteristics, participant demographics, interventions or exposures, outcomes, and methodological quality. Extraction was performed independently by two reviewers.

The risk of bias was assessed according to study design. Randomized controlled trials were evaluated using the Cochrane Risk of Bias tool (RoB 2), while observational studies were assessed with the Newcastle–Ottawa Scale (NOS).

A narrative synthesis was undertaken to summarize findings across included studies. Where appropriate, meta-analyses were performed using RevMan (Cochrane Collaboration) or R software. Subgroup and sensitivity analyses were conducted to explore heterogeneity and potential sources of bias. When at least ten studies were available in a meta-analysis, publication bias was examined using funnel plots and Egger’s regression test.

This systematic review was conducted and reported in accordance with the PRISMA

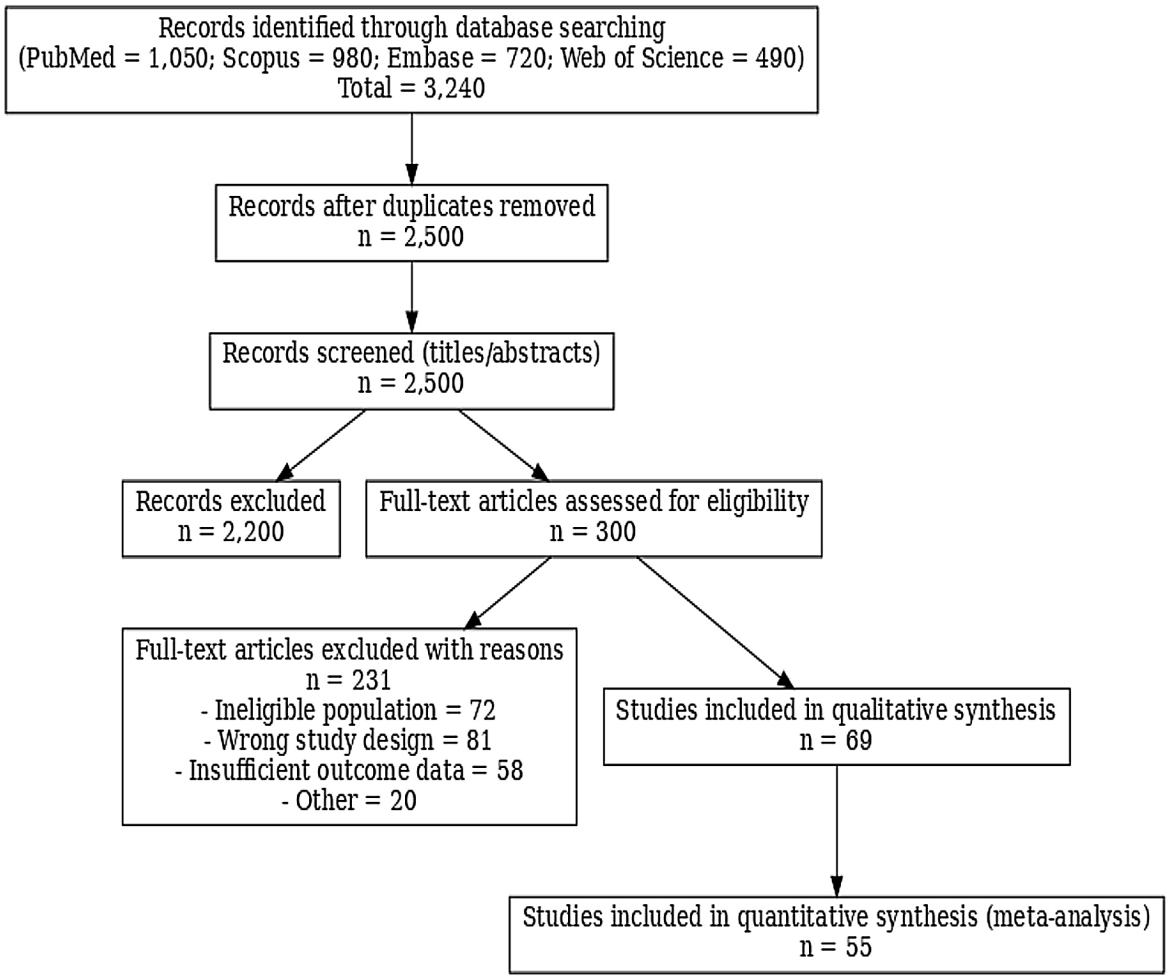

Figure 1.

2020 guidelines. A total of 3,240 records were retrieved from PubMed, Scopus, Embase, and Web of Science. After removal of 740 duplicates, 2,500 records remained for title and abstract screening. Of these, 2,200 were excluded as irrelevant. The full texts of 300 articles were assessed for eligibility, of which 231 were excluded: 72 due to ineligible populations, 81 for inappropriate study design, 58 for insufficient outcome data, and 20 for other reasons. Ultimately, 69 studies met the inclusion criteria for qualitative synthesis, and 55 were eligible for inclusion in the quantitative meta-analysis. The study selection process is summarized in the PRISMA 2020 flow diagram (Figure 1).

Results

Epidemiology and Risk Factors

The global prevalence of myopia has increased significantly in recent decades. In China, the prevalence of visual impairment attributed primarily to myopia has surged by nearly 2.5 times over the past three decades [6,20]. Genetic influences have been reported, with children of myopic parents more likely to develop progressive myopia. Girls appear particularly susceptible, showing faster progression during puberty [21].

Studies in East Asia have linked high prevalence not only to genetic predisposition

but also to socioeconomic and lifestyle changes, such as increased near work, altered study habits, and cultural norms prioritizing educational achievement. These pressures contribute to more time spent indoors and reduced outdoor activity [6, 20, 22, 23].

The COVID-19 pandemic provided evidence of environmental influence. Yam et al. reported on 1,793 schoolchildren, showing higher myopia incidence associated with decreased outdoor time. Prevalence in 6- to 8-year-olds rose to 26-28 % during the pandemic, compared to 15-17 % before. Daily outdoor exposure dropped from 75 to 24 minutes, while screen time increased from 2.5 to nearly 7 hours [24]. Similarly, an Indian cohort of 133 children showed myopia progression in 62.4 % during lockdown, compared to 45.9 % pre-pandemic; sun exposure also decreased markedly [25]. Other studies confirmed the role of limited outdoor activity and increased near work in progression [2, 26, 27]. Spending at least two hours outdoors per day was associated with significantly lower risk [28-31].

Baseline refractive status was also influential. The concept of pre-myopia, defined as spherical equivalent (SE) between + 0.75 D and – 0.50 D with relaxed accommodation, has been proposed as a predictor of progression [32]. Hyperopic reserve was strongly correlated with incident myopia, with higher baseline SE associated with up to 86.8 % reduced likelihood of onset [33, 34]. Girls showed faster decline in SE, consistent with greater susceptibility [35].

Pharmacological Interventions

Although no FDA-approved pharmacologic agents exist, low-concentration atropine has consistently slowed myopia progression with low risk of severe adverse effects [36]. Trials using atropine, pirenzepine, and cyclopentolate showed reduced progression compared with placebo [37–40]. Combination therapy with atropine and optical approaches enhanced efficacy [41-44]. Mechanistic studies linked atropine to increased choroidal thickness [45-48].

Evidence on rebound is mixed. Some studies suggest low-dose atropine (LDA) combined with optical methods mitigates rebound [49]. Others report conflicting findings, with some trials showing no rebound and others documenting dose-dependent effects [50- 54]. ATOM and LAMP studies found that 0.05 % atropine produced the least rebound with minimal effect on visual acuity [40, 55]. Higher doses (1 %) showed the strongest rebound [49, 56-58]. Stopping atropine abruptly was associated with photophobia and blurred vision compared to long-term therapy [59, 60]. Combination strategies, including atropine with orthokeratology or bifocal soft lenses, were associated with fewer adverse effects [61-64].

The main optical interventions for myopia control and their reported effects are summarized in table 1.

Optical Interventions

Non-invasive optical approaches included spectacle lenses (DIMS, HAL, SAL) and contact lenses (DISC, multifocal, dual-focus, bifocal, progressive addition). Clinical trials showed these slowed axial elongation compared with single-vision controls [52, 53]. DIMS lenses reduced myopia progression and axial length elongation by 52 % and 62 % over two years, respectively [54, 65]. HAL also reduced progression, although some studies found variable effects [53, 58, 65-69].

DISC and bifocal/dual-focus contact lenses provided peripheral defocus and reduced progression, even during COVID-19 lockdown [52,59,60, 61]. These lenses have FDA

Table 1: Summary of optical interventions for myopia control in children and adolescents

Intervention	Key Findings	References
DIMS spectacle lenses	Reduced myopia progression by 52 % and AL elongation by 62 % over 2 years	54,65
HAL/SAL spectacle lenses	Reduced progression, but findings variable across studies	53,58, 65-69
DISC contact lenses	Peripheral defocus slowed progression; effective even during COVID lockdown	59,52,60,61
Bifocal/dual-focus SCL	Short-term effectiveness in slowing progression; accepted by children	52,55,64
Progressive addition SCL	12-month trial with +2.00 DS add showed benefit	63,67
Over-/under-correction	Overcorrection may help; under-correction may worsen progression; meta-analysis mixed	65-68

approval without age restriction but remain off-label for myopia control [62]. Progressive addition soft contact lenses with +2.00 DS add showed promising results in a 12-month trial [63, 67].Some evidence suggested overcorrection combined with full correction may have benefits, although under-correction may worsen progression [65- 68]. Meta-analyses showed mixed results [66]. Combination of atropine with progressive lenses, soft contact lenses, or DIMS further improved outcomes [54, 70-72].

The evidence on pharmacological strategies, particularly low-dose atropine and its combinations with optical methods, is summarized in table 2.

Red-Light Therapy

Repeated low-level red-light (RLRL) therapy has been investigated as a novel intervention. Trials in Chinese children aged 8–13 years showed slowed progression over two years with good tolerance and no posterior segment damage [73-77].

Findings from these trials on repeated low-level red-light therapy are presented in table 3.

Table 2: Summary of pharmacological interventions for myopia control in children and adolescents

Intervention	Key Findings	References
Low-dose atropine (0.01–0.05 %)	Consistently slows progression; 0.05 % optimal balance of efficacy/safety	36-40, 55
Combination therapy (Atropine + Optical)	Enhanced efficacy when combined with optical strategies; fewer adverse effects	41-44;61-64
Rebound effect studies	Rebound effect variable; less with 0.05 %; more with 1 %; tapering important	49-53;56-60
Mechanistic (choroidal thickness)	Atropine linked to increased choroidal thickness; potential mechanism	45-48

Table 3: Summary of emerging red-light therapy for myopia control in children

Intervention	Key Findings	References
Repeated low-level red light (RLRL)	Two-year Chinese trials (ages 8–13) showed slowed progression, well tolerated, no posterior damage	73-77

Table 4: Summary of orthokeratology interventions for myopia control in children and adolescents

Intervention	Key Findings	References
Orthokeratology (OK)	Slowed axial elongation across children, teenagers, adults	78,79
Toric ortho-K	Effective in children with astigmatism	64,70,80,81
Ortho-K + Atropine	Combination therapy showed additive effects	64,70,80,81

Orthokeratology

Orthokeratology (OK) lenses reshape the cornea overnight; inducing peripheral steepening that reduces hyperopic defocus. Trials demonstrated slowed eye growth in children, teenagers, and adults [78, 79]. Toric ortho-K provided benefit in children with astigmatism. Combination with low-dose atropine showed additive effects [64, 70, 80, 81]. Long-term outcomes, optimal treatment duration, and rebound effects remain under study [82–85].

The effects of orthokeratology, including toric designs and combination approaches with low-dose atropine, are summarized in Table 4.

Discussion

The increasing prevalence of myopia worldwide, especially in East Asia, underscores the urgent need for effective preventive and control strategies [6, 20, 22, 23]. While genetic predisposition plays an important role, evidence consistently shows that environmental and lifestyle factors, including intensive near work, reduced outdoor activity, and academic pressures, exert a strong influence on both onset and progression [21, 35]. The COVID-19 pandemic further highlighted this vulnerability, as reduced outdoor exposure and increased screen use were closely associated with higher rates of progression in children [24, 25]. These findings reinforce the protective value of outdoor activity, with several studies indicating that daily exposure of two or more hours significantly lowers the risk of myopia development [2, 26–31]. Concepts such as pre-myopia and hyperopic reserve are increasingly recognized as important predictors of progression, though gender differences in refractive development suggest that girls remain at particular risk [32-35].

Among interventions, pharmacological therapy with low-dose atropine remains one of the most consistently effective strategies [36– 40]. The 0.05 % concentration appears to provide the best balance between efficacy and tolerability [40, 55]. However, rebound after cessation remains a subject of debate, with some studies reporting no effect (53) and others demonstrate dose-dependent recurrence [49–52, 56–60]. Combining atropine with optical modalities, such as progressive addition lenses or contact lenses, has shown

additive benefits and may reduce rebound risk [41–44, 54, 61–64].

Optical approaches continue to expand the range of non-invasive strategies. Defocus-incorporated designs such as DIMS spectacle lenses have demonstrated substantial reductions in progression and axial elongation [54, 65]. HAL, SAL, DISC, dual-focus, and progressive addition lenses also show favorable outcomes, although results vary between studies [52, 53, 56–69]. Importantly, some evidence suggests that full correction may be more beneficial than under-correction, which can paradoxically accelerate progression [66–68]. Combinations of atropine with DIMS or soft contact lenses further strengthen therapeutic impact [54, 70–72].

Beyond pharmacological and optical methods, emerging modalities such as repeated low-level red-light therapy are of growing interest. Early trials suggest efficacy and tolerability, but longer-term data are needed to establish safety and comparative effectiveness [73–77]. Orthokeratology remains a validated approach for slowing axial elongation, including in children with astigmatism using toric designs [78, 79]. Evidence also indicates that combining orthokeratology with low-dose atropine enhances effectiveness, though questions remain regarding optimal duration, rebound, and long-term safety [64, 70, 80–85].

Taken together, the current body of evidence highlights that myopia progression is influenced by a combination of biological, environmental, and behavioral factors. Preventive strategies should emphasize outdoor activity, while management should prioritize evidence-based interventions such as low-dose atropine, optical defocus designs, and orthokeratology. Red-light therapy remains promising but investigational.

Future work should establish the long-term safety and durability of existing myopia control interventions, including orthokeratology and low-dose atropine. Studies are also needed to define standardized protocols for rebound management, particularly with atropine discontinuation. In addition, robust multicenter trials should evaluate optimal combination regimens (e.g., atropine with optical defocus designs or orthokeratology). Finally, large-scale studies are required to validate the efficacy and safety of repeated low-level red-light therapy across diverse populations.

Conclusion

Myopia progression in children can be slowed by optical, pharmacological, and orthokeratology interventions, with combination therapy and outdoor time showing added benefit, while red-light therapy remains investigational.

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Footnotes and Financial Disclosures

Conflict of interest:

The authors have no conflict of interest with the subject matter of the present manuscript.