

Advances in myopia progression control – from atropine to personalised treatment

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Summary:

Myopia represents one of the greatest challenges in contemporary ophthalmology, and the primary goal of its management is currently not only refractive correction but also, more importantly, slowing disease progression and reducing the risk of developing high myopia. In recent years, therapeutic strategies have evolved from single interventions toward a comprehensive, personalised approach incorporating pharmacological treatment, advanced optical technologies, and modification of environmental risk factors. Atropine, particularly in low concentrations, remains one of the most extensively studied and evidence-based methods for myopia control; however, the rapid development of optical technologies has enabled the introduction of new solutions, including HALT, DIMS, DOT, and CARE spectacle lenses, which utilise controlled myopic defocus. Increasing attention has also been directed toward innovative light-based approaches, including repeated low-level red-light therapy and digital photobiomodulation, although further studies are required to establish their long-term safety and efficacy. Combination therapy, integrating different mechanisms of action, represents another important direction of development, particularly in children with rapidly progressive myopia. The future of myopia control will rely on individualised treatment strategies that consider each patient's risk profile and rate of axial elongation, and optimal selection of therapeutic interventions.

Key words:

myopia control, myopia progression, atropine, optical defocus, red-light therapy, personalised medicine.

Introduction

Myopia has become one of the greatest challenges in contemporary ophthalmology and public health [1, 2]. Owing to the rapidly increasing prevalence of this refractive error worldwide, current research is focused not only on refractive correction but also, more importantly, on effective strategies to slow myopia progression [3]. Increasing emphasis is also being placed on preventive interventions implemented before the onset of myopia, during the premyopic stage [4, 5]. The primary objective of contemporary myopia management is not only to slow myopia progression in children but also to delay its onset. Such an approach aims to reduce both the overall prevalence of myopia and the number of individuals who develop high myopia, the form of the disease associated with the greatest risk of vision-threatening complications [5, 6]. Over the past two decades, the management of myopia has undergone a profound transformation. Therapeutic strategies have evolved from reliance on single interventions to comprehensive, multimodal approaches incorporating pharmacological treatment, advanced optical interventions, and modification of environmental risk factors [7–9]. At the same time, a better understanding of the mechanisms regulating ocular growth has enabled the development of individualised treatment strategies tailored to each child's risk of progression, age, rate of axial elongation, and other clinical characteristics [10]. Consequently, contemporary myopia management is increasingly based on the principles of precision medicine, with the goal of maximising therapeutic efficacy while maintaining a favourable safety profile. Until little more than a decade ago, atropine was the only intervention supported by robust scientific evidence demonstrating efficacy in slowing myopia progression. Initially, high-concentration atropine (1%) was used because of its excellent therapeutic efficacy; however, its clinical application was limited by adverse effects, including photophobia, impaired accommodation, and difficulties with near vision [11]. Subsequent clinical trials demonstrated that low-concentration atropine (0.05%, 0.025%, and 0.01%) also effectively slows myopia progression while providing a substantially improved safety and tolerability profile [12–15].

Optical technology

One of the major breakthroughs in myopia management has been the improved understanding of the role of peripheral myopic defocus in regulating ocular growth [16, 17]. This concept has led to the development of several innovative spectacle lens technologies, including Highly Aspherical Lenslet Target (HALT), Defocus Incorporated Multiple Segments (D.I.M.S.), Diffusion Optics Technology (DOT), and Cylindrical Annular Refractive Element (CARE) [18–22]. Spectacle lenses based on Highly Aspherical Lenslet Target (HALT) technology incorporate a central single-vision correction zone (the so-called clear vision zone) that provides sharp vision at all distances, together with a therapeutic zone designed to slow myopia progression. The therapeutic zone consists of 1021 contiguous highly aspherical lenslets (HALs) arranged in 11 concentric rings. Within each ring, the lenslets share an identical geometry, whereas their optical parameters vary between adjacent rings [18, 23]. The aspherical design of the lenslets causes incident light not to converge to a single focal point but instead to create a three-dimensional volume of myopic defocus positioned in front of the retina. This defocus volume is also shaped to conform to the natural curvature of the retina. Such a three-dimensional defocus profile is believed to provide a more effective optical stimulus for controlling myopia progression than conventional spectacle designs that generate only a two-dimensional retinal defocus [18, 19, 23]. One of the first randomised clinical trials evaluating this technology demonstrated that Chinese children wearing HALT spectacle lenses for approximately 12 hours per day over two consecutive years experienced 67% slower myopia progression than children wearing conventional single-vision spectacle lenses [24]. Long-term follow-up further confirmed the sustained efficacy of this technology. After five years, only 9% of children who wore HALT lenses developed high myopia (≤ -6.00 D), whereas the extrapolated incidence in the control group reached 38% [25]. Seven-year follow-up results confirmed the long-term effectiveness of HALT lenses in myopia control. Compared with the control group, treatment resulted in a 2.30 D reduction in spherical equivalent myopia progression and a 0.92 mm

reduction in axial elongation. Importantly, the treatment effect was maintained not only in children but also in adolescents and young adults older than 19 years [26]. Another important milestone supporting the efficacy of HALT technology was the authorisation granted by the U.S. Food and Drug Administration (FDA) on 25 September 2025, allowing these lenses to be marketed in the United States. Consequently, they became the first and only spectacle lenses approved in the United States for slowing myopia progression in children. Building upon the favourable clinical outcomes achieved with the original HALT design, the next-generation HALT MAX technology was introduced in 2025 [27]. This new design was specifically developed to further enhance the control of axial elongation. Compared with the first-generation design, the number of highly aspherical lenslets was increased to 1190, while the lenslets were engineered with greater mean optical power and a higher degree of asphericity. This new technology creates twice the depth of volume of non-focused light, positioned further from the retina [27]. A contralateral crossover clinical study demonstrated that HALT MAX lenses slowed axial elongation more effectively than the first-generation HALT lenses while maintaining comparable visual acuity. Children wearing HALT MAX lenses exhibited an annual axial elongation of only 0.11 mm, representing an almost 50% reduction compared with children wearing the first-generation HALT lenses [27]. Other spectacle lenses developed for myopia control include those based on Defocus Incorporated Multiple Segments (D.I.M.S.) technology. These lenses feature a central distance-correction zone surrounded by multiple honeycomb-shaped lenslets arranged in concentric rings. The lenslets, each with a relative positive power of +3.50 D, generate simultaneous peripheral myopic defocus while maintaining clear central vision. This optical design is intended to reduce retinal signals that promote axial eye elongation, thereby slowing myopia progression [19]. A two-year clinical trial conducted in Hong Kong demonstrated that children wearing DIMS lenses exhibited approximately 60% slower myopia progression than those wearing conventional single-vision lenses [19]. This beneficial effect was maintained during extended follow-up. Similar results have subsequently been reported in studies conducted in the United Kingdom, and no clinically significant rebound effect was observed following treatment discontinuation [28]. Particularly noteworthy are the findings from optical coherence tomography (OCT) studies performed in children participating in clinical trials of DIMS technology. These investigations demonstrated not only an attenuation of the physiological choroidal thinning associated with myopia progression but also a significant increase in choroidal thickness compared with the control group. These anatomical changes persisted throughout subsequent years of follow-up [29]. In 2026, the next-generation DIMS TED (Triple Enhanced Design) technology was introduced. This updated design incorporates several structural modifications intended to further improve myopia control efficacy. The DIMS segments were repositioned closer to the geometric centre of the lens, the magnitude of myopic defocus was increased, and the therapeutic zone was expanded to cover a larger portion of the peripheral visual field. Together, these modifications are designed to provide stronger and more continuous peripheral retinal stimulation with myopic defocus.

Among the other spectacle lens designs recommended for myopia control are those based on Diffusion Optics Technology™ (DOT). Their mechanism of action relies on the incorporation of microscopic light-diffusing elements that create a controlled reduction in retinal image contrast, thereby modulating the visual signals involved in the regulation of axial eye growth.

Analysis of three-year follow-up data demonstrated that DOT lenses reduced myopia progression by a mean of 0.84 D and limited axial elongation by 0.32 mm [20]. The greatest treatment

effect was observed in younger children. Four-year follow-up data further confirmed the persistence of the therapeutic effect, supporting the long-term efficacy of this technology compared with conventional single-vision spectacle lenses [30]. Another spectacle lens technology, Cylindrical Annular Refractive Element (CARE) technology, features a central distance-correction zone surrounded by a therapeutic zone composed of cylindrical annular refractive elements that generate peripheral myopic defocus on the retina. This technology is available in two design configurations. The first incorporates a 7-mm central correction zone surrounded by therapeutic microstructures with a mean surface addition power of +4.6 D. It is recommended as the first-line option for children initiating myopia control treatment. The second configuration, called the “S” version, features a 9-mm central correction zone and microstructures with a softer mean addition power of +3.8 D. It is intended primarily for children who experience adaptation difficulties with the first design, thereby allowing treatment to be individualised according to the patient’s visual needs and age [21]. Of particular interest are the findings of a cohort study published in 2026, which compared the effectiveness of three spectacle lens designs for myopia control: HALT, DIMS, and CARE, with conventional single-vision spectacle lenses in children aged 6–16 years from southern India. The analysis included 899 patients (1780 eyes) using data extracted from electronic medical records, with outcomes adjusted for baseline age, sex, parental myopia, and baseline refractive error. All three myopia-control spectacle lens technologies significantly reduced axial elongation compared with conventional single-vision lenses. Within this study, HALT lenses were associated with a greater reduction in axial elongation than DIMS and CARE lenses; however, all three designs demonstrated clinically meaningful efficacy in slowing myopia progression [31].

Red-light therapy

One of the most rapidly evolving areas of research in myopia control is the use of light as a therapeutic modality. In particular, repeated low-level red light (RLRL) therapy has attracted considerable attention [32–36]. To date, studies conducted predominantly in Asian populations have demonstrated that regular exposure to red light with a wavelength of approximately 650 nm can effectively reduce axial elongation and slow myopia progression [13, 14–17]. The exact mechanism underlying the therapeutic effect of RLRL has not yet been fully elucidated. It is believed that RLRL may influence retinal metabolism and scleral remodeling. However, the currently favoured hypothesis attributes its efficacy to increased choroidal blood flow and choroidal thickening, which may contribute to stabilisation of axial eye growth. In addition, red light has been proposed to exert molecular and cellular effects by modulating mitochondrial function, improving cellular metabolism, and activating tissue repair and regenerative pathways [32]. Nevertheless, these hypotheses require further investigation, and the precise biological mechanisms responsible for the therapeutic effect remain to be established. The most commonly used treatment protocol employs a desktop device emitting red light at a wavelength of 650 ± 10 nm, with an illuminance of approximately 1600 lux and a radiant power of approximately 0.29 mW measured for a 4-mm pupil. A standard treatment session lasts 3 minutes (180 seconds) and is performed twice daily, with at least a 4-hour interval between sessions, 5 days per week [36]. This protocol has been adopted in the majority of published clinical studies evaluating the efficacy and safety of RLRL therapy. In a 12-month study by Jiang et al. [36], children treated with RLRL exhibited significantly less axial elongation than those in the control group (0.13 mm vs. 0.38 mm) as well as a smaller myopic shift in spherical equivalent (–0.20 D vs. –0.79 D). An additional noteworthy finding was axial shortening of at least 0.05 mm in ap-

proximately 40% of treated children, accompanied by a mean increase in choroidal thickness of 16 μm . Similarly, Wang et al. [37], in a study involving 896 children, reported approximately a 65% reduction in axial elongation and a 68% reduction in spherical equivalent progression compared with the control group. Current evidence suggests that RLRL therapy may be particularly effective in children with rapidly progressive myopia, marked axial elongation, and high myopia [38]. Increasing attention has also been directed toward its potential role in patients who show an inadequate response to conventional myopia control interventions (so-called non-responders), as well as in children for whom atropine therapy or contact lens wear is unsuitable because of adverse effects or contraindications [32–35]. Most clinical studies have reported no serious adverse events or permanent vision loss associated with RLRL therapy. The most frequently reported side effect has been transient afterimages occurring immediately after treatment, typically resolving within a few minutes [39]. However, a single case has been reported involving a 12-year-old girl who developed bilateral retinal outer segment damage after 5 months of RLRL therapy, with a decline in best-corrected visual acuity from 20/20 to 20/30. Following discontinuation of treatment, both retinal morphology and visual acuity gradually improved over the subsequent three months [40]. Furthermore, cessation of RLRL therapy has been associated with a rebound effect, characterised by renewed acceleration of myopia progression [41]. At present, RLRL therapy is most commonly recommended for children aged 7–16 years with documented rapid myopia progression and ongoing axial elongation. Contraindications include macular disease, glaucoma, cataract, colour vision deficiency, and active uveitis [39]. Owing to the limited long-term safety data, regular follow-up is recommended during treatment, including assessment of visual acuity, colour vision, intraocular pressure, anterior segment examination, fundus evaluation, and OCT of the macula with measurement of choroidal thickness [39]. RLRL therapy may be combined with other myopia control interventions. However, the optimal treatment protocols for combination therapy, including its use together with atropine, have yet to be established and require further clinical investigation.

Combination therapy

One of the most prominent trends in recent years has been the shift from single-modality treatment toward combination therapy. This approach is based on the premise that different interventions target distinct mechanisms involved in the development and progression of myopia. The combinations most frequently investigated include low-dose atropine with DIMS spectacle lenses, highly aspherical lenslet (HAL) spectacle lenses, orthokeratology, or multifocal soft contact lenses [42–45]. Atropine exerts its therapeutic effect through a pharmacological mechanism as a non-selective muscarinic receptor antagonist, inhibiting neurochemical signalling pathways involved in ocular growth. In addition, it has been suggested to influence scleral fibroblasts and scleral remodeling processes, thereby reducing axial elongation [10, 15, 46]. In contrast, optical interventions primarily act by inducing controlled peripheral myopic defocus, which modifies the retinal signals regulating ocular growth [42]. Because these treatment modalities target different pathophysiological pathways, their combined use is believed to produce an additive therapeutic effect [42–45]. Available evidence indicates that combination therapy provides greater efficacy in controlling myopia progression while maintaining a favourable safety profile compared with monotherapy. Current studies suggest that, in children with rapidly progressive myopia, combination treatment may reduce axial elongation more effectively than either intervention alone [47–49]. Combination therapy appears to be particularly beneficial in children with high

baseline refractive error, rapid myopia progression, inadequate response to monotherapy, or positive family history of myopia.

7-Methylxanthine in myopia management

7-Methylxanthine (7-MX) is a methylxanthine derivative whose mechanism of action has not yet been fully elucidated. It is believed to act as a non-selective adenosine receptor antagonist, influencing extracellular matrix remodeling within the sclera. Experimental studies in animal models have demonstrated that 7-MX administration increases scleral thickness and collagen fibril diameter, thereby improving the biomechanical properties of the sclera and reducing its susceptibility to excessive axial elongation [50]. Consequently, 7-MX may slow myopia progression by inhibiting ocular axial growth. The latest findings, presented at the 2025 Annual Meeting of the Association for Research in Vision and Ophthalmology (ARVO), have provided further evidence suggesting that long-term oral administration of 7-methylxanthine may effectively reduce both myopia progression and axial elongation in children [51]. Based on available clinical evidence, the Danish Medicines Agency (DMA) has approved 7-MX for the treatment of myopia in children and adolescents. Since its approval, treatment data from 1171 children and adolescents have shown no serious adverse events or significant safety concerns associated with its long-term use [51]. Despite these encouraging efficacy and safety findings, the current evidence base remains limited. Most available studies are observational, have been conducted by the same research group, and include relatively small patient cohorts. Large, multicentre, randomised clinical trials with long-term follow-up are still needed to establish the efficacy of 7-MX and to compare its performance with evidence-based myopia control interventions, including low-dose atropine, orthokeratology, multifocal soft contact lenses, and RLRL. Therefore, 7-MX should currently be regarded as a promising pharmacological approach to myopia control that still requires further validation before its role in routine clinical practice can be fully established.

Digital photobiomodulation platforms

In recent years, alongside RLRL, novel digital photobiomodulation (PBM) platforms have been developed with the aim of slowing myopia progression through retinal stimulation using light of specific parameters. One of the most recent solutions is the MyopiaX platform, which utilises digitally controlled light pulses emitted by a device resembling a tablet or monitor [52]. In contrast to conventional RLRL devices, PBM therapy is based on precisely programmed sequences of light stimuli with controlled wavelength, intensity, and exposure time [53, 54]. The mechanism of photobiomodulation has not yet been fully elucidated. It is hypothesised that light of appropriate parameters activates cytochrome c oxidase in retinal mitochondria, leading to increased adenosine triphosphate (ATP) production, improved cellular metabolism, and reduced oxidative stress. An additional role may be played by the selective stimulation of intrinsically photosensitive retinal ganglion cells (ipRGCs) containing melanopsin, a photopigment most sensitive to blue light. Activation of these cells may enhance dopamine release in the retina, which plays a key role in regulating ocular growth and inhibiting excessive axial elongation, thereby potentially contributing to the therapeutic effect of photobiomodulation in myopia control [52–54]. The MyopiaX platform delivers short treatment sessions supervised via a digital application, which enables monitoring of treatment adherence and remote follow-up. This feature may improve compliance among patients and caregivers, representing one of the key advantages of digital therapeutic approaches. Preliminary pilot studies suggest that digital photobiomodulation may reduce the rate of axial elongation and slow myopia progression in children [52–54].

However, the number of published clinical studies remains limited, and follow-up periods are relatively short. Furthermore, there are no direct comparative studies evaluating the efficacy of MyopiaX against established myopia control interventions. Despite promising early results, digital photobiomodulation platforms remain experimental and have not yet been included in international guidelines for myopia management. Large, multicentre, randomised controlled trials with long-term follow-up are required to assess both the efficacy and safety of this technology and to define its role in the modern management of progressive myopia in children.

Blue-light therapy

Alongside red-light therapy, the potential use of blue light in myopia control has also attracted increasing research interest. This hypothesis is based on observations suggesting that the wavelength of light may influence the process of emmetropization and the regulation of ocular growth [55]. Particular attention has been given to intrinsically photosensitive retinal ganglion cells (ipRGCs), which contain melanopsin and exhibit peak sensitivity to light at a wavelength of approximately 480 nm. Activation of these cells regulates circadian rhythms, melatonin secretion, and dopaminergic neurotransmission within the retina, one of the key mechanisms involved in inhibiting excessive axial elongation of the eye [56]. Experimental studies conducted in animal models suggest that exposure to short wavelength-enriched light may reduce the development of induced myopia and limit axial elongation [57]. Conversely, deprivation of blue light has been shown to disrupt the emmetropisation process and promote myopia progression. These effects are thought to result from increased retinal dopamine release, improved choroidal function, and modulation of signalling pathways involved in scleral remodeling. Despite these promising preclinical findings, evidence regarding the application of blue-light therapy in humans remains very limited. To date, no standardised treatment protocols have been established, and no large-scale randomised clinical trials have confirmed the efficacy and safety of this approach. Furthermore, the potential risk of phototoxic retinal damage associated with prolonged exposure to short-wavelength light, particularly at high irradiance levels, must be carefully considered. Consequently, the use of blue light for myopia control remains an experimental approach and is not currently recommended for routine clinical practice.

Biomarkers of myopia progression

Growing attention is being directed toward the identification of biomarkers that can predict children at the highest risk of rapid myopia progression. Parameters under investigation include axial length, choroidal thickness, OCT – derived biomarkers, peripheral refraction, and genetic factors. The identification of reliable biomarkers may enable earlier initiation of treatment and more precise monitoring of therapeutic efficacy in the future [58, 59]. Genetic determinants of myopia progression also represent an important area of ongoing research. Numerous genetic variants associated with myopia development have been identified; however, because myopia is a multifactorial condition involving complex interactions between genetic susceptibility and environmental influences, the identification of robust genetic biomarkers with reliable prognostic value remains a significant clinical and research challenge [60, 61].

Conclusion

Advances in research on myopia control in recent years have fundamentally transformed the approach to the management of this condition. From a period in which atropine was the only effective treatment option, the field has progressed to an era of mo-

dern optical interventions, combination therapies, photobiomodulation, and precision medicine. Currently, research is no longer focused on identifying a single universal treatment, but rather on developing individualised therapeutic strategies tailored to the needs of each patient. In the coming years, further development can be expected in biomarker-driven approaches, artificial intelligence applications, as well as novel optical and pharmacological technologies, which may enable even more effective control of myopia progression and further reduce the risk of long-term vision-threatening complications in adulthood.

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