



EFFECTIVENESS OF MYOPIA CONTROL STRATEGIES (ORTHOKERATOLOGY VS ATROPINE VS SPECTACLE LENSES): CURRENT EVIDENCE, COMPARATIVE OUTCOMES, AND FUTURE DIRECTIONS

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ABSTRACT

Myopia has emerged as one of the most rapidly increasing ophthalmic disorders worldwide and is now considered a major public health concern due to its rising prevalence and associated vision-threatening complications. Characterized by excessive axial elongation of the eyeball causing light rays to focus in front of the retina, myopia commonly begins during childhood and often progresses throughout adolescence. According to projections by World Health Organization and epidemiological studies by Brien Holden Vision Institute, nearly 50% of the global population may become myopic by 2050, with approximately 10% developing high myopia. High myopia significantly increases the risk of retinal detachment, myopic macular degeneration, glaucoma, cataract formation, and irreversible visual impairment.

The increasing prevalence of myopia is largely attributed to a combination of genetic predisposition and environmental influences such as prolonged near work, reduced outdoor activity, excessive screen exposure, urbanization, and educational pressures. Traditional corrective methods such as single-vision spectacles and standard contact lenses effectively improve visual acuity but fail to address the underlying progression of axial elongation. Consequently, modern ophthalmology has shifted toward interventions aimed at slowing myopia progression rather than merely correcting refractive error.

Among currently available evidence-based interventions, orthokeratology, low-dose atropine therapy, and specialized spectacle lenses have emerged as the most widely studied strategies for myopia control. Orthokeratology involves overnight wear of specially designed rigid gas-permeable lenses that temporarily reshape the corneal surface and induce peripheral myopic defocus, thereby slowing axial elongation. Several studies report a 40–60% reduction in axial length progression among pediatric populations using orthokeratology. However, challenges include high cost, lens maintenance, and risk of microbial keratitis.

Pharmacological treatment with low-dose atropine has gained widespread popularity following landmark trials such as the ATOM Study and LAMP Study. Low-dose atropine (0.01%, 0.025%, and 0.05%) has demonstrated significant reduction in myopia progression while minimizing adverse effects compared to higher concentrations. However, rebound progression after discontinuation and variable treatment response remain concerns.

Recent advancements in spectacle lens design have introduced non-invasive alternatives such as MiYOSMART and Stellest lenses. These lenses utilize peripheral defocus technology and highly aspherical lenslets to slow myopic progression by approximately 40–60%. Their safety profile and ease of use make them attractive for younger children.

This review critically compares orthokeratology, atropine, and spectacle lens interventions in terms of efficacy, safety, compliance, cost-effectiveness, adverse effects, long-term outcomes, and patient suitability. It also explores combination therapies, artificial intelligence-assisted monitoring, genetic research, and future personalized treatment strategies.

The review concludes that no single intervention is universally superior. Individualized treatment selection based on age, progression rate, lifestyle, refractive status, ocular health, and patient compliance remains essential for optimal long-term myopia management.

KEYWORDS: Myopia control; Orthokeratology; Atropine; Spectacle lenses; Pediatric ophthalmology; Axial elongation; Refractive error; Myopia progression; DIMS lenses; Vision correction

1. INTRODUCTION

Global Burden of Myopia

Myopia is one of the most prevalent refractive disorders worldwide. It affects both developed and developing nations.

Current prevalence estimates:

- East Asia: 70–90% in adolescents

- Europe: 30–50%
- United States: 40%
- India: rapidly increasing prevalence

Projected global burden by 2050:

- 5 billion myopic individuals
- 1 billion high myopia cases



Why Myopia is Becoming a Public Health Crisis

Progressive myopia increases risk of:

- Retinal detachment
- Glaucoma
- Cataract
- Myopic maculopathy
- Permanent blindness

Economic Burden

Myopia creates:

- Healthcare expenses
- Productivity loss
- Educational challenges

Rise of Digital Lifestyle

Children increasingly spend time on:

- Smartphones
- Tablets
- Online learning platforms

Reduced outdoor exposure worsens progression.

Need for Myopia Control

Traditional glasses correct vision only.

Modern ophthalmology aims to slow axial elongation.

Evolution of Myopia Management

Past:

Single vision glasses

Present:

- Orthokeratology
- Atropine
- Specialized lenses

Future:

- AI guided treatment
- Genetic therapies

2. PATHOPHYSIOLOGY OF MYOPIA PROGRESSION

2.1 Introduction

Understanding the pathophysiology of myopia progression is essential for evaluating modern myopia control strategies. Myopia is no longer considered merely a refractive error corrected by spectacles or contact lenses; instead, it is increasingly recognized as a structural ocular disorder involving abnormal ocular growth and axial elongation. Progressive myopia primarily develops during childhood and adolescence when the eye undergoes rapid growth changes. In susceptible individuals, normal emmetropization mechanisms become disrupted, leading to excessive elongation of the eyeball and progressive refractive deterioration.

The pathogenesis of myopia is multifactorial and involves complex interactions between genetic predisposition, environmental influences, retinal signaling pathways, scleral remodeling, biochemical mediators, and visual behavior. Recent scientific advances have improved understanding of these mechanisms and have led to the development of targeted interventions such as orthokeratology, atropine therapy, and peripheral defocus spectacle lenses.

2.2 Normal Emmetropization Process

Emmetropization refers to the natural developmental process through which the eye adjusts its growth to achieve proper focusing of light on the retina.

In normal children:

- Corneal curvature adjusts appropriately
- Lens thickness changes gradually
- Axial length increases in a controlled manner
- Retina receives focused images

This results in normal vision (emmetropia).

The process depends on proper communication between:

- Retina
- Choroid
- Sclera
- Visual cortex

Disruption of this process may lead to refractive errors.

2.3 Axial Elongation: Primary Mechanism of Myopia

The most important structural abnormality in progressive myopia is excessive axial elongation.

Normal axial length:

Approximately 22–24 mm

Myopic axial length:

Often exceeds 24 mm

In high myopia:

May exceed 26–30 mm

When axial length increases excessively:

- Light focuses in front of retina
- Distance vision becomes blurred
- Retinal stretching occurs

This increases risk of pathological complications.

Mechanisms causing axial elongation

- Scleral thinning
- Reduced collagen synthesis
- Increased extracellular matrix degradation
- Altered biomechanical strength of sclera

2.4 Peripheral Hyperopic Defocus Theory

This is one of the most accepted mechanisms explaining progressive myopia.

When conventional single-vision spectacles are used:

Central retina: Clear image

Peripheral retina: Hyperopic defocus

Peripheral retinal blur stimulates eye growth.

The eye responds by elongating further.

This theory led to development of:

- Orthokeratology
- DIMS lenses
- Multifocal lenses

These treatments create peripheral myopic defocus to slow progression.

2.5 Retinal Signaling Mechanisms

The retina plays a central role in regulating eye growth.

Visual signals trigger biochemical pathways that influence scleral remodeling.

Important neurotransmitters include:



- Dopamine
- Acetylcholine
- Nitric oxide
- GABA
- Glutamate

These molecules influence axial growth.

2.6 Dopamine Deficiency Hypothesis

Outdoor exposure stimulates retinal dopamine release.

Dopamine inhibits excessive ocular growth.

Reduced outdoor activity may result in:

- Lower dopamine levels
- Increased axial elongation
- Higher myopia progression

This explains why outdoor activity protects against myopia.

2.7 Scleral Remodeling

The sclera provides structural support to the eye.

In progressive myopia:

- Collagen fibers weaken
- Sclera becomes thinner
- Biomechanical stability decreases

This promotes axial elongation.

Molecular changes include:

- Increased matrix metalloproteinases
- Reduced collagen production
- Altered fibroblast activity

2.8 Choroidal Thickness Changes

The choroid plays an important role in ocular growth regulation.

In myopia:

- Choroid becomes thinner
- Blood flow decreases
- Retinal support reduces

Thinner choroid correlates with faster progression.

2.9 Genetic Factors

Myopia demonstrates strong hereditary influence.

Children with myopic parents have higher risk.

Multiple genes associated include:

- PAX6
- ZFHX1B
- GJD2
- RASGRF1
- TGIF

Genome-wide association studies continue identifying new genes.

2.10 Environmental Risk Factors

Environmental influences significantly contribute.

Near Work

- Reading
- Smartphones
- Computers
- Tablets

Prolonged near work increases risk.

Reduced Outdoor Time

Strongly associated with progression.

Educational Pressure

Higher academic stress increases prevalence.

Urbanization

Urban children show higher myopia rates.

2.11 Digital Screen Exposure

Modern digital lifestyles contribute significantly.

Problems include:

- Reduced blinking
- Prolonged accommodation
- Blue light exposure
- Near fixation stress

COVID-19 lockdown accelerated this issue.

2.12 Accommodation Dysfunction

Excessive near work may cause:

- Accommodative lag
- Retinal defocus

This contributes to progression.

2.13 Intraocular Pressure Theory

Some studies suggest elevated intraocular pressure may contribute to scleral stretching.

Evidence remains inconsistent.

2.14 Role of Nutrition

Potential associations include deficiencies in:

- Vitamin D
- Omega-3 fatty acids

Research remains limited.

2.15 Ethnic Variations

East Asian populations show highest prevalence.

Possible causes:

- Genetics
- Educational systems
- Lifestyle differences

2.16 Pathological Myopia

Severe axial elongation may cause:

- Retinal detachment
- Choroidal neovascularization
- Macular degeneration
- Posterior staphyloma

These may cause permanent vision loss.

2.17 Role of Artificial Intelligence in Understanding Myopia

AI helps identify:

- Progression patterns
- Risk prediction models
- Personalized interventions

2.18 Future Molecular Targets

Researchers are exploring:

- Gene therapy
- Dopamine modulation
- Scleral strengthening therapies



3. ORTHOKERATOLOGY (ORTHO-K): MECHANISM, CLINICAL EFFECTIVENESS, RISKS, AND LONG-TERM OUTCOMES

3.1 Introduction

Orthokeratology (Ortho-K) is a non-surgical, reversible vision correction and myopia control strategy that uses specially designed rigid gas-permeable contact lenses worn overnight to temporarily reshape the cornea. This method not only corrects refractive error during the daytime without the need for spectacles or contact lenses but also plays a significant role in slowing axial elongation in children and adolescents.

Orthokeratology has gained substantial attention in modern pediatric ophthalmology as an effective intervention for myopia control, particularly in progressive moderate myopia. Its clinical importance lies in its dual benefit: optical correction and structural modification of ocular growth patterns.

3.2 Principle and Mechanism of Action

The primary mechanism of orthokeratology is based on controlled corneal reshaping.

3.2.1 Corneal Reshaping

During overnight wear:

- Central corneal epithelium is gently flattened
- Mid-peripheral cornea becomes relatively steeper
- Redistribution of epithelial cells occurs

This leads to temporary reduction in corneal refractive power.

3.2.2 Peripheral Myopic Defocus

One of the most important mechanisms in myopia control is the induction of peripheral myopic defocus.

Ortho-K lenses create:

- Central clear vision
- Peripheral retinal myopic defocus

This reduces the stimulus for axial elongation.

3.2.3 Biomechanical Signaling

Changes in corneal shape influence retinal signaling pathways:

- Reduced retinal stretch signal
- Decreased scleral remodeling activity
- Altered dopamine signaling pathways

These mechanisms slow eyeball elongation.

3.3 Clinical Effectiveness of Orthokeratology

Multiple clinical studies and meta-analyses demonstrate significant effectiveness in controlling myopia progression.

3.3.1 Reduction in Axial Length Growth

Studies show:

- 40%–60% reduction in axial elongation
- Significant slowing compared to single-vision spectacles

3.3.2 Refractive Error Control

Ortho-K effectively reduces:

- Myopic progression rate
- Spherical equivalent progression

3.3.3 Pediatric Effectiveness

Most effective in:

- Children aged 6–14 years

- Rapidly progressing myopes
- Moderate myopia (-1.00D to -6.00D)

3.3.4 Key Clinical Evidence

Large studies have demonstrated:

- Reduced axial elongation over 2–5 years
- Better outcomes with early initiation
- Sustained effect with continuous wear

3.4 Advantages of Orthokeratology

3.4.1 Non-Surgical Vision Correction

- No daytime glasses or contact lenses required
- Improves quality of life

3.4.2 Effective Myopia Control

- Strong evidence for slowing progression
- Works through peripheral defocus mechanism

3.4.3 Reversible Effect

- Corneal changes are temporary
- Vision returns to baseline after discontinuation

3.4.4 High Patient Satisfaction

- Freedom from spectacles
- Improved sports participation

3.5 Limitations and Disadvantages

3.5.1 Risk of Infection

The most serious complication is microbial keratitis.

Risk factors include:

- Poor hygiene
- Overnight lens wear
- Improper handling

3.5.2 High Cost

- Lens fitting and maintenance are expensive
- Requires specialized practitioners

3.5.3 Strict Compliance Required

- Regular cleaning required
- Follow-up visits essential

3.5.4 Temporary Effect

- Myopia control effect stops after discontinuation
- Rebound progression may occur

3.6 Safety Profile

When properly used:

- Generally safe in children
- Low complication rates in compliant users

However, vigilance is required to prevent infections.

3.7 Patient Selection Criteria

Orthokeratology is most suitable for:

- Children with progressive myopia
- Mild to moderate myopia
- Motivated patients and parents
- Good hygiene practices



3.8 Contraindications

- Severe dry eye disease
- Active ocular infections
- Poor hygiene compliance
- Corneal abnormalities

3.9 Comparison with Other Myopia Control Methods

Parameter	Orthokeratology	Atropine	Spectacle Lenses
Effectiveness	High	Moderate-High	Moderate
Invasiveness	Non-surgical	Pharmacological	Non-invasive
Compliance	Moderate	High	High
Infection Risk	Present	None	None
Reversibility	Yes	Yes	Yes

3.10 Long-Term Outcomes

Long-term studies show:

- Sustained reduction in axial elongation
- Better effect when started early
- Possible rebound after discontinuation

Long-term safety remains acceptable with proper follow-up.

3.11 Combination Therapy

Orthokeratology may be combined with:

- Low-dose atropine
- Multifocal spectacle lenses

This may enhance myopia control effect.

3.12 Future Developments

Future improvements include:

- Smart Ortho-K lenses with sensors
- AI-based corneal fitting models
- Customized lens designs using corneal mapping
- Integration with digital monitoring systems

4. ATROPINE THERAPY IN MYOPIA CONTROL: MECHANISM, CLINICAL EVIDENCE, SAFETY, AND COMPARATIVE OUTCOMES

4.1 Introduction

Atropine eye drops represent one of the most extensively studied pharmacological interventions for controlling myopia progression in children. Unlike optical methods such as orthokeratology or specialized spectacle lenses, atropine acts at a biochemical level to influence ocular growth regulation. Over the past two decades, low-dose atropine has emerged as a cornerstone therapy in pediatric myopia management due to its effectiveness, ease of use, and non-invasive nature.

Originally used in higher concentrations for cycloplegia and amblyopia assessment, atropine's role in myopia control was discovered incidentally and later validated through large-scale clinical trials such as the ATOM and LAMP studies. Its growing clinical acceptance has positioned it as a first-line intervention in many Asian countries and increasingly in global ophthalmic practice.

4.2 Mechanism of Action

The exact mechanism of atropine in myopia control is not fully understood; however, multiple pathways have been proposed.

4.2.1 Muscarinic Receptor Blockade

Atropine is a non-selective muscarinic antagonist.

It acts on:

- M1 receptors
- M2 receptors
- M3 receptors

These receptors are present in:

- Retina
- Choroid
- Sclera

Blocking these receptors may reduce abnormal ocular growth signaling.

4.2.2 Scleral Remodeling Inhibition

Atropine may inhibit:

- Fibroblast activity
- Collagen degradation
- Matrix metalloproteinases

This results in reduced axial elongation.

4.2.3 Retinal Dopaminergic Modulation

Atropine may indirectly increase dopamine activity, which is known to inhibit eye growth.

4.2.4 Non-Accommodative Mechanism

Earlier theories suggested accommodation reduction, but modern evidence indicates that atropine's effect is largely independent of accommodation.

4.3 Clinical Evidence of Atropine in Myopia Control

4.3.1 ATOM Studies

ATOM Study

Key findings:

- High-dose atropine (1%) significantly reduced myopia progression
- However, strong side effects were observed
- Rebound effect after discontinuation was significant

This led to exploration of low-dose formulations.

4.3.2 ATOM2 Study

Lower concentrations were tested:

- 0.5%
- 0.1%
- 0.01%

Findings:

- 0.01% atropine had fewer side effects
- Moderate efficacy with better tolerability



- Reduced photophobia and near vision issues

4.3.3 LAMP Study

LAMP Study

Key results:

- 0.05% atropine showed highest efficacy
- Dose-dependent response observed
- 0.01% least effective but safest
- 0.025% balanced efficacy and safety

4.4 Effectiveness of Atropine Therapy

Axial Length Control

- 30%–70% reduction in axial elongation depending on dose

Refractive Progression

- Significant slowing of spherical equivalent progression

Best Responders

- Rapid progressors
- Younger children
- Moderate myopia cases

4.5 Dose-Response Relationship

Concentration	Effectiveness	Side Effects
0.01%	Low–Moderate	Minimal
0.025%	Moderate	Mild
0.05%	High	Moderate
1%	Very high	Severe

4.6 Advantages of Atropine Therapy

4.6.1 Non-Invasive

- Simple eye drop administration
- No device or lens required

4.6.2 High Compliance

- Once daily or nightly dosing
- Easy parental supervision

4.6.3 Cost-Effective

- Lower cost compared to orthokeratology

4.6.4 Strong Evidence Base

- Multiple randomized controlled trials support efficacy

4.7 Limitations and Side Effects

4.7.1 Photophobia

- Due to pupil dilation

4.7.2 Near Vision Difficulty

- Reduced accommodation at higher doses

4.7.3 Rebound Effect

- Myopia progression may accelerate after stopping treatment

4.7.4 Long-Term Safety Uncertainty

- Extended use in very young children requires caution

4.8 Safety Profile

Low-dose atropine (0.01%–0.05%) is generally safe.

Common adverse effects:

- Mild pupil dilation
- Slight near blur
- Occasional ocular irritation

Serious adverse events are rare.

4.9 Patient Selection Criteria

Ideal candidates include:

- Children aged 6–15 years
- Progressive myopia (>0.5D/year)
- Poor tolerance to contact lenses
- Low compliance with optical methods

4.10 Contraindications

- Known hypersensitivity to atropine
- Angle-closure glaucoma risk
- Severe ocular surface disease

4.11 Comparison with Other Myopia Control Methods

Feature	Atropine	Orthokeratology	Spectacle Lenses
Invasiveness	Low	Moderate	Low
Effectiveness	Moderate–High	High	Moderate
Compliance	High	Moderate	High
Side effects	Mild systemic	Infection risk	Minimal
Cost	Low	High	Moderate

4.12 Combination Therapy

Evidence suggests improved outcomes when atropine is combined with:

- Orthokeratology
- Multifocal lenses
- DIMS spectacle lenses

Combination therapy may provide additive effects.

4.13 Long-Term Outcomes

Long-term follow-up studies indicate:

- Sustained reduction in progression during treatment
- Possible rebound after discontinuation
- Better outcomes with prolonged low-dose use

4.14 Future Directions

Future research focuses on:

- Optimizing minimum effective dose
- Sustained-release atropine formulations
- Genetic predictors of response
- AI-based dosing personalization
- Combination pharmacologic-optical strategies

5. SPECTACLE LENS THERAPY FOR MYOPIA CONTROL: MECHANISMS, CLINICAL EVIDENCE, AND COMPARATIVE OUTCOMES

5.1 Introduction

Spectacle lens therapy has evolved significantly from conventional single-vision correction to advanced optical designs specifically engineered for myopia control. Unlike traditional spectacles, which correct refractive error without influencing disease progression, modern myopia control



spectacle lenses aim to modify retinal image signaling to slow axial elongation.

This category of intervention has gained global attention due to its non-invasive nature, ease of use, affordability, and suitability for younger children. Two of the most widely studied and clinically validated designs include Defocus Incorporated Multiple Segments (DIMS) lenses and Highly Aspherical Lenslet Target (HALT) technology-based lenses.

5.2 Mechanism of Action

The fundamental principle behind myopia control spectacle lenses is **peripheral defocus modulation**.

5.2.1 Peripheral Myopic Defocus

Standard single-vision lenses create:

- Clear central vision
- Peripheral hyperopic defocus

This peripheral blur stimulates axial elongation.

In contrast, myopia control lenses create:

- Central clear vision
- Peripheral myopic defocus

This sends a “stop growth” signal to the retina.

5.2.2 Retinal Signaling Pathway Modulation

These lenses influence retinal biochemical pathways:

- Reduced retinal growth stimulation
- Altered dopamine signaling
- Decreased scleral remodelling activity

5.2.3 Optical Zone Segmentation

Special lens designs include multiple optical zones:

- Central correction zone
- Peripheral defocus zones
- Light diffusion segments

5.3 Types of Myopia Control Spectacle Lenses

5.3.1 DIMS Technology

MiYOSMART

Developed using Defocus Incorporated Multiple Segments technology.

Structure:

- Central clear zone
- Surrounding multiple defocus segments

Mechanism:

Creates consistent peripheral myopic defocus.

5.3.2 Highly Aspherical Lenslet Target (HALT)

Stellest

Structure:

- Thousands of aspherical lenslets
- Gradient defocus pattern

Mechanism:

More uniform retinal defocus across visual field.

5.4 Clinical Effectiveness

5.4.1 DIMS Lens Outcomes

Clinical trials show:

- ~60% reduction in myopia progression
- Significant reduction in axial elongation

- Stable effect over 2+ years

5.4.2 HAL Lens Outcomes

Studies demonstrate:

- 50–70% reduction in axial elongation
- Higher efficacy in younger children
- Dose-response relationship observed

5.4.3 Overall Evidence

Spectacle-based interventions provide:

- Moderate to high efficacy
- Strong safety profile
- High compliance rates

5.5 Advantages of Spectacle Lens Therapy

5.5.1 Non-Invasive

- No contact lens handling required
- No pharmacological exposure

5.5.2 High Safety Profile

- No risk of infection
- Minimal adverse effects

5.5.3 Easy Compliance

- Suitable for children
- No daily maintenance beyond normal use

5.5.4 Wide Accessibility

- Easier distribution than contact lenses
- Suitable for primary care settings

5.6 Limitations

5.6.1 Cost

- Higher than standard spectacles
- Insurance coverage varies

5.6.2 Adaptation Period

- Mild visual adaptation required
- Peripheral blur initially noticed

5.6.3 Moderate Efficacy Compared to Ortho-K

- Less effective than orthokeratology in some studies

5.6.4 Dependence on Full-Time Wear

- Requires consistent daily usage

5.7 Safety Profile

Spectacle lenses are among the safest myopia control options. No reported serious adverse effects.

Minor issues:

- Mild headache during adaptation
- Temporary peripheral distortion

5.8 Patient Selection Criteria

Ideal candidates:

- Children aged 5–15 years
- Mild to moderate myopia
- Poor suitability for contact lenses
- Preference for non-invasive therapy



5.9 Contraindications

- Severe anisometropia (relative limitation)

- Non-compliance with spectacle wear

5.10 Comparison with Other Myopia Control Methods

5.11 Combination Therapy Potential

Feature	Spectacle Lenses	Orthokeratology	Atropine
Invasiveness	None	Moderate	Low
Effectiveness	Moderate–High	High	Moderate–High
Safety	Very High	Moderate	High
Compliance	Very High	Moderate	High
Cost	Moderate	High	Low–Moderate

Spectacle lenses may be combined with:

- Low-dose atropine
- Increased outdoor activity
- Digital screen control

Combination therapy may enhance outcomes.

5.12 Long-Term Outcomes

Available evidence suggests:

- Sustained reduction in axial elongation
- Good long-term safety profile
- Continued efficacy with consistent use

Long-term data beyond 5 years is still limited.

5.13 Future Developments

Future innovations include:

- AI-customized spectacle lens design
- Adaptive defocus lenses
- Smart spectacle frames with monitoring sensors
- Integration with digital eye tracking systems

6. COMPARATIVE ANALYSIS OF MYOPIA CONTROL STRATEGIES: ORTHOKERATOLOGY VS ATROPINE VS SPECTACLE LENSES

6.1 Introduction

The management of progressive myopia in children has evolved from simple optical correction to targeted interventions aimed at slowing axial elongation. Among the currently available evidence-based approaches, orthokeratology, low-dose atropine therapy, and advanced spectacle lenses represent the three most widely used strategies worldwide.

Each modality has distinct mechanisms, clinical benefits, limitations, and patient suitability profiles. A comparative evaluation is essential for evidence-based decision-making in clinical practice, particularly when selecting individualized treatment plans for pediatric patients.

6.2 Comparative Mechanisms of Action

6.2.1 Orthokeratology

- Corneal reshaping during overnight wear

- Induction of peripheral myopic defocus
- Mechanical redistribution of corneal epithelial cells

6.2.2 Atropine Therapy

- Muscarinic receptor blockade in retina and sclera
- Inhibition of scleral remodeling
- Possible dopamine pathway modulation

6.2.3 Spectacle Lenses

- Optical manipulation of retinal image
- Peripheral myopic defocus creation
- Multi-zone light distribution

6.3 Effectiveness in Myopia Control

Axial Length Reduction (Approximate Range)

Treatment	Axial Elongation Reduction
Orthokeratology	40%–60%
Atropine (0.05%)	50%–70%
Spectacle Lenses (DIMS/HAL)	40%–60%

Key Observations

- Atropine (0.05%) often shows highest efficacy
- Orthokeratology provides strong mechanical optical control
- Spectacle lenses show consistent moderate-high efficacy

6.4 Safety Profile Comparison

Orthokeratology

- Risk of microbial keratitis (rare but serious)
- Lens hygiene-dependent safety

Atropine

- Mild photophobia
- Near vision blur at higher doses
- Systemic effects negligible in low-dose use

Spectacle Lenses

- Safest profile
- No reported serious adverse effects



6.5 Compliance and Usability

Parameter	Orthokeratology	Atropine	Spectacle Lenses
Ease of use	Moderate	High	Very High
Daily maintenance	High	Low	Low
Child acceptance	High	High	Very High
Parental involvement	High	Moderate	Low

6.6 Cost-Effectiveness

Treatment	Relative Cost
Orthokeratology	High
Atropine	Low
Spectacle Lenses	Moderate

6.7 Rebound Effect After Discontinuation

Treatment	Rebound Risk
Orthokeratology	Low–Moderate
Atropine	Moderate–High
Spectacle Lenses	Low

6.8 Suitability Based on Patient Profile

Orthokeratology

Best for:

- Active children
- Moderate myopia
- High motivation families

Atropine

Best for:

- Rapid progression
- Poor contact lens tolerance
- Younger children

Spectacle Lenses

Best for:

- First-line therapy
- Low compliance risk patients
- Early intervention cases

6.9 Overall Clinical Decision Matrix

Factor	Best Option
Highest efficacy	Atropine (0.05%)
Best safety	Spectacle lenses
Best lifestyle freedom	Orthokeratology
Best compliance	Spectacle lenses
Best cost-effectiveness	Atropine

6.10 Combination Therapy Approach

Evidence suggests additive benefits when therapies are combined:

- Orthokeratology + atropine → enhanced axial control
- Spectacles + atropine → improved progression control
- Behavioral interventions (outdoor time) further enhance outcomes

6.11 Clinical Evidence Summary

Major supporting evidence includes:

- ATOM Study
- LAMP Study

- Orthokeratology cohort studies (multiple meta-analyses)
- DIMS lens trials and HAL lens studies

6.12 Key Clinical Insight

No single modality is universally superior. Instead, treatment selection should be:

- Individualized
- Age-dependent
- Progression-rate dependent
- Lifestyle-adapted
- Compliance-oriented

6.13 Future Perspective

Future myopia control will likely involve:

- AI-guided personalized therapy selection
- Genetic risk profiling
- Smart adaptive lenses
- Drug-device combination systems
- Digital monitoring of axial growth

7. DISCUSSION

7.1 Overview of Evidence Integration

The increasing global burden of myopia has shifted clinical focus from simple refractive correction to active disease modification. Evidence from pharmacological, optical, and hybrid interventions clearly demonstrates that myopia progression is a modifiable process. Orthokeratology, atropine therapy, and advanced spectacle lenses each target different biological and optical pathways involved in axial elongation.

A key observation across all major studies is that **no single intervention completely stops myopia progression**, but all can significantly reduce its rate. The variability in treatment response highlights the multifactorial nature of myopia, involving genetic susceptibility, environmental exposure, retinal signaling, and scleral remodeling.

7.2 Comparative Interpretation of Efficacy

Across clinical trials and meta-analyses:



- Atropine (especially 0.05%) shows the highest average reduction in axial elongation (up to ~70%)
- Orthokeratology demonstrates consistent 40–60% reduction with strong optical control
- Spectacle lenses (DIMS/HAL) provide stable 40–60% reduction with excellent safety

However, efficacy must be interpreted in clinical context:

- Atropine efficacy is dose-dependent but limited by rebound effects
- Orthokeratology efficacy depends on compliance and lens fitting precision
- Spectacle lenses offer consistent but moderate effect across populations

7.3 Biological Mechanism Correlation

All three interventions converge on a shared biological endpoint: **reduction of scleral growth signaling**.

- Orthokeratology alters retinal image defocus patterns
- Spectacle lenses modulate peripheral retinal blur
- Atropine pharmacologically suppresses growth signaling pathways

This supports the theory that retinal signaling is the central regulator of axial elongation.

7.4 Clinical Decision-Making in Practice

Clinical selection of therapy should not be protocol-driven alone but individualized.

Important decision variables include:

- Age of onset
- Baseline refractive error
- Rate of progression ($>0.5D/\text{year}$ considered high risk)
- Lifestyle factors (screen time, outdoor exposure)
- Patient and parental preference
- Financial constraints
- Risk tolerance

A structured approach improves outcomes significantly.

7.5 Role of Combination Therapy

Recent literature supports the superiority of combination strategies in selected cases.

Examples:

- Atropine + Orthokeratology → additive axial length control
- Atropine + Spectacle lenses → improved stabilization in fast progressors
- Behavioural modification (outdoor activity) enhances all interventions

This reflects a shift toward **multimodal myopia control therapy**.

7.6 Limitations of Current Evidence

Despite strong clinical data, several limitations exist:

7.6.1 Heterogeneity in Study Design

Different studies use varying:

- Age groups
- Follow-up durations
- Measurement techniques

7.6.2 Short-Term Follow-Up

Most trials range from 1–3 years; long-term effects into adulthood remain under-studied.

7.6.3 Rebound Effect

Particularly relevant in atropine therapy, where discontinuation may accelerate progression.

7.6.4 Population Bias

Many studies originate from East Asian populations, limiting global generalizability.

7.7 Public Health and Societal Implications

The rising prevalence of myopia has major implications:

- Increased healthcare burden
- Higher risk of irreversible visual impairment
- Economic productivity loss
- Greater demand for pediatric eye care services

Preventive strategies are therefore not only clinical but also public health priorities.

7.8 Role of Emerging Technologies

Advancements are reshaping myopia management:

- Artificial intelligence-based progression prediction
- Smart wearable optical devices
- Digital monitoring of axial length changes
- Personalized genetic risk profiling

These innovations support transition toward **precision ophthalmology**.

7.9 Clinical Recommendations Based on Evidence

Based on current literature:

- **First-line therapy in young children:** Spectacle lenses or low-dose atropine
- **High progression cases:** Combination therapy (atropine + optical control)
- **Lifestyle-active children:** Orthokeratology preferred option
- **Safety-sensitive patients:** Spectacle lens-based interventions

7.10 Future Research Directions

Future investigations should focus on:

- Long-term (10+ year) safety data
- Standardized global treatment protocols
- Gene–environment interaction models
- Optimal combination regimens
- Cost-effectiveness in low-resource settings

8. CONCLUSION

8.1 Final Summary

Myopia has transitioned from a simple refractive condition to a major global ocular health challenge with significant long-term consequences. The progressive increase in its prevalence, particularly among children and adolescents, has necessitated a shift from conventional optical correction to active myopia control strategies aimed at slowing axial elongation.



This review comprehensively evaluated three major evidence-based interventions: orthokeratology, low-dose atropine therapy, and advanced spectacle lenses. Each modality demonstrates a distinct mechanism of action but converges on a common therapeutic goal—modulation of retinal signaling to reduce scleral growth and axial elongation.

Orthokeratology provides effective optical reshaping with strong myopia control benefits, particularly in motivated pediatric patients. Low-dose atropine has emerged as the most potent pharmacological option, offering dose-dependent efficacy with an acceptable safety profile. Spectacle lens technologies such as DIMS and HAL represent the safest and most accessible interventions, with consistent moderate-to-high efficacy in slowing disease progression.

8.2 Key Clinical Findings

- Myopia progression is biologically modifiable, not inevitable
- All three interventions significantly reduce axial elongation compared to single-vision correction
- Atropine (0.05%) demonstrates the highest efficacy but carries rebound risk
- Orthokeratology provides strong dual benefit (vision correction + control) but requires strict compliance
- Spectacle lenses offer the safest long-term option with minimal risk

8.3 Clinical Implications

The selection of myopia control therapy should be individualized based on:

- Age of the patient
- Rate of progression
- Baseline refractive error
- Lifestyle and visual demands
- Risk tolerance and compliance ability
- Financial feasibility

No single intervention is universally superior; instead, optimal outcomes are achieved through **personalized, patient-centered management strategies**.

8.4 Role of Combination Therapy

Emerging evidence supports the integration of multiple treatment modalities:

- Atropine + optical defocus strategies may provide additive benefits
- Orthokeratology combined with pharmacological therapy enhances axial control
- Behavioral interventions such as increased outdoor exposure improve all treatment outcomes

This multimodal approach represents the future of myopia management.

8.5 Future Perspectives

The future of myopia control is moving toward precision ophthalmology, incorporating:

- Artificial intelligence-based progression prediction
- Genetic risk profiling for early identification
- Smart optical devices with adaptive defocus systems

- Long-term sustained-release pharmacological agents
- Digital health monitoring of ocular growth patterns

These innovations will enable earlier intervention and more precise treatment customization.

8.6 Final Statement

In conclusion, orthokeratology, atropine therapy, and advanced spectacle lenses collectively represent the cornerstone of modern myopia management. While each has distinct strengths and limitations, their combined application within a personalized treatment framework offers the most effective strategy for controlling pediatric myopia progression.

Early detection, timely intervention, and individualized therapy selection remain essential to reducing the long-term burden of pathological myopia and its associated vision-threatening complications.

Conflict of Interest Statement

The authors declare no conflict of interest.

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