IJMEAR | International Journal of Medical Education And Research
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REVIEW
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Vol. 6 · No. 5 · October 2026

Physiological Optics, Accommodation and Refractive Errors: A Literature Review of Myopia, Hypermetropia, Astigmatism and Methods for Determining Clinical Refraction

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ABSTRACT

Background: Refractive errors (myopia, hypermetropia and astigmatism) are leading causes of correctable visual impairment worldwide, and their management depends on sound knowledge of ocular optics, accommodation and refraction measurement. Evidence on physiology, epidemiology, diagnosis and treatment is dispersed across specialties.

Objective: To synthesise current literature on physiological optics, accommodation, myopia, hypermetropia, astigmatism and methods for determining clinical refraction.

Methods: A literature review structured according to IMRAD was designed, with searches of PubMed, Scopus and MEDLINE using Boolean combinations of keywords (OR within concepts, AND between concepts). Systematic reviews, meta-analyses, randomised trials, large cohort studies and consensus reports were eligible; data were extracted into a single standard table. Findings were summarised narratively.

Results: Forty sources were synthesised in four thematic domains. Emmetropization is visually guided, and accommodation declines with age through lenticular change. Myopia prevalence is projected to reach nearly half of the world population by 2050, and low-concentration atropine, specialised spectacle and contact lenses, orthokeratology and outdoor time slow progression to varying degrees. Hypermetropia is common in early childhood and later adulthood, and astigmatism is highly prevalent with effective optical and surgical correction. Cycloplegic refraction remains the reference method for children and young adults, supported by autorefraction, retinoscopy, keratometry and subjective refinement.

Conclusion: Accurate, cycloplegia-aware refraction combined with age-appropriate correction and evidence -based myopia control offers the most reliable route to preventing avoidable visual loss. Standardised definitions, long-term trials and wider population data from underserved regions remain priorities. Clinicians should prefer cycloplegic measurement whenever accommodation may mask the true refractive state.

Keywords: *Myopia; Hypermetropia; Astigmatism; Accommodation; Clinical refraction*

1. Introduction

1.1 Background

The eye is a compound optical system in which the cornea and crystalline lens focus incoming light onto the retina, and image clarity depends on how closely total refractive power matches axial length [1]. During childhood, coordinated changes in corneal power, lens power and eye length move the initially hypermetropic eye toward emmetropia, a visually guided process called emmetropization [2], [3]. Accommodation, the dynamic increase in ocular power that allows near vision, gradually declines with age, culminating in presbyopia [4]. When this optical balance fails, refractive errors arise: myopia, hypermetropia and astigmatism, defined by where light focuses when accommodation is relaxed [5]. Together they represent the commonest cause of correctable visual loss; in 2010 an estimated 285

million people were visually impaired, and uncorrected refractive error accounted for 43% of impairment [6]. Presbyopia adds to this burden, affecting an estimated 1.8 billion people in 2015 [7]. Myopia has attracted particular attention because its prevalence is rising and could reach 49.8% of the global population by 2050, including 9.8% with high myopia [8]. A coherent understanding of physiological optics is therefore the foundation for diagnosis, correction and prevention across all refractive conditions. This review integrates these domains for clinical readers.

1.2 Problem Statement

Despite advances in optics and ophthalmic care, refractive errors remain a growing clinical and public health problem. Myopia is now regarded as a major cause of visual disability and a risk factor for serious ocular disease [9], [10], and childhood prevalence has risen markedly, particularly in East Asia [11]. High myopia predisposes to pathological complications, including myopic maculopathy and uncorrectable visual impairment [12], [13], and the associated lost productivity is substantial [14]. Yet the evidence base is fragmented. Definitions and thresholds differ between studies, which alters prevalence estimates and risk-factor associations [15]. Measurement practice also varies: non-cycloplegic refraction overestimates myopia and misclassifies emmetropia and hypermetropia, especially in the young [16]. Treatment evidence is similarly heterogeneous, with optical, pharmacological and behavioural interventions showing variable efficacy between individuals [17]. For hypermetropia, astigmatism and presbyopia, evidence is dispersed in separate literatures and is rarely linked to the practical question of how refraction should be measured. Students and clinicians consequently lack a single, current synthesis that connects optical physiology with diagnosis and treatment decisions. The central problem is therefore how best to integrate and apply dispersed evidence on refractive errors in everyday clinical refraction. Closing this gap is essential for preventing avoidable visual loss.

1.3 Novelty and Objective

Previous syntheses have mostly addressed single topics. Network meta-analyses compare myopia-control interventions [18], international consensus reports standardise terminology and trial instrumentation [5], [19], and dedicated reviews examine astigmatism [20] or presbyopia correction [21]. Few reviews connect the physiology of refraction and accommodation with the epidemiology, diagnosis and treatment of myopia, hypermetropia and astigmatism within one framework. The novelty of this review lies in four features. First, it links optical physiology and accommodation directly to clinical diagnosis. Second, it covers the three principal refractive errors together rather than separately. Third, it pairs treatment evidence with the measurement methods used to detect and monitor each error. Fourth, it presents extracted study data in a structured table and discusses them in a contextual, practice-oriented manner. The objective was to synthesise recent and landmark literature on physiological optics, refraction, accommodation, myopia, hypermetropia, astigmatism, diagnostic approaches and treatment, and to describe methods for determining clinical refraction. By doing so, the review aims to support evidence-based decisions by students, clinicians and researchers working in eye care and medical education. It also identifies gaps that merit further investigation. Emphasis is placed on sources that are verifiable in PubMed through PMID and DOI. Findings are organised in four thematic domains.

2. Methods

2.1 Review design

This study is a literature review prepared in IMRAD format, using a structured and reproducible search so that the selection of sources can be audited. Reporting followed the logic of a systematic search (identification, screening, eligibility, inclusion), while synthesis was narrative because the included

designs were heterogeneous.

2.2 Information sources and search strategy

Three databases were searched from inception to [insert search date]: PubMed, Scopus and MEDLINE (via Ovid). Search terms were organised into concept blocks. Synonyms within a block were joined with the Boolean operator OR, and blocks were combined with AND.

- **Block A (optics and refraction):** "physiological optics" OR "refraction, ocular" OR "refractive errors" OR accommodation OR emmetropization OR emmetropisation
- **Block B (conditions):** myopia OR nearsightedness OR hyperopia OR hypermetropia OR farsightedness OR astigmatism OR presbyopia
- **Block C (diagnosis):** diagnosis OR retinoscopy OR autorefraction OR "subjective refraction" OR cycloplegia OR keratometry OR "visual acuity"
- **Block D (treatment):** treatment OR therapy OR atropine OR orthokeratology OR spectacles OR "contact lenses" OR "refractive surgery" OR "toric intraocular lens"

The final expression was (Block A OR Block B) AND (Block C OR Block D). In PubMed it was combined with MeSH terms (for example, "Myopia"[Mesh] OR "Hyperopia"[Mesh] OR "Astigmatism"[Mesh]); in Scopus and MEDLINE the same logic was applied to title, abstract and keyword fields. Reference lists of key reviews were screened manually.

2.3 Eligibility criteria

Eligible sources were peer-reviewed systematic reviews, meta-analyses, randomised clinical trials, large cohort or population-based studies, and international consensus reports on human refractive error, accommodation or refraction methods, published in English and indexed in PubMed. Case reports, conference abstracts, editorials and animal studies were excluded, except where needed to explain foundational physiology.

2.4 Selection, data extraction and appraisal

Titles and abstracts were screened first, followed by full texts. Records identified: n = [___]; after duplicate removal: n = [___]; screened: n = [___]; full texts assessed: n = [___]; included: n = 40. For each source, the first author, year, design, population, intervention or measurement method, main outcome, PMID and DOI were extracted into a standard table. Sources were appraised narratively according to design hierarchy (consensus reports and systematic reviews, randomised trials, then cohort and cross-sectional studies).

3. Results

Four themes emerged (Sections 3.1 to 3.4), and the extracted data are summarised in Table 1.

3.1 Physiological optics, accommodation and emmetropization

The refractive state of the eye depends on the combined power of the cornea and crystalline lens relative to axial length; in emmetropia, parallel rays are focused on the retina when accommodation is relaxed [1], [5]. Neonates are typically hypermetropic, and coordinated reductions in corneal and lenticular power, offset by axial growth, shift the eye toward emmetropia in early childhood [1], [2]. This emmetropization appears to be controlled by visual feedback: retinal image quality is thought to regulate scleral remodelling and eye growth through a homeostatic mechanism [3]. Longitudinal cohort data show that eyes that later become myopic undergo accelerated axial elongation several years before onset [2], and that a baseline refraction close to emmetropia is the strongest single predictor of future myopia in school-aged children [22]. Parental myopia and early refractive status further refine

risk prediction [23].

Accommodation is the dynamic increase in ocular refractive power produced by ciliary muscle contraction, zonular relaxation and a change in lens shape, allowing clear vision at near [4]. Its amplitude falls steadily with age, and presbyopia, the resulting functional loss of near focus, is attributed chiefly to age-related changes in the crystalline lens rather than to failure of the ciliary muscle [4]. The scale of the problem is considerable: an estimated 1.8 billion people were presbyopic in 2015, and a large proportion lacked adequate near correction [7]. Correction strategies include spectacles, contact lenses, intraocular lenses and corneal procedures, with effectiveness depending on patient needs and visual demands [21]. These data indicate that accommodation is both a physiological resource in youth and a measurement confounder that must be controlled during refraction.

Accommodation also determines how refractive error is measured. Active accommodation during testing induces an apparent myopic shift and masks hypermetropia, so latent hypermetropia may be missed in children and young adults unless cycloplegia is used [5], [16]. The International Myopia Institute therefore defines myopia as a spherical equivalent of −0.50 D or more minus when accommodation is relaxed, and high myopia as −6.00 D or more minus [5]. Pre-myopia is defined as a refraction of +0.75 D or less and greater than −0.50 D in children whose risk factors justify preventive measures [5]. Taken together, the sources show that physiological optics underpins both the definition and the detection of refractive errors. Recognising these physiological principles is a prerequisite for interpreting any refraction result.

3.2 Myopia: epidemiology, diagnosis and treatment

Myopia prevalence has risen steeply. A meta-analysis of 145 studies projected that 4,758 million people (49.8%) would be myopic and 938 million (9.8%) highly myopic by 2050 [8], and a separate analysis of childhood data confirmed rising prevalence, especially in East Asia [11]. Risk factors identified in cohort studies include parental myopia, near work, educational exposure and reduced outdoor time [24], [25], while genome-wide data implicate light-induced retinal signalling pathways [26]. Outdoor exposure is the most consistently protective modifiable factor: lower prevalence was observed in children with more outdoor activity [27], and a cluster randomised trial in Guangzhou showed that an extra 40-minute outdoor class lowered three-year myopia incidence from 39.5% to 30.4% [28].

Diagnosis rests on cycloplegic refraction supported by axial length biometry and fundus assessment [5], [19]. Axial length is increasingly used because axial elongation drives most myopia progression [5]. Complications scale with severity: eyes with high myopia face greater risks of myopic maculopathy, whose progression has been documented over 18 years [29], and the photographic META-PM system grades myopic maculopathy from category 0 (none) to category 4 (macular atrophy) [30]. The risk of uncorrectable visual impairment increases with axial length [13], which explains why even small reductions in progression are clinically meaningful. Consequently, early identification of children at risk, using baseline refraction and axial length, is advocated [22]. Structured classification also allows consistent monitoring across clinics and studies.

Treatment aims to correct blur and slow progression. Atropine remains the best-studied drug: in ATOM2, 0.01% atropine retained comparable efficacy to 0.1% and 0.5% doses with minimal side effects [31], and in the LAMP study 0.05% atropine had roughly twice the effect of 0.01% over two years [32]. Optical options include defocus-incorporated multiple-segment spectacle lenses, which slowed progression and axial elongation over two years [33], dual-focus soft contact lenses, which reduced progression over three years [34], and orthokeratology, which slowed axial elongation in a two-year trial [35]. A Cochrane review found that multifocal spectacles slowed progression modestly (0.14 D) whereas topical antimuscarinics were more effective [36], consistent with network meta-analysis

ranking antimuscarinic drugs highest [18]. Behavioural measures, notably outdoor time, complement these interventions [17]. Overall, no single treatment is uniformly effective, and individual response varies [17].

3.3 Hypermetropia and astigmatism: diagnosis and treatment

Hypermetropia is a refractive state in which parallel light focuses behind the retina when accommodation is relaxed, usually because the eye is axially short. Prevalence depends on age and definition: pooled estimates suggest about 4.6% in children and 30.9% in adults [37], and among school-aged children it falls with age and varies between ethnic groups [38]. Young hypermetropes can compensate by accommodating, so symptoms may be absent or appear as asthenopia, and high uncorrected hypermetropia risks amblyopia and strabismus. Population-based data link higher degrees of refractive error, including hypermetropia and astigmatism, with poorer visual acuity [39]. Diagnosis therefore requires cycloplegic refraction in children to reveal total hypermetropia [16]; correction is reserved for symptomatic or high errors, plus lenses are first-line treatment, and refractive surgery or lens-based procedures are options in selected adults.

Astigmatism arises when corneal or lenticular curvature differs between meridians, producing two focal lines and blur at all distances. Pooled prevalence is about 14.9% in children and 40.4% in adults [37]. Uncorrected astigmatism reduces visual acuity, reading performance and visual comfort, and its impact depends on magnitude and axis orientation [20]. Diagnosis combines keratometry or topography, autorefraction, retinoscopy and subjective cylinder refinement [20]. Management includes spectacles, toric or rigid contact lenses, corneal refractive surgery and, during cataract surgery, toric intraocular lenses [20]. A meta-analysis of toric IOL studies found improved uncorrected distance vision and reduced residual astigmatism and spectacle dependence compared with non-toric lenses [40]. Because even low levels of cylinder can degrade vision, astigmatism should be corrected deliberately rather than neglected [20].

Across the two conditions, several points emerge. First, hypermetropia is often hidden by accommodation, whereas astigmatism is detected by meridional analysis, so both depend on appropriate measurement technique. Second, treatment follows a similar hierarchy: optical correction, contact lenses, then surgery for selected patients. Third, children require attention to amblyopia risk, whereas older adults require attention to presbyopia and lens-related astigmatic change. Fourth, pooled prevalence data (Table 1) show a different age profile for each error: hypermetropia and astigmatism are more frequent in adulthood, whereas myopia rises through school age and into young adulthood.

3.4 Methods for determining clinical refraction

Clinical refraction combines objective and subjective techniques. Objective methods include retinoscopy, autorefraction, keratometry and, increasingly, wavefront and biometric measurements, while subjective refraction uses trial lenses or a phoropter with visual acuity charts to refine sphere, cylinder and axis [19]. Cycloplegic refraction is considered the reference standard for epidemiological studies: non-cycloplegic measurement overestimates myopia and gives marked errors in estimates of emmetropia and hypermetropia [16]. The evidence indicates that this applies not only to children but also to adults up to about 50 years of age [16]. The International Myopia Institute similarly regards cycloplegia as the gold standard for studies of refraction in children [5], [19].

Measurement choices should be matched to the question. In clinical care, cycloplegic autorefraction or retinoscopy establishes the objective endpoint in children and in suspected latent hypermetropia, followed by subjective refinement to best-corrected acuity. In population studies, standardised cycloplegic protocols and clear thresholds are essential, since changing the myopia threshold by as little as 0.25 D can create false associations with risk factors [15]. Axial length biometry complements

refraction by separating axial from refractive myopia and by monitoring progression in trials [5], [19]. Keratometry or corneal topography quantifies corneal astigmatism, which is vital for planning toric lenses and surgery [20], [40].

Practical limits remain. Autorefractors may be less accurate in young children or when accommodation is not controlled, subjective refraction depends on patient responses and examiner skill, and cycloplegic drugs cause temporary blur and photophobia and require appropriate safety checks. Standard reporting should therefore state the method, the cycloplegic agent, the refractive parameter used (for example, spherical equivalent) and the thresholds applied [5]. Using these principles consistently improves comparability between clinics and studies and reduces misclassification of refractive error [15], [16]. In school screening, non-cycloplegic photorefraction or autorefraction may be acceptable for triage, but positive screens should be confirmed by cycloplegic examination. Measuring visual acuity with and without correction remains the simplest functional test and should accompany every refraction.

Table 1. Extracted data from the included sources

Ref.	Design	Population / scope	Key extracted finding
[6]	Global estimates	World, 2010	285 million visually impaired; uncorrected refractive error accounted for 43% of impairment
[7]	Systematic review, meta-analysis, modelling	World, 2015	About 1.8 billion people presbyopic; large unmet need for near correction
[8]	Systematic review, meta-analysis	145 studies; 2.1 million participants	Projected by 2050: 49.8% myopia and 9.8% high myopia
[5]	International consensus (IMI)	Clinical and epidemiological standards	Myopia ≤ −0.50 D; high myopia ≤ −6.00 D; pre-myopia ≤ +0.75 D and > −0.50 D; cycloplegia as gold standard
[22]	Cohort (CLEERE)	School-aged children	Near-emmetropic baseline refraction was the best single predictor of later myopia
[28]	Cluster randomised trial	12 primary schools, Guangzhou; grade 1 children	Myopia incidence 30.4% vs 39.5% (difference −9.1%) with an extra 40-minute outdoor class
[31]	Randomised trial (ATOM2)	400 children aged 6–12 years	Atropine 0.01% had comparable efficacy to 0.1% and 0.5% with minimal side effects
[32]	Randomised trial (LAMP, phase 2)	Children, Hong Kong	Atropine 0.05% efficacy about twice that of 0.01% over two years
[33]	Randomised trial, 2 years	Children	DIMS spectacle lenses slowed progression and axial elongation vs single-vision lenses
[34]	Randomised trial, 3 years	Children	MiSight dual-focus lenses reduced myopia progression vs single-vision lenses
[35]	Randomised trial, 2 years	Children	Orthokeratology slowed axial elongation vs spectacle wearers
[36]	Cochrane systematic review	Randomised trials in children	Multifocal spectacles: 0.14 D less progression (95% CI 0.08–0.21; n = 1,463); topical antimuscarinics effective
[37]	Systematic review, meta-analysis	Global	Children: myopia 11.7%, hypermetropia 4.6%, astigmatism 14.9%. Adults: 26.5%, 30.9%, 40.4%
[40]	Systematic review, meta-analysis	Cataract surgery	Toric IOLs improved uncorrected distance vision and reduced residual astigmatism vs non-toric IOLs
[16]	Evidence review	Epidemiological studies	Non-cycloplegic refraction overestimates myopia and misclassifies hypermetropia; applies to adults up to about 50 years

† Values from sources marked † in the reference list should be confirmed against the original abstracts.

4. Discussion

This review set out to connect physiological optics with the diagnosis and treatment of the common refractive errors, and the sources reviewed support that connection. Emmetropization, accommodation and the definition of refractive state are inseparable: the same visual feedback that guides eye growth [3] is accompanied by an accommodative demand that can mask hypermetropia and exaggerate myopia during testing [5], [16]. The practical consequence is that diagnostic accuracy in children and young adults depends on controlling accommodation. Within this framework, myopia dominates the literature because its prevalence is rising [8], [11] and because high myopia carries a risk of irreversible complications [12], [13], [29]. By contrast, hypermetropia, astigmatism and presbyopia are common across the lifespan [4], [7], [37], yet appear less often in recent intervention trials, which suggests an imbalance between disease burden and research attention.

The treatment literature illustrates both promise and limitation. Low-concentration atropine, specialised spectacle and contact lenses, orthokeratology and outdoor time all slow myopia progression [28], [31]–[35], but effects are partial and heterogeneous [17], [36]. The ATOM2 and LAMP trials point to different optimal atropine concentrations [31], [32], reminding clinicians that dose, population and follow-up length change conclusions. Network and Cochrane syntheses rank antimuscarinics highest, while multifocal spectacles show only a modest average effect [18], [36]. Because axial elongation, not refraction alone, is the biological driver, trial instrumentation and outcome choice matter [19]. For hypermetropia and astigmatism the evidence is mostly observational or procedural: toric intraocular lenses reduce residual astigmatism after cataract surgery [40], and the visual cost of uncorrected cylinder is well documented [20], [39], but long-term comparative trials in children are scarcer.

Context shapes how these findings should be applied. Uncorrected refractive error is a leading cause of visual impairment worldwide [6], so the greatest gains may come from reliable, affordable refraction and spectacle provision rather than from advanced myopia-control technology. Cycloplegic refraction and axial biometry are resource-dependent; where they are unavailable, clinicians should recognise the likely direction of error, since non-cycloplegic measurement overestimates myopia and misclassifies hypermetropia [16]. The sources included here were drawn mainly from East Asian, European and North American populations, so applicability to rural and lower-resource settings, with different environmental exposures and school systems, cannot be assumed. Variation in thresholds and definitions further complicates comparison between regions [5], [15], which is why adopting consensus definitions is a practical first step.

This review has limitations. It is a narrative synthesis of heterogeneous designs, restricted to English-language, indexed publications, and it relies partly on secondary sources and consensus reports, so publication bias and selection bias are possible. Effect sizes from different trials are not directly comparable because populations, baseline refraction and follow-up differ. Future work should prioritise harmonised definitions, long-term follow-up after treatment cessation, comparative trials of combined therapies, studies of hypermetropia and astigmatism in children, economic evaluation of myopia control and refraction services, and population-based cycloplegic surveys in under-represented regions. Such evidence would allow physiological principles, measurement standards and treatment choices to be combined into practical, context-sensitive guidelines for everyday eye care.

5. Conclusion

This literature review shows that physiological optics, accommodation and refraction measurement form one connected clinical framework. Emmetropization is a visually guided process, accommodation declines with age through lenticular change, and refractive state can only be defined reliably when accommodation is controlled [1]–[5], [16]. Myopia is increasing worldwide and may affect nearly half of

the global population by 2050 [8], with high myopia carrying a risk of irreversible complications [12], [13]. Hypermetropia, astigmatism and presbyopia are also highly prevalent, particularly in adults [7], [37], and each has effective optical or surgical correction [20], [21], [40]. Together these domains explain why accurate refraction is the starting point of nearly every eye-care decision.

Several practical conclusions follow. First, cycloplegic refraction should be the reference method in children, in suspected hypermetropia and in epidemiological work [16]. Second, standardised definitions, with myopia at −0.50 D or more minus and high myopia at −6.00 D or more minus, should be used and reported together with the method and agent [5], [15]. Third, myopia control should be offered early to children at risk, selecting from atropine, specialised optical devices, orthokeratology and increased outdoor time according to age, progression rate, safety and availability [17], [28], [31]–[36]. Fourth, astigmatism and hypermetropia deserve deliberate correction, and toric solutions should be considered in cataract surgery [20], [40]. Fifth, presbyopia requires accessible near correction [7], [21].

Important gaps remain. Evidence is concentrated in a few regions, long-term outcomes after stopping myopia treatment are incompletely understood, and trials of hypermetropia and astigmatism management in children are limited. Future research should harmonise outcomes, combine axial length with refraction in follow-up, evaluate costs and access, and generate local cycloplegic data in under-represented populations. Educationally, integrating physiological optics with practical refraction training can improve the quality of care delivered by new clinicians. If these steps are taken, refractive services can move from simply correcting blur to preventing avoidable visual loss across the life course. In summary, accurate measurement, standard definitions, age-appropriate correction and evidence-based myopia control are the pillars of modern refractive care.

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