Clinical Ophthalmology

Dovepress
Taylor & Francis Group

Open Access Full Text Article

REVIEW

Effectiveness of Low-Dose Atropine (0.01% to 0.05%) in Reducing Myopia Progression: A Systematic Review and Meta-Analysis

Abdullah S Alqahtani[1–3], Salma Hamdan Almarwani[2,3], Basmah Saeed Alweal[2,3], Mohammad Albadri[2,3], Lama Nasser Alghamdi[2,3], Bushra Wadi Bin Saddiq[4], Ahmed Salah Morad[4]

[1]Department of Ophthalmology, National Guard Hospital, Jeddah, Saudi Arabia; [2]College of Medicine, King Saud bin Abdulaziz University for Health Sciences, Jeddah, Saudi Arabia; [3]King Abdullah International Medical Research Center, Jeddah, Saudi Arabia; [4]General Medicine Practice Program, Batterjee Medical College, Jeddah, Saudi Arabia

Correspondence: Salma Hamdan Almarwani, Email Salmaaalmarwani@gmail.com

Purpose: Low-dose atropine has been increasingly investigated as a pharmacological intervention to slow myopia progression in children. However, variability in atropine concentrations and reported outcomes across randomised clinical trials has led to uncertainty regrading its overall efficacy and safety. This systematic review and meta-analysis evaluated the efficacy and safety of low-dose atropine eye drops (0.01–0.05%) in slowing myopia progression in children.

Patients and Methods: This review followed PRISMA guidelines and was registered in PROSPERO (CRD42025635523). A comprehensive search of PubMed, ScienceDirect, MedLine, and the Cochrane Library was conducted in January 2025. Eligible studies were randomized controlled trials from 2019 to 2024 involving children aged 4–18 years with progressive myopia. Low-dose atropine concentrations evaluated across studies included 0.01%, 0.02%, 0.025%, and 0.05%, compared with placebo or control interventions. Data extraction and risk of bias assessment using the Cochrane Risk of Bias 2.0 tool were performed independently by multiple reviewers. Meta-analysis was conducted using Review Manager (RevMan) 5.4 on Mean changes in axial length and spherical equivalent. Fixed or random effects models were applied based on heterogeneity (I^2).

Results: Thirteen randomized controlled trials involving 2529 children were included. Low-dose atropine (0.01–0.05%) significantly reduced axial elongation compared with placebo (mean difference [MD]: −0.11 mm; 95% CI: −0.13 to −0.09; $p < 0.00001$) with substantial heterogeneity ($I^2 = 92\%$). Similarly, atropine was effective in slowing spherical equivalent progression (MD: +0.24 D; 95% CI: +0.14 to +0.33; $p < 0.00001$; $I^2 = 79\%$). Sensitivity analyses confirmed the robustness of these findings. Risk of bias was generally low across included trials, particularly for randomisation and incomplete outcome data, although some studies showed concerns related to participants blinding and outcome assessment. No substantial evidence of publication bias was observed.

Conclusion: Low-dose atropine (0.01–0.05%) may be an effective and generally safe intervention for slowing myopia progression in children. While the findings support its potential role in myopia control, further long-term trials are needed to clarify optimal dosing strategies and sustained post-treatment effects.

Keywords: myopia, low-dose atropine, axial length, spherical equivalent, children

Introduction

Myopia is the most common refractive error worldwide and represents a growing public health concern, with a current global prevalence estimated at 33.9% and projections indicating that nearly 50% of the world's population will be affected by 2050.[1] The burden of myopia is particularly high in Saudi Arabia, where local studies report prevalence approaching 50%, exceeding rates observed in many Western countries.[2] In response to this increasing prevalence, several interventions have been investigated to slow myopia progression, including increased time spent outdoors,[3,4] optical strategies such as multifocal spectacles and contact lenses, and pharmacological approaches using topical antimuscarinic agents.[5] Among these interventions, atropine eye drops have demonstrated consistent efficacy in reducing

https://doi.org/10.2147/OPTH.S564944
Received: 22 October 2025
Accepted: 25 March 2026
Published: 7 May 2026

myopia progression across multiple randomized controlled trials.[6–8] Although the precise mechanism of action of atropine remains incompletely understood, it is believed to involve M-cholinergic receptor antagonism with downstream effects on retinal signaling pathways and ocular growth, prompting investigation into whether its clinical efficacy is dose dependent.[8] Evidence suggests that higher atropine concentrations provide greater myopia control but are also associated with increased adverse effects that may limit long term tolerability.[9] Consequently, recent studies have shifted focus toward low-dose atropine regimens to balance efficacy and safety; however, findings regarding the comparative effectiveness and side effect profiles of low concentrations (0.01–0.05%) remain inconsistent across individual trials.[6,7,10] Moreover, previous meta-analyses have evaluated a wide range of atropine doses or have not specifically focused on the low-dose spectrum most commonly used in current clinical practice.[9] Therefore, this systematic review and meta-analysis aims to address this evidence gap by synthesizing available data on low-dose atropine (0.01–0.05%) to assess its effectiveness in reducing myopia progression measured by changes in axial length and refractive error while also evaluating associated adverse effects and tolerability, thereby providing clinically relevant evidence to guide optimal myopia management.

Methodology

Protocol and Registration

This systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency and methodological rigor (Supplementary File 1). The protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) under the ID CRD42025635523. Ethical approval was not required as the study involved only the secondary analysis of previously published data.

Literature Search Strategy

A comprehensive literature search was conducted in January 2025 across four electronic databases: PubMed, ScienceDirect, MedLine, and the Cochrane Library. No restrictions were placed on geographic region or publication date. The search strategy utilized both Medical Subject Headings (MeSH) and free-text terms, connected with Boolean operators. The terms used included: (Myopia OR Progressive Myopia) AND (Atropine) AND (Low-Dose Atropine OR 0.01% Atropine) AND (Axial Length OR Refractive Errors). The search strategy was guided by the PICOS framework (Population, Intervention, Comparison, Outcomes, and Setting) to identify relevant studies.

Study Selection

Eligible studies met the following inclusion criteria: randomized controlled trial (RCT) design, participants aged 4–18 years with progressive myopia, intervention with low-dose atropine (0.01–0.05%), and the use of a placebo, no treatment, or alternative myopia control method as a comparator. Studies were required to report outcomes related to myopia progression, including changes in axial length and spherical equivalent, as well as secondary outcomes such as side effects, tolerability, and quality of life. Studies were excluded if they were non-randomized, retrospective, case reports, or review articles; involved adults over 18 years or participants with other refractive errors; used high-dose atropine (>0.05%); or lacked a comparator group or relevant outcome measures.

Screening and Data Extraction

All articles retrieved during the database search were organized using a Google spreadsheet. Two independent reviewers (BB, AM) screened the titles and abstracts using Rayyan, a web-based tool for systematic reviews. Conflicts were resolved through discussion or by involving a third reviewer. Full texts of potentially eligible studies were then assessed against the inclusion criteria. Data extraction was conducted by one reviewer (SA) and verified by two others (BB, AM). Extracted variables included study characteristics, participant demographics, intervention details, and primary and secondary outcome measures. When data were presented only in graphical form, the GetData Graph Digitizer software was used to extract numerical values. In instances where mean changes from baseline were not directly reported, these

values were calculated manually using the baseline and follow-up data provided in the studies. Missing standard deviations were estimated from confidence intervals or standard errors when necessary. All extracted data were double-checked to ensure accuracy and completeness.

Assessment of Quality and Risk of Bias

The methodological quality and risk of bias of each included RCT were independently evaluated by two reviewers (BB, BA) using the Cochrane Risk of Bias 2.0 (RoB 2) tool. This tool assesses five domains related to bias arising from the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Each domain was judged as having a low risk of bias, some concerns, or a high risk of bias. These judgments were then used to determine the overall risk of bias for each study.

Statistical Analysis and Meta-Analysis

Meta-analysis was performed using Review Manager (RevMan) software, version 5.4. Statistical heterogeneity among studies was assessed using the Cochrane Q test and the I^2 statistic. A random-effects model was used when significant heterogeneity was present ($p < 0.05$, $I^2 > 50\%$), while a fixed-effects model was applied in cases of low heterogeneity ($p > 0.05$, $I^2 < 50\%$). The primary outcomes were pooled using mean difference (MD) and reported with corresponding 95% confidence intervals (CIs). The analysis focused on the mean change from baseline in axial length and spherical equivalent refractive error. When mean changes were not reported, they were manually calculated by the authors based on baseline and endpoint values. A p-value of less than 0.05 was considered statistically significant.

Results

Search Result and Study Selection

A total of 1089 articles were retrieved from four databases: PubMed (n = 300), ScienceDirect (n = 167), MedLine (n = 430), and Cochrane (n = 192). After removal of duplicates, 914 records were screened by title and abstract. Of these, 31 studies were assessed for full-text eligibility. Eighteen were excluded for not meeting inclusion criteria: 5 used high-dose atropine, 4 were not focused on children, 1 was not in English, and 8 had incompatible designs. Finally, 13 RCTs were included in the systematic review and meta-analysis (Figure 1).

Study Baseline Characteristics

Thirteen RCTs comprising 2,497 children aged 4–16 years were included. The mean follow-up duration across studies was 13.6 months, ranging from 12 to 24 months. Gender distribution was generally balanced, with males comprising an average of 49.5% of the sample. The mean baseline axial length ranged from 22.21 mm to 24.85 mm, while the mean baseline spherical equivalent refractive error ranged from −1.19 D to −3.93 D across included trials. Additional characteristics including study design, sample sizes, and treatment durations are detailed in Tables 1 and 2.

Change in Axial Length

A total of thirteen studies were included in the analysis of axial length change, encompassing 1,620 participants in the low-dose atropine group and 909 in the placebo group. As shown in Figure 2), this meta-analysis revealed a statistically significant reduction in axial elongation among those receiving low-dose atropine compared to placebo (Mean Difference = −0.11 mm, 95% CI [−0.13, −0.09], $P < 0.00001$). Heterogeneity across studies was substantial ($I^2 = 92\%$, $\chi^2 = 143.65$, $P < 0.00001$). The greatest reduction in axial length was observed in the study by Can Cui et al (MD = −0.56 mm, 95% CI [−0.65, −0.48]), whereas other studies, such as Henry H. L. Chan et al and Wei et al, demonstrated smaller or non-significant differences. Despite variability in effect sizes, the direction of effect was consistent, favoring low-dose atropine over placebo.[18,19,20] Sensitivity analysis was conducted by excluding the study by Can Cui et al, which reported the largest treatment effect. This exclusion

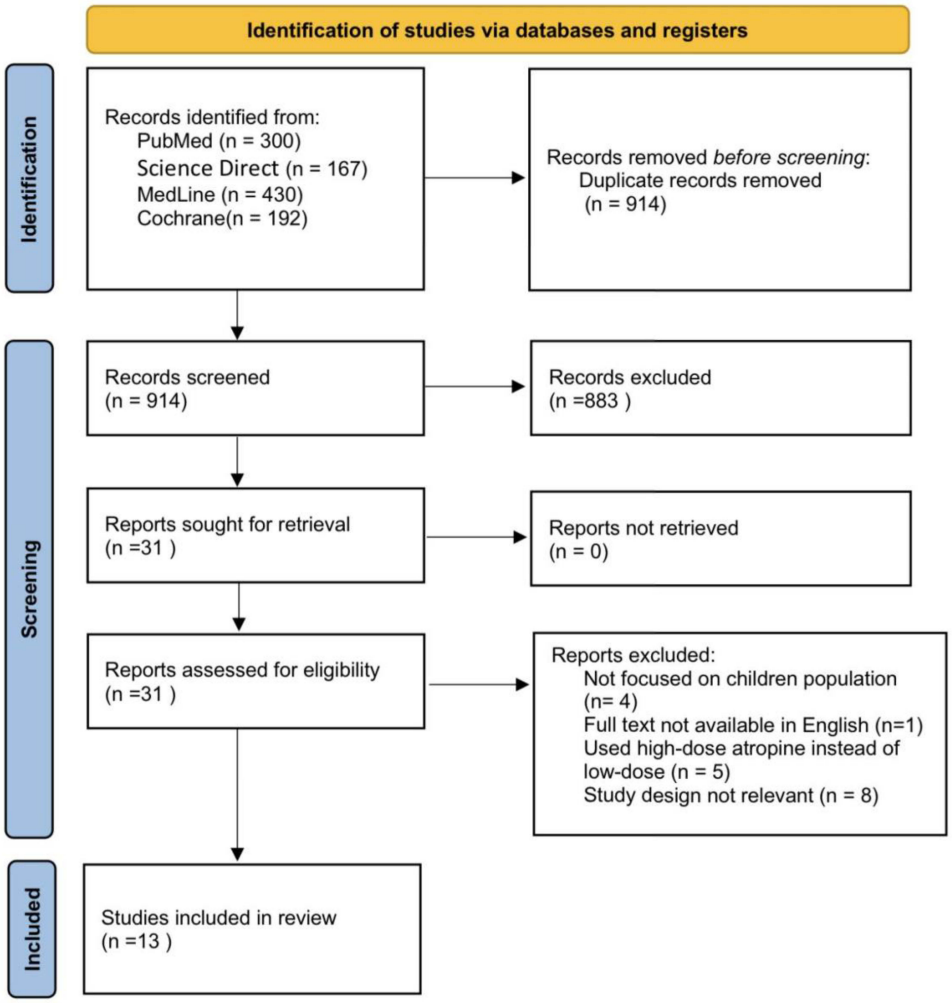

Figure 1 PRISMA flow chart for screening and selection of included studies.

resulted in a slightly reduced overall mean difference (MD = −0.08 mm, 95% CI [−0.11, −0.06], P < 0.00001), with a substantial drop in heterogeneity (I^2 = 25%, χ^2 = 14.64, P = 0.20). This suggests that the findings are robust, and the originally observed heterogeneity was primarily attributable to the outlier effect of a single study.[18,20] The high heterogeneity observed in the primary analysis likely reflects underlying clinical and methodological differences among trials, including variation in atropine concentration within the low-dose range (0.01–0.05%), baseline axial length and severity of myopia, duration of follow-up, and population characteristics. Although subgroup analyses stratified by dose, baseline refractive status, or follow-up duration would be clinically informative, such analyses were not feasible due to inconsistent reporting and limited availability of stratified data across the included studies.

Change in Spherical Equivalent Refraction (SER)

Twelve of the thirteen included studies reported data on changes in spherical equivalent refraction, comprising a total of 1,370 participants in the low-dose atropine group and 827 in the placebo group. According to Figure 3, the pooled analysis showed a statistically significant improvement in SER among children treated with low-dose atropine, compared to those receiving placebo (Mean Difference = 0.24 D, 95% CI [0.14, 0.33], P < 0.00001). Moderate heterogeneity was observed (I^2 = 79%, χ^2 = 49.49, P < 0.00001). The most substantial treatment effect was seen in Shweta Chaurasia et al (MD = 0.46 D, 95% CI [0.35, 0.57]), while Henry H. L. Chan et al and Wei et al

Table 1 Summary of Included Studies

Study	Year	Sample Size (n)		Age Range	Gender %		Follow-Up Duration (Months)
		intervention	Control		Male	Female	
Wang et al, (2024)[11]	2024	200	100	6-12	50.7	49.3	12
Audrey Chia et al (2023)[12]	2023	73	26	6-11	47.5	52.5	12
Liping Xia et al (2023)[13]	2023	82	82	6-16	Group1: 537 Group2: 524	Group1: 46.3 Group2: 47.6	12
Liang et al (2023)[14]	2023	76	83	6-12	50	50	12
Jason C Yam et al (2019)[6]	2019	327	111	4-12	50	50	12
Henry H L Chan et al (2022)[15]	2022	34	27	7-10	NA	NA	18
Shweta Chaurasia et al (2022)[16]	2022	40 right eye	40 left eye	6-16	50	50	12
Simonaviciute et al (2024)[17]	2024	55	66	6-12	35	65	12
James Loughman et al (2024)[18]	2024	167	83	6-16	38.9	61.1	24
Wei et al (2023)[19]	2023	65	68	6-12	NA	NA	24
Weiqun Wang et al (2022)[20]	2023	30	30	6-12	46.7	53.3	13
Can Cui et al (2021)[21]	2021	117: 001% 119: 002%	100	6-14	52	48	24
Shifei Wei et al (2020)[22]	2020	110	110	6-12	46.8	53.2	12

showed little or no difference between groups.[19,20] The study by Simonaviciute et al did not provide data suitable for inclusion in the SER meta-analysis. A sensitivity analysis was conducted by excluding Henry H. L. Chan et al and Wei et al, both of which had near-null effects. The revised meta-analysis included 1,271 participants in the atropine group and 732 in the placebo group. The updated pooled estimate remained statistically significant (MD = +0.29 D, 95% CI [+0.21, +0.36], $P < 0.00001$), with a moderate decrease in heterogeneity ($I^2 = 66\%$, $\chi^2 = 26.39$, $P = 0.002$).[20,23] These findings support the robustness of the observed SER effect in favor of low-dose atropine The observed heterogeneity is likely attributable to inter-study variability in atropine dosage, baseline refractive error, duration of treatment, and study population characteristics. Although subgroup analyses based on these factors were considered, inconsistent reporting and insufficient stratified data across trials precluded meaningful subgroup comparisons.[23]

Risk of Bias Assessment

The risk of bias of the included randomized controlled trials was independently evaluated using the Cochrane Risk of Bias 2 (RoB 2) tool, which assesses five predefined domains: bias arising from the randomization process, bias due to deviations from intended interventions, bias resulting from missing outcome data, bias in the measurement of outcomes, and bias in the selection of the reported result. Most trials were judged to be at low risk of bias with

https://doi.org/10.2147/OPTH.S564944

Table 2 Baseline Characteristics

Study	Baseline Axial Length Change				Baseline Spherical Equivalent Refractive Error			
	Atropine		Placebo		Atropine		Placebo	
	Mean (SD)	Total	Mean (SD)	Total	Mean (SD)	Total	Mean (SD)	Total
Wang et al, (2024)[11]	24.58 (0.83)	200	24.42 (0.88)	100	−2.32 (1.29)	200	−2.27 (1.31)	100
Audrey Chia et al (2023)[12]	2477 (0.7)	25	24.79 (0.8)	26	−3.25 (1.1)	25	−3.93 (1.31)	26
Liping Xia et al (2023)[13]	2221 (1.48)	82	22.58 (1.62)	82	−2.76 (0.39)	82	−2.79 (0.42)	82
Liang et al (2023)[14]	2464 (0.78)	76	24.73 (0.97)	83	−2.69 (1.27)	76	−2.85 (1.45)	83
Jason C. Yam et al (2019)[6]	247 (0.99)	110	24.82 (0.97)	111	−3.77 (1.85)	110	−3.85 (1.95)	111
Henry H. L. Chan et al (2022)[15]	2417 (0.79)	34	24.09 (0.74)	27	−1.88 (1.08)	34	−1.74 (0.71)	27
Shweta Chaurasia et al (2022)[16]	24.52 (1.16)	43	24.56 (1.1)	43	−3.04 (1.36)	43	−3.07 (1.32)	43
Simonaviciute et al (2024)[17]	24.46 (0.65)	55	24.16 (1.03)	66	−2.38	55	−2.06	66
James Loughman et al (2024)[18]	24.85 (1.02)	167	24.93 (1.09)	83	−3.21	167	−3.38	83
Wei et al (2023)[19]	24.62 (0.8)	65	24.72 (0.96)	68	−2.65 (1.29)	65	−2.74 (1.48)	68
Weiqun Wang et al (2022)[20]	23.59 (0.77)	30	23.61 (0.75)	30	−1.19 (0.28)	30	−0.21 (0.32)	30
Can Cui et al (2021)[21]	24.6 (0.72)	106	24.54 (0.69)	89	−2.76 for 0.01% −2.81 for 0.02% (1.56 for 0.01% 1.47 for 0.02%)	106 for 0.01% 105 for 0.02%	−2.66 (1.39)	89
Shifei Wei et al (2020)[22]	24.5 (0.76)	110	24.69 (0.97)	110	−2.52 (1.33)	110	−2.64 (1.46)	110

Abbreviation: SD, Standard deviation.

respect to randomization procedures, allocation concealment, and selective outcome reporting. Some concerns were noted in domains related to blinding of participants, study personnel, and outcome assessors, primarily due to insufficient or unclear reporting of masking methods. In addition, a limited number of studies demonstrated high or unclear risk of bias in the outcome measurement domain. Overall, the included trials were considered to have a low to moderate risk of bias, indicating acceptable methodological quality and supporting the internal validity of the pooled effect estimates. Detailed domain-level risk of bias judgments for each study are presented in Figures 4 and 5.

Axial length and spherical equivalent both show symmetry, indicating a low risk of publication bias. Results are shown in the funnel plots in Figures 6 and 7.

Discussion

This meta-analysis reinforces the effectiveness of low-dose atropine (0.01%—0.05%) in managing myopia progression in children as evidenced by axial length (AL) increase and spherical equivalent refraction (SER) changes. Our findings are consistent with other meta-analyses[23,24] but also expand their scope by showing that low-dose atropine does substantially decrease axial elongation compared to control (MD: −0.11 mm; 95% CI: −0.13 to −0.09) and SER progression (MD: +0.24 D; 95% CI: +0.14 to +0.33). Reduction in axial elongation is especially important because it correlates anatomically with myopia progression. Moreover, it directly strengthens the link with incidence of sight threatening complications like myopic maculopathy and retinal detachment in adulthood.[25,26] Their impact on axial length has

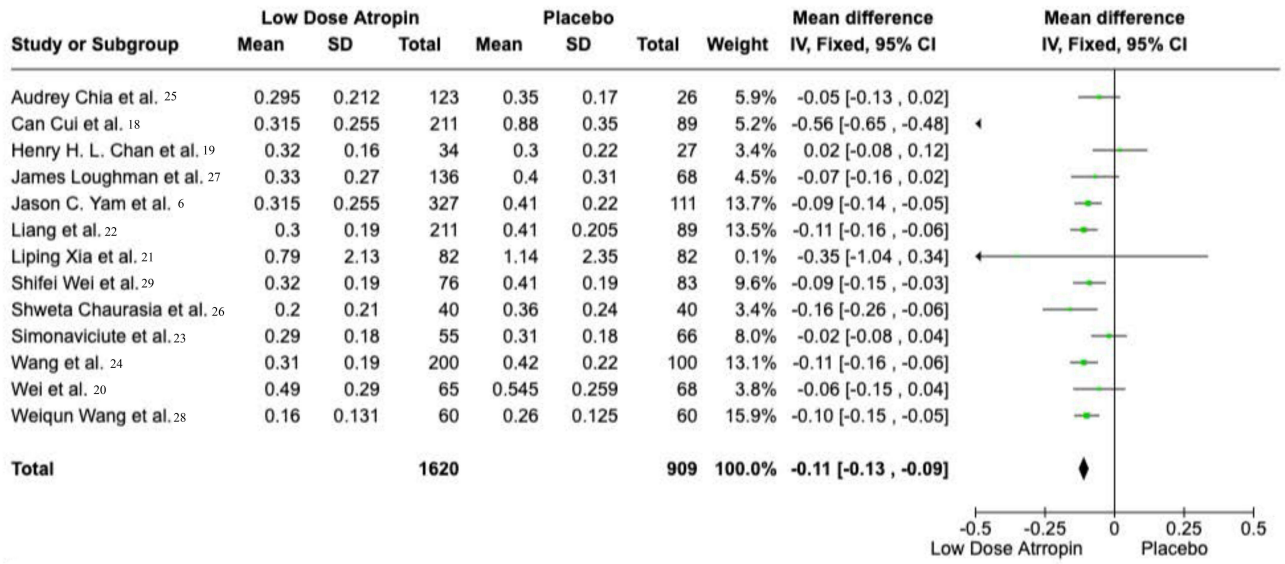

Figure 2 Forest plot for change in axial length. Forest plot comparing the mean change in axial length between low-dose atropine and placebo groups. Each green square represents the mean difference for an individual study, and the size of the square reflects the study weight in the meta-analysis. Horizontal lines indicate 95% confidence intervals (CI). The vertical line at 0 represents no difference between groups. The diamond represents the pooled mean difference with its 95% CI. The overall pooled effect (fixed-effect model) showed a statistically significant reduction in axial length progression in the low-dose atropine group compared with placebo (mean difference −0.11 mm, 95% CI −0.13 to −0.09; Z = 11.91, P < 0.00001). Statistical heterogeneity was high (Chi^2 = 143.65, *df* = 12, P < 0.00001; I^2 = 92%).

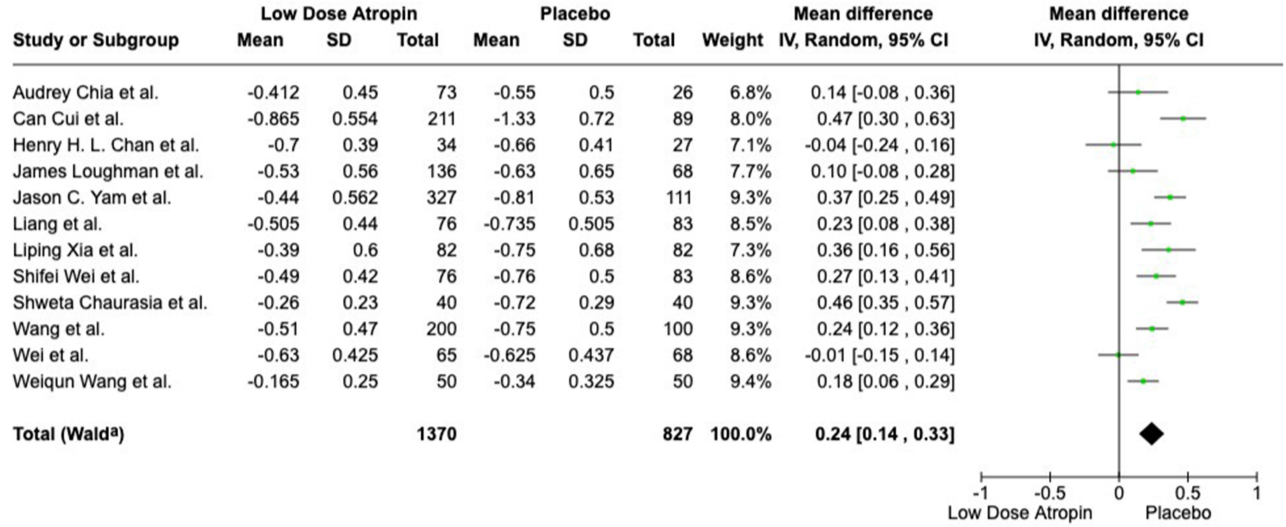

Figure 3 Forest plot for change in SER. Forest plot comparing the mean change in spherical equivalent refraction (SER) between low-dose atropine and placebo groups. Each green square represents the mean difference for an individual study, with square size proportional to study weight. Horizontal lines indicate 95% confidence intervals (CI). The vertical line at 0 represents no difference between groups. The diamond represents the pooled mean difference with its 95% CI. The pooled analysis (random-effects model) demonstrated a statistically significant benefit favoring low-dose atropine (mean difference 0.24 D, 95% CI 0.14 to 0.33; Z = 5.03, P < 0.00001). Heterogeneity was substantial (Tau^2 = 0.02; Chi^2 = 49.49, *df* = 11, P < 0.00001; I^2 = 79%). Superscript "a" indicates the Wald test statistic used to calculate the overall pooled effect.

clinical significance, meaning even minimal concentration of atropine may alter the eye's elongation dynamics during key developmental periods. Moderate to high levels of heterogeneity were seen in both the AL and SER analyses (I^2 = 92%, 79% respectively). However, sensitivity analyses (for example, exclusion of Can Cui et al and Henry H. L. Chan et al studies) proved the robustness of such results, increasing treatment effect consistency and significantly decreasing

https://doi.org/10.2147/OPTH.S564944

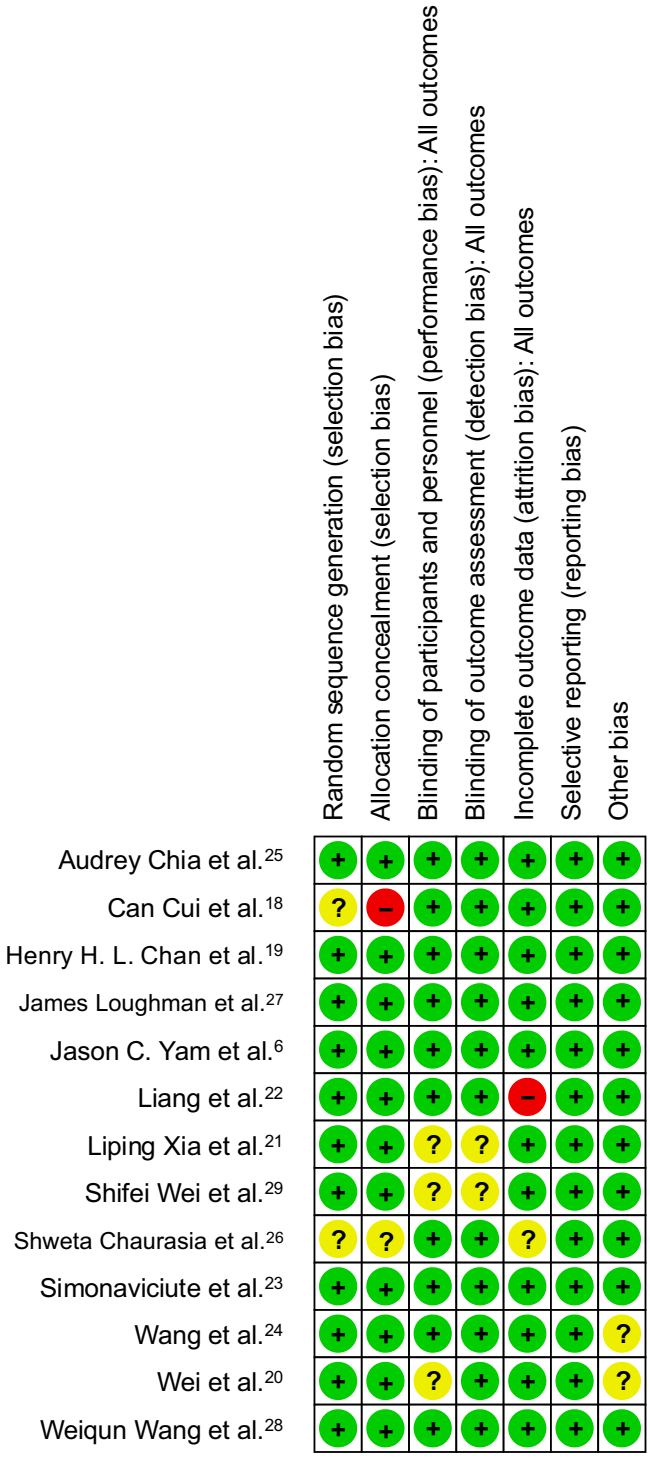

Figure 4 Risk of bias graph for included studies. Risk of bias assessment for each included study across predefined domains (random sequence generation, allocation concealment, blinding, incomplete outcome data, selective reporting, and other bias). Each row represents an individual study and each column represents a risk of bias domain. Green circles with a "+" indicate low risk of bias, yellow circles with a "?" indicate unclear risk of bias, and red circles with a "–" indicate high risk of bias.

heterogeneity.[18,19] This implies that variability may stem from methodological differences or outliers rather than fundamental inconsistency in atropine's efficacy.[19] It is noteworthy that studies using slightly higher concentrations within the low-dose range (eg., 0.05%) reported relatively greater treatment effects, which supports the dose-dependent

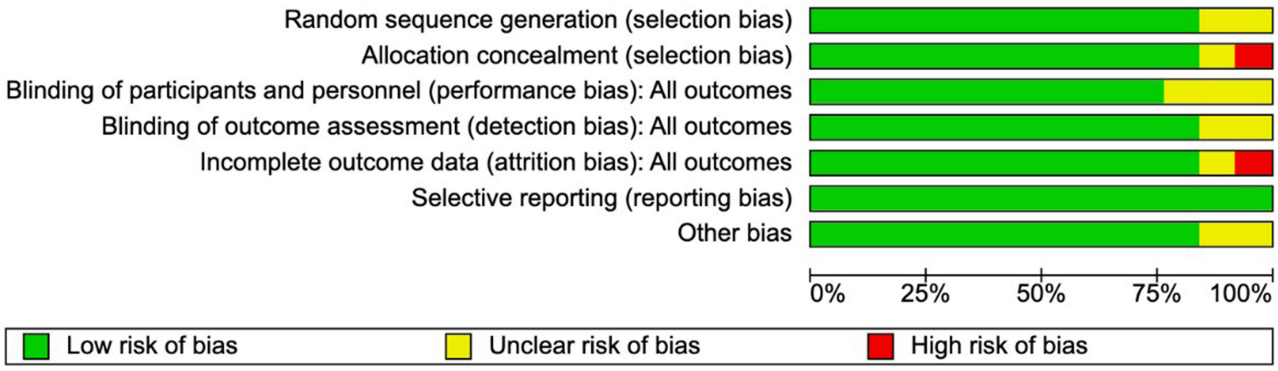

Figure 5 Risk of Bias Summary.

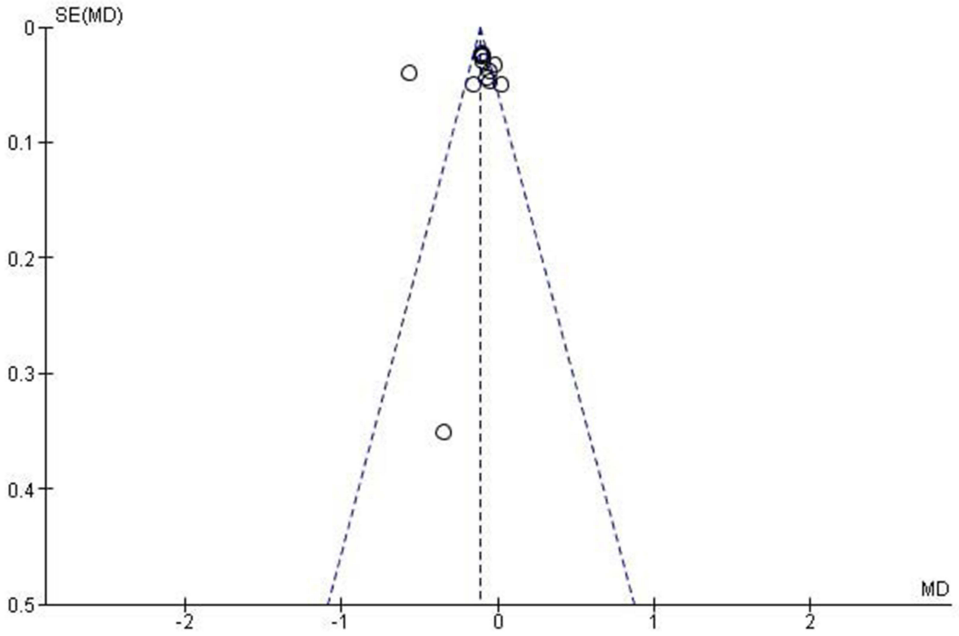

Figure 6 Funnel plot for Axial Length. Funnel plot assessing potential publication bias for studies reporting axial length change. Each open circle represents an individual study plotted according to its mean difference (MD) and standard error (SE). The vertical dashed line represents the pooled effect estimate. The outer dashed diagonal lines indicate the pseudo 95% confidence limits around the pooled effect. Symmetry of the distribution suggests absence of significant publication bias.

response seen in other investigations.[6] However, higher doses may be associated with more side effects such as photophobia or near vision blur, which must be weighed against clinical benefits.[27] Importantly, the risk of bias was generally low across the included randomized controlled trials, with most studies showing adequate randomization, blinding, and outcome reporting. However, a few studies presented unclear or high risks in allocation concealment and outcome assessor blinding, which should be considered when interpreting the pooled results. These findings are particularly relevant given the global rise in childhood myopia prevalence, especially in East Asia.[1] Early intervention with safe and effective pharmacological agents like low-dose atropine can significantly alter the course of myopia progression, offering long-term visual and economic benefits.[28] Despite the encouraging results, limitations should be acknowledged. Follow-up durations varied between studies, and long-term efficacy and safety data beyond 2–3 years are still limited. Additionally, racial and environmental factors—such as outdoor activity and near work—were inconsistently reported, though they are known to influence myopia development.[4,29]

https://doi.org/10.2147/OPTH.S564944

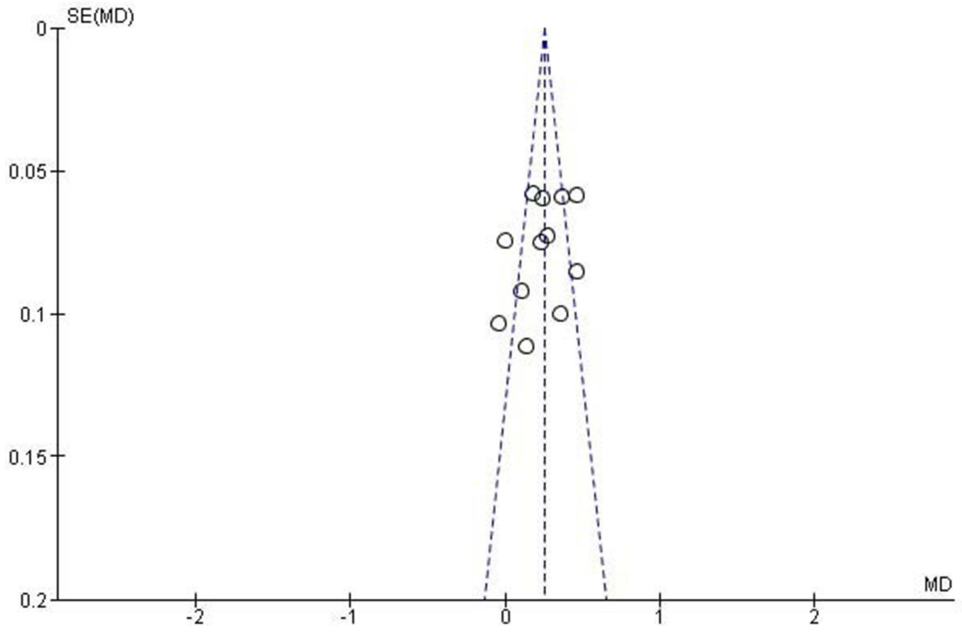

Figure 7 Funnel plot for spherical equivalent refraction (SER). Funnel plot assessing potential publication bias for studies reporting spherical equivalent refraction (SER) change. Each open circle represents an individual study plotted according to its mean difference (MD) and standard error (SE). The vertical dashed line represents the pooled effect estimate. The outer dashed diagonal lines indicate the pseudo 95% confidence limits around the pooled effect. Symmetry of the distribution suggests absence of significant publication bias.

Conclusion

This systematic review and meta-analysis indicates that Low-dose atropine (0.01–0.05%) is associated with a statistically significant reduction in axial elongation and spherical equivalent progression in children with myopia compared with placebo. The findings suggest a potential beneficial role for low-dose atropine in myopia control; however, the observed heterogeneity across studies and methodological limitations in some trials warrant cautions interpretation. While low-dose atropine appears to be generally well tolerated, current evidence is insufficient to definitively establish its role as a universal first-line therapy. Further large scale, long term randomised controlled trials are needed to determine optimal dosing strategies, assess sustained efficacy after treatment cessation, and better characterise long term safety outcomes.

Data Sharing Statement

All data generated or analyzed during this study are included in this published article.

Funding

There is no funding to report.

Disclosure

The authors declare no competing interest in this work.

References

1. Holden BA, Fricke TR, Wilson DA, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology*. 2016;123(5):1036–1042. doi:10.1016/j.ophtha.2016.01.006
2. Almudhaiyan T, Alhamzah A, AlShareef M, et al. The prevalence of refractive errors among Saudi adults in Riyadh, Saudi Arabia. *Saudi J Ophthalmol*. 2020;34(1):30–34. doi:10.4103/1319-4534.301297
3. Sherwin JC, Hewitt AW, Coroneo MT, Kearns LS, Griffiths LR, Mackey DA. The association between time spent outdoors and myopia using a novel biomarker of outdoor light exposure. *Invest Ophthalmol Visual Sci*. 2012;53(8):4363–4370. doi:10.1167/iovs.11-8677
4. He M, Xiang F, Zeng Y, et al. Effect of time spent outdoors at school on the development of myopia among children in China: a randomized clinical trial. *JAMA*. 2015;314(11):1142–1148. doi:10.1001/jama.2015.10803

5. Walline JJ, Lindsley KB, Vedula SS, et al. Interventions to slow progression of myopia in children. *Cochrane Database Syst Rev*. 2020;1(1): CD004916. doi:10.1002/14651858.CD004916.pub4
6. Yam JC, Jiang Y, Tang SM, et al. Low-Concentration Atropine for Myopia Progression (LAMP) Study: a Randomized, double-blinded, placebo-controlled trial of 0.05%, 0.025%, and 0.01% atropine eye drops in myopia control. *Ophthalmology*. 2019;126(1):113–124. doi:10.1016/j.ophtha.2018.05.029
7. Sen S, Yadav H, Jain A, Verma S, Gupta P. Effect of atropine 0.01% on progression of myopia. *Indian J Ophthalmol*. 2022;70(9):3373–3376. doi:10.4103/ijo.IJO_256_22
8. Li FF, Yam JC. Low-concentration atropine eye drops for myopia progression. *Asia-Pac J Ophthalmol*. 2019;8(5):360–365. doi:10.1097/APO.0000000000000256
9. Ha A, Kim SJ, Shim SR, Kim YK, Jung JH. Efficacy and safety of 8 atropine concentrations for myopia control in children: a network meta-analysis. *Ophthalmology*. 2022;129(3):322–333. doi:10.1016/j.ophtha.2021.10.016
10. Fu A, Stapleton F, Wei L, et al. Effect of low-dose atropine on myopia progression, pupil diameter and accommodative amplitude: low-dose atropine and myopia progression. *Br J Ophthalmol*. 2020;104(11):1535–1541. doi:10.1136/bjophthalmol-2019-315440
11. Wang Z, Li T, Zuo X, et al. 0.01% atropine eye drops in children with myopia and intermittent exotropia: the AMIXT randomized clinical trial. *JAMA Ophthalmol*. 2024;142(8):722–730. doi:10.1001/jamaophthalmol.2024.2295
12. Chia A, Ngo C, Choudry N, Yamakawa Y, Tan D. Atropine ophthalmic solution to reduce myopia progression in pediatric subjects: the randomized, double-blind multicenter phase II APPLE study. *Asia-Pac J Ophthalmol*. 2023;12:370–376. doi:10.1097/APO.0000000000000609
13. Xia L, Zhao H, Wang Y. Effect of 0.01% atropine on diopter and optic axis in adolescents and children with myopia. *J Pak Med Assoc*. 2023;73(3):656–658. doi:10.47391/JPMA.6241
14. Liang X, Wei S, Li SM, et al. Effect of atropine 0.01% eye drops on the difference in refraction and axial length between right and left eyes. *Ophthalmic Res*. 2023;66(1):496–505. doi:10.1159/000528878
15. Chan HHL, Choi KY, Ng ALK, et al. Efficacy of 0.01% atropine for myopia control in a randomized, placebo-controlled trial depends on baseline electroretinal response. *Sci Rep*. 2022;12(1):11588. doi:10.1038/s41598-022-15686-6
16. Chaurasia S, Negi S, Kumar A, et al. Efficacy of 0.01% low dose atropine and its correlation with various factors in myopia control in the Indian population. *Sci Rep*. 2022;12(1). doi:10.1038/s41598-022-10079-1
17. Simonaviciute D, Gelzinis A, Kapitanovaite L, Grzybowski A, Zemaitiene R. Myopia control in caucasian children with 0.01% atropine eye drops: 1-year follow-up study. *Medicina*. 2024;60(7):1022. doi:10.3390/medicina60071022
18. Loughman J, Kobia-Acquah E, Lingham G, et al. Myopia outcome study of atropine in children: two-year result of daily 0.01% atropine in a European population. *Acta Ophthalmologica*. 2023;102:e245–e256. doi:10.1111/aos.15761
19. Wei S, Li SM, An W, et al. Myopia progression after cessation of low-dose atropine eyedrops treatment: a two-year randomized, double-masked, placebo-controlled, cross-over trial. *Acta ophthalmologica*. 2023;101(2):e177–e184. doi:10.1111/aos.15235
20. Wang W, Zhang F, Yu S, et al. Prevention of myopia shift and myopia onset using 0.01% atropine in premyopic children–a prospective, randomized, double-masked, crossover trial. *Res Square*. 2022.
21. Cui C, Li X, Lyu Y, et al. Safety and efficacy of 0.02% and 0.01% atropine on controlling myopia progression: a 2-year clinical trial. *Sci Rep*. 2021;11(1):22267. doi:10.1038/s41598-021-01708-2
22. Wei S, Li SM, An W, et al. Safety and efficacy of low-dose atropine eyedrops for the treatment of myopia progression in Chinese children. *JAMA Ophthalmol*. 2020;138(11):1178. doi:10.1001/jamaophthalmol.2020.3820
23. Lee SH, Tseng BY, Wang JH, Chiu CJ. Efficacy and safety of low-dose atropine on myopia prevention in premyopic children: systematic review and meta-analysis. *J Clin Med*. 2024;13(5):1506. doi:10.3390/jcm13051506
24. Navarra P, Buzzonetti L, Amico V, Cro M, Federico B. A systematic review with meta-analysis on the efficacy of 0.01% atropine eyedrops in preventing myopia progression in worldwide children's populations. *Front Pharmacol*. 2025;16:1497667. doi:10.3389/fphar.2025.1497667
25. Morgan IG, Ohno-Matsui K, Saw SM. Myopia. *Lancet*. 2012;379(9827):1739–1748. doi:10.1016/S0140-6736(12)60272-4
26. Jonas JB, Ohno-Matsui K, Panda-Jonas S. Myopia: anatomic changes and consequences for its etiology. *Asia-Pac J Ophthalmol*. 2019;8(5):355–359. doi:10.1097/01.APO.0000578944.25956.8b
27. Clark TY, Clark RA. Atropine 0.01% eyedrops significantly reduce the progression of childhood myopia. *J Ocul Pharmacol Ther*. 2015;31(9):541–545. doi:10.1089/jop.2015.0043
28. Chua WH, Balakrishnan V, Chan YH, et al. Atropine for the treatment of childhood myopia. *Ophthalmology*. 2006;113(12):2285–2291. doi:10.1016/j.ophtha.2006.05.062
29. Sherwin JC, Reacher MH, Keogh RH, Khawaja AP, Mackey DA, Foster PJ. The association between time spent outdoors and myopia in children and adolescents: a systematic review and meta-analysis. *Ophthalmology*. 2012;119(10):2141–2151. doi:10.1016/j.ophtha.2012.04.020