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Original Article

Repeated low-intensity red light therapy for childhood myopia: a retrospective cohort study

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Abstract: Objectives: To evaluate the efficacy and safety of repeated low-intensity red light (RLRL) therapy in slowing myopia progression and improving accommodative function in children. Methods: This retrospective cohort study reviewed electronic medical records of 202 myopic children aged 6-12 years treated at Ganzhou People's Hospital between October 2022 and October 2024. Participants were assigned to an RLRL group (n = 101; 650 nm, 1600 lx, 3 min, twice daily) or a control group (n = 101; single-vision spectacles only). Primary outcomes included axial length and spherical equivalent refraction. Secondary outcomes were uncorrected and best-corrected visual acuity, macular choroidal thickness, accommodative amplitude and facility, intraocular pressure (IOP), and corneal endothelial cell density (ECD). Results: Baseline demographics and ocular characteristics were comparable between groups (all $P > 0.05$). Up to 12 months, the RLRL group exhibited significantly less axial elongation and myopic refractive progression ($P < 0.05$ from 6 months onward), greater improvement in uncorrected visual acuity, thicker macular choroid, and enhanced accommodative function compared to controls (all $P < 0.05$). No significant between-group differences were observed in IOP or corneal ECD (both $P > 0.05$). Conclusion: RLRL therapy significantly slowed myopia progression and improved visual and accommodative function in children over 12 months, with no major safety concerns. These findings support RLRL as a promising, safe intervention for pediatric myopia control.

Keywords: Myopia control, repeated low-intensity red-light therapy, pediatric ophthalmology, axial length, refractive error, ocular safety

Introduction

Myopia is a chronic, progressive ocular disorder characterized by excessive axial eye elongation, causing images to focus in front of the retina and leading to blurred distance vision [1]. Its prevalence has risen sharply in recent decades, especially in East Asia, where rates among children and adolescents exceed 70%, and global estimates project that nearly half of the world's population may be myopic by 2050 [2]. This trend represents a major public health challenge, as high myopia substantially increases the risk of sight-threatening complications in adulthood, including myopic maculopathy, retinal detachment, glaucoma, and early cataract [3]. Developing effective, safe, and accessible interventions for childhood myopia control is therefore of critical clinical and societal importance [3].

Conventional correction methods - primarily single-vision spectacles (SVS) and contact lenses-remain the mainstay for restoring distance vision [4]. However, these approaches do not target the underlying pathophysiologic process of axial elongation and thus fail to halt disease progression [5]. In recent years, additional strategies have been introduced, including pharmacologic therapy (notably low-dose atropine), optical interventions (such as multifocal and orthokeratology lenses), and lifestyle modification (e.g., increased outdoor activity, reduced near-work) [6]. While these interventions can slow myopic progression, they face challenges in compliance, tolerability, potential side effects, and socioeconomic accessibility [7]. Moreover, inter-individual variability in treatment response underscores the need for additional safe and effective modalities [8].

Emerging evidence highlights the importance of environmental and optical factors in ocular growth regulation, with ambient light exposure identified as a key modifiable determinant [9]. Epidemiological studies consistently report an

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inverse association between outdoor time and myopia incidence or progression in children, implicating bright light exposure as protective [9, 10]. Animal experiments further demonstrate that both light intensity and wavelength influence refractive development: long-wavelength (red) light can modulate choroidal thickness, alter retinal dopamine release, and suppress scleral remodeling-mechanisms central to axial growth control [11]. Based on these findings, repeated low-intensity red light (RLRL) therapy has been developed as a novel, non-pharmacologic intervention for pediatric myopia [12].

RLRL therapy uses a semiconductor laser diode to deliver controlled, low-level red light (typically ~650 nm) to the retina through the pupil [13]. Its proposed mechanisms, initially informed by photobiomodulation studies and preclinical models, include modulation of local retinal signaling, enhancement of choroidal perfusion, and inhibition of abnormal ocular growth pathways [14]. Early clinical trials indicate that RLRL can significantly reduce axial elongation and slow refractive progression in children, with a favorable safety profile [7]. However, the precise biological mechanisms remain incompletely understood, and data regarding its effects on ocular function-particularly accommodation-and long-term safety remain limited [15].

Accommodation, the eye's ability to dynamically adjust optical power for clear focus at varying distances, is closely linked to refractive development [16]. Deficits in accommodative amplitude and facility have been associated with myopia progression and visual strain, particularly among school-aged children engaged in intensive near-work [16]. Thus, evaluating both structural outcomes (e.g., axial length) and functional abilities (e.g., accommodation) is essential for comprehensively assessing new interventions for myopia control [17].

Against this background, the present retrospective cohort study was conducted to evaluate the efficacy of repeated low-intensity red light therapy in slowing myopia progression in children wearing SVS. In addition, we assessed its effect on accommodative amplitude and facility, and examined safety by monitoring intraocular pressure and corneal endothelial cell density (ECD). By leveraging detailed electronic medical records from a large pediatric cohort over 12 months, this study aims to provide clinically relevant evidence for the effectiveness, safety, and mechanisms of RLRL therapy, thereby informing future practice and policy in pediatric myopia management.

Materials and methods

Study setting

This retrospective cohort study collected electronic medical record data of myopic children treated at Ganzhou People's Hospital between October 2022 and October 2024 [18]. Inclusion criteria: age 6-12 years; cycloplegic spherical equivalent refraction (SER) between -1.00 D and -5.00 D; best-corrected visual acuity (BCVA) ≥ 20/20 (Snellen) in the study eye; no prior myopia control treatment (e.g., atropine, orthokeratology) within 6 months; and complete clinical data. Exclusion criteria: astigmatism ≥ 2.50 D; anisometropia > 1.50 D; strabismus; systemic diseases; history of refractive or intraocular surgery; congenital ocular abnormalities; secondary myopia (e.g., retinopathy of prematurity); media opacities; active ocular surface inflammation; other ocular pathologies affecting refraction (e.g., cataract, keratoconus); or systemic conditions influencing ocular growth (e.g., Marfan syndrome).

A total of 202 eligible patients were divided into two groups according to whether they received RLRL therapy: the RLRL group (n = 101) and the control group (n = 101). Only right eyes were analyzed. The study was approved by the Institutional Review Board of Ganzhou People's Hospital. Patient data were anonymized, and because the study involved no potential harm, IRB approval was granted without requiring informed consent. The study complied with all relevant ethical standards and regulatory requirements.

Intervention

All participants wore SVS lenses throughout the study. In addition, the RLRL group received treatment using a portable desktop device (Eyerising International) incorporating a semiconductor laser diode that emitted low-intensity red light (650 nm, 1600 lx) through the pupil. With a pupil diameter of 4 mm, retinal irradiance was 0.29 mW, which corresponds to IEC

Class 1 safety and poses no risk of photothermal damage. After baseline evaluation, participants underwent twice-daily 3-minute sessions, 7 days per week, until the 12-month follow-up. Follow-up visits were scheduled at 1, 3, 6, 9, and 12 months.

Data collection

(1) Data sources: demographic data (age, gender, myopia degree, family history) and baseline clinical findings (axial length, refraction, visual acuity) were extracted from medical records. Follow-up data at 3, 6, 9, and 12 months included axial length, refraction, visual acuity, choroidal thickness, accommodative function, IOP, and corneal ECD.

(2) Visual acuity: uncorrected visual acuity (UCVA) and BCVA were assessed by trained optometrists using the Early Treatment Diabetic Retinopathy Study (ETDRS) logMAR chart (Guangzhou Xieyi Visioncare) at 4 m.

(3) Axial length (AL) was measured using IOLMaster 500 (Carl Zeiss Meditec, Germany). The average of three measurements (error ≤ 0.05 mm) was recorded.

(4) Cycloplegia: induced every 6 months with 1% cyclopentolate (Alcon, USA). Two drops were instilled 5 min apart; if inadequate, a third drop was added. Complete cycloplegia was confirmed when the pupil was ≥ 6 mm and the light reflex was absent 30 min after instillation.

(5) Refraction: measured with an auto-refractor (KR8800, Topcon, Japan) after cycloplegia; the mean of three readings was recorded (precision 0.25 D).

(6) Optical Coherence Tomography (OCT) and fundus imaging: macular choroidal thickness (mCT) was measured using spectral-domain OCT (DRI OCT Triton, Topcon, Japan) with 9 mm radial scanning. Values were obtained using built-in segmentation software.

(7) Accommodative amplitude: assessed by the near push-up test with standard optotypes. The blur point was recorded, and accommodative demand (D) calculated as 1 ÷ distance (m).

(8) Accommodative facility: measured under standardized illumination using +2.00 D/-2.00 D flipper lenses. The number of cycles completed within 1 min (cycles/min) was recorded.

(9) IOP pressure: measured using a non-contact tonometer (CT-80, Topcon, Japan).

(10) Corneal ECD: assessed by a non-contact specular microscope (SP-3000P, Topcon, Japan).

Outcomes

Primary outcomes were AL and spherical equivalent refraction (SER), which directly reflect myopia progression and are standard indicators of treatment efficacy. Secondary outcomes included UCVA, BCVA, mCT, accommodative amplitude and facility, and two safety indicators including IOP and corneal ECD, providing a comprehensive assessment of RLRL's effect on ocular structure, function, and safety.

Statistical analysis

All analyses were performed using SPSS version 29.0 (IBM Corp., Armonk, NY, USA). Continuous variables were tested for normality using the Shapiro-Wilk test. Normally distributed data were expressed as mean ± standard deviation (SD) and compared using independent-samples t-tests. Repeated measures ANOVA with LSD post hoc tests was applied for longitudinal data. Categorical variables were expressed as counts (percentages) and compared using chi-square tests. All tests were two-tailed, and $P < 0.05$ was considered significant.

Results

Baseline characteristics

At baseline, no significant differences were observed between the RLRL and control groups in age, sex distribution, height, weight, or parental history of myopia (all $P > 0.05$). Baseline SER and AL were also comparable, indicating well-balanced demographic and ocular characteristics prior to intervention (all $P > 0.05$, **Table 1**).

Axial length

Repeated measures ANOVA of AL revealed significant main effects for Group ($P = 0.003$) and

Table 1. Baseline characteristics of study participants

Characteristic	RLRL group (n = 101)	Control group (n = 101)	t/χ^2	P
Age, years	7.05±0.45	7.11±0.43	0.988	0.325
Sex, n (%)			0.020	0.888
Male	49 (48.51%)	48 (47.52%)		
Female	52 (41.49%)	53 (52.48%)		
Height, cm	125.48±6.28	126.12±6.05	0.735	0.463
Weight, kg	26.52±6.19	26.33±6.36	0.220	0.826
Parents with myopia, n (%)			0.097	0.952
Both	17 (16.83%)	18 (17.82%)		
None	49 (48.51%)	50 (49.50%)		
Either	35 (34.66%)	33 (32.68%)		
SER at baseline, diopter	-2.45±0.85	-2.58±1.01	1.042	0.299
AL at baseline, mm	23.00±0.69	23.10±0.75	1.043	0.298

AL: Axial Length; SER: Spherical Equivalent Refraction.

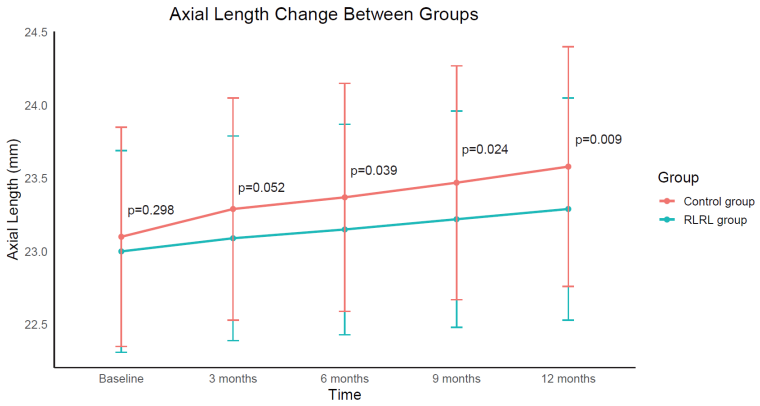

Figure 1. Axial Length (AL, mm) change between the two groups. AL: Axial Length. p: RLRL group vs. Control group.

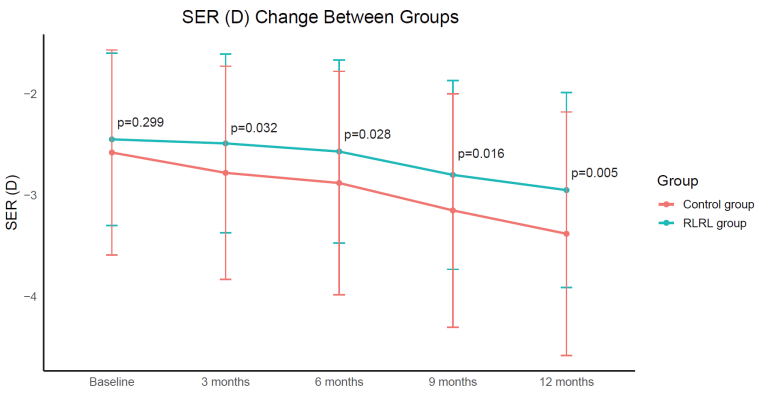

Figure 2. SER (D) change between the two groups. SER: Spherical Equivalent Refraction. p: RLRL group vs. Control group.

Time (P < 0.001), as well as a significant Group × Time interaction (P < 0.001), indicating differential AL trajectories between groups (Table S1). As shown in **Figure 1**, no significant group differences were present at baseline or 3 months. From 6 months onward, however, the RLRL group exhibited consistently smaller increases in AL than controls, with significant differences at 6, 9, and 12 months.

SER

Repeated measures ANOVA of SER showed significant main effects for Group (P = 0.007) and Time (P < 0.001), with a significant Group × Time interaction (P < 0.001), reflecting different patterns of refractive change between groups (Table S2). At baseline, SER did not differ between groups (P > 0.05, **Figure 2**). From 3 months onward, the RLRL group showed significantly less myopic progression than controls. At 3 months, mean SER was -2.49 D in the RLRL group versus -2.78 D in controls, with significant differences maintained at 6, 9, and 12 months.

Visual function

As shown in **Table 2**, significantly fewer children in the RLRL group experienced a two-line worsening in UCVA compared to controls (P = 0.005), while a greater proportion achieved a two-line improvement (P = 0.021). The proportion of participants whose UCVA remained within one line of baseline was similar between groups (P = 0.471). The incidence of BCVA < 0.8 was low and comparable across groups (P = 0.679).

mCT

Repeated measures ANOVA of mCT demonstrated significant main effects for both Group

Table 2. Vision function between the two groups

Characteristic	RLRL group (n = 101)	Control group (n = 101)	χ^2	P
Change in UCVA, n (%)				
2 Lines worsening	15 (14.85%)	32 (31.68%)	8.013	0.005
Within 1 line	64 (63.37%)	59 (58.42%)	0.520	0.471
2 Lines improvement	22 (21.78%)	10 (9.90%)	5.347	0.021
BCVA < 0.8, n (%)	2 (1.98%)	4 (3.96%)	0.172	0.679

UCVA: uncorrected visual acuity; BCVA: best corrected visual acuity.

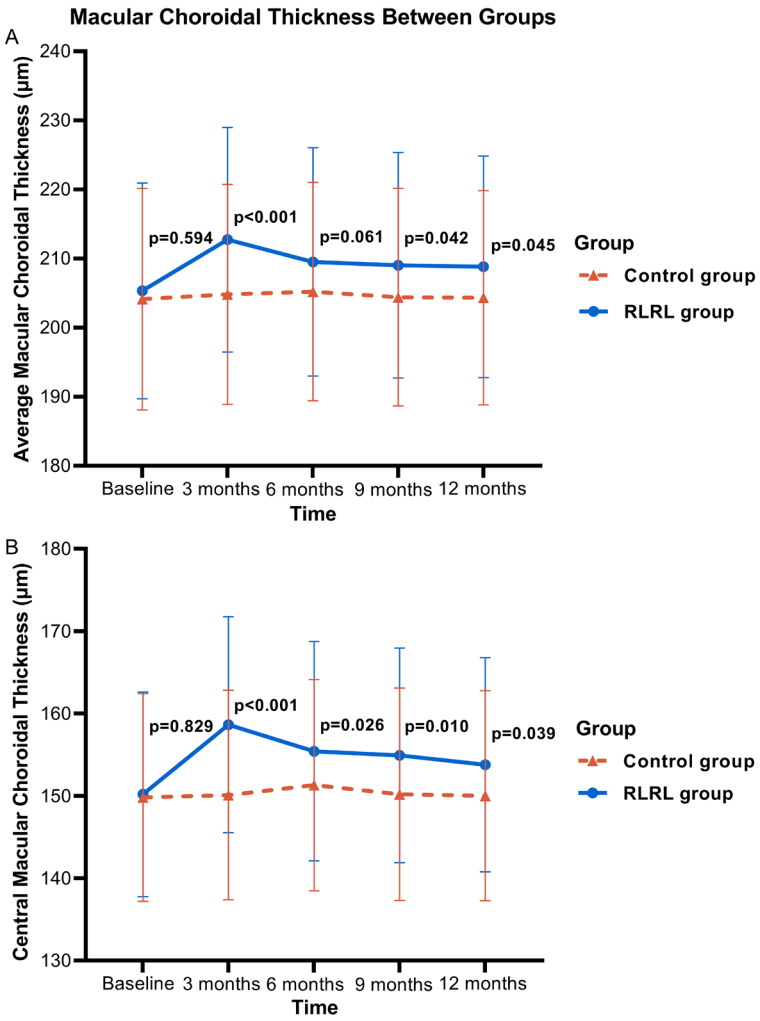

Figure 3. Macular choroidal thickness (mCT, μm) between the two groups. A: Central macular choroidal thickness; B: Average macular choroidal thickness. mCT: macular choroidal thickness. p: RLRL group vs. Control group.

and Time (P < 0.001), as well as significant interaction effects for average mCT and central mCT (P < 0.001). For average mCT, effects were significant for Group (P = 0.024) and Time (P < 0.001), with a significant Group × Time interaction (P < 0.001). For central mCT, effects were significant for Group (P = 0.016) and Time (P < 0.001), with a significant interaction (P < 0.001) (Table S3).

At baseline, average and central mCT did not differ between groups (P > 0.005, **Figure 3**). From 3 months onward, average mCT was significantly greater in the RLRL group, with differences persisting at 9 and 12 months. Central mCT also increased significantly in the RLRL group compared to controls from 3 months through 12 months.

Accommodative indicators

Repeated measures ANOVA revealed significant main effects of Group and Time, and significant Group × Time interactions for both accommodative amplitude and accommodative facility (all P < 0.001) (Table S4). At baseline, both of these indicators were similar between groups (both P > 0.005, **Figures 4**, **5**). Following intervention, the RLRL group showed significantly greater improvements in accommodative amplitude and facility at each follow-up. At 3 months, accommodative amplitude was already higher in the RLRL group, with differences widening and remaining significant at 6, 9, and 12 months (all P < 0.005). Accommodative facility also improved continuously, exceeding control values from 3 months onward, with significance maintained through 12 months.

Safety assessment

Repeated measures ANOVA of IOP and corneal ECD revealed no significant effects of Group, Time, or Group × Time interaction (all P > 0.7) (Table S5). Neither factor showed meaningful

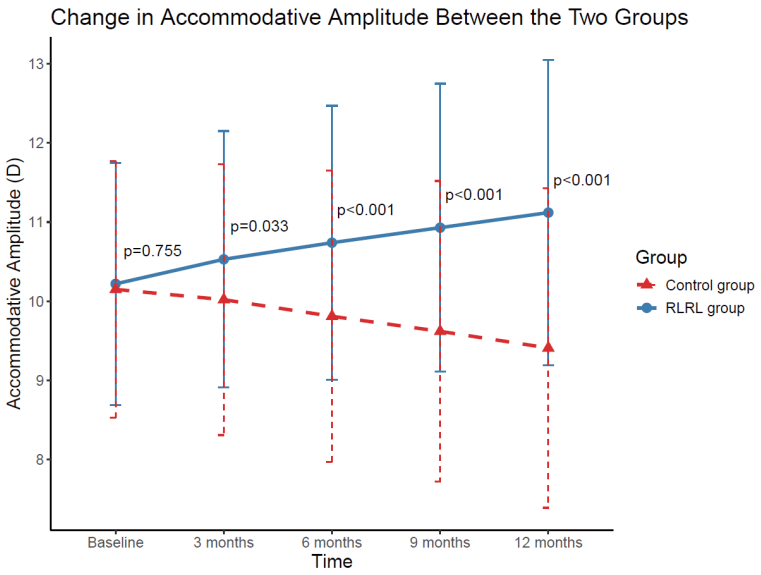

Figure 4. Change in accommodative amplitude between the two groups. p: RLRL group vs. Control group.

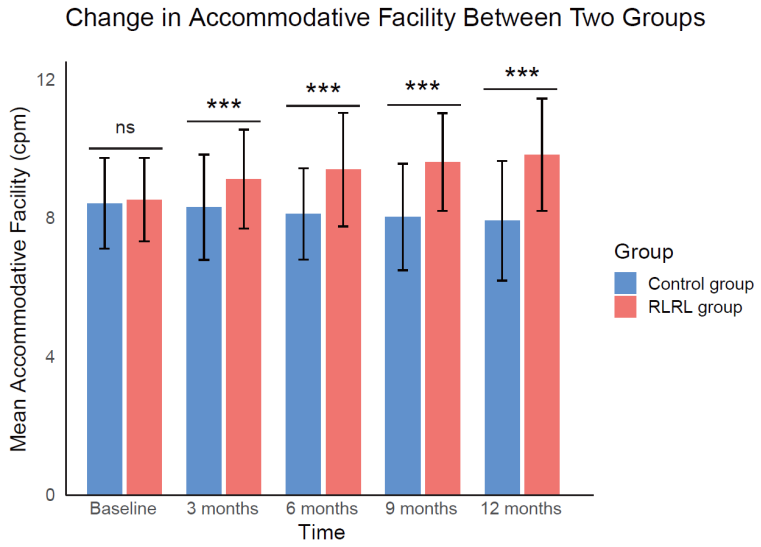

Figure 5. Change in accommodative facility between the two groups. ns: no significant difference, RLRL group vs. Control group; ***: P < 0.001, RLRL group vs. Control group.

changes during follow-up. Consistently, no significant differences in IOP or corneal ECD were observed between groups at baseline or subsequent visits (**Table 3**). IOP remained stable over 12 months, and corneal ECD showed no detectable changes.

Discussion

This study evaluated the efficacy of RLRL therapy in slowing axial elongation and improving accommodative function in children, while rigorously assessing its safety profile. Over 12 months, RLRL therapy significantly reduced axial elongation and refractive progression and enhanced accommodative function compared to controls. These findings are consistent with emerging evidence that photobiomodulation with long-wavelength light may regulate ocular growth, offering a promising non-pharmacologic strategy for myopia control, particularly where conventional single-vision spectacles fail to address pathological elongation [19-21].

The observed benefits of RLRL likely derive from multiple interrelated mechanisms at the tissue, cellular, and molecular levels. One proposed mechanism involves the modulatory effects of long-wavelength visible light on choroidal physiology and scleral remodeling [22]. Animal studies have shown that red light exposure promotes choroidal thickening and is associated with transient hyperopic shifts, likely mediated by increased choroidal blood flow and fluid retention [23]. In avian models, red light has been shown to inhibit excessive axial growth by promoting release of retinal dopamine, a neurotransmitter known to suppress ocular elongation [24]. Dopamine upregulation subsequently inhibits scleral fibroblast proliferation and collagen synthesis, thereby restraining axial elongation-a mechanism that may be conserved in primates [25].

The sustained increase in mCT observed in the RLRL group further supports this choroidal pathway. A thicker choroid is hypothesized to serve as both a physical and biochemical barrier to axial elongation by modulating the diffusion of growth-related signaling molecules from

Table 3. Intraocular pressure and corneal endothelial cell density changes between the two groups

Characteristic	RLRL group (n = 101)	Control group (n = 101)	t	P
Change in intraocular pressure, mmHg				
Baseline	10.55±1.25	10.60±1.30	0.319	0.750
3 months after invention	10.62±1.32	10.58±1.41	0.243	0.808
6 months after invention	10.58±1.35	10.45±1.48	0.679	0.498
9 months after invention	10.65±1.38	10.52±1.55	0.616	0.539
12 months after invention	10.60±1.41	10.48±1.50	0.605	0.546
Change in corneal endothelial cell density				
Baseline	2600.12±200.08	2600.25±200.06	0.005	0.996
3 months after invention	2598.50±210.25	2595.75±220.15	0.091	0.928
6 months after invention	2596.22±220.07	2591.51±230.25	0.149	0.882
9 months after invention	2596.14±220.33	2591.48±230.21	0.147	0.883
12 months after invention	2594.02±225.05	2588.11±235.06	0.182	0.855

retina to sclera, as well as influencing intraocular pressure dynamics and oxygenation [26]. Enhancement of choroidal thickness following RLRL may thus reflect both a direct structural response and an indirect marker of reduced ocular growth drive [27]. Notably, choroidal responses to light are dose- and wavelength-dependent, with red light in the range used in this study previously demonstrated to elicit physiological effects without inducing retinal thermal or photochemical damage [27].

The improvement in accommodative amplitude and facility within the RLRL group is another important finding with both mechanistic and clinical implications. Accommodative dysfunction, characterized by reduced amplitude and facility, has been implicated as both a risk factor for and a consequence of myopic progression [28]. Sustained near-work combined with limited outdoor activity may cause ciliary muscle fatigue and impaired responsiveness, leading to hyperopic defocus during near tasks-an established stimulus for axial elongation [28]. RLRL exposure may alleviate accommodative spasm and restore muscle function through several pathways [28, 29]: by improving local blood flow and oxygenation, thereby enhancing ciliary body metabolism and contractility; and by modulating retinal photobiomodulation, which may alter neuromodulatory signaling in accommodation-related neural circuits, reducing maladaptive responses to defocus.

Notably, the reductions in myopia progression and accommodative dysfunction observed in the RLRL group may be mutually reinforcing. Improved accommodative dynamics reduce the occurrence of hyperopic defocus signals that drive axial elongation, while reduced eye growth may help stabilize accommodative function by maintaining physiological ocular geometry.

The favorable safety profile observed in this study also addresses a critical consideration for clinical implementation. Neither intraocular pressure nor corneal ECD changed significantly over 12 months, consistent with prior evidence [30] indicating that the intensity and duration of RLRL exposure are well below established harmful thresholds. The minimal photothermal effect further supports its safety for repeated direct pupil exposure. Nonetheless, confirmation of long-term ocular and systemic safety requires larger and more diverse pediatric cohorts with extended follow-up.

Several limitations should be acknowledged. The retrospective design, although enabling clinical data collection, introduces potential unmeasured confounding. Although baseline characteristics were balanced, unrecorded behavioral factors such as near-work intensity or outdoor exposure may have influenced outcomes. Selection bias cannot be excluded, as families opting for RLRL therapy may differ in health-seeking behavior or adherence compared to controls. Additionally, although cycloplegic refraction and standardized AL measurements strengthen internal validity, the absence of objective compliance monitoring for RLRL device use may have led to variable treatment exposure.

Despite these limitations, the present study adds to growing evidence that light can serve as an active modulator of ocular growth and refractive development. Compared to pharmacological and optical interventions, RLRL offers several unique advantages: it is non-invasive, well tolerated, and free from drug-related adverse effects such as photophobia or allergic conjunctivitis. It may be particularly useful as an adjunctive option for children who respond inadequately to or cannot tolerate existing therapies.

Future research should clarify the optimal wavelength, dose, and treatment regimen for RLRL and distinguish between effects mediated by circadian rhythm entrainment and direct retinal pathways. Elucidating the downstream molecular cascades-potentially involving growth factors, matrix metalloproteinases, and other signaling pathways-will inform the development of targeted therapy. Identifying patient-level modifiers such as genetic predisposition, baseline choroidal thickness, or accommodative reserve may also guide personalized RLRL therapy for pediatric myopia.

In conclusion, repeated low-intensity red light therapy is a promising, non-pharmacologic intervention for controlling myopia progression and improving accommodative function in children. Its likely mechanisms include modulation of choroidal structure, retinal neurotransmitter balance, and ocular biomechanics. Given its demonstrated efficacy and safety, RLRL warrants further investigation in larger and multiethnic studies with long-term follow-up to establish its role in comprehensive pediatric myopia management.

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Disclosure of conflict of interest

None.

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Table S1. Repeated measures ANOVA of Axial Length (AL)

Effect	F	P
Group	8.92	0.003
Time	412.37	< 0.001
Group × time	6.15	< 0.001

Table S2. Repeated measures ANOVA of Spherical Equivalent Refraction (SER)

Effect	F	P
Group	7.35	0.007
Time	387.64	< 0.001
Group × time	5.83	< 0.001

Table S3. Repeated measures ANOVA of Macular Choroidal Thickness (mCT)

Effect	F	P
Average mCT		
Group	5.21	0.024
Time	18.34	< 0.001
Group × time	4.87	< 0.001
Central mCT		
Group	6.02	0.016
Time	22.67	< 0.001
Group × time	5.93	< 0.001

Table S4. Repeated measures ANOVA of Accommodative Parameters

Effect	F	P
Accommodative Amplitude		
Group	27.64	< 0.001
Time	34.82	< 0.001
Group × time	29.15	< 0.001
Accommodative Facility		
Group	32.19	< 0.001
Time	41.05	< 0.001
Group × time	19.87	< 0.001

Table S5. Repeated measures ANOVA of Intraocular Pressure and Corneal Endothelial Cell Density

Effect	F	P
Intraocular Pressure		
Group	0.11	0.742
Time	0.28	0.891
Group × time	0.17	0.952
Corneal Endothelial Cell Density		
Group	0.09	0.765
Time	0.35	0.843
Group × time	0.21	0.931