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Exploring the effectiveness of photobiomodulation therapy in axial length management: A comprehensive review

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Abstract
Background: Axial length elongation is a critical factor in the progression of myopia, a global public health issue affecting millions. Traditional interventions to control axial length growth have shown limited success, prompting the exploration of novel therapeutic approaches. Photo biomodulation therapy (PBMT), a non-invasive technique that utilizes low-level light to modulate cellular function, has emerged as a potential candidate for managing axial length.
Purpose: This comprehensive review aims to explore the effectiveness of PBMT in the regulation of axial length and its potential implications for myopia management.
Methodology: A systematic review of the current literature was conducted using databases such as PubMed, Medline and Google scholar. Studies examining the effects of PBMT on axial length in both clinical trials were included. Data were extracted and analyzed for parameters such as wavelength, dosage, treatment duration, and outcomes related to axial length changes.
Results: The review revealed that PBMT shows promise in influencing axial length growth, with several studies demonstrating significant reduction in axial elongation. The effects were found to be wavelength-dependent, with certain wavelengths proving more effective than others. Treatment dosage and duration were also critical factors influencing outcomes. However, variability in study design and heterogeneity in patient populations highlight the need for standardized protocols and larger-scale trials.
Conclusion: Photobiomodulation therapy presents a promising, non-invasive approach to axial length management, potentially offering a new pathway for myopia control. While preliminary results are encouraging, further research with standardized methodologies is necessary to fully understand the therapeutic potential and to optimize treatment protocols for clinical application.

Keywords: Photobiomodulation therapy, axial length, myopia management, low-level light therapy, non-invasive treatment, wavelength, dosage, clinical trials

Introduction
Myopia, or nearsightedness, has become a global public health issue due to its increasing prevalence, particularly in children and adolescents. It is characterized by excessive elongation of the eye's axial length, causing light to focus in front of the retina, resulting in blurred vision for distant objects. The progression of myopia, if left unchecked, can lead to pathological conditions such as retinal detachment, myopic maculopathy, and glaucoma. Therefore, controlling axial length growth is crucial in managing myopia progression.
Photobiomodulation therapy (PBM) has emerged as a potential non-invasive treatment for controlling axial length elongation and managing myopia. PBM, also known as low-level light therapy (LLLT), involves the use of low-energy red or near-infrared light to stimulate cellular processes. In the context of axial length management, PBM is believed to influence ocular tissues, particularly the sclera and choroid, to reduce the rate of axial elongation. While traditional methods, such as atropine eye drops, orthokeratology, and multifocal lenses, have shown promise in myopia control, PBM offers a novel approach that warrants further exploration.
This literature review aims to evaluate the current evidence surrounding the effectiveness of photobiomodulation therapy in managing axial length, focusing on its mechanisms of action, clinical outcomes, and potential for integration into myopia control strategies.

Methodology
The review was conducted by searching peer-reviewed journals, academic databases (PubMed, Google Scholar, and Scopus), and clinical trial registries. Search terms included

"photobiomodulation therapy," "axial length," "myopia control," "light therapy," and "low-level laser therapy in myopia." The inclusion criteria were studies published between 2010 and 2023 that focused on the application of PBM in axial length management, with particular emphasis on clinical trials, case studies, and experimental models. Excluded from the review were studies that focused on PBM for other conditions unrelated to eye health or axial length. The selected articles were analyzed based on their methodology, clinical results, and relevance to axial length control.

Discussion

1. Understanding Photobiomodulation Therapy

Photobiomodulation therapy (PBM) is a therapeutic approach that uses specific wavelengths of light (ranging from 600 to 1000 nm) to modulate biological processes at the cellular level. The light used in PBM is non-thermal, meaning it does not cause tissue heating, but instead promotes cellular activity through photochemical and photobiological effects. When absorbed by mitochondria, light at these wavelengths enhances adenosine triphosphate (ATP) production, promotes anti-inflammatory effects, and encourages tissue repair and regeneration [1].

In ophthalmology, PBM has been applied in the treatment of various conditions such as macular degeneration, diabetic retinopathy, and ocular inflammation. More recently, PBM has gained attention for its potential to influence axial length growth in the context of myopia control. The exact mechanism by which PBM affects axial elongation is not yet fully understood, but it is hypothesized that PBM can modulate cellular processes in the sclera and choroid, leading to changes in the structural properties of the eye [2].

2. Mechanisms of Action in Axial Length Management

PBM's potential effectiveness in managing axial length in myopia is believed to stem from its influence on the sclera and choroid, two key tissues involved in regulating eye growth. The sclera provides structural support to the eye and plays a critical role in maintaining its shape. Excessive axial elongation in myopia is linked to scleral remodeling, which weakens the sclera and allows for continued elongation of the eye.

Scleral Remodeling and PBM

Research has shown that PBM can stimulate cellular processes that inhibit scleral thinning and promote collagen production. By increasing ATP production and enhancing the activity of fibroblasts within the sclera, PBM may counteract the remodeling processes that lead to excessive axial elongation [3]. Studies in animal models have demonstrated that PBM can reduce scleral thinning and strengthen the biomechanical properties of the sclera, thus limiting axial elongation [4].

Choroidal Thickness and PBM

The choroid, a vascular layer situated between the retina and the sclera, is also believed to play a role in axial length regulation. It has been observed that increased choroidal thickness is associated with slower axial elongation, while a thinning choroid is linked to faster myopia progression. PBM has been shown to increase choroidal thickness, possibly by enhancing blood flow and promoting tissue repair [5]. By modulating the choroidal response, PBM may indirectly influence axial elongation by altering the mechanical properties of the eye.

3. Clinical Evidence and Trials

Clinical studies on the use of PBM for axial length control are still in their early stages, with limited but promising results. Several experimental models, case reports, and pilot studies have investigated PBM's efficacy in reducing myopia progression by influencing axial length growth.

Animal Studies

Animal models have been critical in establishing the foundational understanding of PBM's effects on axial length. Studies in guinea pigs and chickens, common models for myopia research, have shown that PBM can significantly reduce the rate of axial elongation compared to control groups [6]. These studies support the hypothesis that PBM can modulate scleral and choroidal processes to slow down myopic progression.

For example, a study by Zhang *et al*. (2021) demonstrated that PBM applied to guinea pigs with form-deprivation myopia resulted in a significant reduction in axial elongation after six weeks of treatment [7]. Histological analysis revealed enhanced scleral collagen production and increased choroidal thickness in treated animals compared to untreated controls.

Human Trials

While human clinical trials are still limited, the available studies indicate that PBM may be a viable option for controlling axial length in myopia. A pilot study conducted by Lim *et al*. (2020) involved the use of a portable PBM device on children with progressive myopia. The study found that daily use of the device for three months resulted in a significant reduction in the rate of axial length growth compared to the baseline progression rate [8]. Furthermore, no adverse effects were reported, suggesting that PBM is a safe and well-tolerated therapy.

Another study by Wu *et al*. (2022) investigated the long-term effects of PBM in young adults with low-to-moderate myopia. Over the course of six months, participants who received PBM therapy showed a reduction in axial elongation compared to those in the control group, with some participants exhibiting complete stabilization of axial length [9].

Combination Therapies

There is growing interest in combining PBM with other established myopia control interventions, such as atropine eye drops and orthokeratology lenses. A study by Tong *et al*. (2021) explored the synergistic effects of PBM and low-dose atropine in myopic children. The results indicated that the combination therapy was more effective in reducing axial length growth compared to atropine alone, suggesting that PBM could enhance the efficacy of existing treatments [10].

4. Safety and Usability of PBM Devices

Safety is a crucial factor in evaluating the viability of PBM for axial length management, particularly for long-term use in children and adolescents. PBM uses low-level light that is non-ionizing and does not cause tissue heating, making it inherently safe for ocular applications. To date, no significant adverse effects have been reported in human or

animal studies involving PBM for axial length control.

The ease of use and portability of PBM devices also play a critical role in their adoption. Several devices designed for home use have been developed, allowing patients to administer therapy themselves. These devices typically require short treatment sessions (5–10 minutes per day), making them convenient for regular use. However, long-term adherence to the therapy is a challenge, especially in younger populations, where consistent usage is crucial for achieving optimal results.

5. Challenges and Limitations

Despite the promising results from early studies, several challenges and limitations need to be addressed before PBM can be widely adopted as a standard treatment for axial length management.

Limited Long-Term Data

One of the primary limitations of current research is the lack of long-term data. Most studies have focused on short-term outcomes (3–6 months), and it is unclear whether the effects of PBM on axial length are sustained over longer periods. Long-term follow-up studies are needed to determine whether PBM can provide lasting benefits in controlling myopia progression.

Variability in Treatment Protocols

There is no consensus on the optimal parameters for PBM in axial length management, including the wavelength, intensity, and duration of treatment. Different studies have used varying treatment protocols, making it difficult to standardize PBM for clinical use. Further research is needed to establish evidence-based guidelines for PBM therapy in myopia control.

Cost and Accessibility

The cost of PBM devices may also be a barrier to widespread adoption, particularly in low-resource settings. While the devices are relatively affordable compared to surgical interventions, they may still be out of reach for many families. Ensuring that PBM devices are affordable and accessible is crucial for their integration into mainstream myopia management strategies.

Conclusion

Photobiomodulation therapy holds significant promise as a non-invasive treatment for managing axial length growth and controlling myopia progression. Early studies suggest that PBM can modulate key ocular tissues, such as the sclera and choroid, to reduce axial elongation. Clinical evidence from animal models and human trials indicates that PBM can effectively slow down myopia progression, particularly when used in combination with other interventions such as atropine or orthokeratology.

However, further research is needed to fully understand the long-term effects of PBM, optimize treatment protocols, and address challenges related to accessibility and cost. As the global prevalence of myopia continues to rise, PBM represents a novel and exciting addition to the arsenal of myopia control strategies. With continued research and development, PBM could become a valuable tool for preserving vision and reducing the burden of myopia-related complications.

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