

## The Effectiveness of Photobiomodulation on Orthodontic Movement, Relapse, and Stem Cell Activation: A Systematic Literature Review

Lila Muntadir<sup>1</sup>, Eka Setyawardana<sup>2</sup>, Tontowi Ashari<sup>3</sup>, Windy Yuliantanti<sup>4</sup>, Marisa Elvi Dayan<sup>5</sup>, Wanda Karisma Dian Sari<sup>6</sup>, Rizqi Aulia Kusuma Andini<sup>7</sup>, Reni Puspa Daniati<sup>8</sup>  
<sup>1,2,3,4,5,6,7,8</sup>Muhammadiyah University of Sidoarjo, Indonesia



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### ABSTRACT

**Objective:** This systematic review aims to evaluate the effectiveness of LLLT with wavelengths of 650 nm and 660 nm in supporting orthodontic tooth movement, reducing post-treatment relapse, and stimulating stem cell activation involved in the regeneration of supporting tissues. **Method:** Literature search was conducted on PubMed and Scopus databases for articles published in the last five years. Studies were selected based on predefined inclusion and exclusion criteria. A total of 58 relevant articles were analyzed qualitatively. **Results:** The literature review findings indicate that LLLT consistently contributes to accelerating orthodontic tooth movement, reducing post-treatment relapse risk, and enhancing stem cell activation and proliferation, which supports the remodeling of periodontal tissues. **Novelty:** LLLT with wavelengths of 650 nm and 660 nm has proven to be effective and safe as an adjunct therapy in orthodontic treatment, with the 660 nm wavelength demonstrating superior tissue penetration, potentially enhancing long-term stability and tissue regeneration through stem cell activation.

## INTRODUCTION

Orthodontic treatment is a dental procedure aimed at adjusting the position of teeth to improve chewing function, periodontal health, and aesthetics. Tooth movement during orthodontic treatment occurs as a biological response to mechanical forces applied through orthodontic appliances. However, orthodontic treatment results in a risk of relapse, a condition where teeth tend to return to their original position after treatment is completed (Utari et al). Furthermore, orthodontic patients often complain of long treatment durations and discomfort, which can decrease patient compliance and increase the risk of caries, periodontal disease, and root resorption. Therefore, various approaches have been developed to accelerate tooth movement and shorten orthodontic treatment time (Baser Keklikci et al).

One non-invasive approach that has received considerable attention is Low-Level Laser Therapy (LLLT), also known as photobiomodulation (PBM). PBM utilizes low-energy light, typically in the red to near-infrared spectrum, to stimulate cellular activity and accelerate tissue repair. This therapy works by targeting cell mitochondria, thereby increasing the production of adenosine triphosphate (ATP), which plays a crucial role in cell proliferation, differentiation, and regeneration (Lawrence & Sorra; Rola et al).

In dentistry, PBM shows significant potential in the treatment of periodontal disease, reducing inflammation, and managing relapse after orthodontic treatment. The biological mechanisms of PBM involve the activation of fibroblasts and mesenchymal

stem cells, increased collagen synthesis, and stimulation of bone remodeling. Furthermore, PBM plays a role in reducing pro-inflammatory cytokines and increasing angiogenesis and vascular regeneration, thereby accelerating the healing process of periodontal tissue (Zhong et al).

The effectiveness of PBM is further enhanced when combined with photodynamic therapy (PDT). PDT involves the activation of a photosensitizer by a light source with a specific wavelength to produce reactive oxygen species (ROS), which play a role in eliminating pathogenic microorganisms and improving tissue health. The combination of PBM and PDT, particularly with the use of photosensitizers such as chlorophyll derivatives, provides a synergistic effect of cellular stimulation and antimicrobial effects, thus supporting tissue repair and infection control (Wianto et al).

Photodynamic therapy has also been reported to be effective in reducing pain, suppressing inflammation, and accelerating tissue healing. PDT requires three main components: a photosensitizer, tissue oxygen, and a light energy source. Activation of the photosensitizer by light produces high levels of ROS, which increase cytotoxicity against target cells, including pathogenic microorganisms (Santos et al; Adnane et al).

In both PBM and PDT, LLLT increases ATP production in cell mitochondria, which accelerates proliferation, differentiation, and tissue repair. LLLT stimulates fibroblasts to produce collagen, which strengthens the periodontal ligament (PDL), accelerates the differentiation of mesenchymal progenitors into osteoblasts and cementoblasts for alveolar bone and cementum regeneration, and modulates osteoclast activity to control bone resorption. Furthermore, LLLT has anti-inflammatory effects by modulating macrophage activity and increasing blood flow through angiogenesis (Shi et al; X. Zhao et al).

Various studies have reported that LLLT plays a role in preventing relapse after orthodontic tooth movement by strengthening and stabilizing the periodontal structure. The biostimulatory effect of LLLT is also associated with increased growth factor production, which plays a role in tissue remodeling and stabilizing tooth position after orthodontic treatment is completed (Rathod et al).

At a wavelength of 650 nm, LLLT has been shown to increase the proliferation, migration, and formation of vascular endothelial cells, as well as reduce inflammatory mediators such as IL-1 $\beta$  and PGE<sub>2</sub>, which contribute to accelerated periodontal tissue healing (Y. Li et al; Hermanto et al). Meanwhile, LLLT at a wavelength of 660 nm shows deeper tissue penetration and significantly increases the proliferation and viability of mesenchymal stem cells and gingival fibroblasts, thus supporting the regeneration of periodontal tissues, including alveolar bone, gingiva, periodontal ligament, and cementum (Etemadi, Khajehmougahi, et al; Etemadi, Koochak Hosseini, et al).

In the orthodontic context, LLLT accelerates tooth movement by stimulating osteoclast and osteoblast activity in the periodontal tissue, thereby accelerating alveolar bone remodeling during orthodontic force application. Furthermore, LLLT plays a role in modulating the OPG/RANKL pathway, which is crucial for maintaining the balance

between bone resorption and formation, thus contributing to the prevention of post-orthodontic relapse (Chintavalakorn et al.; Xu et al ; Berni et al).

Overall, LLLT shows great potential as an adjuvant therapy in orthodontic treatment. However, further research is needed to determine optimal laser parameters and comprehensively understand its biological mechanisms. The varying results of existing studies indicate that the effectiveness of LLLT is significantly influenced by differences in application protocols and target tissue characteristics. Therefore, this review aims to systematically discuss the effects of LLLT on orthodontic tooth movement and post-treatment relapse based on studies published between 2016 and 2024, both in vitro and in vivo models, and in clinical applications. It also examines the molecular mechanisms underlying its therapeutic effects (Inchingolo et al).

## **RESEARCH METHOD**

### **Study Design**

This study is a Systematic Literature Review (SLR) prepared according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. This review aims to evaluate the effectiveness of Low-Level Laser Therapy (LLLT) with wavelengths of 650 nm and 660 nm in supporting orthodontic tooth movement, reducing post-treatment relapse, and stimulating stem cell activation, which plays a role in periodontal tissue regeneration.

### **Literature Search Strategy**

A systematic literature search was conducted using two major academic databases: PubMed/MEDLINE and Scopus, as both provide extensive coverage of biomedical and dental literature. The search was limited to publications published within the last five years (2019–2024) to ensure the freshness and relevance of the data. The search strategy used a combination of keywords and Boolean operators as follows:

"low-level laser therapy" OR "photobiomodulation" AND "orthodontic tooth movement" OR "tooth movement" AND "post-orthodontic relapse" AND "stem cell activation." Keywords were adjusted according to the characteristics of each database.

### **Inclusion and Exclusion Criteria**

The inclusion criteria for this study included:

1. Articles discussing the use of LLLT or PBM in the context of orthodontic tooth movement, post-orthodontic treatment relapse, and/or stem cell activation.
2. Original research articles, including in vitro, in vivo, and human clinical studies.
3. Articles that have undergone peer review.
4. Articles written in English.

### **Exclusion criteria included:**

1. Duplicate articles.
2. Articles in the form of single case reports, editor's letters, opinion pieces, or conference abstracts.
3. Articles that do not provide data relevant to the research objectives.

#### 4. Articles with inaccessible full text.

### Study Selection Process

The article selection process was conducted through several stages according to the PRISMA flowchart. In the initial stage, all articles retrieved from the database were identified and duplicates were removed. Next, screening was performed based on the title and abstract to assess compliance with the inclusion criteria. Articles meeting the initial criteria were then subjected to a full-text review to determine final eligibility. From the entire selection process, 50 articles meeting all inclusion criteria were included in the final analysis.

### Data Extraction and Analysis

Data from the selected articles were systematically extracted using an extraction form that included: author name, year of publication, study design, sample characteristics, LLLT parameters (wavelength, power, energy density, irradiation duration), and primary outcomes related to orthodontic tooth movement, post-treatment relapse, and stem cell activation.

Data analysis was conducted qualitatively using a descriptive approach to identify patterns of findings, consistency of results, and the biological mechanisms underlying the therapeutic effects of LLLT. Given the heterogeneity of study designs and intervention parameters, a meta-analysis was not performed.

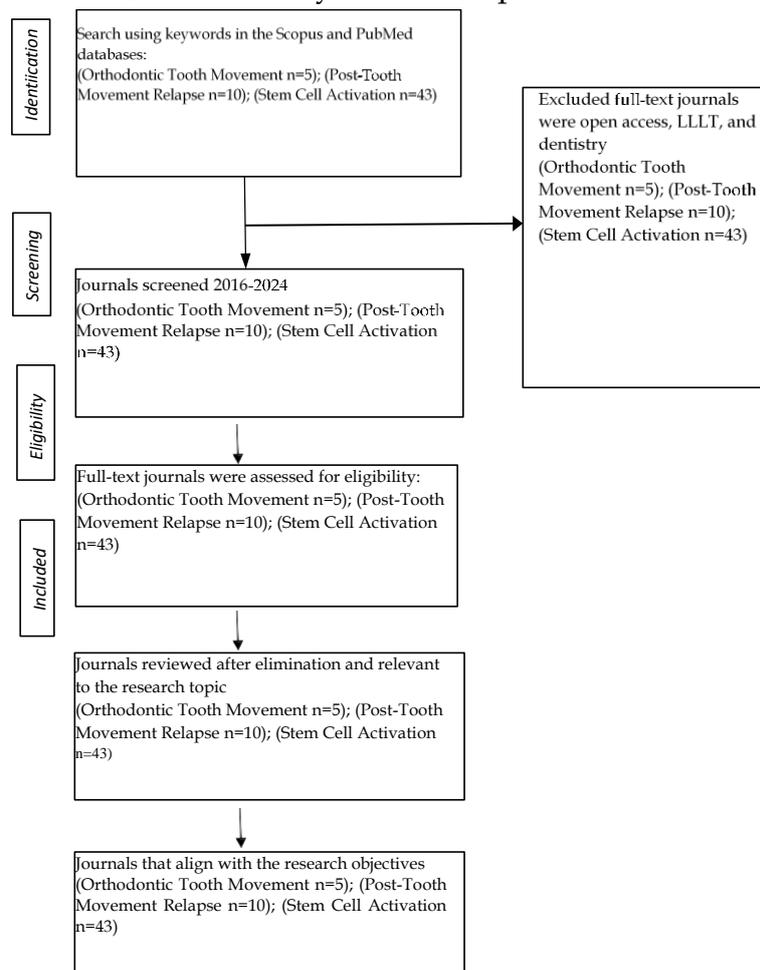


Figure 1. PRISMA flowchart diagram

## RESULT AND DISCUSSION

### Results

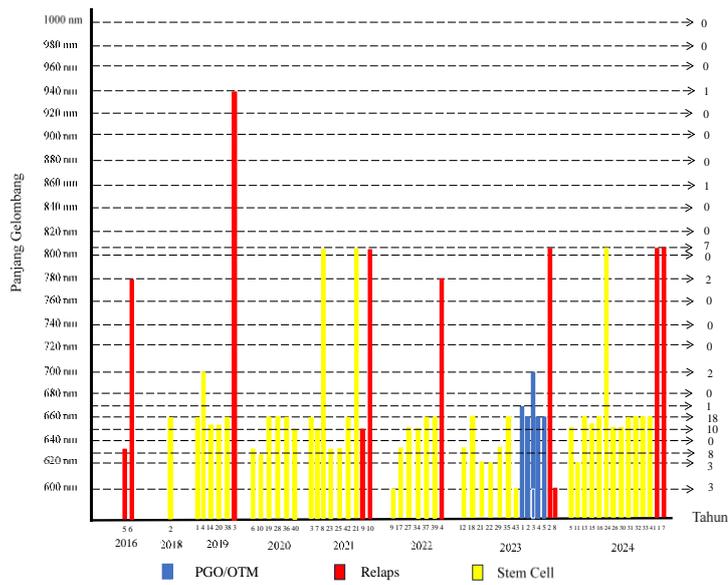


Figure 1. LLLT Wavelength in Literature Review used from 2016-2024.

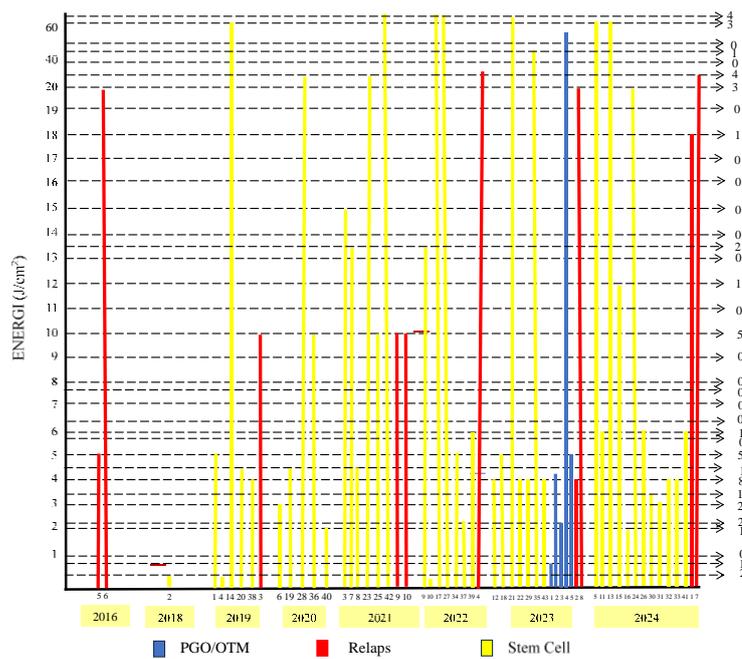


Figure 2. LLLT Energy in Literature Review used from 2016-2024.

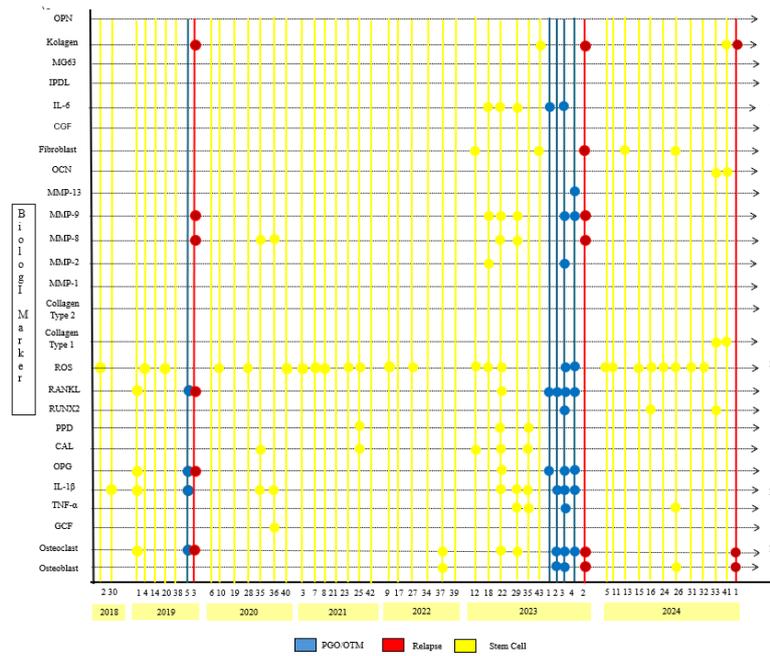


Figure 3. Biological Markers studied in the Literature Review used from 2016-2024

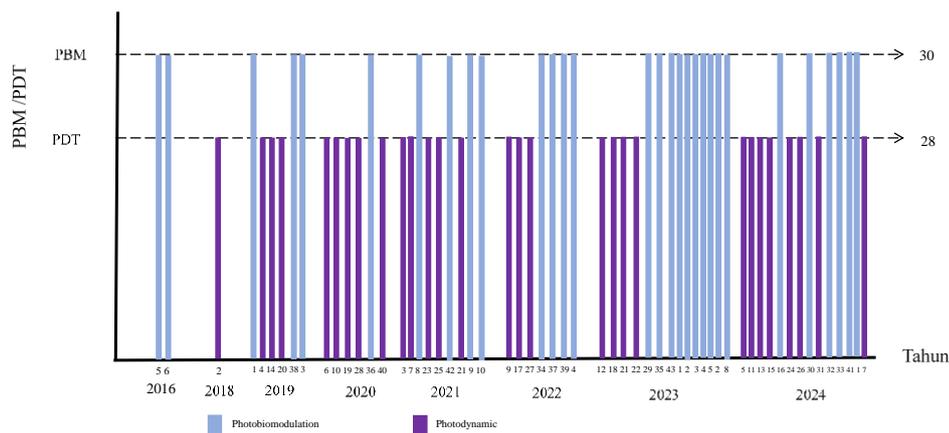


Figure 4. Photobiomodulation and photodynamics journals in Literature Review used from 2016-2024

Table 1. LLLT Stimulates Stem Cell Activation

No	Article Title	Model of study	Year	Results
1.	Comparative Study of 660 and 830 nm Photobiomodulation in Promoting Orthodontic Tooth Movement (Huan Yang, Jingwen Liu, and Kai Yang) [1]	An in vivo experimental study involving the application of photobiomodulation (PBM) with wavelengths of 660 nm and 830 nm on the right upper molar	2019	Both 660 nm and 830 nm PBMs can accelerate the movement of orthodontic teeth and promote remodeling of the alveolar bone on the compression side. Although the

No	Article Title	Model of study	Year	Results
		teeth of mice, with a control group without laser irradiation		difference in tooth movement over 14 days between the two groups was not statistically significant, the 660 nm PBM showed a stronger acceleration of bone remodeling in the early stages than the 830 nm PBM
2.	Effect of photodynamic therapy on surface decontamination in clinical orthodontic instruments (Foggiato, Augusto Alberto Silva, Douglas Fernandes Castro, Renata Cristina Faria Ribeiro, 2018) [2]	<i>In Vitro Experimental Design</i>	2018	The results showed that PID with methylene blue at a concentration of 100 µmol/L was effective in reducing microbes on the surface of orthodontic instruments. This device is considered an atoxic and low-cost alternative to disinfection of non-critical instruments
3.	Photodynamic Inactivation of Microorganisms Using Semisynthetic Chlorophyll and Derivatives as Photosensitizers (Uliana, Marciana P da Cruz Rodrigues, Andréia Ono, Bruno A Pratavieira, Sebastião de Oliveira, Kleber T Kurachi, Cristina)[3]	<i>In vitro</i>	2021	It is not specifically mentioned the distance between the LED and the sample, but light exposure is given to the surface of the sample for inactivation of microorganisms
4.	A comprehensive investigation of amino grafted mesoporous silica nanoparticles supramolecular assemblies to host photoactive chlorophyll and in aqueous solution	<i>In vitro</i>	2019	Amino grafted mesoporous silica nanoparticles are effective in maintaining chlorophyll a in the form of photoactive monomers in aqueous

No	Article Title	Model of study	Year	Results
	(Rizzi, Vito Gubitosa, Jennifer Yours truly, Paola. Fanelli, Fiorenza Fraix, Aurore Sortino, Salvatore Agostiano, Angela De Cola, Luisa Nacci, Angelo Cosma, Pinalysa)[4]			environments, with potential applications in PDT and aPDT. The system exhibits stable photoactive activity, and can increase the capacity of chlorophyll a in aqueous solution for therapeutic applications
5.	Antimicrobial photodynamic therapy using a low-power 650 nm laser to inhibit oral <i>Candida albicans</i> activity: an in vitro study  (Reporting by Osamah Adnan, Hussein Ali Jawad) [5]	<i>In vitro</i>	2024	PDT with a 650 nm laser and MB is effective in reducing the number of <i>C. albicans</i> colonies. The combination of laser therapy with antifungal agents results in a significant reduction in colonies, making it a potential alternative to treating oral fungal infections
.6.	Evaluation of Photodynamic Therapy Using a Diode Laser 635 nm as an Adjunct to Conventional Chemo-Mechanical Endodontic Procedures against <i>Enterococcus faecalis</i> Biofilm: Ex-Vivo Study  (Tenore, Gianluca Palaia, Gaspare Migliau, Guido Mohsen, Ahmed Rocchetti, Federica Gaimari, Gianfranco Impellizzeri, Alessandra Salapata, Yolanda Berlutti, Francesca Polimeni, Antonella	<i>Ex vivo</i>	2020	Photodynamic therapy or PDT in addition to conventional endodontic treatment shows potential in increasing disinfection capacity, with a significant reduction in bacterial burden in the group receiving a combination of PDT and chemo-mechanical treatment compared to the control group

No	Article Title	Model of study	Year	Results
	Romeo, Umberto)[6]			
7.	A novel synthesis of a chlorophyll b-gold nanoconjugate used for enhancing photodynamic therapy: In vitro study (Alexeree, Shaimaa ElZorkany, Heba ElSayed Abdel-Salam, Zienab Harith, Mohamed Abdel)[7]	<i>In vitro</i>	2021	The results showed that the b-gold chlorophyll conjugate increased the photostability and effectiveness of photodynamic therapy in killing cancer cells. This conjugate exhibits low toxicity in dark conditions, but increases the production of reactive oxygen (ROS) when irradiated, resulting in significant anticancer effects
8.	Low-Level Laser Therapy Promotes Bone Regeneration by Coupling Angiogenesis and Osteogenesis (Bai, Jie Li, Lijun Yours truly, Ni Hey hey hey he Zhang, Yaoyang Lu, Yun Gao, Lu Wang, Fu) [8]	Experimental in vitro and in vivo studies, using a mouse model (C57BL/6) with co-culture therapy between BMSCs and HUVECs to study the mechanisms and effects of LLLT	2021	LLLT promotes bone regeneration of vascularization by increasing crosstalk between angiogenesis and osteogenesis via the ROS/HIF-1 $\alpha$ pathway. The expression of VEGF, TGF- $\beta$ , and HIF-1 $\alpha$ is significantly increased, supporting the formation of bone and H-type blood vessels
9.	The combinational application of photodynamic therapy and nanotechnology in skin cancer treatment: A review (Annane, Fadya El-Zayat, Emad Fahmy, Heba)[9]	Literature review	2022	This review concludes that the combination of PDT and nanoparticles has great potential in improving the effectiveness of skin cancer therapy. The use of nanoparticles helps in improving

No	Article Title	Model of study	Year	Results
				the efficiency of photosensitizer delivery and improving therapeutic outcomes, especially in skin cancers that are difficult to treat with conventional therapies
10	Antimicrobial Photodynamic Effectiveness of Light Emitting Diode (LED) For Inactivation on <i>Staphylococcus aureus</i> Bacteria and Wound Healing in Infectious Wound Mice (Astuti, S D Ardyana, and Arificanto, D Winarno Puspita, P S Yvonne, Y.Y. Pradhana, A A S)[10]	In vitro	2020	Antimicrobial photodynamic therapy with LEDs is effective for inactivation of <i>Staphylococcus aureus</i> bacteria and accelerates wound healing in mice
11	Green Synthesis of Silver Nanoparticles using <i>Moringa oleifera</i> : Implementation to Photoantimicrobial of <i>Candida albicans</i> with LED Light (Imelda, Imelda Astuty, Sri Dewi Gareso, Paulus Lobo Dwyana, Zaraswati Arifin, Nur Fadhillah Astuti, Suryani Dyah)[11]	In vitro	2024	The green synthesis of silver nanoparticles from <i>Moringa oleifera</i> is effective in inhibiting the growth of <i>Candida albicans</i> biofilms with LEDs as a light source. The use of blue LEDs is more optimal than red LEDs in inhibiting biofilm
12	Efficacy of synthesized cubic spirulina platensis photosensitizer in	In vitro	2023	CSP and MSP are effective as photosensitizers in PDT with CSP

No	Article Title	Model of study	Year	Results
	anticancer photodynamic therapy: An in vitro study (Saberi, Sogol Modiri-Delshad, Tayebeh Etemad-Moghadam, Shahroo Alaeddini, Mojgan Jamshidloo, Rahele Ramazani, Ali Mohammadpour, Hadiseh Hanna, Reem Khoobi, Mehdi Shahabi, Sima)[12]			exhibiting a more dominant apoptosis effect, whereas MSP tends to induce necrosis. Pc has a higher phototoxic potential in normal cells compared to CSP and MSP
13	In Vitro Effect of Photodynamic Therapy With Curcumin in Combination With Photobiomodulation Therapy by 660 nm on the Viability of Human Gingival Fibroblasts (Etemadi, Ardavan; Koochak Hosseini,; Seyed Khashayar; Neshandar, Morteza; Chiniforush, Nasim 2024)	Experimental in vitro studies	2024	The combination of PDT using curcumin as a photosensitizer and PBMT with a 660 nm laser increases the viability of human gingival fibroblast cells. The results showed a significant improvement in cell viability in the group that was given laser irradiation many times compared to the control group. The conclusion of this study is that the combination of PDT and PBMT may be a safe alternative to aid in periodontal tissue regeneration due to its non-invasive and effective procedure in improving cell viability

No	Article Title	Model of study	Year	Results
14	Ethosomes and lipid-coated chitosan nanocarriers for skin delivery of achlorophyll derivative: A potential treatment of squamous cell carcinoma by photodynamic therapy (Nasr, Soad Rady, May Gomaa, Faith Syrovet, Tatiana Simmet, Thomas Fayad, W. Abdel-Kader, Mahmoud, 2019)	In vitro study on human squamous cell carcinoma (SCC) cells and ex vivo study on mouse skin for assessing the effect of photodynamic therapy (PDT) using chlorophyll-based nanocarriers	2019	Both nanocarriers (ethosomes and PC/CHI) show potential for the treatment of SCC using PDT. Ethosomes have deeper penetration into the skin layer, suitable for invasive SCCs, while PC/CHI have higher cytotoxicity on SCC cells and are suitable for superficial SCCs
15	Evaluation of chlorophyll-loaded mesoporous silica nanoparticles for photodynamic therapy on cancer cell lines (Fadya Adnane, Soliman Mehawed Abdellatif Soliman, Emad ElZayat, Essam M Abdelsalam, Heba Mohamed Fahmy, 2024)	In vitro study on cancer cell lines, specifically targeting the effects of chlorophyll-loaded nanoparticles in photodynamic therapy (PDT)	2024	Chl-MSNs are effective in enhancing the cytotoxic effects on cancer cells when using PDT, especially under blue light excitation. Blue lasers show higher efficacy than red lasers in inhibiting the growth of HepG2 and MDA-MB-231 cancer cells
16	Osteoblastic differentiation and changes in the redox state in pulp stem cells by laser treatment (Lina M. Escobar, Marggie Grajales, Zita Bendahan, Sully Jaimes, and Paula Baldi3n ) [13]	In vitro research on human dental pulp stem cells (hDPSCs), using two laser wavelengths (660 nm and 940 nm) with different exposure times to study osteoblastic differentiation and redox changes	2024	LLLT promotes osteoblastic differentiation through increased expression of RUNX2 and BMP2 genes, production of calcified nodules, and increased mitochondrial membrane potential as well as ROS, although it leads to reduced cell proliferation
17	Photodynamic Therapy in Root Canal Disinfection: A Case Series and Mini-Review	a case study in three patients undergoing photodynamic therapy	2022	PDT with LED at 630 nm is effective for root canal disinfection, shows a

No	Article Title	Model of study	Year	Results
	(Shahbazi, Soheil Esmaeili, Saharnaz Feli, Mojgan. Asnaashari, Mohammad, 2022)[14]	(PDT) for root canal disinfection		significant reduction in bacterial load and provides positive clinical outcomes in all treated patients, with signs of good healing at follow-up examination after 6 months
18	Photodynamic Therapy in Oral Cancer: A Narrative Review (Mosaddad, Seyed Ali Mahootchi, Pegah Rastegar, Zahra, 2023)[15]	This study is a narrative review that analyzes relevant research on the application of photodynamic therapy (PDT) in the management of oral cancer	2023	PDT is considered effective for treating early-stage head and neck cancer lesions as well as superficial tumors, resulting in minimal tissue damage and good cosmetic results. However, the limitation of PDT is the depth of light penetration, making it more effective on superficial lesions. This therapy is also considered an effective adjunct to other treatments such as surgery or radiotherapy
19	Effect of antimicrobial photodynamic therapy with Radachlorin and a 660 nm diode laser on <i>Pseudomonas aeruginosa</i> : An in vitro study (Kim, Ji won Lim, Hyun so, 2020)[16]	In vitro	2020	PDT with Radachlorin and a 660 nm diode laser was effective in inhibiting the growth of <i>Pseudomonas aeruginosa</i> , achieving a kill rate of up to 95.8% at an energy density of 5 J/cm <sup>2</sup> . The results showed that the group with a low energy delivery rate was more effective at reducing bacteria compared to

No	Article Title	Model of study	Year	Results
20	The efficacy of photodynamic inactivation of the diode laser in inactivation of the <i>Candida albicans</i> biofilms with exogenous photosensitizer of papaya leaf chlorophyll (Astuty, Sri Dewi São Paulo, São Paulo Baktir, Afaf Astuti, Suryani Dyah, 2019)[17]	In vitro studies	2019	the high energy delivery rate Papaya leaf chlorophyll activated with a 650 nm laser showed 32% inactivation of <i>Candida albicans</i> biofilm, higher compared to a 445 nm laser which resulted in 25% inactivation. Increased levels of malondialdehyde also showed that chlorophyll effectively increased biofilm cell damage by laser activation
21	Short-term improvement of clinical parameters and microbial diversity in periodontitis patients following Indocyanine green-based antimicrobial photodynamic therapy: A randomized single-blind split-mouth cohort (AlSarhan, Mohammed A. Altammami, Musaad A. Alaqeely, Razan S. AlEbdi, Ahmad Jasser, Reham Al Otaibi, Dalal Al Oraini, Saleh Al Habib, Syed Rashid Alqahtani, Lama Alduhaymi, Ibtehal S. Alrabiah, Deema K. Alaradi, Mashael Alyamani, Essam J.)[18]	Randomized single-blind split-mouth cohort design	2021	ICG-based PDT therapy improves clinical parameters such as reduced periodontal depth and clinical attachment loss better than controls
22	Effects of Antimicrobial Photosensitizers of Photodynamic Therapy (PDT) to Treat Periodontitis	This study is a literature review evaluating photodynamic therapy	2023	PDT with this photosensitizer is effective in reducing the bacterial burden

No	Article Title	Model of study	Year	Results
	(Bourbour, Samaneh Darbandi, Atieh Bostanghadiri, Narjess Ghanavati, Roya Taheri, Behrouz Bahador, Abbas, 2023)[19]	(PDT) for the treatment of periodontitis using antimicrobial photosensitizers		of periodontitis without damaging non-target tissues and exhibits additional therapeutic effects on periodontitis
23	A Multifunctional Nanosystem Based on Bacterial Cell-Penetrating Photosensitizer for Fighting Periodontitis Via Combining Photodynamic and Antibiotic Therapies (Li, Zhiyuan Pan, Wei Shi, Enyu Bai, Liya Liu, Hui Li, Changyi Money, Yinsong Deng, Jiayin Wang, Yue, 2021)[20]	In vitro and in vivo experimental studies	2021	TAT-Ce6 nanoparticles with a combination of PDT and antibiotic therapy showed high effectiveness in reducing the bacterial burden of periodontitis and reducing alveolar bone damage in mouse models
24	Carbon Dots in Photodynamic/Photothermal Antimicrobial Therapy (Wang, Siqi McCoy, Colin P. Li, Peifeng Li, Yining Zhao, Yinghan Andrews, Gavin P. Wylie, Matthew P. Ge, Yi, 2024)[21]	A literature review discussing the applications of carbon dots in photodynamic therapy (PDT) and photothermal (PTT) for antimicrobials	2024	Carbon dots show high effectiveness in PDT and PTT for antimicrobial applications, capable of generating ROS and heating target cells to effectively kill resistant bacteria
25	Efficacy of antimicrobial photodynamic therapy (aPDT) for nonsurgical treatment of periodontal disease: a systematic review (Moro, Marcella Goetz	randomised controlled trials (RCTs)	2021	The combination of SRP with aPDT resulted in a significant increase in CAL and a reduction in PPD in patients with chronic

No	Article Title	Model of study	Year	Results
	by Carvalho, Veronica Franco Godoy-Miranda, Bianca A. Checkout, Claudio Teruo Horliana, Anna Prates, Renato Araujo, 2021) [22]			periodontitis. Studies show positive effects especially with high concentrations of phenothiazine chloride and indocyanine green
26	Impact of Photobiomodulation and Melatonin on Periodontal Healing of Periodontitis in Immunosuppressed Rats (Latifa Mohamed Abdelgawad, Yomna Gamal Mahmoud Ibrahim Salem, and El-Sayed Abd Allah El Tayeb, 2024)[23]	Controlled clinical research in animals (Wistar mice)	2024	The combination of PBM with melatonin provided a better histological response in terms of decreased inflammation and improved periodontal healing compared to the use of PBM or melatonin separately in mice with immunosuppressive conditions
27	The Role of Laser Photobiomodulation (PBM) in the Management of Patients at Risk or Affected by MRONJ (Alessandro Del Vecchio, Gianluca Tenore, Daniele Pergolini, Federica Rocchetti, Gaspare Palaia, and Umberto Romeo, 2022)[24]	A narrative review of the use of laser photobiomodulation in patients at risk of or affected by MRONJ (Medication-Related Osteonecrosis of the Jaw)	2022	PBM has the potential to accelerate healing and reduce pain in MRONJ patients. This provides a preventive, anti-pain, and supportive effect on the treatment process
28	Photodynamic inactivation using a chlorin-based photosensitizer with blue or red-light irradiation against single-species biofilms related to periodontitis (Garcia de Carvalho, Gabriel Sanchez-Puetate, Julio Cesar Donatton, Maria Carolina Maquera Huacho, Patricia Milagros	In vitro	2020	PDI using Ce6 showed a significant reduction in bacterial viability on all single biofilms. The largest reduction effect was achieved by blue light irradiation at 200 mM Ce6, showing total elimination in some biofilms and reductions of up to 4 log <sub>10</sub> in others

No	Article Title	Model of study	Year	Results
	by Souza Rastelli, Alessandra Nara de Oliveira, Kleber Thiago Palomari Spolidorio, Denise Madalena Leal Zandim-Barcelos, Daniela, 2020)[25]			
29	Management of Medication-Related Osteonecrosis of the Jaw with Photobiomodulation and Minimal Surgical Intervention (Marwan El Mobadder, Zuzanna Grzech-Lesniak, Wassim El Mobadder, Mohamad Rifai, Maher Ghandour, and Samir Nammour, 2023)[26]	Clinical case report in an 83-year-old female patient with drug-related jaw osteonecrosis (MRONJ)	2023	The combination of PBM and surgical intervention was minimally effective in reducing pain (reducing VAS score from 8/10 to 2/10) and improving soft tissue healing in areas where there was previously open bone
30	Effectiveness of 650 nm Red Laser Photobiomodulation Therapy to Accelerate Wound Healing Post Tooth Extraction (S.D. Astuti, R. Nashichah, P. Widiyanti, E.M. Setiawatie, 2024)[27]	Experimental research with therapy groups and control groups using mice as research models	2024	PBM therapy with a 650 nm red laser showed significant decreases in IL-1 $\beta$ , PGE2, HBD2, and gingival (GI) index levels, suggesting that this therapy is effective in reducing inflammation and accelerating wound healing
31	Effect of photodynamic therapy with four light-sensitive materials on the bond strength of fiber posts to root dentin (Sedighe Sadat Hashemikamangar, Shadi Pourahmadi, and Nasim Chiniforush, 2024)[28]	An in vitro study testing the push-out bond strength (PBS) of post fiber to root dentin after photodynamic therapy with four different photosensitive materials	2024	Curcumin exhibits a similar bond strength to controls, whereas methylene blue, indocyanine green, and toluidine blue decrease bond strength
32	Investigating the Effect of Photobiomodulation Therapy With Different Wavelengths of Diode	In vitro research on human gingival fibroblasts tested with diode lasers at various	2024	PBM therapy at a wavelength of 915 nm at an energy of 4 J/cm <sup>2</sup> showed the

No	Article Title	Model of study	Year	Results
	Lasers on the Proliferation and Adhesion of Human Gingival Fibroblast Cells to a Collagen Membrane: An In Vitro Study (Mohammad Reza Karimi, Shahrzad Abdollahi, Ardavan Etemadi, and Neda Hakimiha, 2024)[29]	wavelengths to assess cell proliferation and adhesion to collagen membranes		best results in the proliferation and adhesion of gingival fibroblasts, followed by wavelengths of 660 nm and 808 nm
33	In Vitro Photobiomodulation Effects of Blue and Red Diode Lasers on Proliferation and Differentiation of Periodontal Ligament Mesenchymal Stem Cells (Ferena Sayar, Ahmad Garebigloo, Sogol Saberi, and Ardavan Etemadi, 2024)[30]	An in vitro experimental study assessing the effects of photobiomodulation (PBM) on periodontal ligament mesenchymal stem cells (PDLMSCs) with laser exposure to red and blue diodes	2024	Blue (445 nm) and red (660 nm) lasers significantly improved osteogenic differentiation in PDLMSC cells, with the 12 J/cm <sup>2</sup> blue laser group showing the most significant increase in calcification on day 14
34	Quantifying light energy from 450 nm, 650 nm, 810 nm, and 980 nm wavelength lasers delivered through dental hard tissue (Alex Simon Chan, Adam G. Chan, Judith M. Dawes, Andrew Jonathan Chan, and Ambrose Chan, 2022) [31]	Ex-vivo experimental studies on extracted human teeth to measure the transmission of laser energy through the hard tissues of teeth of various wavelengths	2022	The wavelength, tooth thickness, and tooth type affect energy transmission. Lasers with longer wavelengths (980 nm) are better at penetrating the thickness of teeth compared to shorter wavelengths (450 nm), which indicates the lowest transmission
35	Comparison of the effect of wavelength 660 with 808 nm diode as a low-level laser on non-surgical periodontal treatment in chronic periodontitis: a double-blind split-mouth randomized controlled clinic (Amir Reza	A controlled, double-blind, split-mouth clinical study involving 71 patients with chronic periodontitis	2023	Lasers with a wavelength of 660 nm showed a more significant improvement in periodontal clinical parameters compared to 808 nm lasers, especially in reductions in periodontal pouch

No	Article Title	Model of study	Year	Results
	Ahmadinia and Faezeh Staji, 1 trial, 2023)[32]			depth, gingival index, and clinical attachment rate
36	Randomized controlled clinical effectiveness of adjunct 660-nm light-emitting diode irradiation during non-surgical periodontal therapy (Yi-Wen Chen, Olivia Hsieh, Yueh-An Chen, Lan-Lin Chiou, and Po-Chun Chang, 2020)[33]	Randomized controlled clinical study with a split-mouth design in patients with chronic periodontitis	2020	660 nm showed significant results in reducing periodontal sac depth and clinical adhesion levels, especially in areas with severe periodontal damage, compared to controls
37	Laser-photobiomodulation on titanium implant bone healing in rat model: comparison between 660- and 808-nm wavelength (Guilherme Aparecido Monteiro Duque da Fonseca, Marcos Fernando Xisto Braga Cavalcanti, José Daniel de Souza Maior, Juliana da Silva Pereira, Leandro Augusto Pinto, and Lucio Frigo, 2022)[34]	In vivo experimental research on a Wistar mouse model, comparing the effects of two laser wavelengths (660 nm and 808 nm) on bone healing around titanium implants	2022	L-PBM at 660 nm and 808 nm showed accelerated healing of the peri-implant bone on day 7. On day 14, the control group showed a larger area of bone matrix than the irradiated group, suggesting that L-PBM accelerated but did not increase the formation of clean bone
38	Clinical Evaluation of 660 nm Diode Laser Therapy on the Pain, Size and Functional Disorders of Recurrent Aphthous Stomatitis (Hisham Abdelmonem Soliman and Diana Mostafaa, 2019)[35]	Controlled clinical trial, using a randomized design with two groups (treatment and control groups) in patients with recurrent aphthous minor stomatitis	2019	660 nm laser therapy significantly reduced pain, accelerated healing, and reduced lesion size in patients with recurrent minor aphthous stomatitis compared to the control group
39	Comparison of 660-nm low-level and defocused 810-nm high-power laser for treatment of herpes labialis (Mostafa Ahmadi, Amir Mansour Shirani, Shirin Zahra Farhad, Maryam	A single-blind controlled clinical trial, involving patients with herpes labialis in the prodromal phase or early vesicles divided into two groups	2022	Both laser methods are effective in reducing pain and speeding up healing, but the high-power 810 nm laser shows a faster time to pain reduction and a longer recurrence

No	Article Title	Model of study	Year	Results
	Khosravi, and Maziar Mir, 2022)[36]			interval than the 660 nm laser
40	Synthesis and evaluation of novel chlorophyll and derivatives as potent photosensitizers for photodynamic therapy (Synthesis and evaluation of novel chlorophyll and derivatives as potent photosensitizers for photodynamic therapy, 2020)[37]	Experimental research that includes synthesis and testing of the activity of chlorophyll a-derived photosensitizers for photodynamic therapy (PDT) in in vitro and in vivo models of lung cancer	2020	Chlorophyll a derivatives exhibit effective photodynamic activity against cancer cells, produce high ROS and have significant antitumor effects with a low risk of skin phototoxicity
41	Osteogenic potential of apical papilla stem cells mediated by platelet-rich fibrin and low-level laser (David Gutiérrez Ramírez, Carolina Inostroza, Mahmoud Rouabhia, Camilo Alfonso Rodriguez, Lina Andrea Gómez, Mónica Losada, and Ana Luisa Muñoz, 2024)[38]	In vitro experimental research using human papilla apical stem cells (SCAPs) to evaluate osteogenesis mediated by platelet-rich fibrin (PRF) and low-level laser therapy (LLLT)	2024	The combination of PRF and LLLT improved mineral nodule formation and more significant osteogenic gene expression compared to a single treatment, demonstrating great potential for bone tissue regeneration
42	Comparative Evaluation of the Effects of Diode Laser and Desensitizing Agents on the Treatment of Dentin Hypersensitivity: a Clinical Study (Mirjana Gojkov-Vukelic, Sanja Hadzic, Indira Mujic Jahic, Enes Pasic, and Arma Muharemovic, 2021)[39]	A controlled clinical study in patients divided into five groups to compare the effects of a 660 nm diode laser and a desensitizing agent on dentin hypersensitivity, 2 W (watts) in continuous mode, 60 seconds per session	2021	The combination of Vivasens with 660 nm diode laser irradiation provides the most effective results in reducing dentin hypersensitivity, both immediately and within one month post-treatment
43	Efficacy of Low-Level Laser Therapy in Wound Healing and Pain Reduction After Gingivectomy: A Systematic Review and Meta-analysis (Farida Abesi, Nahid Derikvand)[40]	This study was a systematic review and meta-analysis that analysed data from a variety of randomised controlled and non-randomised studies	2023	LLLT significantly improves wound healing and reduces post-gingivectomy pain on the 3rd and 7th days after surgery

**Table 2.** LLLT Supports Orthodontic Tooth Movement

No.	Article Title	Year	Results
1.	The effectiveness of low-level laser therapy on orthodontic tooth movement: a systematic review (Ranim Elgadi, Youssef Sedky, and Rene Franzen)[41]	2023	LLLT can increase the speed of tooth movement by up to 30-40% compared to controls, although results vary based on the parameters used
2	Effectiveness of photobiomodulation with low-level lasers on the acceleration of orthodontic tooth movement: a systematic review and meta-analysis of split-mouth randomised clinical trials (Grajales et al.)[42]	2023	LLLT can accelerate the movement of orthodontic teeth with an increase in efficiency of up to 30% depending on the parameters used
3.	Photobiomodulation Therapy-Assisted Orthodontic Tooth Movement: Potential Implications, Challenges, and New Perspectives (Jiawen Yong, <i>et al</i> )[43]	2023	PBMT can help reduce pain, speed up the movement of orthodontic teeth, and improve alveolar bone remodeling. However, research is still needed to determine the appropriate dosage and mechanism of action
4.	The Effects and Mechanisms of PBM Therapy in Accelerating Orthodontic Tooth Movement (Xinyuan Wang, Qian Liu, Jinfeng Peng, Wencheng Song, Jiajia Zhao, and Lili Chen)[44]	2023	PBM has been shown to accelerate orthodontic tooth movement by reducing hyalinization areas, improving bone remodeling, and modulating the expression of cytokines such as RANKL and IL-1 $\beta$
5.	Comparative Study of 660 and 830 nm Photobiomodulation in Promoting Orthodontic Tooth Movement (Huan Yang, Jingwen Liu, and Kai Yang)[45]	2023	Both 660 nm and 830 nm wavelengths can accelerate orthodontic tooth movement and alveolar bone remodeling. However, the 660 nm wavelength acceleration effect is stronger than 830 nm in the early stages

**Table 3.** LLLT for Post-Orthodontic Relapse

No.	Article Title	Year	Results
1.	Ameliorating orthodontic relapse using laser bio-stimulation and mesenchymal stem cells in rats (Samer S. Othman and colleagues)[46]	2024	LLLTs and MSCs significantly reduce orthodontic relapse by improving bone regeneration through remodeling of periodontal ligaments and alveolar bones. The combination of LLLTs and MSCs showed a stronger synergistic effect than each method separately
2.	Evaluation of the Effects of Low-Level Laser Therapy on the Rate of Relapse of Mandibular Incisors after Fixed Orthodontic Treatment: A Randomized Controlled Trial (Mirzaei, R. Arash, V. Rahmati-Kamel, M. Abesi, F. Bijani, A.)[47]	2023	LLLT at 808 nm wavelength can slow down the relapse rate, so it is considered an effective additional method to reduce relapse immediately after treatment
3.	Effects of different parameters of diode laser on acceleration of orthodontic tooth movement and its effect on relapse: An experimental animal study (Reporting by Ehab Elkattan, Mostafa Gheith, Mona Salah Fayed, M. Abo El Yazeed, Abdel-Razik H. Farrag, Wagdy K. B. Khalil)	2019	High-dose lasers showed a more significant acceleration of tooth movement compared to control and low doses
4.	Effectiveness of low-level laser therapy in facilitating maxillary expansion using bone-borne hyrax expander: A randomized clinical trial[48]	2022	Both groups experienced significant increases in nasal and maxillary width.  The group that received LLLT showed a significant increase in the angle of SNA and ANB.  There was no significant difference in expansion efficiency between the

No.	Article Title	Year	Results
			<p>group that received LLLT and those that did not.</p> <p>No significant differences in posterior tooth inclination were found between the two groups.</p>
5.	Efficacy of low-level laser therapy in accelerating tooth movement, preventing relapse and managing acute pain during orthodontic treatment in humans: a systematic review[49]	2016	<p>Accelerated Tooth Movement: Some studies have shown that LLLT speeds up tooth movement by up to 30%, while other studies have found no significant difference.</p> <p>Relapse prevention: No studies were found that met the inclusion criteria related to orthodontic relapse prevention.</p> <p>Modulation of Acute Pain: The majority of studies reported a significant reduction in pain after the application of LLLT, although there were some studies that did not find a significant effect.</p> <p>Quality of the evidence: The quality of the evidence for accelerated tooth movement was categorised as very low, while the quality of the evidence for pain modulation was judged to be low.</p>
6.	Combined effect of photobiomodulation with a matrix metalloproteinase inhibitor on the rate of relapse in rats[50]	2016	<p>LLLT increased relapse rates by 1.57 times compared to controls.</p> <p>Doxycycline (an MMP inhibitor) lowered the relapse rate by up to 0.83 times compared to controls.</p> <p>The combination of LLLT and doxycycline negates the effects of each other, resulting in a relapse rate that does not differ significantly from control.</p> <p>There was a positive correlation between the rate of relapse and MMP expression.</p>

No.	Article Title	Year	Results
			<p>LLLT increases osteoclast activity and collagen degradation in PDL, whereas doxycycline suppresses this activity.</p>
7.	<p>The Effects of Fulvic Acids and Low-Level Laser Therapy on Orthodontic Retention in Rats[51]</p>	2024	<p>Orthodontic retention was more stable with LLLT than without intervention.</p> <p>Fulvic acid (FAs) has no significant effect on relapse rates.</p> <p>The combination of FAs and LLLTs does not provide any additional effects compared to LLLTs themselves.</p> <p>LLLT and FAs + LLLT show decreased osteoclastic activity, reduced cement resorption, and improved the arrangement of periodontal ligament fibers.</p> <p>All groups with the intervention showed increased BMP-2 expression, but there was no synergistic effect between LLLTs and FAs.</p>
8.	<p>Effect of Blue-light-emitting Diode Exposure on Osteoprotegerin Level During Orthodontic Relapse in Rats[52]</p>	2023	<p>OPG levels in the Blue-LED group were higher than controls during the orthodontic relapse phase.</p> <p>Significant increases in OPG levels began on days 3, 7, and 14 during the relapse phase (<math>p &lt; 0.05</math>).</p> <p>Blue-LED accelerates bone remodeling, increases osteoblast activity, and suppresses osteoclasty.</p> <p>Exposure for 30 seconds per day for 7 days resulted in an optimal increase in OPG levels.</p>
9.	<p>Comprehensive Effects of Photobiomodulation Therapy as an Adjunct to Post-orthodontic Treatment Care: A Systematic Review[53]</p>	2021	<p>PBM has a positive effect on the maintenance of tooth position after orthodontic treatment, but the results are still controversial.</p>

No.	Article Title	Year	Results
			<p>Studies in animals and humans show that PBM can reduce orthodontic relapse, but some studies report opposite results.</p> <p>The effects of PBM on root resorption rehabilitation are promising, with almost all studies showing improved root regeneration and tooth stability after orthodontics.</p> <p>Large variations in laser parameters, application time, and study methodology make definitive conclusions difficult to reach.</p>
10.	Evaluation of Efficiency of Low-Level Laser on Relapse After Orthodontic Tooth Movement: An Experimental Study[54]	2021	<p>The group with LLLT showed the lowest relapse rate, followed by bonded retainers (BRs), and finally vacuum-formed retainers (VFRs).</p> <p>The LLLT group showed an improvement in the stability of orthodontic outcomes, with a decrease in the ABO discrepancy index score.</p> <p>The duration of retainer use can be reduced with the use of LLLT, with the time required to achieve 12-hour retainer use reduced to 8.33 weeks (compared to 24 weeks in conventional protocols).</p> <p>The use of LLLTs with VFRs significantly reduced relapse rates and improved retention quality.</p>

### Characteristics of Included Studies

Based on the literature selection process according to PRISMA guidelines, 50 articles were included in the final analysis. The studies analyzed included in vitro studies, in vivo studies (animal models), controlled clinical trials, and systematic reviews. The publications reviewed ranged from 2016 to 2024, with a primary focus on the use of Low-Level Laser Therapy (LLLT) and photobiomodulation (PBM) in dentistry, specifically orthodontics and periodontal tissue regeneration.

## **LLLT Wavelength Distribution and Energy Parameters**

Analysis of laser parameters revealed that the most frequently used wavelengths in studies were 650 nm and 660 nm, followed by other wavelengths such as 808 nm, 830 nm, and 915 nm. The wavelength distribution graph shows that red lasers (650–660 nm) dominate research due to their effectiveness in stimulating soft and cellular tissue, as well as their adequate tissue penetration for periodontal and orthodontic applications. In terms of energy density, most studies used doses in the range of 3–7 J/cm<sup>2</sup>, with 4 J/cm<sup>2</sup> being the most frequently reported value. This energy range has been consistently associated with increased cell proliferation, osteogenic differentiation, and modulation of inflammation without causing cytotoxic effects.

## **Biological Biomarkers Evaluated**

Biological biomarker analysis indicates that LLLT and PBM influence various molecular pathways involved in orthodontic tooth movement, tissue regeneration, and relapse prevention. The most frequently studied biomarkers include RANKL, OPG, IL-1 $\beta$ , VEGF, TGF- $\beta$ , BMP-2, RUNX2, and other indicators of angiogenesis and osteogenesis. In general, studies report that LLLT increases the expression of osteogenic and angiogenic markers, decreases inflammatory mediators, and modulates the balance of osteoclast and osteoblast activity, which is crucial for alveolar bone remodeling.

## **Effects of LLLT on Stem Cell Activation**

Most in vitro and in vivo studies have shown that LLLT significantly increases the proliferation, viability, and differentiation of various stem cell types, including mesenchymal stem cells (MSCs), human gingival fibroblasts (HGFs), periodontal ligament stem cells (PDLMSCs), and dental pulp stem cells (DPSCs). A 660 nm laser consistently demonstrates superior results in increasing cell viability, osteogenic gene expression (such as RUNX2 and BMP-2), and calcification nodule formation. The combination of PBM with photodynamic therapy (PDT), particularly using photosensitizers such as curcumin or chlorophyll derivatives, has been reported to have a synergistic effect in supporting periodontal tissue regeneration.

## **Effects of LLLT on Orthodontic Tooth Movement**

Based on analyses of clinical and experimental studies, LLLT has been shown to accelerate orthodontic tooth movement by 30–40% compared to control groups. This acceleration effect is associated with a decrease in hyalinization, increased alveolar bone remodeling, and increased RANKL and IL-1 $\beta$  expression at the compression site. Several comparative studies have shown that the 660 nm wavelength provides a stronger initial acceleration effect than near-infrared wavelengths, although the long-term differences are not always statistically significant.

## **Effectiveness of LLLT in Reducing Post-Orthodontic Treatment Relapse**

Several in vivo studies and clinical trials have demonstrated that LLLT plays a role in reducing orthodontic relapse rates, particularly in the early post-treatment phase. The mechanisms underlying this effect include increased periodontal ligament stability, modulation of the OPG/RANKL pathway, decreased osteoclast activity, and increased

expression of growth factors that promote new bone formation. However, some studies report varying results, particularly when laser parameters, application time, and study design differ. Some studies have also suggested that the effect of LLLT on relapse may be influenced by interactions with other factors, such as retainer use or combination with additional biologic agents.

### *Discussion*

The results of this systematic review indicate that Low-Level Laser Therapy (LLLT) plays a significant role in supporting the success of orthodontic treatment, particularly in accelerating tooth movement, reducing the risk of post-treatment relapse, and stimulating the activation of stem cells that play a role in periodontal tissue regeneration. These findings are consistent with various experimental, clinical, and in vitro studies reporting the biostimulatory effects of LLLT on oral hard and soft tissues.

The accelerated orthodontic tooth movement observed in most studies is closely related to LLLT's ability to modulate alveolar bone remodeling. The application of orthodontic force triggers a biological response in the form of osteoclast activity on the compression side and osteoblasts on the tension side. LLLT has been shown to increase the expression of early inflammatory mediators such as IL-1 $\beta$  and RANKL in a controlled manner, which play a role in osteoclast differentiation and bone resorption necessary for tooth movement. Furthermore, LLLT also reduces the area of hyalinization in the periodontal ligament, thereby accelerating tissue adaptation to orthodontic forces and increasing the efficiency of tooth movement.

Laser wavelength is a crucial factor in determining therapeutic effectiveness. Based on the analysis, 650 nm and 660 nm wavelengths were the most frequently used in the reviewed studies. Red lasers in this range have adequate tissue penetration to reach the periodontal ligament and alveolar bone. However, the 660 nm wavelength demonstrated superiority over 650 nm, particularly in terms of deeper tissue penetration and a more consistent biostimulation effect. This was reflected in increased cell proliferation, osteogenic differentiation, and the expression of regenerative markers such as RUNX2, BMP-2, VEGF, and TGF- $\beta$  in both in vitro and in vivo studies.

Stem cell activation was a key finding in this review. Various types of stem cells, including mesenchymal stem cells (MSCs), periodontal ligament stem cells (PDLMSCs), human gingival fibroblasts (HGFs), and dental pulp stem cells (DPSCs), showed a positive response to LLLT irradiation. Increased ATP production in mitochondria due to photobiomodulation stimulation accelerated cell proliferation and differentiation, and increased cell viability without causing cytotoxic effects. This stem cell activation directly contributed to periodontal tissue regeneration, including the formation of alveolar bone, periodontal ligament, and cementum, which are crucial for maintaining tooth stability after orthodontic treatment.

In addition to supporting tooth movement, LLLT also showed potential in reducing post-orthodontic relapse. Relapse results from an imbalance in periodontal

tissue remodeling after orthodontic force release. Several *in vivo* and clinical studies have reported that LLLT can improve periodontal tissue stability through modulation of the OPG/RANKL pathway. Increased osteoprotegerin (OPG) expression and decreased osteoclast activity contribute to inhibiting excessive bone resorption and accelerating periodontal tissue maturation, thereby reducing the likelihood of relapse. However, research results regarding relapse still show variation, likely influenced by differences in laser parameters, application time, and retention methods used.

The combination of photobiomodulation with photodynamic therapy (PDT) also contributes significantly to improving treatment outcomes. PDT, through the activation of photosensitizers and the production of reactive oxygen species (ROS), exerts antimicrobial and anti-inflammatory effects that support periodontal tissue health. When combined with LLLT, this therapy not only increases cell viability and activity but also creates a tissue environment more conducive to regeneration. This synergistic effect is particularly evident in studies using natural photosensitizers such as curcumin and chlorophyll derivatives, which have shown increased gingival fibroblast viability and accelerated tissue healing.

While the results of this review demonstrate the promising benefits of LLLT in orthodontic treatment, there are still limitations that need to be considered. Significant variations in study designs, laser parameters (wavelength, power, energy density, irradiation duration), and differences in research models lead to significant heterogeneity in the results. Furthermore, the number of clinical studies with large sample sizes and standardized protocols is still limited. Therefore, interpretation of the results should be approached with caution, and further research with randomized controlled clinical trials is needed to strengthen the scientific evidence.

Overall, this discussion confirms that LLLT, particularly at wavelengths of 650 nm and 660 nm, is a promising adjuvant therapy in modern orthodontic treatment. With optimization of laser parameters and integration of standardized protocols, LLLT has the potential to improve treatment efficiency, reduce the risk of relapse, and support periodontal tissue regeneration through stem cell activation. These findings open the door to the development of more biological, effective, and long-term stability-oriented orthodontic approaches.

## CONCLUSION

**Fundamental Finding :** Low-Level Laser Therapy (LLLT) with wavelengths of 650 nm and 660 nm has significant potential as an adjunct therapy in orthodontic treatment. LLLT has been proven to accelerate orthodontic tooth movement, reduce post-treatment relapse risk, and stimulate stem cell activation, which plays a crucial role in periodontal tissue regeneration and remodeling. **Implication :** LLLT with 660 nm wavelength shows deeper tissue penetration and stronger biostimulatory effects compared to 650 nm. This characteristic makes 660 nm LLLT more recommended for clinical applications, especially in supporting the stability of periodontal tissues and long-term orthodontic

treatment outcomes. **Limitation** : Further research is needed with more standardized methodologies to determine the optimal LLLT usage parameters, including intensity, duration, and irradiation frequency. Clinical protocols need standardization, and a deeper understanding of the biological mechanisms of LLLT is required for its effective and safe integration into modern orthodontic practices. **Future Research** : Further studies should focus on standardizing clinical protocols and exploring the biological mechanisms of LLLT in depth. More research with uniform methodological designs is needed to optimize the parameters of LLLT for effective and safe clinical use. This research will help integrate LLLT more effectively into orthodontic practices and improve the long-term stability of treatment outcomes.

## REFERENCES

- [1] H. Yang, J. Liu, and K. Yang, "Comparative Study of 660 and 830 nm Photobiomodulation in Promoting Orthodontic Tooth Movement," *Photobiomodulation, Photomedicine, and Laser Surgery*, vol. 37, no. 6, pp. 349–355, 2019, doi: 10.1089/photob.2018.4615.
- [2] A. A. Foggiato, D. F. Silva, and R. C. F. R. Castro, "Effect of photodynamic therapy on surface decontamination in clinical orthodontic instruments," *Photodiagnosis and Photodynamic Therapy*, vol. 24, pp. 123–128, 2018, doi: 10.1016/j.pdpdt.2018.09.003.
- [3] M. P. Uliana, A. da Cruz Rodrigues, B. A. Ono, S. Pratavieira, K. T. de Oliveira, and C. Kurachi, "Photodynamic Inactivation of Microorganisms Using Semisynthetic Chlorophyll and Derivatives as Photosensitizers," 2022. doi: 10.3390/molecules27185769.
- [4] V. Rizzi *et al.*, "A comprehensive investigation of amino grafted mesoporous silica nanoparticles supramolecular assemblies to host photoactive chlorophyll and in aqueous solution," *Journal of Photochemistry and Photobiology A: Chemistry*, vol. 377, pp. 149–158, 2019, doi: <https://doi.org/10.1016/j.jphotochem.2019.03.041>.
- [5] R. O. Adnan and H. A. Jawad, "Antimicrobial photodynamic therapy using a low-power 650 nm laser to inhibit oral *Candida albicans* activity: an in vitro study," *Journal of Medicine and Life*, vol. 17, no. 1, pp. 28–34, 2024, doi: 10.25122/jml-2023-0285.
- [6] G. Tenore *et al.*, "Evaluation of Photodynamic Therapy Using a Diode Laser 635 nm as an Adjunct to Conventional Chemo-Mechanical Endodontic Procedures against *Enterococcus faecalis* Biofilm: Ex-Vivo Study," 2020. doi: 10.3390/app10082925.
- [7] S. Alexeree, H. E. ElZorkany, Z. Abdel-Salam, and M. A. Harith, "A novel synthesis of a chlorophyll b-gold nanoconjugate used for enhancing photodynamic therapy: In vitro study," *Photodiagnosis and Photodynamic Therapy*, vol. 35, p. 102444, 2021, doi: <https://doi.org/10.1016/j.pdpdt.2021.102444>.
- [8] J. Bai *et al.*, "Low level laser therapy promotes bone regeneration by coupling angiogenesis and osteogenesis," *Stem Cell Research and Therapy*, vol. 12, no. 1, pp. 1–18, 2021, doi: 10.1186/s13287-021-02493-5.
- [9] F. Adnane, E. El-Zayat, and H. Fahmy, "The Combinational Application of Photodynamic Therapy and Nanotechnology in Skin Cancer Treatment: a Review," *Tissue and Cell*, vol. 77, p. 101856, Oct. 2022, doi: 10.1016/j.tice.2022.101856.
- [10] S. D. Astuti *et al.*, "Antimicrobial Photodynamic Effectiveness of Light Emitting Diode (LED) for Inactivation on *Staphylococcus aureus* Bacteria and Wound Healing in Infectious Wound Mice," *Journal of Physics: Conference Series*, vol. 1505, no. 1, 2020, doi: 10.1088/1742-6596/1505/1/012060.

- [11] I. Imelda, S. D. Astuty, P. L. Gareso, Z. Dwyana, N. F. Arifin, and S. D. Astuti, "Green Synthesis of Silver Nanoparticles using *Moringa oleifera*: Implementation to Photoantimicrobial of *Candida albicans* with LED Light," *Trends in Sciences*, vol. 21, no. 9, p. 8032, 2024, doi: 10.48048/tis.2024.8032.
- [12] S. Saberi *et al.*, "Efficacy of synthesized cubic spirulina platensis photosensitizer in anticancer photodynamic therapy: An in vitro study," *Photodiagnosis and Photodynamic Therapy*, vol. 42, no. January, p. 103511, 2023, doi: 10.1016/j.pdpdt.2023.103511.
- [13] L. M. Escobar, M. Grajales, Z. Bendahan, S. Jaimes, and P. Baldi3n, "Osteoblastic differentiation and changes in the redox state in pulp stem cells by laser treatment," *Lasers in Medical Science*, vol. 39, no. 1, 2024, doi: 10.1007/s10103-024-04016-z.
- [14] S. Shahbazi, S. Esmaeili, M. Feli, and M. Asnaashari, "Photodynamic Therapy in Root Canal Disinfection: A Case Series and Mini-Review," *Journal of Lasers in Medical Sciences*, vol. 13, pp. 1–6, 2022, doi: 10.34172/jlms.2022.19.
- [15] S. A. Mosaddad *et al.*, "Photodynamic Therapy in Oral Cancer: A Narrative Review," *Photobiomodulation, Photomedicine, and Laser Surgery*, vol. 41, no. 6, pp. 248–264, 2023, doi: 10.1089/photob.2023.0030.
- [16] J. Won Kim and H. S. Lim, "Effect of antimicrobial photodynamic therapy with Radachlorin and a 660 nm diode laser on *Pseudomonas aeruginosa*: An in vitro study," *Photodiagnosis and Photodynamic Therapy*, vol. 31, no. July, p. 101931, 2020, doi: 10.1016/j.pdpdt.2020.101931.
- [17] S. D. Astuty, Suhariningsih, A. Baktir, and S. D. Astuti, "The efficacy of photodynamic inactivation of the diode laser in inactivation of the *Candida albicans* biofilms with exogenous photosensitizer of papaya leaf chlorophyll," *Journal of Lasers in Medical Sciences*, vol. 10, no. 3, pp. 215–224, 2019, doi: 10.15171/jlms.2019.35.
- [18] M. A. AlSarhan *et al.*, "Short-term improvement of clinical parameters and microbial diversity in periodontitis patients following Indocyanine green-based antimicrobial photodynamic therapy: A randomized single-blind split-mouth cohort," *Photodiagnosis and Photodynamic Therapy*, vol. 35, no. March, p. 102349, 2021, doi: 10.1016/j.pdpdt.2021.102349.
- [19] S. Bourbour, A. Darbandi, N. Bostanghadiri, R. Ghanavati, B. Taheri, and A. Bahador, "Effects of Antimicrobial Photosensitizers of Photodynamic Therapy (PDT) to Treat Periodontitis," *Current Pharmaceutical Biotechnology*, vol. 25, no. 10, pp. 1209–1229, 2023, doi: 10.2174/1389201024666230720104516.
- [20] Z. Li *et al.*, "A Multifunctional Nanosystem Based on Bacterial Cell-Penetrating Photosensitizer for Fighting Periodontitis Via Combining Photodynamic and Antibiotic Therapies," *ACS Biomaterials Science and Engineering*, vol. 7, no. 2, pp. 772–786, 2021, doi: 10.1021/acsbomaterials.0c01638.
- [21] S. Wang *et al.*, "Carbon Dots in Photodynamic/Photothermal Antimicrobial Therapy," *Nanomaterials*, vol. 14, no. 15, 2024, doi: 10.3390/nano14151250.
- [22] M. G. Moro, V. F. de Carvalho, B. A. Godoy-Miranda, C. T. Kassa, A. C. R. T. Horliana, and R. A. Prates, "Efficacy of antimicrobial photodynamic therapy (aPDT) for nonsurgical treatment of periodontal disease: a systematic review," *Lasers in Medical Science*, vol. 36, no. 8, pp. 1573–1590, 2021, doi: 10.1007/s10103-020-03238-1.
- [23] L. M. Abdelgawad, Y. G. M. I. Salem, and E. S. A. A. El Tayeb, "Impact of Photobiomodulation and Melatonin on Periodontal Healing of Periodontitis in Immunosuppressed Rats," *Journal of Lasers in Medical Sciences*, vol. 15, 2024, doi: 10.34172/JLMS.2024.39.

- [24] A. Del Vecchio, G. Tenore, D. Pergolini, F. Rocchetti, G. Palaia, and U. Romeo, "The Role of the Laser Photobiomodulation (PBM) in the Management of Patients at Risk or Affected by MRONJ," *Oral*, vol. 2, no. 1, pp. 7–15, 2022, doi: 10.3390/oral2010002.
- [25] G. Garcia de Carvalho *et al.*, "Photodynamic inactivation using a chlorin-based photosensitizer with blue or red-light irradiation against single-species biofilms related to periodontitis," *Photodiagnosis and Photodynamic Therapy*, vol. 31, no. July, p. 101916, 2020, doi: 10.1016/j.pdpdt.2020.101916.
- [26] M. El Mobadder, Z. Grzech-Lesniak, W. El Mobadder, M. Rifai, M. Ghandour, and S. Nammour, "Management of Medication-Related Osteonecrosis of the Jaw with Photobiomodulation and Minimal Surgical Intervention," *Dentistry Journal*, vol. 11, no. 5, pp. 1–9, 2023, doi: 10.3390/dj11050127.
- [27] S. E. M. 1 Astuti S.D.1, Nashichah R.1, Widiyanti P.1, W. , Amir M.S.1, Apsari A.2, and A. N. 4 Hermanto E.2, Susilo Y.3, Yaqubi A.K.1, Nurdin D.Z.I.1, "Aluminum phthalocyanine nanoparticles activation for local fluorescence spectroscopy in dentistry," *Biomedical Photonics*, vol. 7, no. 3, pp. 4–20, 2018, doi: 10.24931/2413.
- [28] S. S. Hashemikamangar1 and N. C. , Shadi Pourahmadi2, "Effect of Photodynamic Therapy with Four Light- Sensitive Materials on the Bond Strength of Fiber Posts to Root Dentin," *Journal of Lasers in Medical Sciences*, vol. Volume 15, 2024, doi: 10.34172/jlms.2024.16.
- [29] Mohammad Reza Karimi1 and N. H. , Shahrzad Abdollahi1, Ardavan Etemadi1\* ID, "Investigating the Effect of Photobiomodulation Therapy With Different Wavelengths of Diode Lasers on the Proliferation and Adhesion of Human Gingival Fibroblast Cells to a Collagen Membrane: An In Vitro Study," *Journal of Lasers in Medical Sciences*, vol. Volume 15, 2024, doi: 10.34172/jlms.2024.53.
- [30] F. Sayar, A. Garebigloo, S. Saberi, and A. Etemadi, "In Vitro Photobiomodulation Effects of Blue and Red Diode Lasers on Proliferation and Differentiation of Periodontal Ligament Mesenchymal Stem Cells," *Journal of Lasers in Medical Sciences*, vol. 15, p. e5, 2024, doi: 10.34172/JLMS.2024.05.
- [31] A. S. Chan, A. G. Chan, J. M. Dawes, A. J. Chan, and A. Chan, "Quantifying light energy from 450 nm, 650 nm, 810 nm, and 980 nm wavelength lasers delivered through dental hard tissue," *Lasers in Dental Science*, vol. 6, no. 2, pp. 89–97, 2022, doi: 10.1007/s41547-022-00154-1.
- [32] A. R. Ahmadinia and F. Staji, "Comparison of the effect of wavelength 660 with 808 nm diode as a low level laser on non-surgical periodontal treatment in chronic periodontitis: a double-blind split-mouth randomized controlled clinical trial," *Lasers in Dental Science*, vol. 7, no. 3, pp. 103–109, 2023, doi: 10.1007/s41547-023-00185-2.
- [33] Y. W. Chen, O. Hsieh, Y. A. Chen, L. L. Chiou, and P. C. Chang, "Randomized controlled clinical effectiveness of adjunct 660-nm light-emitting diode irradiation during non-surgical periodontal therapy," *Journal of the Formosan Medical Association*, vol. 119, no. 1P1, pp. 157–163, 2020, doi: 10.1016/j.jfma.2019.01.010.
- [34] G. A. M. D. da Fonseca *et al.*, "Laser-photobiomodulation on titanium implant bone healing in rat model: comparison between 660- and 808-nm wavelength," *Lasers in Medical Science*, vol. 37, no. 4, pp. 2179–2184, Jun. 2022, doi: 10.1007/s10103-021-03481-0.
- [35] H. A. Soliman and D. Mostafaa, "Clinical evaluation of 660 nm diode laser therapy on the pain, size and functional disorders of recurrent aphthous stomatitis," *Open Access Macedonian Journal of Medical Sciences*, vol. 7, no. 9, pp. 1516–1522, 2019, doi: 10.3889/oamjms.2019.268.

- [36] M. Ahmadi, A. M. Shirani, S. Z. Farhad, M. Khosravi, and M. Mir, "Comparison of 660-nm low-level and defocused 810-nm high-power laser for treatment of herpes labialis," *Lasers in Dental Science*, vol. 6, no. 4, pp. 211–218, 2022, doi: 10.1007/s41547-022-00164-z.
- [37] Y. H. Gao *et al.*, "Synthesis and evaluation of novel chlorophyll and derivatives as potent photosensitizers for photodynamic therapy," *European Journal of Medicinal Chemistry*, vol. 187, p. 111959, 2020, doi: 10.1016/j.ejmech.2019.111959.
- [38] D. G. Ramírez *et al.*, "Osteogenic potential of apical papilla stem cells mediated by platelet-rich fibrin and low-level laser," *Odontology*, vol. 112, no. 2, pp. 399–407, 2024, doi: 10.1007/s10266-023-00851-8.
- [39] M. Gojkov-Vukelic, S. Hadzic, I. M. Jahic, E. Pasic, and A. Muharemovic, "Comparative evaluation of the effects of diode laser and desensitizing agents on the treatment of dentin hypersensitivity: A clinical study," *Medical Informatics Act*, vol. 29, no. 2, pp. 125–129, 2021, doi: 10.5455/AIM.2021.29.125-129.
- [40] F. Abesi and N. Derikvand, "Efficacy of Low-Level Laser Therapy in Wound Healing and Pain Reduction After Gingivectomy: A Systematic Review and Meta-analysis," *Journal of Lasers in Medical Sciences*, vol. 14, 2023, doi: 10.34172/jlms.2023.17.
- [41] R. Elgadi, Y. Sedky, and R. Franzen, "The effectiveness of low-level laser therapy on orthodontic tooth movement: a systematic review," *Lasers in Dental Science*, vol. 7, no. 3, pp. 129–137, 2023, doi: 10.1007/s41547-023-00190-5.
- [42] M. Grajales, N. Ríos-Osorio, O. Jimenez-Peña, J. Mendez-Sanchez, K. Sanchez-Fajardo, and H. A. García-Perdomo, "Effectiveness of photobiomodulation with low-level lasers on the acceleration of orthodontic tooth movement: a systematic review and meta-analysis of split-mouth randomised clinical trials," Dec. 2023, *Springer Science and Business Media Deutschland GmbH*. doi: 10.1007/s10103-023-03870-7.
- [43] J. Yong *et al.*, "Photobiomodulation therapy assisted orthodontic tooth movement: potential implications, challenges, and new perspectives," *Journal of Zhejiang University: Science B*, vol. 24, no. 11, pp. 957–973, 2023, doi: 10.1631/jzus. B2200706.
- [44] X. Wang, Q. Liu, J. Peng, W. Song, J. Zhao, and L. Chen, "The Effects and Mechanisms of PBM Therapy in Accelerating Orthodontic Tooth Movement," *Biomolecules*, vol. 13, no. 7, pp. 1–30, 2023, doi: 10.3390/biom13071140.
- [45] H. Yang, J. Liu, and K. Yang, "Comparative Study of 660 and 830 nm Photobiomodulation in Promoting Orthodontic Tooth Movement," *Photobiomodulation, Photomedicine, and Laser Surgery*, vol. 37, no. 6, pp. 349–355, 2019, doi: 10.1089/photob.2018.4615.
- [46] S. S. Othman *et al.*, "Ameliorating orthodontic relapse using laser bio-stimulation and mesenchymal stem cells in rats," *Journal of Genetic Engineering and Biotechnology*, vol. 22, no. 1, p. 100331, 2024, doi: 10.1016/j.jgeb.2023.100331.
- [47] A. B. R. Mirzaei, V. Arash, M. Rahmati-Kamel, F. Abesi, "Evaluation of the Effects of Low-Level Laser Therapy on the Rate of Relapse of Mandibular Incisors after Fixed Orthodontic Treatment: A Randomized Controlled Trial," *Journal of Babol University of Medical Sciences*, vol. 25, no. 1, pp. 152–159, 2023.
- [48] S. H. Abdelwassie, M. A. Kaddah, A. E. El-Dakroury, D. El-Boghdady, M. A. El-Ghafour, and N. F. Seifeldin, "Effectiveness of low-level laser therapy in facilitating maxillary expansion using bone-borne hyrax expander: A randomized clinical trial," *Korean Journal of Orthodontics*, vol. 52, no. 6, pp. 399–411, 2022, doi: 10.4041/kjod22.095.
- [49] A. Farsaii and T. Al-Jewair, "Insufficient Evidence Supports the Use of Low-Level Laser Therapy to Accelerate Tooth Movement, Prevent Orthodontic Relapse, and Modulate Acute Pain During Orthodontic Treatment," *Journal of Evidence-Based Dental Practice*, vol. 17, no. 3, pp. 262–264, 2017, doi: 10.1016/j.jebdp.2017.06.008.

- [50] S. H. Lee, K. A. Kim, S. Anderson, Y. G. Kang, and S. J. Kim, "Combined effect of photobiomodulation with a matrix metalloproteinase inhibitor on the rate of relapse in rats," *Angle Orthodontist*, vol. 86, no. 2, pp. 206–213, 2016, doi: 10.2319/022515-118.1.
- [51] J. Zhao, Q. Liu, C. Zhang, K. Zhang, and P. Xin, "The effects of fulvic acids and low-level laser therapy on orthodontic retention in rats," *BMC Oral Health*, vol. 24, no. 1, p. 1155, 2024, doi: 10.1186/s12903-024-04943-x.
- [52] D. A. Zahra, C. Christnawati, and C. A. Farmasyanti, "Effect of Blue-light-emitting Diode Exposure on Osteoprotegerin Level During Orthodontic Relapse in Rats," *Malaysian Journal of Medicine and Health Sciences*, vol. 19, pp. 58–64, 2023.
- [53] Z. Shan, K. W. F. Wong, C. McGrath, M. Gu, and Y. Yang, "Comprehensive Effects of Photobiomodulation Therapy as an Adjunct to Post-orthodontic Treatment Care: A Systematic Review.," *Oral health & preventive dentistry*, vol. 19, no. 1, pp. 203–216, 2021, doi: 10.3290/j.ohpd.b1075107.
- [54] O. A. Ayach, R. Hadad, and O. Hamadah, "Evaluation of Efficiency of Low-Level Laser on Relapse After Orthodontic Treatment: a Randomized Controlled Clinical Trial," *Journal of Stomatology*, vol. 74, no. 3, pp. 140–146, 2021, doi: 10.5114/JOS.2021.108838.

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**\*Lila Muntadir (Corresponding Author)**

Muhammadiyah University of Sidoarjo, Indonesia

Email: [lilamuntadir@umsida.ac.id](mailto:lilamuntadir@umsida.ac.id)

**Eka Setyawardana**

Muhammadiyah University of Sidoarjo, Indonesia

**Tontowi Ashari**

Muhammadiyah University of Sidoarjo, Indonesia

**Windy Yuliantanti**

Muhammadiyah University of Sidoarjo, Indonesia

**Marisa Elvi Dayan**

Muhammadiyah University of Sidoarjo, Indonesia

**Wanda Karisma Dian Sari**

Muhammadiyah University of Sidoarjo, Indonesia

**Rizqi Aulia Kusuma Andini**

Muhammadiyah University of Sidoarjo, Indonesia

**Reni Puspa Daniati**

Muhammadiyah University of Sidoarjo, Indonesia

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