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Efficacy of Photobiomodulation in Accelerating Orthodontic Tooth Movement: A Systematic Review of Literature

Houssem Hmida[1*], Nadia Madhi[1], Wiem Ben Amor[2], Ines Dallel[3], Samir Tobji[3], Adel Ben Amor[4]

[1]Resident, Department of Orthodontics, Dental Clinic of Monastir, Tunisia
[2]Assistant Professor, Department of Orthodontics, Dental Clinic of Monastir, Tunisia
[3]Professor, Department of Orthodontics, Dental Clinic of Monastir, Tunisia
[4]Professor and Head of Department, Department of Orthodontics, Dental Clinic of Monastir, Tunisia

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***Corresponding author:** Houssem Hmida
Resident, Department of Orthodontics, Dental Clinic of Monastir, Tunisia

Abstract

***Aim and background*:** This systematic review aimed to investigate the efficacy of photobiomodulation (PBM) on the acceleration of orthodontic tooth movement (OTM). ***Review methods*:** An extensive electronic search for randomized control trials via Medline (via PubMed), The Cochrane Controlled Clinical Trials Register, and Science Direct up to October 15, 2023 was done. Hand searching was performed for relevant journals. Reference articles were retrieved and exported to Zotero software. The risk of bias was assessed using Version 2 of the Cochrane risk-of-bias tool for randomized trials (RoB 2). ***Results*:** A total of 14 articles were considered for systematic review. Most of the studies arrived at the consensus that photobiomodulation (PBM) indeed accelerates the pace of tooth movement and significantly diminishes the time required for achieving proper tooth alignment. ***Conclusion*:** The synthesis of available evidence in our analysis reveals a substantial body of research suggesting a positive effect of PBM on accelerating tooth movement. However, the existing variations in PBM parameters, and outcome measurements emphasize the necessity for more standardized approaches in future investigations.

Keywords: Laser, Systematic Review, Movement, Orthodontic, Photobiomodulation.

1. INTRODUCTION

Orthodontic treatment is an effective solution for addressing both functional and aesthetic issues resulting from malocclusion. In contemporary society, an increasing number of children and adults are opting for orthodontic treatment. As per available literature, the standard duration for orthodontic treatment typically ranges from 12 to 24 months, with an additional variable period for post-treatment retention using appliances or fixed splints [1]. This extended process poses challenges for both orthodontists and patients. Extended treatment duration may cause inconvenience to patients in their daily routines and increase the risk of experiencing various side effects such as root resorption, caries, and periodontal diseases. This leads to a decrease in patient compliance and acceptance of the treatment [2]. Consequently, there has been a continuous pursuit of methods to augment the speed and effectiveness of orthodontic tooth movement [3].

Presently, there are three primary strategies aimed at improving treatment efficiency. The first involves creating precise treatment plans mapping the endpoint of orthodontic treatment to anticipate potential challenges in a case [4]. They often offer the most direct route from the initial malpositioned tooth to its final position, facilitating optimal biomechanical planning.

The second strategy focuses on enhancing the mechanical aspects of tooth movement [5]. Traditional efforts in this regard have concentrated on improving the biomaterial properties and biomechanical interactions of orthodontic brackets and wires through innovations in orthodontic wires and self-ligating systems [6]. A third approach seeks to enhance the pace of orthodontic tooth movement through biologically based methods [7]. One of the extensively studied techniques is surgical corticotomy-accelerated orthodontic tooth movement [8]. Despite being highly effective and predictable, surgery carries potential risks for morbidity and requires meticulous planning aligned with the orthodontic protocol and precise timing for maximum impact during the treatment course [9].

Exploration of nonsurgical alternatives has involved testing endothelial growth factors [10], osteoclast precursors like osteocalcin, prostaglandins [11], bone resorptive factors like RANKL [12], leukotrienes [13], and macrophage colony-stimulating factors. However, studies in these areas are limited, making it challenging to fully comprehend these mechanisms.

A recent avenue of exploration involves device-assisted therapy to biologically enhance orthodontic tooth movement. Systems utilizing light, electrical currents [14], cyclic forces [15], and resonance vibration [16] have been introduced, but many of these methods are still in the emerging stage.

Photobiomodulation or low-level light therapy (LLLT) holds promise in providing noninvasive stimulation to the dentoalveolar complex, potentially impacting ATP production by mitochondrial cells. During the tooth movement phase, higher ATP availability facilitates more efficient cellular turnover, leading to increased remodeling and accelerated tooth movement. Additionally, PBM may function through increased vascular activity [17], contributing to rapid bone turnover.

Considering the crucial role of bone remodeling in orthodontic therapy, the stimulatory effect of laser therapy appears to have the potential to influence orthodontic treatment duration.

2. MATERIALS AND METHODS

2.1. Protocol and registration:

The Cochrane Handbook for Systematic Reviews of Interventions mentioned using the PICOS framework as a model for developing a review question, thus ensures that the relevant components of the question are well defined.

PICOS framework specifies the type of Patient or Population, type of Interventions and Comparisons if there is any, the type of Outcomes that are of interest, and the studies design [20].

The eligibility criteria of this review followed the PICOS criteria as such:

- ✓ **Population** = Orthodontic patients receiving photobiomodulation therapy (PBM).
- ✓ **Intervention** = PBM used as an aid intervention in fixed orthodontic treatment.
- ✓ **Compared with** = Control groups receiving fixed orthodontic treatment without any other interventions and/or placebo group receiving simulated PBM treatment.
- ✓ **Outcome of interest** = Time needed for dental alignment, orthodontic tooth movement rate (tooth displacement in a determined period of time), pain score perception, orthodontic root resorption crater volume.
- ✓ **Study type** = Randomized controlled clinical trial (parallel group or split mouth design).

2.1.1 Inclusion criteria:

The included articles met the following criteria:

- ✓ Articles in English dating from 01/01/2017 to 15/10/2023.
- ✓ The articles must meet all PICOS criteria with the design of randomized clinical trials (RCTs) conducted on humans (parallel group or split mouth design).
- ✓ Human teeth subjected to orthodontic force application in any direction.
- ✓ PBM interventions conducted with LEDs or LLLs equipment.
- ✓ Studies presenting the parameters of PBM and the individual characteristics of patients.
- ✓ Outcome variables were defined as Overall treatment time, orthodontic tooth movement rate (tooth displacement in a determined period of time), pain score perception, orthodontic root resorption crater volume.

2.1.2. Exclusion criteria:

- ✓ Non-randomized clinical trials
- ✓ In-vitro studies or animal studies
- ✓ Studies without a control/comparison group
- ✓ Review articles, case reports, case series, and letters to editor.
- ✓ Studies available only in languages other than English.
- ✓ Studies that included fewer than 10 patient or hemiarch (quadrant) per group.
- ✓ Patients of studies exposed to previous orthodontic treatment.
- ✓ Studies involving participants suffering from metabolic disorders, or taking medications impeding or hastening tooth movement.
- ✓ Studies involving participants who had a high caries index or periodontal disease.
- ✓ Studies that used high-level laser or red laser.

2.2. Information sources and search strategy

The review authors performed an extensive electronic search for randomized controlled trials realized on humans up to October 15, 2023, in three databases: PubMed, Science Direct, and Cochrane Library. The search strategies employed are outlined in Table 1.

Table I: Search strategies in the three databases

Database	Search strategy
PubMed	("low-level laser" OR "low-level laser therapy" OR photobiomodulation) AND orthodontic* AND acceleration
ScienceDirect	("low-level laser" OR "low-level laser therapy" OR photobiomodulation) AND orthodontic AND acceleration
Cochrane Library	("low-level laser" OR "low-level laser therapy" OR photobiomodulation) AND orthodontic* AND acceleration

All articles and manuscripts published in English or with English translations available were incorporated in the search and only articles published from 01-01-2017 were selected. The search was complemented by a manual review of the references of the studies included.

2.3. Data extraction

Titles and abstracts were selected independently by the investigators to verify their eligibility. In cases of discrepancy, consensus was obtained by discussion. The same reviewers then examined the references that appeared to meet the inclusion criteria in their entirety.

The information regarding the selected studies was recorded using three data extraction forms specifically created for this purpose to systematically and uniformly analyze and compare each selected article.

A first form for the extraction of the following data: author and date, total number of patients / Teeth ,number of subjects in PBM group, number of subjects in control group, mean age of patients, the orthodontic mechanics and the clinical assessement used in the trial, and the principal outcome of the trial.

A second form for the extraction of light parameters data: the equipement used, wavelength, irradiation points, dose of energy and the phototherapy session protocol.

A third and final form for the extraction of: the mean values of the main outcome, the results and the conclusion of each article.

Then, the gathered information was grouped and synthesized into tables for discussion and analysis to address the main question of the research.

2.4. Risk of bias assessment

The assessment of the risk of bias in the included studies was conducted using Version 2 of the Cochrane risk-of-bias tool for randomized trials (RoB 2). RoB 2 is the recommended tool for evaluating the risk of bias in randomized trials included in Cochrane Reviews [19]. The tool is organized into five domains that identify potential sources of bias in the study results, the five domains are:

1. Bias arising from the randomization process.
2. Bias due to deviations from intended interventions.
3. Bias due to missing outcome data.
4. Bias in the measurement of the outcome.
5. Bias in the selection of the reported result.

Within each domain, a set of questions known as 'signalling questions' is designed to gather information relevant to the risk of bias. An algorithm utilizes the responses to these questions to generate a proposed judgment regarding the risk of bias for each domain. This judgment can be categorized as 'Low' or 'High' risk of bias or expressed as 'Some concerns' [19].

Two reviewers [B.A and H.H] independently assessed the risk of bias using an excel tool designed to implement RoB 2, and the differences between the reviewers were resolved by discussion.

2.5. Level of Evidence

The evaluation of the level of evidence was carried out utilizing the Grading of Recommendation Assessment, Development, and Evaluation (GRADE) system by the two reviewers independently.

The GRADE system principles were applied to assess the overall quality of the body of evidence associated with the primary outcomes. To facilitate this assessment, a "Summary of Findings" (SoF) table was constructed using the GRADEpro GDT software available at http://gdt.guidelinedevelopment.org .

The evaluation of the body of evidence considered factors such as the overall risk of bias in the included studies, directness of the evidence, inconsistency of results, precision of estimates, risk of publication bias, and the magnitude of the effect. Depending on the severity, the quality of evidence can be downgraded by one or two levels for each aspect. We categorized the quality of the body of evidence for each primary outcome as high, moderate, low, or very low.

3. RESULTS

3.1. Study selection

The electronic search retrieved 527 results from all the databases.

451 results remained after removal of duplicates, which were then screened by titles and abstracts. 56 of those were of the desired study design.

Six articles were not accessible for full text screening and 36 articles were excluded for not matching the eligibility criteria, which left us with a total of 14 articles to be included in this systematic review.

A flowchart of the article selection process for each stage of the review is presented in Figure 1.

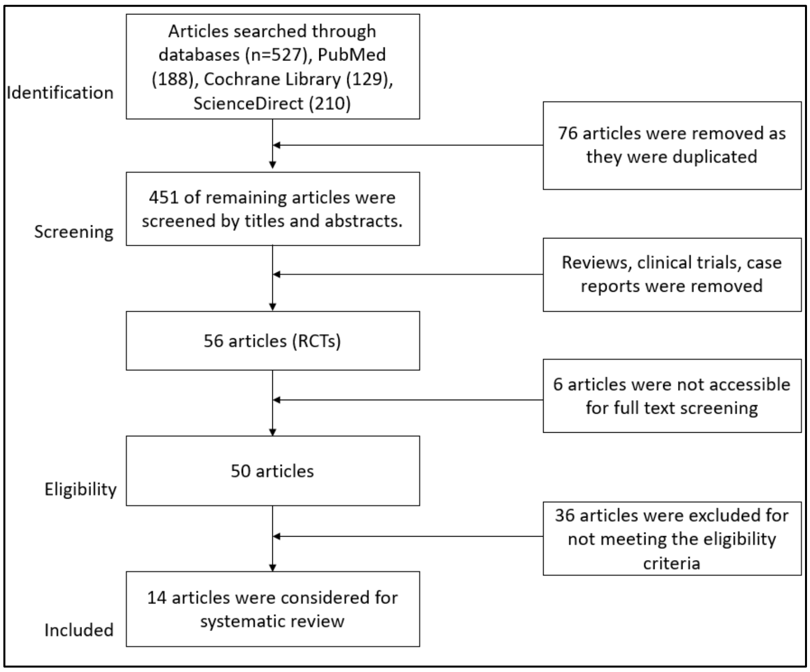

Figure 1: Flowchart of the articles selection process

3.2. Characteristics of included studies

Fourteen relevant publications assessing the effectiveness of PBM in accelerating orthodontic tooth movement were identified as eligible according to the predefined inclusion criteria for this review. The gathered data was grouped into the tables II, III and IV below:

Table II: Clinical characteristics of the RCTs exploring orthodontic tooth movement acceleration

Author and date	Patients / Teeth	Number in PBM group	Number in control group	Mean age	Orthodontic mechanics and clinical assessement	Outcome
Nahas *et al*., 2017[21]	n = 34 patients	n = 18	n = 16	Cont : 21.1 Test : 21.8	Leveling and aligning of the lower anterior segment during non extraction orthodontic treatment in patients who have a score of 2–10 mm Little's irregularity index score (lower anterior crowding) : both groups received a self-ligating bracket appliance with an MBT prescription. The arch wire sequence was standardized across groups a 0.016-in Heat Activated NiTi followed by a 0.018-in NiTi until alignment of the lower anterior teeth was achieved In both groups.	Treatment time (in days) required to align the lower anterior teeth (when the Little's irregularity index score was down to 0– 1 mm)

Üretürk *et al.*, 2017[22]	n = 15 patients n = 30 teeth	n = 15	n = 15	16.2	The maxillary first premolars had been extracted 2 weeks before starting aligning and levelling. After complete aligning and levelling canines were distalized by nickel-titanium closed-coil spring between the bracket of the canine and the head of the mini implant. Canine distalization was evaluated at a 90-day period.	Evaluation of the canine distalization amount on digital models at (T0), day 30 (T1), day 60 (T2), and day 90 (T3).
AlSayed Hasan *et al.*, 2017[23]	n = 26 patients	n = 13	n = 13	20.07	Five to 7 days after first premolar extraction in patients with Little's irregularity index (LII) in the anterior maxilla of 7 mm or more, fixed orthodontic appliances of the MBT prescription were bonded. The archwire sequence used was 0.014-inch NiTi followed by 0.016 * 0.016-inch and 0.017 * 0.025-inch NiTi, and finally 0.019 * 0.025-inch stainless steel.	The overall time needed to complete leveling and aligning (OLAT) the maxillary dental arch.
Caccianiga *et al.*, 2017[24]	n = 36 patients	n = 18	n = 18	16.97	All participants were treated with 0.022-inch self-ligating with MBT prescription. Both groups received the same archwire sequence, that is, a 0.014-inch thermal NiTi archwire followed by 0.016 * 0.022-in and 0.017 * 0.025-in thermal NiTi archwires.	the average time for dental alignment (The resolution of dental crowding was assessed basing on visual inspection of correction of the 11 mandibular interproximal contacts.
Qamruddin *et al.*, 2017[25]	n = 20 patients n = 40 teeth	n = 20	n = 20	19.80	In Angle Class II Division 1 malocclusion patients requiring extraction of first premolars bilaterally in the maxillary arch only the orthodontic treatment was initiated with a banding procedure followed by bonding passive self-ligating MBT brackets. After alignment and leveling, extractions were performed, canine retractions were started using nickel-titanium closed-coil springs, placed from the first molar band hook to the power arm of the canine brackets.	The rate of canine retraction : value of canine retraction after 9 weeks
Arumughan, *et al.*, 2018[26]	n = 12 patients n = 24 teeth	n = 12	n = 12		The en masse retraction was carried out on 0.019" × 0.025" SS wires using closed coil spring in patients requiring extraction of 1st premolar as a part of orthodontic treatment.	The rate of orthodontic tooth movement: amount of space closure after 12 weeks.
Guram, *et al.*, 2018[27]	n = 20 patients n =	n = 20	n = 20	19.75	The initial orthodontic treatment includes sectional alignment and leveling of canines, second premolars, and the first molars. Canines were retracted using sectional closing loops placed in the middle of the extraction site. The loops were reactivated on both sides every month for 2 mm.	Amount of canine retraction Rate of canine retraction
Isola *et al.*, 2019[28]	n = 41 patients n = 82 teeth	n =41	n = 41	13.4	After the initial alignment and levelling phase the extractions of the first premolars were performed. A segmented arch of 0.016–0.022 ss was applied in association with a closed nickel-titanium (NiTi) coil spring in order to obtain the space closure of the first premolars. Reactivation of the spring was carried out every 21 days until a total closure of the extraction space was obtained	the overall time needed to complete the levelling and closing space, measured on a study cast.
Lo Giudice *et al.*, 2020[29]	n = 89 patients	n =43	n = 46	18.4	The arch-wire sequence included 0.014-in thermal NiTi arch-wire followed by 0.016 · 0.022-in and 0.019 · 0.025-in thermal NiTi.	Treatment time (Mandibular Decrowding)

Junyi Zheng and Kai Yang 2021[30]	n = 12 patients n = 24 teeth	n = 12	n = 12		The orthodontic treatment was initiated 2 weeks after the maxillary frst premolars were extracted. The canines were leveled and after that, a fnal working wire of 18*25-in stainless steel was placed. A transpalatal arch was cemented on both frst molars to provide posterior anchorage. A nickel-titanium closed-coil spring was used to retract each canine.	the amount of canine retraction at the end of 4 weeks
Al-Shafi *et al.*, 2021[31]	n = 20 patients n = 40 teeth	n = 20	n = 20	15.8	Patients underwent bilateral extraction of maxillary first premolars. Bonding of fixed appliances was then carried out. A standardized wire sequence was used to achieve leveling and alignment. Canines were distalized using an 0.020-in SS wire and medium super-elastic NiTi closed coil springs from the canine to the first molars.	The primary outcome was the amount of tooth movement.
Pérignon *et al.*, 2021[32]	n = 42 patients split mouth	n = 42	n = 42	13.6±1.5	Class II elastics were placed by the patient from the maxillary canine to the frst mandibular molar to retract the maxillary canine. The elastic size was 5/6″, and the force level was 4½ OZ.	The rate of change toward Class I occlusion.
Ghaffar *et al.*, 2022[33]	n = 30 patients	n =15	n=15	21.5±3.5	In both groups, an initial archwire of 0.014-inch (Cu-NiTi) was inserted immediately after bonding. Proceeding to 0.016-inch Cu-NiTi then 0.016 * 0.022-inch NiTi wire was carried out when 50% and 80% reduction in Little's irregularity index (LII) was achieved, respectively. Finally, on completion of alignment (LII < 0.25), a 0.017 * 0.025-inch stainless steel wire was inserted.	The OLAT of the crowded mandibular anterior segment.
Kharat *et al.*, 2023[34]	n = 20 patients	n = 20	n = 20		After banding the first molars, bracket bonding of both the maxillary arch and mandibular arch was done. Archwires were replaced with a rectangular 0.019" x 0.025" stainless steel archwire. A mini-implant was placed on both the right and left sides for maximum anchorage. Retraction of individual canines was initiated using a nickel-titanium (NiTi) closed coil spring.	The rate of movement of teeth orthodontically was measured as the amount of tooth movement divided by the time taken.

Table III: Phototherapy parameters of RCTs exploring orthodontic tooth movement acceleration

Author and date	Equipment	Wave length	Irradiation points	Energy density per session	Laser session
Nahas *et al.*, 2017 [21]	OrthoPulse device	850 nm	surface of the cheek	108 J/ cm2	daily for 20 min
Üretürk *et al.*, 2017 [22]	gallium-aluminumarsenide (GaAlAs) diode low-level laser	820 nm	A total of ten points: five from the buccal side and five from the palatal side; two irradiation points on the cervical third (one mesial one distal), two irradiation points on the apical third (one mesial one distal), and one irradiation point on the middle third (on the center of the root).	Total energy: 2 J / treatment time (0.2 J of energy per point)	The laser application (10 s per point) was applied on day 0, the 3rd, 7th, 14th, 21th, 30th, 33rd, 37th, 44th, 51st, 60th, 63rd, 67th, 74th, 81st, 84th, 90th days.

AlSayed Hasan *et al.*, 2017 [23]	gallium-aluminumarsenide (GaAlAs) diode low-level laser	830-nm	The laser beam was applied to each root of the six maxillary incisors roots. Each root was divided into two halves: cervical and apical. The laser device tip was applied to the center of each half, from both the buccal and palatal sides so that there were four application points for each tooth with an exposure time of 1 minute/tooth.	2J / point 8J / tooth / treatment time	The laser application was repeated on days 3, 7, and 14 after the first application and every 15 days starting from the second month until the leveling and the alignment stage was complete.
Caccianiga *et al.*, 2017 [24]	Diode laser emitting infrared radiation	980 nm	Irradiation was administered by positioning the optical fiber tip along the mandibular dental arch (beam spot size of 1 cm2), 4 dental segments (right first premolar-canine, right lateral-central incisors, left central-lateral incisors, left canine-first premolar) were consecutively irradiated for 8 sec and two dental segments (right first molar-second premolar, left second premolar-first molar) for 9 sec, for a total of 50 sec	The total energy density for the entire mandibular dental arch 150 J/cm2	The procedure was repeated 3 times at intervals of 2 min corresponding to an exposure time of 150 sec. A single monthly administration of LLLT was performed
Qamruddin *et al.*, November 2017 [25]	A gallium-aluminum-arsenic diode laser	940 nm	10 points, 5 on the buccal side and 5 on the palatal side. The points to be irradiated on the buccal sides were mesial and distal to the apical area of the canine, and mesial and distal to the cervical area of the canine, and 1 point was approximately at the middle of the root. The same areas on the palatal side were also irradiated.	3J / tooth / treatment time.	Irradiation was applied for 3 seconds at each point (T0). The patients were called for their follow-ups every 3 weeks for 3 more consecutive visits (T1, T2, and T3). Laser therapy was repeated at T1 and T2.
Arumughan *et al.*, 2018 [26]	GaAlAs diode laser	810 nm	A total of 10 irradiations was given 5 on the buccal side and 5 on the palatal side, the distribution and order were as follows: On the buccal and palatal side, 2 irradiation doses on the cervical third of the root (1 mesial and 1distal), 2 on the apical third of the root (1 mesial and 1 distal), and 1 on the middle third (center of the root) of canine lateral and central incisor of experimental side.	at each application: 10 J / tooth	The experimental side was irradiated for 10 sec per site with an interappointment gap of 3 weeks; on days 1, 21, 42, and 63.
Guram, *et al.*, 2018 [27]	A gallium-aluminum-arsenide semiconductor diode laser	810 nm	close contact to apical, middle, and cervical third of root on buccal and lingual side	6J / tooth	The laser was applied to the buccal and palatal aspect of the tooth for 80 s weekly for 21 days

Isola *et al.*, 2019 [28]	diode laser	810 nm	The laser device was applied, with the laser tip in contact with gingival tissues to both the buccal and palatal side starting from the center of the root on 3 points/side (distal, medial and mesial) Each area was irradiated for 15 s	8J/ tooth	Irradiation was performed at baseline and after 3, 7, and 14 days after the first application and every 15 days until levelling and closure of the tooth extraction space was achieved
Lo Giudice *et al.*, 2020 [29]	ATP38. This device features a multi-panel system emitting cold polychromatic lights	combination of wavelengths from 450 to 835 nm	three panels placed at a 4 cm distance from the patient's cheeks (lateral panels) and lips (frontal panel).	144 J/cm2	Each PBM session was performed every 14 days, including the date of bracket bonding, up to the end of the alignment stage.
Junyi Zheng and Kai Yang 2021 [30]	Semi conductor diode laser	810 nm	The laser irradiation was applied at 4 points (mesial buccal, distal buccal, mesial lingual, and distal lingual) for 40 s on each surface.	8 J/ tooth	LLLT was initiated at the beginning of retraction, and it was repeated on days 7, 14, and 21 by the same operator.
Al-Shafi *et al.*, 2021 [31]	The OrthoPulse device	850 nm	surface of the cheek	60 mW/cm2	10 min/d
Pérignon *et al.*, 2021 [32]	diode laser	970 nm	Irradiation was performed at six points per tooth on four teeth (the canine, the frst and second premolar, and the frst maxillary molar). For each tooth, there were 3 vestibular application points and 3 palatal application points: one point at the coronary third of the root, one point at the median third and one point at the apical third	total energy received was 21.6 J.	The second laser application session was carried out 1 month afer the frst application
Ghaffar *et al.*, 2022 [33]	diode laser	940 nm	Tooth-whitening handpiece (35 mm * 8 mm) = (2.8 cm2)	25.7 J/cm2 per application	Day 0, 3, 7, 14, 30 and then repeated every 2 weeks until alignment completion
Kharat *et al.*, 2023 [34]	semiconductor-type diode aluminum gallium arsenide laser	940 nm	A total of 10 irradiations were performed: five on the buccal side and five on the palatal side as follows: irradiation of the cervical one-third of the canine root (one dose on the mesial and one on the distal); irradiation of the apical one-third of the canine root (one dose on the mesial and one on the distal); irradiation of the middle one-third of the canine root (the center part of the root) once-a similar kind of irradiation was done on the palatal aspect.	100 mW with a continuous wave and a 10-second exposure time 10 J / tooth	The laser therapy was performed on days 0, 3, 7, and 14 in the first month. Subsequently, laser irradiation was applied every 15 days till the retraction of the canine was complete on the test side.

Table IV: Findings of RCTs exploring orthodontic tooth movement acceleration

Author and date	**Outcome (Mean) Test Control**		**Results**	**Conclusion**
Nahas *et al.*, 2017 [21]	The treatment duration was 68.3 days	The treatment duration was 87.8 days	The test group exhibited a significant reduction in the treatment time required to align the lower anterior teeth by 22 %.	The use of photobiomodulation for 20 min daily at a 850-nm wavelength might reduce the time required to resolve lower anterior crowding.
Üretürk *et al.*, 2017 [22]	The average amount of canine distalization : at 1 month :1.3±0.5 mm at 3 months :3.9±1.4 mm	0.94 ± 0.49 mm 2.77 ± 1.49 mm	There was significant difference in the amount of canine distalization on the laser group compared with the control group ($P < 0.01$). The mean increase in the rate of tooth movement at 3 months was 40%.	The results of this study suggest that low-level laser application significantly accelerates tooth movement in humans.
AlSayed Hasan *et al.*, 2017 [23]	OLAT: 81.23	OLAT: 109.23	A statistical significance was found between the two groups with 26% decrease in overall treatment time in favor of the laser group.	Low-level laser therapy, used with the described parameters, is an effective method for accelerating orthodontic tooth movement in dental crowding cases.
Caccianiga *et al.*, 2017 [24]	ATDA : 211.8	ATDA : 284.1	the average time for dental alignment was significantly shorter ($p < 0.001$) in the tested group compared to the control	LLLT significantly increases the efficiency of orthodontic treatment during dental alignment
Qamruddin *et al.*, 2017 [25]	Mean value of canine retraction after 9 weeks : 1.60 ± 0.38 mm	Mean value of canine retraction after 9 weeks : 0.79 ± 0.35 mm	The overall movement of the canines on the experimental side was 2.02 times greater compared with the placebo side.	LLLI is a beneficial modality that can double the rate of OTM if applied at 3-week intervals.
Arumughan, *et al.*, 2018 [26]	Rate of retraction : 0.694167	Rate of retraction : 0.50000	Low-level laser therapy accelerates the orthodontic tooth movement by 12.555% than that of conventional retraction technique in every dose of laser application (21 days)	Biostimulation carried out using an 810 nm diode laser is capable of increasing the rate of extraction space closure. Hence, it is capable of increasing the rate of orthodontic tooth movement.
Guram, *et al.*, 2018 [27]	max mand T1 1.17 1.01 T2 1.78 1.38 T3 1.97 1.57	max mand T1 0.78 0.68 T2 0.87 0.85 T3 0.97 0.88	There was 1.17– 1.9-fold increase in the rate of canine tooth movement in Group A. The results were statistically significant	LLLT can increase the fixed OTM timing during orthodontic procedure.
Isola *et al.*, 2019 [28]	Time to achieve space closure : 84.35 ± 12.34 days	Time to achieve space closure :97.49 ±11.44 days	The laser group yielded less mean time (84.35 ± 12.34 days) to accomplish space closure compared to the control group (97.49 ± 11.44 days), with a significant reduction in the overall treatment time for the test	In conclusion, the results of the present study suggest the positive effects of LLLT by means of diode laser for accelerating OTM

			side compared to the control side (p < 0.001)	
Lo Giudice *et al.*, 2020 [29]	203 days	260 days	The median treatment time was significantly shorter in the PBM group (203 days) compared with the control group (260 days) (p < 0.001).	PBM significantly reduces treatment time duration during dental alignment.
Junyi Zheng and Kai Yang 2021 [30]	1.15±0.29 mm	0.85±0.23 mm	The laser group showed signifcantly larger distalization than the control group. The mean retraction velocity was signifcantly greater in the laser group than in the control group until the 4th week.	In the conditions of this present randomized controlled trial, we concluded that LLLT could have clinical utility in accelerating OTM,
Al-Shafi *et al.*, 2021 [31]				No significant biostimulatory effects were found on the rate of maxillary extraction space closure using LED phototherapy with the OrthoPulse device.
Pérignon *et al.*, 2021 [32]	1mm / month	0.7 mm / month	the rate of change toward Class I occlusion in the laser half was signifcantly higher than that in the placebo half (p=0.037).	Based on our results and within the limitations of our sample size a signifcant impact on the acceleration of tooth movement was observed on the irradiated side.
Ghaffar *et al.*, 2022 [33]	OLAT = 68.2	OLAT = 109.5	The laser group showed a statistically significantly lower mean OLAT of compared to the control group (P .05).	Within the limits of the current study, administration of LLLT can efficiently reduce the OLAT
Kharat *et al.*, 2023 [34]	0.80	0.58		The rate of canine retraction increases when it is combined with LILT-assisted accelerated orthodontics in comparison with conventional canine retraction using mini-implants.

3.3. Risk of bias of included studies

Given the inherent characteristics of these studies, achieving blinding of both patients and operators was nearly impractical, as the laser and the simulation (placebo) are typically administered in the same session. Consequently, the absence of single or double blinding was not deemed to significantly affect the assessment of the risk of bias in all the studies.

The risk of bias of the included RCTs is shown in Figs 2.

Figure 2: Risk-of-bias graph of the studies exploring movement acceleration

Out of the total 14 RCTs, four trials by Nahas *et al.*, Arumughan *et al.*, Guram *et al.*, Kharat *et al.*, were assessed as having “some concerns” in the risk of biais, the rest were defined as having a low risk of biais.

Despite the exclusive inclusion of randomized studies, it was noted that three trials conducted by Arumughan *et al.*, Guram *et al.*, Kharat *et al.*, did not provide explicit descriptions of how the randomization sequence was generated.

None of the studies included in the analysis reported "incomplete outcome data" resulting from the withdrawal of a substantial number of participants. One studie, conducted by Nahas *et al*., acknowledged losses in patients during the intervention phase. Nevertheless, the losses did surpass 10% of the total number of patients, and the study explicitly indicated which group experienced participant losses. Consequently, it can be affirmed that the absence of patient follow-up had no discernible impact on the study results.

Quality of Evidence Summary

In our systematic review, we investigated two distinct outcomes: time needed for dental alignment and tooth movement rate. A crucial aspect of our analysis involved assigning a quality rating to the body of evidence for each outcome across the included studies. To accomplish this, we employed the GRADE approach, a systematic method for evaluating the quality of evidence.

The GRADE approach initiates the assessment by considering the study design, distinguishing between trials and observational studies. Subsequently, it delves into five potential factors that might warrant a downgrade in the quality of evidence. These factors include the risk of bias, inconsistency, indirectness, imprecision, and publication bias.

While all the studies encompassed in our analysis adhered to the randomized controlled trial design, methodological concerns emerged that restricted the overall quality of evidence pertaining to the "tooth movement rate" outcome.

The quality of evidence for the "tooth movement rate" outcome underwent a downgrade primarily attributed to the risk of bias assessment. This evaluation revealed that 50% of the studies were identified as having "some concerns" regarding bias associated with the randomization process. This factor introduced a level of uncertainty and potential skewing of results, influencing our confidence in the overall quality of evidence for this outcome.

Consequently, our final assessment categorized "tooth movement rate" outcome as presenting a moderate quality of evidence. In contrast, "time needed for dental alignment" outcome exhibited a high quality of evidence, as detailed in Table V. The findings from our research are carefully compiled and displayed in a detailed Summary of Findings table (Table VI), utilizing the software Garde Pro GDT. This table is designed to be a central element, capturing the core essence of our research efforts with accuracy and clarity.

Table V: Quality of evidence assessement for each outcome

Certainty assessment							Certainty
№ of studies	**Study design**	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Other considerations**	
Treatment time							
6	randomised trials	not serious	not serious	not serious	not serious	none	⊕⊕⊕⊕ High
tooth movement rate							
8	randomised trials	serious[a]	not serious	not serious	not serious	none	⊕⊕⊕◯ Moderate

Explanations

a. 3 out of the 8 RCTs had a 'some concerns' risk of biais assessment

Table VI: Summary of Findings table

Photobiomodulation compared to non-photobiomodulation for fixed orthodontic treatment
Patient or population: fixed orthodontic treatment
Setting:
▪ Intervention: photobiomodulation
▪ Comparison: non-photobiomodulation

Outcome **№ of participants (studies)**	**Impact**	**Certainty**
time needed for teeth alignment № of participants: 297 (6 RCTs)	All six trials consistently reported that the application of photobiomodulation (PBM) significantly diminishes the time required for achieving proper tooth alignment.	⊕⊕⊕⊕ High
tooth movement rate № of participants: 322 (8 RCTs)	Seven out of these eight studies arrived at the consensus that photobiomodulation (PBM) indeed accelerates the pace of tooth movement in human subjects.	⊕⊕⊕◯ Moderatea

4. DISCUSSION

Photobiomodulation (PBM), often known as low-level laser therapy (LLLT), involves using light energy to induce biological responses in cells and normalize cell function. PBM's impact on stem cells and progenitor cells, with potential benefits in enhancing differentiation and improving tissue healing rates, is a focal point of interest. Numerous studies have highlighted the positive effect of photobiomodulation on stem cell proliferation, including gingival fibroblasts, dental pulp stem cells from permanent or deciduous teeth, and mesenchymal stem cells from bone marrow or adipose tissue [35].

The prevailing theory suggests that PBM engages with target cells through a photochemical process. The fundamental biological mechanism revolves around the absorption of red and near-infrared (NIR) light by mitochondrial chromophores, possibly also by photo-receptors in the cell membrane.

It is widely acknowledged that the mitochondria of eukaryotic cells serve as the primary sites for initial absorption of radiation in the visible-to-near-infrared optical range. The photo-receptor responsible for this process is cytochrome c oxidase (CCO) [36]. This absorption of light energy is believed to initiate a cascade of events within the mitochondria, leading to the biostimulation of various processes such as enhanced enzyme activity, electron transport, mitochondrial respiration, and adenosine triphosphate (ATP) production [37].

Furthermore, the absorption of light by these receptors brings modifications in the affinity of transcription factors linked to crucial cellular processes, including cell proliferation, survival, tissue repair, and regeneration [38].

The clinical outcomes of laser therapy result not only from the direct irradiation of the tissue but also from secondary effects. These effects encompass an increase in lymphatic flow and circulation, the stimulation of fibroblasts, osteoblasts, odontoblasts, and endorphins. Additionally, there is a reduction in the depolarization of nerve fibers and modulation of inflammatory chemicals, all contributing to the observed clinical effects of LLLT.

Studies by Ozawa *et al*., [39] found that pulsed laser irradiation has a stimulating effect on bone formation, promoting cellular proliferation, especially in osteoblast lineage, and enhancing cellular differentiation, resulting in increased bone formation. The same group [40] investigated the effect of low-level laser irradiation during tooth movement in rats, finding an increased rate of tooth movement accompanied by accelerated bone formation and resorption. This study indicated an accelerating effect of laser therapy not only on bone formation at the tension side but also on the resorptive activity at the compression side of the moved tooth. Further studies, such as that by Habib *et al*., [41], examined histological changes in the alveolar bone during tooth movement with irradiation therapy. This study revealed an increased number of osteoclasts on the pressure side of the irradiation group and higher osteoblast numbers on the tension side, along with greater amounts of collagen matrix on the pressure side. Although numerous clinical case series have demonstrated improved results using LAO, including higher velocity in canine movement and notable acceleration in retraction, certain studies raise doubts about its effectiveness. Specifically, there's a deficiency in extensive human studies that establish a correlation between the utilization of LAO devices, administering low-level light therapy to the alveolus, and the pace of orthodontic tooth movement.

One innovative aspect of our systematic review is the comprehensive analysis we conducted on the effectiveness of PBM on tooth movement acceleration in different phases of orthodontic treatment. We scrutinized each phase, including the alignment phase (studies by Nahas *et al*., AlSayed Hasan *et al*., Caccianiga *et al*., Isola *et al*., Lo Giudice *et al*., Ghaffar *et al*.,), the space closure phase, whether involving canine retraction only (studies by Ureturk *et al*., Qamruddin *et al*., Guram *et al*., Junyi Zheng and Kai Yand, Al Shafi *et al*., Kharat *et al*.,), or en masse retraction (study by Arumughan *et al*.,), and the utilization of intermaxillary elastics (study by Pérignon *et al*.,) which lacks support from any published systematic review.

While the effectiveness of photobiomodulation (PBM) in promoting tooth movement during the alignment phase finds support in a one single systematic review published by T. Huang *et al*., [42], there is a broader spectrum of perspectives on the impact of PBM during the space closure phase, highlighting the need for additional research and comprehensive analyses to establish a more conclusive understanding of its role in this specific aspect of orthodontic treatment.

The included trials in our systematic review used varying wavelengths of low-level lasers (LLLs) and light-emitting diodes (LEDs), ranging from 810 to 980 nm in almost all fourteen studies, except the trial by Lo Giudice *et al*., which utilized the ATP38 device with a multi-panel system emitting cold polychromatic lights ranging from 450 to 835 nm. Most researchers conducted their studies with a total energy density ranging from 25 to 150 J/CM2 per session, applying PBM to patients 2–4 times a month in almost all trials. Despite the existence of inconsistent protocols and considerable variation in irradiation parameters observed across studies, a prevailing trend emerges from the majority of these investigations, suggesting the efficacy of photobiomodulation (PBM) in facilitating tooth movement.

Six distinct trials concentrated on assessing the duration necessary for the leveling and alignment of teeth. Remarkably, all six trials consistently reported that the application of photobiomodulation (PBM) significantly diminishes the time required for achieving proper tooth alignment. Notably, Alsayed Hasan *et al*., reported a 26% decrease in overall treatment time in favor of the laser group. The result received a high-quality evidence rating based on the rigorous criteria outlined in the GRADE approach employed in our systematic review. This underscores the strength and dependability of the evidence, affirming the positive influence of PBM in accelerating the alignment phase of orthodontic procedures.

The remaining eight articles explored tooth movement rate acceleration, and compellingly, seven out of these eight studies arrived at the consensus that photobiomodulation (PBM) indeed accelerates the pace of tooth movement in human subjects. This collective affirmation from a significant portion of the studies underscores the growing body of evidence supporting the positive impact of PBM on expediting the rate of tooth movement during orthodontic interventions.

Ureturk *et al*., observed a mean increase of 40% in the rate of tooth movement during canine retraction at 3 months, while Arumughan *et al*., found that LLLT can increase the rate of extraction space closure during en masse retraction by 12.5% with each dose of laser application (every 21 days). However, the trial conducted by Al Shafi *et al*., revealed statistically insignificant differences between the intervention and control groups for extraction space closure over time. This lack of significance might be attributed, at least in part, to the application of a distinct laser dosage and treatment protocols. PBM therapy follows a biphasic curve, signifying a minimum threshold of energy is required to initiate a cellular response, elevating the energy level enhances this response until a saturation point is reached, beyond which further increases lead to inhibitory effects [43]. In fact, the Al Shafi *et al*., trial, utilizing the OrthoPulse device, delivered approximately 60 mW/cm2 power. The daily dosage amounted to around 18 J, which falls on the higher end of dosages when compared to the other reported studies illustrating an augmented rate of tooth movement following laser therapy that employed energy levels ranging from 2 to 10 J per application. Interestingly, the findings of the Al Shafi *et al*., study align with a previous 2006 study by Limpanichkul *et al*., which utilized a laser delivering 18.4 J per session and found no discernible differences in the rate of canine retraction between the laser and control groups.

The light equipment used in the fourteen studies exhibited notable variations. With the exception of Nahas *et al*., Lo Giudice *et al*., and Al Shafi *et al*., who employed LED devices in their trials, the remaining eleven studies utilized infrared radiation-emitting lasers.

According to the majority of studies employing laser-emitting devices, energy densities ranging from 0.71 to 8 J/cm2 (equivalent to 2–10 J per tooth), with 2 to 4 monthly applications in clinical settings, proved effective in accelerating tooth movement.

In the study by Nahas *et al*., an extraoral LED device, incorporating a facemask embedded with LED arrays, was utilized to irradiate the lower anterior segment at a wavelength of 850 nm for 20 minutes daily. The estimated irradiation dose on the cheek's surface per session was approximately 108 J/cm2.

Additionally, Lo Giudice *et al*., employed an extraoral LED device featuring a multi-panel system emitting cold polychromatic lights with wavelengths ranging from 450 to 835 nm. The protocol included two sessions of PBM per month, producing a total monthly energy density of 288 J/cm2.

The initial high dose at the cheek surface level is justified due to LED lights having reduced depth of penetration into target tissues compared to laser light, attributed to the inability of LED light to be focused. Moreover, the photo beams need to penetrate both extraoral and intraoral tissues, contrasting handheld laser devices that irradiate a specific area of the target quadrant directly on the target tooth. Also the two studies applied PBM simultaneously to both arches. Consequently, it can be theorized that when irradiating both the maxillary and mandibular arches, a higher fluency is necessary due to potential absorption of part of the irradiation by the opposite arch. Al-Shafi *et al*., utilized an intraoral LED device delivering a wavelength of 850 nm and approximately 60 mW/cm2 power for 5 minutes per day.

The use of an extraoral photobiomodulation device may pose challenges for both patients and clinicians in terms of compliance, device fitting, and wearing time. However, adopting an intraoral approach has shown a reduction in wearing time since the required dose can be delivered directly to the target tissues without energy loss to extraoral tissues.

5. CONCLUSION

Through this review, our main goal was to assess the effectiveness of PBM in overcoming orthodontic treatment challenges primarily the extended treatment duration. To achieve this, 14 articles were selected and analyzed.

Following a thorough examination of these articles, the following conclusion was drawn:
The synthesis of available evidence in our analysis reveals a substantial body of research suggesting a positive effect of PBM on accelerating tooth movement. However, the existing variations in PBM parameters, and outcome measurements emphasize the necessity for more standardized approaches in future investigations.

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