



Photobiomodulation for accelerating orthodontic tooth movement with fixed appliances: a systematic review of clinical trials

Fotobiomodulación para acelerar el movimiento dentario ortodóncico con aparatología fija: revisión sistemática de ensayos clínicos

Marta María Capote Fernández¹  

¹ Universidad de Ciencias Médicas de La Habana, Facultad de Ciencias Médicas “Miguel Enríquez”, Departamento de Estomatología General Integral. La Habana, Cuba.

Submitted: 03-02-2023 | Revised: 05-04-2023 | Accepted: 27-07-2023 | Published: 23-08-2023

Corresponding Author: Marta María Capote Fernández 

ABSTRACT

Introduction: Fixed-appliance orthodontic treatment lasts around 20 months, and prolonged treatment increases the risk of root resorption and enamel demineralization. Photobiomodulation with low-level laser or light-emitting diode light has been proposed to accelerate tooth movement, but reviews reach discordant conclusions. **Methods:** Systematic review reported according to PRISMA 2020. PubMed, OpenAlex, Crossref and Scopus were searched for randomized and controlled clinical trials (2015-2023) comparing low-level laser or light-emitting diode photobiomodulation with no or sham irradiation for the rate of tooth movement in patients with fixed appliances. Risk of bias was assessed with the Cochrane RoB 2 tool. A meta-analysis was not performed because of clinical heterogeneity. **Results:** Ten trials with 264 participants were included. Seven reported a statistically significant acceleration of tooth movement with photobiomodulation, two reported no significant difference and one reported a shorter time to space closure with similar total movement. Reported effects ranged from a cumulative canine retraction of 4.45 mm versus 3.16 mm over 12 weeks to an alignment rate of 1.27 mm per week versus 0.44 mm per week. Effects concentrated in the red and near-infrared range (650-980 nm), whereas the single blue-light trial found no effect. One trial was at low risk of bias, seven had some concerns and two were at high risk. **Conclusions:** Near-infrared low-level laser photobiomodulation appears to accelerate short-term orthodontic tooth movement, but the certainty of this evidence is limited by risk of bias, small samples and heterogeneous protocols. Standardized, prospectively registered trials are needed before routine clinical use.

Keywords: low-level light therapy; photobiomodulation; tooth movement techniques; orthodontics; randomized controlled trial.

RESUMEN

Introducción: El tratamiento ortodóncico con aparatología fija dura unos 20 meses y su prolongación aumenta el riesgo de reabsorción radicular y desmineralización. La fotobiomodulación con láser de baja intensidad o diodo emisor de luz se ha propuesto para acelerar el movimiento dentario, pero las revisiones llegan a conclusiones discordantes. **Métodos:** Revisión sistemática según PRISMA 2020. Se buscó en PubMed, OpenAlex, Crossref y Scopus ensayos aleatorizados y controlados (2015-2023) que compararan fotobiomodulación frente a ausencia de irradiación o irradiación simulada sobre la velocidad del movimiento dentario en pacientes con aparatología fija. El riesgo de sesgo se evaluó con RoB 2. No se realizó metaanálisis por heterogeneidad clínica. **Resultados:** Se incluyeron diez ensayos con 264 participantes. Siete informaron una aceleración estadísticamente significativa, dos no hallaron diferencias y uno informó un menor tiempo de cierre con movimiento total similar. Los efectos abarcaron desde una retracción canina de 4,45 mm frente a 3,16 mm en 12 semanas hasta una velocidad de alineación de 1,27 mm por semana frente a 0,44 mm por semana. Los efectos se concentraron en el rango rojo e infrarrojo cercano (650-980 nm), mientras que el único ensayo con luz azul no halló efecto. Un ensayo tuvo riesgo bajo, siete algunas preocupaciones y dos riesgo alto. **Conclusiones:** La fotobiomodulación con láser de baja intensidad en el infrarrojo cercano parece acelerar el movimiento dentario a corto plazo, pero la certeza es limitada por el riesgo de sesgo, las muestras pequeñas y los protocolos heterogéneos. Se requieren ensayos estandarizados y registrados prospectivamente.

Palabras clave: terapia por luz de baja intensidad; fotobiomodulación; técnicas de movimiento dentario; ortodoncia; ensayo clínico controlado aleatorio.

INTRODUCTION

Fixed-appliance orthodontic treatment corrects malocclusion through controlled tooth movement, yet the process remains slow and this is one of the main reasons patients decline or interrupt care. The Cochrane review of non-surgical adjuncts reports an average treatment duration of about 20 months, with a range that commonly reaches two to three years, and prolonged treatment is associated with external apical root resorption, enamel demineralization, gingival inflammation and declining patient compliance.(1,2) These adverse outcomes, together with the demand of adult patients for shorter treatment, have made acceleration of tooth movement a research priority in orthodontics.(3) Acceleration strategies are broadly divided into surgical procedures, such as corticotomy and piezosurgery, and non-surgical adjuncts, among which photobiomodulation stands out because it is painless, reversible and free of the morbidity associated with cutting bone.(3,4)

Tooth movement depends on remodeling of the periodontal ligament and alveolar bone, an inflammatory and mechanically regulated process in which compression and tension of the ligament recruit osteoclasts and osteoblasts.(5,6) Photobiomodulation, also termed low-level light therapy or low-level laser therapy, delivers red or near-infrared light that is absorbed by cytochrome c oxidase in the mitochondria, increasing adenosine triphosphate production and modulating oxidative and inflammatory signaling without heating the tissue.(7,8) In orthodontics, low-level laser and light-emitting diode devices have been tested for accelerating tooth movement, but published systematic reviews reach discordant conclusions, and protocols differ widely in wavelength, energy density, application points and frequency.(9-12) The response is dose-dependent and follows a biphasic curve, in which too little energy produces no measurable effect and too much energy can abolish the benefit, so the choice of wavelength and energy density is central to any clinical translation.(13,14) Several prior syntheses are limited by narrow outcomes, by mixed populations that include children and adults without stratification, or by bibliographic windows that exclude recent trials, which justifies an updated appraisal of the question.(15,16) Light-emitting diodes deliver the same red and near-infrared wavelengths with lower coherence and lower cost than lasers, which has expanded the range of devices tested and introduced a further source of variability across studies.(17)

The aim of this systematic review was to synthesize the evidence on photobiomodulation for accelerating orthodontic tooth movement in patients with fixed appliances. Three questions guided the review. P1, does low-level laser or light-emitting diode photobiomodulation increase the rate of tooth movement compared with no or sham irradiation? P2, does the effect vary by light source, wavelength or irradiation protocol? P3, what is the risk of bias of the included trials and the resulting confidence in the estimates?

METHODS

A systematic literature review was conducted following the PRISMA methodology.(18) Eligibility was defined by the elements needed to answer P1 and P2. Population, patients undergoing orthodontic tooth movement with fixed appliances, without restriction by age or malocclusion. Intervention, photobiomodulation delivered by a low-level laser or a light-emitting diode, irrespective of wavelength or application schedule. Comparison, no irradiation or sham irradiation, including the contralateral quadrant or side in split-mouth designs. Outcome, the rate of tooth movement expressed in millimeters per week or per month, cumulative movement in millimeters, or the time required to complete a defined movement or space closure. Designs, randomized controlled trials and controlled clinical trials published between 2015 and 2023, the bibliographic window of this review. Animal studies, laboratory studies, case reports and studies whose primary outcome was root resorption or pain were excluded. No restriction was placed on the country of origin, and the search was not limited by language, although full-text screening depended on documents readable in English, Spanish or Portuguese. The lower bound of 2015 was chosen to include the first controlled trials with light-emitting diodes and to exclude the earliest laser reports whose devices and dosimetry predate current photobiomodulation practice, while the upper bound reflects the volume-year constraint of this review.

Information sources and search

The search strategy (PubMed, OpenAlex, Crossref) combined terms for photobiomodulation with terms for orthodontic tooth movement. The main query was “photobiomodulation orthodontic tooth movement”, complemented by “low-level laser therapy orthodontic tooth movement”,

“low level light therapy tooth movement acceleration” and “light-emitting diode orthodontic tooth movement”. Each query was run in each source, and for PubMed the equivalent structured string was (photobiomodulation OR low-level light therapy OR low-level laser therapy OR light-emitting diode) AND (tooth movement OR orthodontic tooth movement). A complete log of every query, source, date and number of records retrieved was retained so that the search can be reproduced. Citation chasing of the included studies was not performed. The four sources were chosen because PubMed and Scopus provide the largest biomedical and dental coverage, while OpenAlex and Crossref additionally expose open-access full texts that some publisher sites block to automated retrieval. Records were restricted to the window 2015-2023, and no record published after 2023 was retained.

Selection process

Records were deduplicated by digital object identifier and, when this was absent, by normalized title and year, and then screened in two stages. Titles and abstracts were screened against the eligibility criteria, and uncertain records proceeded to full text. Full texts were retrieved only from legitimate open-access locations, including publisher open-access portals and open repositories, and screened again against the criteria. Screening was assisted by automated tools and verified by the author; it did not involve two independent reviewers, and this single-reviewer procedure is declared in the limitations. Reports that could not be retrieved as open-access full text were recorded as not retrieved rather than excluded on the basis of the abstract alone. The reasons recorded at title and abstract screening were the study design, namely animal studies, reviews, editorials or case reports, an outcome other than the rate of movement, and lack of relevance to orthodontic tooth movement.

Data extraction

The author, year, country, design, sample, movement evaluated, device and wavelength, irradiation protocol, comparator, outcome and the main estimate with its measure of dispersion were extracted into a structured table, with each datum recorded together with its location in the source document. The irradiation protocol, including wavelength, energy density and application schedule, was extracted specifically to support the subgroup description that answers P2. When a study reported several time points, both the final cumulative value and the rate, when available, were extracted. When a study did not report a measure of dispersion or the exact sample per arm, the value was recorded as not reported rather than imputed, and no contact with the authors was attempted.

Risk of bias

Randomized trials were assessed with the Cochrane risk-of-bias tool for randomized trials (RoB 2) across its five domains, namely the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome and selection of the reported result. The controlled clinical trial without randomization was flagged as at high risk, because the absence of random allocation and the use of different bracket systems between groups confound the comparison.^(19,20) Judgments were based only on what the reports stated; missing information was not assumed to indicate low risk. A judgment of some concerns was applied whenever a report omitted the method of sequence generation or concealment, when the blinding of the outcome assessor was not described, or when the handling of missing data was unclear. A judgment of high risk was reserved for the non-randomized comparison and for the trial in which neither participants nor assessors were blinded. The judgments were recorded per study and per domain so that each trial could be weighed in the synthesis according to its specific weaknesses rather than by a single global label.

Certainty of the evidence

The certainty of the evidence was considered for the main comparison, namely the rate of tooth movement, following the domains of the GRADE approach.⁽²¹⁾ Risk of bias was judged serious because most trials raised some concerns and two were at high risk. Imprecision was serious because several trials enrolled fewer than 30 participants and the dispersion around the reported rates was wide. Inconsistency could not be quantified without a pooled estimate, but the presence of two null trials alongside seven positive ones indicates moderate clinical heterogeneity. Indirectness was limited, because every trial measured tooth movement in patients with fixed appliances,

although the specific movements differed. Publication bias could not be excluded, because the review relied on published reports and retrieved only open-access full texts. Taken together, the certainty of the evidence was graded as low to very low, meaning that the true effect could differ substantially from the point estimates reported here.

Effect measures and synthesis

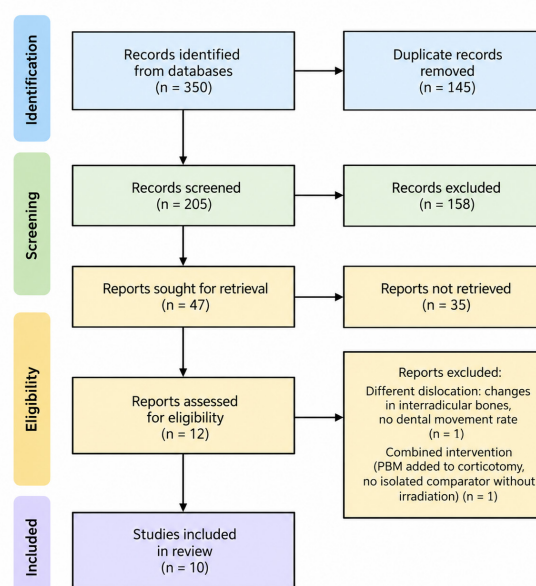
Movement was expressed by each trial in heterogeneous units, so estimates were tabulated per study and synthesized narratively rather than pooled. A meta-analysis was not performed because the outcome constructs, namely weekly or monthly rate, cumulative distance, residual space and time to closure, and the follow-up durations differed across trials, and several trials did not report measures of dispersion. Subgroup descriptions by light source and by wavelength band were planned to answer P2 but remained descriptive because of the small number of studies per subgroup. Because a simple count of statistically significant studies can be misleading when power differs across trials, the synthesis relied on the direction and magnitude of each estimate rather than on the number of p-values below a threshold. The certainty of the evidence was considered qualitatively following the GRADE logic, without producing a formal evidence profile.⁽²¹⁾ A pooled analysis would have forced together millimeters per week, millimeters per month, cumulative distances over different periods and residual-space measures, and the resulting average would not correspond to any single clinical quantity, which is why the review reports the estimates side by side instead.

RESULTS

Study selection

The searches identified 350 records, 100 from PubMed, 100 from OpenAlex, 100 from Crossref and 50 from Scopus. After removing 145 duplicates, 205 records were screened by title and abstract, of which 158 were excluded and 47 reports were sought for retrieval. Full text could not be retrieved for 35 reports because they were not available through legitimate open access. Of the 12 reports assessed for eligibility, 2 were excluded, one for a combined corticotomy plus photobiomodulation intervention without an isolated irradiation comparator and one because the outcome was interradicular bone changes rather than the rate of movement. This left 10 studies for inclusion (Figure 1). All the included trials examined patients treated with fixed appliances, which matches the population of the review question, and none was excluded on the basis of publication year within the window.

Figure 1. Flow of records through the review.



Note: Numbers are drawn from the PRISMA 2020 flow of this review. Source: Elaborated from the search and screening records.

The ten included studies enrolled 264 participants, and nine used a split-mouth design that compared an irradiated quadrant or side with a contralateral control, which reduces interindividual variability but introduces the possibility of local or systemic carryover (Table 1). Eight trials used low-level lasers with wavelengths from 650 to 980 nm, and two used light-emitting diodes, one intraoral at 850 nm and one at 430 to 480 nm. Canine retraction or distalization was the movement evaluated in eight trials, molar distalization or uprighting in one and anterior alignment in one. Sample sizes ranged from 6 patients in a pilot trial to 42 patients, and follow-up ranged from 28 days to 12 weeks. The studies were conducted in Egypt, France, China, India, Italy, Thailand and the United States. One trial described four losses to follow-up among 40 participants, another stated that all participants completed the study, and the remaining reports did not describe withdrawals.

Table 1. Characteristics of the included studies.

Study (author-year)	Country	Design	Sample	Movement evaluated	Device and wavelength
Eid 2022	Egypt	Split-mouth RCT	20 patients	Canine retraction	GaAlAs diode laser 980 nm
Perignon 2021	France	RCT placebo-controlled	42 patients	Canine movement with Class II elastics	Diode laser 970 nm
Zheng 2021	China	Split-mouth RCT	12 patients	Canine retraction	Diode laser 810 nm
Jayavarma 2023	India	Split-mouth RCT four quadrants	24 subjects	Canine retraction	Photobiomodulation 10 J
Shaughnessy 2016	United States	Controlled clinical trial	19 subjects 28 arches	Anterior alignment	Intraoral LED 850 nm
Impellizzeri 2020	Italy	RCT placebo-controlled pilot	6 patients 8 canines	Canine distalization	Laser 650 nm
Prathapan Santhakumari 2023	India	Split-mouth RCT	40 patients	Canine distalization	GaAlAs diode laser 980 nm
Kalia 2023	India	Split-mouth RCT open label	40 patients 80 sites	Canine retraction	GaAlAs low-level laser
Isola 2019	Italy	Split-mouth RCT	41 patients 82 canines	Canine distalization	Diode laser 810 nm
Viwattanatipa 2018	Thailand	Split-mouth RCT double-blind	20 adults	Canine retraction	LED 430-480 nm

Note: RCT = randomized controlled trial; LED = light-emitting diode; PBM = photobiomodulation. Source: Elaborated from the full texts of the included studies.

Photobiomodulation increased the rate of tooth movement in most trials

Seven of the ten included studies reported a statistically significant acceleration of tooth movement with photobiomodulation (Table 2). Eid and colleagues measured cumulative maxillary canine retraction over 12 weeks and reported 4.45 mm (SD 0.13) on the laser side against 3.16 mm (SD 0.14) on the control side, and both the frequent and the less frequent irradiation schedules accelerated movement, with no difference between them.⁽²²⁾ Pérignon and colleagues reported a monthly rate of 1.1 mm (SD 0.7) with a 970 nm diode laser against 0.74 mm (SD 0.6) with placebo during Class II elastic treatment.⁽²³⁾ Zheng and Yang observed 1.15 mm (SD 0.29) of canine retraction over 28 days on the laser side compared with 0.85 mm (SD 0.23) on the control side.⁽²⁴⁾ The largest relative difference came from the intraoral light-emitting diode device studied by Shaughnessy and colleagues, with an anterior alignment rate of 1.27 mm per week (SD 0.53) against 0.44 mm per week (SD 0.20) in the control group.⁽²⁵⁾ Smaller trials confirmed the same direction, including a pilot of six patients in which distal displacement after one month was 1.98 mm with irradiation and 1.35 mm without it,⁽²⁶⁾ and a split-mouth trial in which residual extraction space at three months was 0.62 mm (SD 0.21) on the laser side against 2.11 mm (SD 0.24) on the control side.⁽²⁷⁾ Kalia and colleagues likewise found a greater reduction of the canine-to-molar distance on the laser side.⁽²⁸⁾ Two of the positive trials were placebo-controlled rather than simply untreated. Pérignon and colleagues used sham irradiation and still detected a difference in the rate, and the pilot by Impellizzeri and colleagues compared irradiated canines with placebo on the same arch, which reduces the risk that the results reflect expectation rather than the light itself.^(23,26) Three studies did not show a uniform acceleration.

Jayavarma and colleagues compared photobiomodulation, piezocision and their combination against a conventional control quadrant and found no statistically significant difference in the rate of canine retraction, although the mean rate was higher on the photobiomodulation quadrant at the first two time points before declining by the third.(29) Isola and colleagues found no difference in the total space closure, 4.56 mm against 4.49 mm, but a shorter time to complete closure, 84.35 days (SD 12.34) against 97.49 days (SD 11.44).(30) Viwattanatipa and colleagues found no difference in the total rate of canine movement, 0.28 mm per week with a blue light-emitting diode against 0.27 mm per week with placebo.(31)

Across the movement types, the benefit was not confined to a single measurement. Acceleration was reported for canine retraction, for anterior alignment and for molar distalization, which argues against a movement-specific artifact and in favor of a general biological effect on the remodeling of the periodontal ligament.(22,25,30)The magnitude, however, was inconsistent, with fold changes between roughly 1.4 and 2.9 in the studies that reported both arms, and this variability is the central reason a single pooled estimate was considered inappropriate.

Several trials also measured secondary outcomes in gingival crevicular fluid. Interleukin-1 beta was higher on the irradiated side in the trials by Eid, Zheng and Prathapan Santhakumari, and receptor activator of nuclear factor kappa-B ligand rose while osteoprotegerin fell in the trial by Zheng and Yang, a pattern consistent with accelerated bone resorption on the pressure side. (22,24,27,28)Pain scores, when reported, did not show a consistent difference between the irradiated and control sides.(23)

Table 2. Outcome data for tooth movement extracted from the included studies.

Study	Outcome	Photobiomodulation	Control	Reported p	Direction
Eid 2022	Cumulative retraction 12 weeks (mm)	4.45 (SD 0.13)	3.16 (SD 0.14)	< 0.001	Favours PBM
Perignon 2021	Rate of movement (mm/month)	1.1 (SD 0.7)	0.74 (SD 0.6)	0.037	Favours PBM
Zheng 2021	Cumulative movement 4 weeks (mm)	1.15 (SD 0.29)	0.85 (SD 0.23)	< 0.05	Favours PBM
Jayavarma 2023	Canine retraction rate T1-T3	higher mean T1-T2	lower	not significant	No difference
Shaughnessy 2016	Alignment rate (mm/week)	1.27 (SD 0.53)	0.44 (SD 0.20)	0.0002	Favours PBM
Impellizzeri 2020	Distal displacement 1 month (mm)	1.98	1.35	< 0.05	Favours PBM
Prathapan Santhakumari 2023	Residual space 3 months (mm)	0.62 (SD 0.21)	2.11 (SD 0.24)	< 0.01	Favours PBM
Kalia 2023	Canine-to-molar reduction	greater	lower	significant	Favours PBM
Isola 2019	Space closure (mm) and time (days)	4.56; 84.35 (SD 12.34)	4.49; 97.49 (SD 11.44)	0.456	Faster time only
Viwattanatipa 2018	Rate of movement total (mm/week)	0.28	0.27	not significant	No difference

Note: SD = standard deviation. Lower residual space indicates greater space closure. Values are reported as in the original studies. Source: Extracted from the full texts of the included studies.

The effect concentrated in the red and near-infrared range

The pattern across devices and wavelengths was consistent with the photobiological action spectrum of photobiomodulation. Six of the eight laser trials, all operating between 650 and 980 nm, reported a statistically significant acceleration, whereas the two light-emitting diode trials diverged by wavelength (Table 1). The 850 nm intraoral diode produced the largest relative acceleration, and the 430 to 480 nm blue diode produced none.(25,31) Irradiation protocols also differed widely, with applications repeated every three days to every three weeks and reported energy densities between 6.29 and 66.7 J per square centimeter. No single combination of wavelength, energy density and frequency was consistently associated with a larger effect, and the trial that reported the largest absolute difference used a near-infrared laser applied at short intervals, while the trial with the largest relative difference used a daily near-infrared light-emitting diode.(22,25)

The two trials that reported the clearest acceleration both delivered near-infrared light, one at 850 nm daily and one at 980 nm at short intervals, whereas the null blue-light trial delivered light outside this band, which reinforces the interpretation that wavelength, and not the light source, drives the response.(22,25,31)

The wavelength used within the effective band was nonetheless variable. Three trials used diodes at 810 nm, two at 980 nm, one at 970 nm and one at 650 nm, and the reported energy densities ranged from 6.29 J per square centimeter delivered at four sessions to 66.7 J per square centimeter repeated at baseline and then every two weeks (Table 1). The irradiation schedules were equally heterogeneous, from a single weekly application to daily home use, and this dispersion of parameters is the principal obstacle to translating the aggregate positive signal into a clinical prescription. The two light-emitting diode devices also differed in their mode of use: the 850 nm intraoral device was worn at home daily, whereas the 430 to 480 nm curing light was applied in the clinic every three weeks, so the null result of the blue diode could reflect either its wavelength or its less frequent application, a confound that only a factorial trial could separate.(25,31)

Risk of bias limited confidence in the estimates

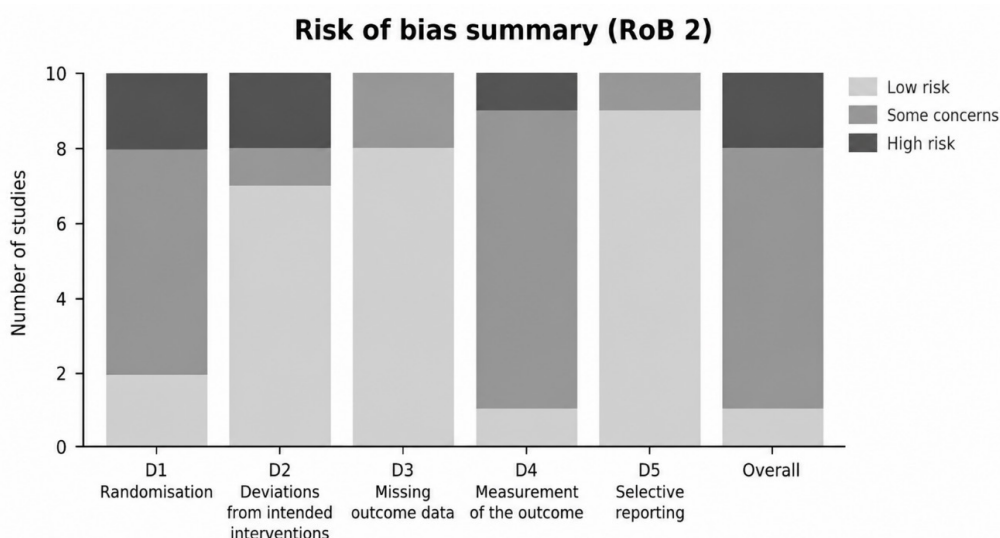
One trial was at low risk of bias across all five RoB 2 domains, seven had some concerns and two were at high risk (Table 3, Figure 2). The most frequent problems were incomplete reporting of the randomization process and uncertainty about the blinding of outcome assessors. The non-randomized controlled trial by Shaughnessy and colleagues was rated at high risk because the comparison groups used different bracket systems, and the open-label split-mouth trial by Kalia and colleagues was rated at high risk because neither participants nor assessors were blinded.(25,28) Only the double-blind trial by Viwattanatipa and colleagues reported sufficient safeguards across all domains to merit a low rating.(31) Within the individual domains, the randomization process was the item downgraded in the largest number of trials, because several reports described allocation as random without specifying the sequence generation or its concealment, and the blinding of the outcome assessor was stated explicitly in only a minority of trials. Missing data raised few concerns, because most trials measured a short window within a fixed course of treatment and only one described dropouts; the more consequential weaknesses were therefore in allocation concealment and outcome blinding.

Table 3. Risk of bias of the included studies (Cochrane RoB 2).

Study	D1 randomization	D2 deviations	D3 missing data	D4 outcome measurement	D5 selective reporting	Overall
Eid 2022	Some concerns	Low	Low	Some concerns	Low	Some concerns
Perignon 2021	Some concerns	Low	Low	Some concerns	Low	Some concerns
Zheng 2021	Some concerns	Low	Low	Some concerns	Low	Some concerns
Jayavarma 2023	Some concerns	Low	Some concerns	Some concerns	Some concerns	Some concerns
Shaughnessy 2016	High	High	Low	Some concerns	Low	High
Impellizzeri 2020	Some concerns	Low	Low	Some concerns	Low	Some concerns
Prathapan Santhakumari 2023	Some concerns	Low	Some concerns	Some concerns	Low	Some concerns
Kalia 2023	Some concerns	High	Low	High	Low	High
Isola 2019	Low	Some concerns	Low	Some concerns	Low	Some concerns
Viwattanatipa 2018	Low	Low	Low	Low	Low	Low

Note: D1 randomization process; D2 deviations from intended interventions; D3 missing outcome data; D4 measurement of the outcome; D5 selection of the reported result. Source: Assessed by the authors from the full texts.

Figure 2. Summary of the risk of bias across domains and studies.



Note: D1 randomization process; D2 deviations from intended interventions; D3 missing outcome data; D4 measurement of the outcome; D5 selection of the reported result. Source: Elaborated from the RoB 2 judgments of this review.

DISCUSSION

The first question asked whether photobiomodulation increases the rate of orthodontic tooth movement compared with no or sham irradiation. The evidence supports a cautious affirmative answer. Seven of the ten included trials reported a statistically significant acceleration, and the point estimates were directionally consistent even though their magnitude varied more than tenfold depending on the movement evaluated and the metric used. The two null trials, one combining photobiomodulation with piezocision and one using blue light, are the most recent caution that the effect is not guaranteed under every parameter set. This finding agrees with earlier syntheses that pooled split-mouth randomized trials and reported a favorable effect of low-level laser therapy on canine retraction and on anterior alignment.^(9,10,12) It also agrees with the direction reported by reviews restricted to children and to the alignment phase of treatment.^(12,32) The finding diverges, however, from the Cochrane review of non-surgical adjuncts, which judged the evidence on low-level laser therapy uncertain because of small samples and heterogeneous protocols.⁽¹⁾ That divergence is explained largely by the eligibility windows and by how each review handled quasi-experimental and split-mouth designs, rather than by a disagreement about the underlying point estimates themselves.^(33,34)

A further source of support comes from reviews that examined adjacent questions. Syntheses focused on the alignment phase and on split-mouth canine retraction both concluded that low-level laser therapy shortens the measured phase, and a network synthesis of interventions for maxillary canine retraction ranked photobiomodulation among the non-surgical options with a measurable benefit.^(11,12) Reviews that examined the wavelength question narrowed the effective range to the red and near-infrared band, which is exactly where the positive trials of this review sit.^(14,16) Older syntheses, by contrast, concluded that the evidence was insufficient, and their skepticism is understandable given that many of the trials they included reported only means without dispersion and used split-mouth designs that make independent pooling difficult.^(15,35,36) The evolution of the literature across the window of this review, from early inconclusive reports to more recent placebo-controlled trials, explains why an updated synthesis reaches a more favorable conclusion than its predecessors.

The three trials that did not report a uniform benefit carry information of their own. Jayavarma and colleagues found no statistically significant difference for isolated photobiomodulation, which echoes the caution expressed in the Cochrane review and suggests that the acceleratory signal, while common, is not universal.^(1,29) Isola and colleagues found that irradiation did not enlarge the final distance but shortened the time needed to close the same space, a distinction that matters

because trials measuring only the distance could miss a genuine gain in speed and mislabel it as a null result.(30) Viwattanatipa and colleagues used blue light and found no effect, a result that is better attributed to the wavelength than to the intervention itself.(31)

The predominance of split-mouth designs deserves a comment of its own. Split-mouth trials compare the irradiated and control sides within the same patient, which removes interindividual variation and makes small samples informative, but they assume that the two sides are biologically independent. That assumption is doubtful for a photobiomodulatory effect that acts, at least partly, through local and possibly systemic mediators, and any contralateral carryover would bias the comparison toward the null.(19) The two placebo-controlled trials, one of which randomized quadrants within patients, are therefore important because they preserve the within-patient comparison while controlling the placebo effect, and both still found a benefit, which weakens the concern that the positive results are an artifact of the design.(23,26)

The clinical meaning of the measured endpoints also varies. Canine retraction into a premolar extraction space is a convenient and bounded model, but it is only one phase of a treatment that also includes alignment, leveling, torque and space closure elsewhere.(3) Anterior alignment, measured as the weekly change in the irregularity index, is arguably closer to what patients notice first, and the largest relative benefit in this review was reported for that endpoint.(25) Molar distalization and uprighting were each evaluated in a single trial, so the evidence for those movements is thinner. A treatment that accelerates one phase may not shorten the whole course, and only Isola and colleagues measured a time-to-completion outcome, which is the metric that matters most for treatment planning.(30)

The second question asked whether the effect varies by light source, wavelength or protocol. The data indicate that wavelength matters more than the distinction between laser and diode. Effects were concentrated in the red and near-infrared range between 650 and 980 nm, which coincides with the absorption window of cytochrome c oxidase and with the therapeutic window described in dose and wavelength reviews.(7,13,14) The single blue-light trial at 430 to 480 nm found no effect, a biologically plausible outcome because blue light penetrates soft tissue less deeply and its chromophores lie outside the mitochondrial action spectrum that drives photobiomodulation.(8,31) Energy density and application frequency varied so widely across the included studies that no dose-response relationship could be isolated, a gap that protocol reviews have also emphasized.(15,37) The inflammatory mediator data reported in several included trials, with raised interleukin-1 beta and RANKL in gingival crevicular fluid on the irradiated side, offer a mechanistic link between irradiation and the accelerated bone remodeling observed clinically.(24,27,38) This molecular evidence is consistent with the mitochondrial and inflammatory model of photobiomodulation described for periodontal tissues.(6,8)

The biological cascade that could explain these observations is now reasonably well described. Red and near-infrared photons are absorbed by cytochrome c oxidase, which raises mitochondrial membrane potential and adenosine triphosphate production, releases a small burst of reactive oxygen species and nitric oxide, and thereby activates transcription factors that govern proliferation and matrix turnover.(7,8) In the compressed periodontal ligament this signaling converges on the osteoclastogenic axis, with higher receptor activator of nuclear factor kappa-B ligand and lower osteoprotegerin in gingival crevicular fluid, the molecular signature of faster bone resorption on the pressure side.(5,24) The same mechanism has been invoked for the acceleration reported in animal models and for the modulation of inflammatory mediators summarized in a dedicated meta-analysis.(38,39) These data do not prove that photobiomodulation accelerates movement in every patient, but they make the direction of the clinical findings biologically coherent rather than an artifact of measurement.

The relative magnitude also varied by endpoint in a way that is biologically informative. The alignment endpoint, measured in the earliest weeks of treatment, showed the largest relative difference, roughly 2.9-fold, whereas the cumulative canine retraction measured over twelve weeks showed a more modest fold change of about 1.4.(22,25) This pattern is consistent with the known phasing of tooth movement, in which the early, cell-mediated stage is the most responsive to a metabolic stimulus, while later stages depend more on the mechanical resolution of the extraction space.(5) If the benefit is concentrated in the early weeks, its clinical value lies in shortening the lag phase rather than in a uniform acceleration across the whole course, which again argues for measuring time to a defined endpoint.

The surrogate nature of the endpoints deserves emphasis as well. A faster canine or a faster alignment is a proxy for the outcome patients care about, which is a shorter, safe course of treatment, and the surrogate may not translate linearly. One trial that measured both distance and time showed that the distance alone would have missed the benefit, a concrete demonstration of this

risk.(30) Until trials report the time to a predefined treatment goal, the clinical importance of the acceleration remains an inference rather than a demonstrated outcome.

The question of age also remains open. The trials reviewed enrolled adolescents and young adults predominantly, and the review specific to children reported a favorable effect of laser photobiomodulation on movement in that population, so the benefit is unlikely to be restricted to adults. (32) None of the included trials compared age strata within the same protocol, and growth-related remodeling in adolescents could mask or magnify the effect of irradiation, which is another reason to stratify by age in future trials.

The third question asked about risk of bias and the resulting confidence in the estimates. Most trials raised some concerns, mainly because the randomization procedure and the blinding of outcome assessors were incompletely described, and two trials were at high risk. Confidence is further reduced by the small samples, some as few as six patients, and by the split-mouth design, which controls interindividual variability but cannot exclude a local or systemic carryover of the photobiomodulatory effect to the contralateral control side.(19,26) Because no pooled estimate was computed, this review cannot quantify the acceleration or its imprecision, and the overall certainty of the evidence is best described as low to moderate. Applying the GRADE domains, the risk of bias is serious, the imprecision is serious because the positive trials enrolled between 6 and 42 participants and the dispersion around the reported rates was wide, and the inconsistency is at least moderate given the two null trials.(21) Indirectness is limited, but publication bias cannot be ruled out because the review could access only open-access reports and small positive trials are more likely to reach print. These considerations place the certainty of the evidence between low and very low, and the direction of the effect is therefore more trustworthy than its magnitude.

The strengths of this review are a transparent search across four bibliographic sources, a reproducible PRISMA flow and an appraisal restricted to what the reports actually stated rather than to assumptions about their quality. By tabulating the raw estimates alongside the direction of each trial, the review preserves the heterogeneity that a pooled average would have concealed.

This review has limitations that should be read together with its conclusions. Only open-access full texts could be retrieved, so 35 otherwise eligible reports, including several randomized trials, were not assessed, and their exclusion may distort the estimate of effect and restrict generalizability. Screening and extraction were performed by a single reviewer assisted by automated tools rather than by two independent reviewers, so selection errors cannot be excluded. The protocol was not registered prospectively, and no meta-analysis or formal GRADE assessment was undertaken. Each limitation has a specific remedy: future updates should obtain licensed access to the non-open-access reports or request data from their authors, adopt independent dual screening with a third arbiter for disagreements, register the protocol in a public registry, and standardize the outcome as a weekly or monthly rate with measures of dispersion so that a pooled estimate becomes possible. Publication bias is plausible because small trials with favorable results are more likely to be published, and the predominance of positive findings among the included studies should be read with that in mind. Early reports within the window were likewise mixed, and the reviews that summarized them cautioned against overinterpreting single small trials.(35,40) The maturation from those early reports to the placebo-controlled trials published in the last years of the window is the main reason the present conclusions are more favorable, and it also implies that the estimate of effect will continue to move as larger, sham-controlled trials accumulate.

The clinical implication is that near-infrared low-level laser photobiomodulation is a promising, non-invasive adjunct for shortening specific phases of fixed-appliance treatment, but routine use cannot yet be recommended on this evidence. The parameters that produced effects in the included trials were too varied to be converted into a single prescription, and the strongest effect came from an intraoral light-emitting diode rather than a laser, which indicates that the device category is less informative than the wavelength and the delivered dose.(13,25) Clinicians who choose to apply photobiomodulation should document the wavelength, energy density, application points and frequency precisely, because these are the variables that future meta-analyses will need to isolate.(37) The safety profile is reassuring: none of the included trials reported damage to the periodontium, and separate reviews found no increase in root resorption with photobiomodulation, with one trial reporting a reduction.(41,42) The trial by Eid and colleagues likewise found the acceleration accompanied by raised interleukin-1 beta without adverse tissue effects, and reviews of root resorption reach the same conclusion, which addresses the main biological concern a clinician would have about accelerating tooth movement.(22,41) Longer follow-up is still needed to exclude late effects that the short windows of these trials could not capture. What remains open is whether the acceleration persists beyond the initial weeks, whether it shortens total treatment time rather than only the measured phase, whether a near-infrared light-emitting diode can re-

plicate the laser effect at lower cost, and whether a single standardized protocol reproduces the effect across centers.(4,16,17,35,36,39,40) Answering these questions will determine whether the acceleratory signal observed here is a genuine clinical gain or only a laboratory and short-window phenomenon, and the trials needed to settle them are now clearly defined.

Future trials should be prospectively registered, use sham irradiation in both arms, blind the outcome assessor, and report the rate as millimeters per week or month with standard deviations for both arms so that a random-effects meta-analysis becomes possible. The parameters should be selected from the effective range identified here, near-infrared wavelengths between roughly 800 and 980 nm, and the schedule should be standardized while a second arm varies one parameter at a time. Because the daily intraoral light-emitting diode produced the largest relative effect, a three-arm trial comparing a near-infrared laser, a near-infrared diode and sham would isolate the role of the device at a constant wavelength.(25,37) Reporting should include the total treatment time to a defined endpoint, not only the rate of a single phase.(4)

Cost and workflow also condition adoption. A near-infrared laser requires a capital investment and chair time for each application, whereas the daily intraoral light-emitting diode was used by the patient at home and yet produced the largest relative gain in this review, which suggests that patient-administered devices deserve specific attention in future trials.(25) The application schedule ranged from daily to every three weeks, and the finding by Eid and colleagues that a low-frequency schedule performed as well as a high-frequency one, if replicated, would make treatment more feasible.(22) None of the included trials measured whether the acceleration carried through to a shorter total treatment duration, so the clinically relevant endpoint remains unproven, and trials that report only the rate of a single phase risk overstating the benefit to patients.(4)

CONCLUSIONS

The evidence indicates that photobiomodulation with low-level laser or light-emitting diode light accelerates orthodontic tooth movement in most controlled trials in patients with fixed appliances, particularly in the red and near-infrared range.

The effect appears to depend on wavelength and irradiation protocol more than on the light source itself, but the available reports do not allow a single optimal parameter set to be identified.

Confidence in these findings is limited by the risk of bias of the included trials, small samples, heterogeneous outcome measures and the absence of a pooled quantitative estimate, and this should be addressed by prospectively registered, sham-controlled and adequately powered trials with standardized outcomes.

REFERENCES

1. El-Angbawi A, McIntyre G, Fleming PS, Bearn D. Non-surgical adjunctive interventions for accelerating tooth movement in patients undergoing orthodontic treatment. *Cochrane Database Syst Rev*. 2023;2023(6):CD010887. doi: 10.1002/14651858.cd010887.pub3
2. Segal G, Schiffman P, Tuncay O. Meta analysis of the treatment-related factors of external apical root resorption. *Orthod Craniofac Res*. 2004;7(2):71-78. doi: 10.1111/j.1601-6343.2004.00286.x
3. Kacprzak A, Strzecki A. Methods of accelerating orthodontic tooth movement: A review of contemporary literature. *Dent Med Probl*. 2018;55(2):197-206. doi: 10.17219/dmp/90989
4. Yi J, Xiao J, Li H, Li Y, Li X, Zhao Z. Effectiveness of adjunctive interventions for accelerating orthodontic tooth movement: a systematic review of systematic reviews. *J of Oral Rehabilitation*. 2017;44(8):636-654. doi: 10.1111/joor.12509
5. Krishnan V, Davidovitch Z. Cellular, molecular, and tissue-level reactions to orthodontic force. *American Journal of Orthodontics and Dentofacial Orthopedics*. 2006;129(4):469.e1-469.e32. doi: 10.1016/j.ajodo.2005.10.007
6. Yamaguchi M, Fukasawa S. Is Inflammation a Friend or Foe for Orthodontic Treatment?: Inflammation in Orthodontically Induced Inflammatory Root Resorption and Accelerating Tooth Movement. *IJMS*. 2021;22(5):2388. doi: 10.3390/ijms22052388
7. Karu TI. Mitochondrial Signaling in Mammalian Cells Activated by Red and Near-IR Radiation. *Photochem & Photobiology*. 2008;84(5):1091-1099. doi: 10.1111/j.1751-1097.2008.00394.x
8. R Hamblin M, 1 Wellman Center for Photomedicine, Massachusetts General Hospital, BAR414, 40 Blossom Street, Boston, MA 02114, USA, 2 Department of Dermatology, Harvard Medical School, Boston, MA 02115, USA, 3 Harvard-MIT Division of Health Sciences and Technology, Cambridge, MA 02139, USA. Mechanisms and applications of the anti-inflammatory effects of photobiomodulation. *AIMS Biophysics*. 2017;4(3):337-361. doi: 10.3934/biophy.2017.3.337
9. Sonesson M, De Geer E, Subraian J, Petrén S. Efficacy of low-level laser therapy in accelerating tooth movement, preventing relapse and managing acute pain during orthodontic treatment in humans: a systematic review. *BMC Oral Health*. 2017;17(1):11. doi: 10.1186/s12903-016-0242-8
10. Bakdach WMM, Hadad R. Effectiveness of low-level laser therapy in accelerating the orthodontic tooth movement: A systematic review and meta-analysis. *Dent Med Probl*. 2020;57(1):73-94. doi: 10.17219/dmp/112446
11. Grajales M, Ríos-Osorio N, Jimenez-Peña O, Mendez-Sanchez J, Sanchez-Fajardo K, García-Perdomo HA. 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. *Lasers Med Sci*. 2023;38(1):200. doi: 10.1007/s10103-023-03870-7
12. Huang T, Wang Z, Li J. Efficiency of photobiomodulation on accelerating the tooth movement in the alignment phase of orthodontic treatment—A systematic review and meta-analysis. *Heliyon*. 2023;9(2):e13220. doi: 10.1016/j.heliyon.2023.e13220
13. Cronshaw M, Parker S, Anagnostaki E, Mylona V, Lynch E, Grootveld M. Photobiomodulation Dose Parameters in Dentistry: A Systematic Review and Meta-Analysis. *Dentistry Journal*. 2020;8(4):114. doi: 10.3390/dj8040114
14. Domínguez Camacho A, Montoya Guzmán D, Velásquez Cujar SA. Effective Wavelength Range in Photobiomodulation for Tooth Movement Acceleration in Orthodontics: A Systematic Review. *Photobiomodulation, Photomedicine, and Laser Surgery*. 2020;38(10):581-590. doi: 10.1089/photob.2020.4814
15. Cronshaw M, Parker S, Anagnostaki E, Lynch E. Systematic Review of Orthodontic Treatment Management with Photobiomodulation Therapy. *Photobiomodulation, Photomedicine, and Laser Surgery*. 2019;37(12):862-868. doi: 10.1089/photob.2019.4702
16. Jedliński M, Romeo U, del Vecchio A, Palaia G, Galluccio G. Comparison of the Effects of Photobiomodulation with Different Lasers on Orthodontic Movement and Reduction of the Treatment Time with Fixed Appliances in Novel Scientific Reports: A Systematic Review with Meta-Analysis. *Photobiomodulation, Photomedicine, and Laser Surgery*. 2020;38(8):455-465. doi: 10.1089/photob.2019.4779
17. Yong J, Gröger S, Von Bremen J, Martins Marques M, Braun A, Chen X, et al. Photobiomodulation therapy assisted orthodontic tooth movement: potential implications, challenges, and new perspectives. *J Zhejiang Univ Sci B*. 2023;24(11):957-973. doi: 10.1631/jzus.b2200706
18. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;n71. doi: 10.1136/bmj.n71
19. Sterne JAC, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*. 2019;l4898. doi: 10.1136/bmj.l4898
20. Higgins JP, Savović J, Page MJ, Elbers RG, Sterne JA. Assessing risk of bias in a randomized trial. *Cochrane Handbook for Systematic Reviews of Interventions*. 2019:205-228. doi: 10.1002/9781119536604.ch8
21. Guyatt G, Oxman AD, Akl EA, Kunz R, Vist G, Brozek J, et al. GRADE guidelines: 1. Introduction—GRADE evidence profiles and summary of findings tables. *Journal of Clinical Epidemiology*. 2011;64(4):383-394. doi: 10.1016/j.jclinepi.2010.04.026
22. Eid FY, El-Kenany WA, Mowafy MI, El-Kalza AR, Guindi MA. A randomized controlled trial evaluating the effect of two low-level laser irradiation protocols on the rate of canine retraction. *Sci Rep*. 2022;12(1):10074. doi: 10.1038/s41598-022-14280-0
23. Pérignon B, Bandiaky ON, Fromont-Colson C, Renaudin S, Peré M, Badran Z, et al. Effect of 970 nm low-level laser therapy on orthodontic tooth movement during Class II intermaxillary elastics treatment: a RCT. *Sci Rep*. 2021;11(1):23226. doi: 10.1038/s41598-021-02610-7

24. Zheng J, Yang K. Clinical research: low-level laser therapy in accelerating orthodontic tooth movement. *BMC Oral Health*. 2021;21(1):324. doi: 10.1186/s12903-021-01684-z
25. Shaughnessy T, Kantarci A, Kau CH, Skrenes D, Skrenes S, Ma D. Intraoral photobiomodulation-induced orthodontic tooth alignment: a preliminary study. *BMC Oral Health*. 2016;16(1):3. doi: 10.1186/s12903-015-0159-7
26. Impellizzeri A, Horodyski M, Fusco R, Palaia G, Polimeni A, Romeo U, et al. Photobiomodulation Therapy on Orthodontic Movement: Analysis of Preliminary Studies with a New Protocol. *IJERPH*. 2020;17(10):3547. doi: 10.3390/ijerph17103547
27. Prathapan Santhakumari P, Varma Raja V, Joseph J, Devaraj A, John E, Oommen Thomas N. Impact of Low-Level Laser Therapy on Orthodontic Tooth Movement and Various Cytokines in Gingival Crevicular Fluid: A Split-Mouth Randomized Study. *Cureus*. 2023;15(8):e42809-e42809. doi: 10.7759/cureus.42809
28. Kalia A, Bobade S, Nene S, Mirdehghan N, Patil V, Khan AA. Evaluation of effectiveness of low level laser therapy in accelerating orthodontic tooth movement-An in vivo study. *IJODR*. 2023;9(1):53-62. doi: 10.18231/j.ijodr.2023.011
29. S AJ, R S, A P, Nandakumar A, Kumaran NK, A L. Evaluation Of The Effectiveness Of Combined Photobiomodulation And Piezocision On the Rate Of Orthodontic Tooth Movement. A Randomized Control Trial. *Bangladesh J Med Sci*. 2023;22(Special Issue):138-147. doi: 10.3329/bjms.v22i20.66322
30. Isola G, Matarese M, Briguglio F, Grassia V, Picciolo G, Fiorillo L, et al. Effectiveness of Low-Level Laser Therapy during Tooth Movement: A Randomized Clinical Trial. *Materials*. 2019;12(13):2187. doi: 10.3390/ma12132187
31. Viwattanatipa N. Effect of Light Emitting Diodes (LED) with 430-480 nm Wavelength Upon Tooth Movement. *BJSTR*. 2018;10(3). doi: 10.26717/bjstr.2018.10.001947
32. Yavagal CM, Matondkar SP, Yavagal PC. Efficacy of Laser Photobiomodulation in Accelerating Orthodontic Tooth Movement in Children: A Systematic Review with Meta-analysis. *Int J Clin Pediatr Dent*. 2021;14(S1):S91-S97. doi: 10.5005/jp-journals-10005-1964
33. Olmedo-Hernández OL, Mota-Rodríguez AN, Torres-Rosas R, Argueta-Figueroa L. Effect of the photobiomodulation for acceleration of the orthodontic tooth movement: a systematic review and meta-analysis. *Lasers Med Sci*. 2022;37(5):2323-2341. doi: 10.1007/s10103-022-03538-8
34. AlShahrani I, Togoo RA, Hosmani J, Alhaizaey A. Photobiomodulation in acceleration of orthodontic tooth movement: A systematic review and meta analysis. *Complementary Therapies in Medicine*. 2019;47:102220. doi: 10.1016/j.ctim.2019.102220
35. Faculty of Dentistry, Universidad de la Frontera, Temuco, Chile., Deana NF, Alves N, Center of Excellence in Surgical and Morphological Research (CEMyQ), Faculty of Medicine, Universidad de la Frontera, Temuco, Chile., Applied Morphology Research Center (CIMA), Faculty of Dentistry, Universidad de la Frontera, Temuco, Chile., Sandoval P, et al. Effectiveness of photobiomodulation therapy in accelerating orthodontic tooth movement: a meta-analysis of randomized clinical trials. *J Oral Res*. 2020;8(5):416-432. doi: 10.17126/joralres.2019.057
36. Li J, Ge X, Guan H, Jia L, Chang W, Ma W. The Effectiveness of Photobiomodulation on Accelerating Tooth Movement in Orthodontics: A Systematic Review and Meta-Analysis. *Photobiomodulation, Photomedicine, and Laser Surgery*. 2021;39(4):232-244. doi: 10.1089/photob.2020.4954
37. Chintavalakorn R, Saengfai NN, Sipiyaruk K. The Protocol of Low-level Laser Therapy in Orthodontic Practice. *J Int Soc Prev Community Dent*. 2022;12(3):267-286. doi: 10.4103/jispcd.jispcd_328_21
38. Reis CLB, de Souza Furtado TC, Mendes WD, Matsumoto MAN, Alves SYF, Stuaní MBS, et al. Photobiomodulation impacts the levels of inflammatory mediators during orthodontic tooth movement? A systematic review with meta-analysis. *Lasers Med Sci*. 2022;37(2):771-787. doi: 10.1007/s10103-021-03425-8
39. Wang X, Liu Q, Peng J, Song W, Zhao J, Chen L. The Effects and Mechanisms of PBM Therapy in Accelerating Orthodontic Tooth Movement. *Biomolecules*. 2023;13(7):1140. doi: 10.3390/biom13071140
40. Kim SJ, Chou MY, Park YG. Effect of low-level laser on the rate of tooth movement. *Seminars in Orthodontics*. 2015;21(3):210-218. doi: 10.1053/j.sodo.2015.06.008
41. Nayyar N, Tripathi T, Ganesh G, Rai P. Impact of photobiomodulation on external root resorption during orthodontic tooth movement in humans – A systematic review and meta-analysis. *Journal of Oral Biology and Craniofacial Research*. 2022;12(4):469-480. doi: 10.1016/j.jobcr.2022.05.014
42. Sambevski J, Papadopoulou AK, Foley M, Dalci K, Petocz P, Darendeliler MA, et al. Physical properties of root cementum: Part 29. The effects of LED-mediated photobiomodulation on orthodontically induced root resorption and pain: a pilot split-mouth randomized controlled trial. *Eur J Orthod*. 2022;44(6):650-658. doi: 10.1093/ejo/cjac022

FUNDING

No financing

CONFLICT OF INTEREST

None

AUTHORSHIP CONTRIBUTIONS

Drafting – original draft: Marta María Capote Fernández.

Writing–review and editing: Marta María Capote Fernández.