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Systematic Review

Low-Level Light Therapy in Orthodontic Treatment: A Systematic Review

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Abstract: This current review aims to provide an overview of the most recent research from the last 10 years on the potential of low-level light therapy (LLLT) in the orthodontic field, particularly focusing on studies about tooth movement, root resorption, pain perception during treatment, and the stability of orthodontic miniscrews. "Low-level laser," "orthodontic," and "LLLT" were the search terms utilized on the databases Scopus, Web of Science, and PubMed, and the Boolean operator "AND" was utilized. Of the 974 studies found, 41 publications related to our topic were included in this review. Many authors agree that LLLT could trigger an enhanced biological reaction next to the tooth in the periodontium, promoting osteoblast proliferation and differentiation, while it could also have a positive impact on bone regeneration and on increasing the rate of tooth movement, enhancing the stability of miniscrews and minimizing the occurrence of root resorption. Regarding pain management during treatment studies, the results have been controversial. Conclusions: even though further studies are still needed, the use of LLLT can improve both clinical results and patient comfort during treatment by reducing treatment duration, improving clinical aspects, such as miniscrew stability, and minimizing root resorption. Further investigations are needed to assess whether LLLT offers any real benefits regarding pain relief.

Keywords: low-level laser therapy (LLLT); orthodontic; tooth movement

Citation: Inchingolo, F.; Inchingolo, A.M.; Latini, G.; Del Vecchio, G.; Trilli, I.; Ferrante, L.; Dipalma, G.; Palermo, A.; Inchingolo, A.D. Low-Level Light Therapy in Orthodontic Treatment: A Systematic Review. *Appl. Sci.* **2023**, *13*, 10393. https://doi.org/10.3390/app131810393

Academic Editor: Bruno Chrcanovic

Received: 28 August 2023
Revised: 13 September 2023
Accepted: 14 September 2023
Published: 17 September 2023

1. Introduction

LLLT in dentistry makes different dental procedures more comfortable for the patient since it is a potential alternative to some standard devices and techniques, such as local anesthesia, scalpels, and drills [1]. LLLT is a "cold light" therapy because it maintains a constant temperature throughout the procedure, which is in contrast to others that are utilized for thermal coagulation or tissue cutting and involve increasing the temperature in tissues [2,3]. Regarding the biomolecular pathway of action, LLLT employs a photochemical mechanism in which energy is transferred to intracellular mitochondrial chromophores, i.e., light-absorbing molecules, such as endogenous porphyrins and respiratory chain components such as cytochrome-C oxidase, which are capable of transferring absorbed laser energy to the mitochondria; at this level, laser energy is converted into metabolic energy via the respiratory chain with the production of adenosine triphosphate (ATP) [4,5]. The mitochondrial respiratory chains act as the main photoreceptors for LLLT at wavelengths in the visible spectrum, whereas the calcium channels at the cell membrane level serve as the key photoreceptors for LLLT at wavelengths in the infrared spectrum [6,7]. The short-term activation of the respiratory chain and oxidation of nicotinamide adenine dinucleotide (NADH) brought on by the respiratory chain's absorption of light results in modifications to the mitochondrial and cytoplasmic redox states. The electron transport chain becomes active and causes the cytoplasm to become more alkaline, the electrical potential of the mitochondrial membrane to increase, the reserve of ATP to increase, and then the synthesis of nucleic acids to begin [8,9].

LLLT activates cells through two mechanisms:

1. A direct mechanism through photobiological action (respiratory chain), where intracellular signaling is activated in redox chains (ATP increase);
2. An indirect mechanism of the activation of cells via secondary messengers released by the activated cells directly [10].

Past results have demonstrated great LLLT compliance, no invasiveness, no traumatic side effects, and no collateral impacts [11,12]. These numerous advantages have made it possible to intervene in a safer and easier way, especially in patients with special needs and in small children [13]. Therefore, over recent decades, the results of LLLT have been studied in many branches of dentistry. For example, it can be used to alleviate the painful sensation caused by the needle insertion of needed anesthesia [14] or to disinfect carious lesions or root canals during ongoing devitalization through photoactivation [15], and it may also be useful in the treatment of sore mouth syndrome, although this has yet to be demonstrated with large-scale clinical trials [16]. Thanks to its effect on osteoblast proliferation and bone formation, its ability to interact selectively with the mouth cavity's tissues, its healing effect, and its biostimulating effect favoring the healing process, the dental laser is particularly suitable for surgery/implantology [9,17]. In recent years, it has also gained popularity in the orthodontic branch, particularly for tooth movement, root resorption, pain perception during treatment, and the stability of orthodontic miniscrews.

Orthodontics has grown considerably in recent decades due to the development of extremely high-performance alloy wires and low-friction brackets. However, for most patients undergoing orthodontic treatment, pain persists as a common problem, particularly in the first 3 to 4 days after fixed orthodontic appliances have been fitted [18,19]. It is clear that this suggested symptom could reduce patients' compliance [20] or discourage them from treatment [21]. Moreover, the average time for orthodontic treatment varies considerably from case to case, ranging from 12 to 24/36 months. The mechanical pressures used in orthodontic therapy encourage alveolar bone remodeling and consequent tooth movement, the acceleration of which is desirable, obviously within a framework of biocompatibility that does not involve damage to the tooth and supporting tissues, in order to precisely reduce the time of the therapy in question.

In this regard, due to its anti-inflammatory, analgesic, and biostimulatory effects on the tooth and periodontium, the use of LLLT has an impact on the results of orthodontic therapy [22]. Several studies have investigated whether LLLT can promote the epithelialization of the treated tissues, accelerate bone remodeling at the extraction site, improve (accelerate) tooth movement in orthodontics, promote collagen formation, including through the breakdown of pro-inflammatory cascades with analgesic/anti-inflammatory effects [5,6] and, finally, minimize pain [18,19].

In this review, we address current knowledge of the application and use of orthodontic LLLT, with a focus on studies reporting contradictory results, in an attempt to outline future perspectives and pathways.

Limitations of LLLT

Low-level light therapy (LLLT) is a promising technique, but it has some limitations:

1. Variable effectiveness: it varies depending on the individual, the correct application, and the choice of light parameters;
2. Results are not immediate: it often takes many operating sessions before you see significant results;
3. Depth limitations: LLLT is effective primarily in treating superficial conditions, but it has limitations in deep tissue penetration;

4. Risk of misuse: excessive or improper use of lasers can cause tissue damage, so they should be administered by experienced operators;
5. Cost and affordability: some laser equipment can be expensive and not always affordable for everyone;
6. Ongoing research: despite promising results, some applications of LLLT require further research to confirm long-term efficacy and safety.

LLLT is a complementary therapy that may be beneficial for some conditions but should be used with care and under the supervision of experienced healthcare professionals [23,24].

2. Materials and Methods

2.1. Protocol and Registration

This systematic review was conducted by the standards of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 statement [25]. The review protocol was registered at PROSPERO under the unique number 461827.

2.2. Search Processing

LLLT and **Orthodontic** were the search terms utilized on the databases (Scopus, Web of Science, and PubMed) to select the papers under evaluation, with the Boolean operator "AND." The search was restricted to just items released in English during the previous ten years (March 2013–March 2023) (Table 1).

Table 1. Database search indicators.

Article screening strategy	Database: Scopus, Web of Science, and PubMed Keywords: A: "**Low-Level Laser Therapy**;" B: "**Orthodontic**" Boolean variable: "AND" Timespan: 2013–2023 Language: English

2.3. Eligibility Criteria

The reviewers, who worked in pairs, chose works that satisfied the following criteria for inclusion: (1) human subjects-only research, (2) clinical studies or case reports, and (3) research conducted on people receiving LLLT during orthodontic treatment.

Exclusion criteria were (1) in vitro studies, (2) animal studies, and (3) systematic reviews, narrative reviews, and meta-analyses. Duplicate studies were removed manually.

The review was conducted using the PICO criteria:

− Population: adults and children, both male and female, who received LLLT treatment;
− Intervention: LLLT during orthodontics;
− Comparison: orthodontics without LLLT;
− Outcome: effectiveness of the LLLT in orthodontic treatment, in particular regarding tooth movement, root resorption, and pain perception during treatment and the stability of orthodontic miniscrews.

2.4. Data Processing

The screening procedure, which was carried out by reading the article titles and abstracts chosen in the earlier identification step, allowed for the exclusion of any publications that varied from the themes looked at.

The complete text of publications that had been determined to match the predetermined inclusion criteria was then read.

Reviewer disagreements on the choice of the article were discussed and settled.

Quality Assessment

The quality of the included papers was assessed by two reviewers, RF and EI, using the reputable Cochrane risk-of-bias assessment for randomized trials (RoB 2). The following six areas of possible bias are evaluated by this tool: random sequence generation, allocation concealment, participant and staff blinding, outcome assessment blinding, inadequate outcome data, and selective reporting. A third reviewer (FI) was consulted in the event of a disagreement until an agreement was reached.

3. Results

Keyword searches of the Web of Science (264), Scopus (355), and PubMed (362) databases yielded a total of 981 articles. The subsequent elimination of duplicates (391) resulted in the inclusion of 590 articles. Of these 590 studies, 555 were excluded because they deviated from the previously defined inclusion criteria. The screening phase ended with the selection of 35 publications for this work (Figure 1). The results of each study are reported in Table 2.

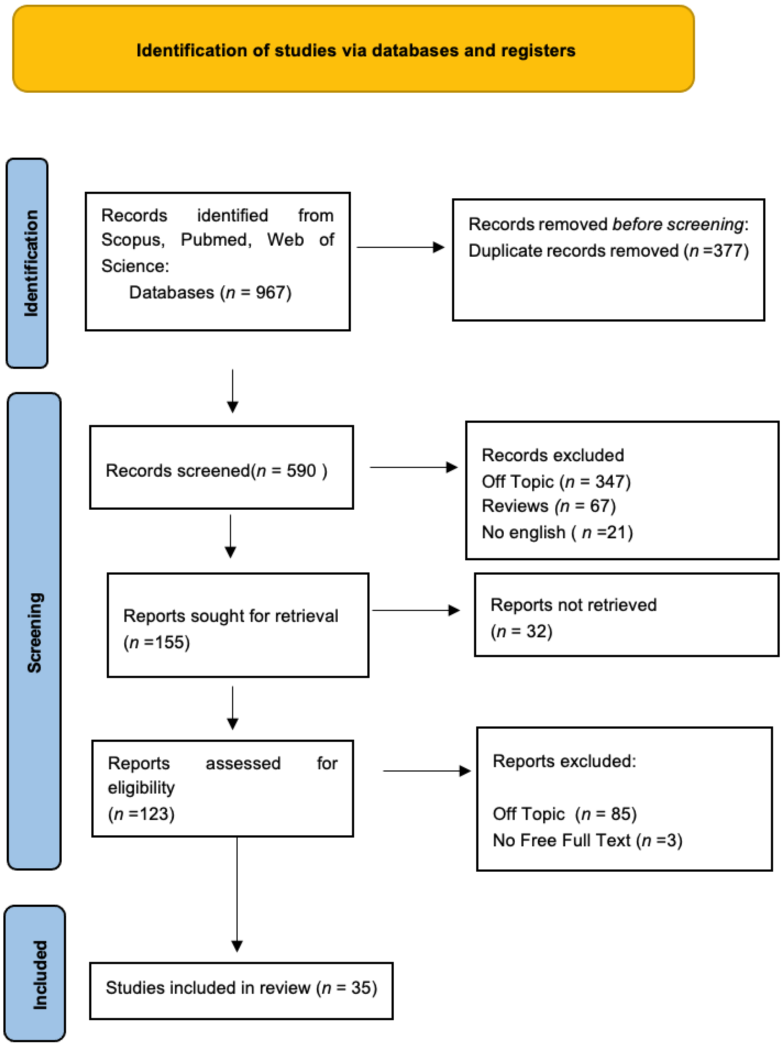

Figure 1. PRISMA flowchart diagram of the inclusion process. The literature search's preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram.

Quality Assessment and Risk of Bias

The risk of bias in the included studies is reported in Figure 2. Regarding the randomization process, 50% of studies present a high risk of bias and allocation concealment. All other studies ensure a low risk of bias. In total, 75% of studies exclude a performance; half of the studies confirm an increased risk of detection bias (self-reported outcome), and 75% of the included studies present a low detection bias (objective measures) (Figure 2). A total of 75% of studies ensure a low risk regarding attrition and reporting bias.

Table 2. Characteristics of the studies included in the analysis.

Authors (Year)	Type of Study	Aim of the Study	Materials	Results
Abdullah Ekizer et al. (2016) [26].	A randomized controlled clinical trial (RCT)	Evaluating the effects of photobiomodulation therapy (LPT) using light-emitting diodes on the stability of MI, the speed of orthodontic teeth movement, and the levels of interleukin-1 in the genito-peri-implantitis fluid.	In 20 patients who had undergone maxillary first premolar extraction, maxillary MIs were placed bilaterally. LPT was applied for 21 consecutive days (20 min per day) on the canines to be retracted on the test side.	LPT accelerated orthodontic tooth movement and improved MI stability.
Adriana Monea et al. (2015) [27].	RCT	Determining LLLT combined with mechanical forces increased the speed of tooth movement in orthodontic treatment.	The research involved 10 young adults who needed to have their maxillary canines retracted into places where their first premolars would be extracted. On the canine's test side, LLLT was buccally administered for 10 days. On the placebo site, a fake application was made.	When compared to the control, all individuals had a substantial acceleration of the canine retraction on the side treated with LLLT.
Alissa Maria Varella et al. (2018) [28].	RCT	Assess how lLLLT affected gingival crevicular fluid interleukin-1 (IL-1) levels and their relationship to tooth mobility during orthodontic treatment.	A force of 150 g was used to distalize the experimental and control canines using nickel–titanium closed-coil springs. Five time points for LLLT were used to collect gingival crevicular fluid from the control and experimental sides.	The use of low-level light treatment enhanced the levels of IL-1 in gingival crevicular fluid and sped up orthodontic tooth movement when combined with light orthodontic force.
Amer R Nasser et al. (2023) [11].	RCT	LLLT is applied in a case of upper incisor intrusion with the aim of reducing the root resorption inevitable in the specific type of malocclusion.	Mini-implants with an intrusive force of 40 g with a coil spring were applied. A low-level 808 nm laser was used in continuous mode, 4J7 point for 16 s in the third, seventh, and 14th of the first month. The second month is every 15 days. In the control group, the spring was adjusted every four weeks.	The results were significantly better for the groups with LLLt therapies than the control groups.
Bénédicte Pérignon et al. (2021) [29].	RCT	Evaluate the impact of the LLT on the movement of the teeth during treatment with Class II intermuscular elastics.	Forty-two patients with Class II malocclusions, whose mascellar quadrants were divided into two groups: active laser treatment and placebo group.	LLLT (970 nm) has not decreased the time required to achieve Class I occlusion, although it has been shown that dental movement in the exposed group has accelerated significantly.
Beren Özsoy et al. (2023) [30].	Single-blind, RCT	Examine, throughout a 12-week observation period, the impact of LLLT on orthodontic mobility during maxillary molar distalization.	A total of 16 different points on the first and second molars were treated with light therapy for 10 s at a time.	Although the LLLT has statistically significant results in terms of accelerating dental movement, the effect of the LLLT has not been clinically significant.

Table 2. *Cont.*

Authors (Year)	Type of Study	Aim of the Study	Materials	Results
Carmelo Nicotra et al. (2020) [31].	A clinical study	Use of LLLT to reduce pain after application of orthodontic bands between treated, placebo, and control groups. Pain assessment was performed with a numerical rating scale (NRS).	Three groups were randomly evaluated to receive light therapy, a placebo effect, and a control group. LLLT was performed with an AlGaAs diode laser with irradiation at 980 nm continuous wave 1 W, density 1 J/cm^{2,} and was conducted three times at an interval of 10 s.	The pain measured in the treated group was significantly lower than in the two placebo and control groups, which between them reported no difference according to the comparison tests.
Dipika Mistry et al. (2020) [32].	Triple-blind, split-mouth, RCT	Study the impact of LLLT on the degree of canine mascellar distalization after 12 weeks of four-week applications.	After the exclusions and the leveling alignment, the dogs were brought back using spiral-shaped nickel–titanium alloys that could exert 150 g of force. The LLLT was used at eight intraoral points around the canine’s neck for 10 s each, on the vestibular and dental planes.	Application of LLLT every four weeks has not resulted in differences in the amount of dental movement, loss of courage, or canine rotation during the closing of the skeletal space.
Doreen Ng et al. (2018) [12].	RCT	Evaluation of the effect of LLLT on root resorption after application of orthodontic forces.	The study was performed with the application of AlGaAs diode laser with wavelength 808 for 9 s continuous and 4.5 pulsed. The measurement was performed on 40 premolars.	Patients treated with LLLT presented less total root resorption than the placebo group, with no difference between the pulsed and continuous.
Farah Y. Eid et al. (2022) [33].	RCT	Evaluating the impact of two PBM protocols, one of which requires more frequent application every two weeks and the other of which requires less frequent application every three weeks.	This study had participation from 20 patients. The first premolar had to be therapeutically removed. Two groups were created. Group A received PBM in an arbitrary manner on days 0, 3, 7, 14, and successively every two weeks, whereas group B was randomly chosen to obtain PBM every three weeks.	There were no discernible differences in the amounts of OIIRR between the laser and control groups in either group A or B. Furthermore, no significant differences between the laser latitudes in the two groups have been reported.
Farhad Sobouti et al. (2015) [34].	RCT	Use of LLLT with neon helium laser (He-Ne) as an analgesic treatment.	Split-mouth, single-blind placebo-controlled RCT with VAS assessment of pain. Variations in pain were analyzed by ANOVA test.	Through ANOVA, reductions in pain values were found in the groups of patients treated.
Fazal Shahid et al. (2023) [35].	RCT	Highlighting the properties of LLLT on root resorption in orthodontic treatments.	Study performed with application of LLLT with orthodontic forces on self-ligating brackets. Four groups were formed: two with light therapy and self-bonding and two with brackets only. Quantitative measurements were performed with CBCT.	The Mann–Whitney test compared the different groups and found no notable differences in root resorption except for the left lateral incisor.

Table 2. *Cont.*

Authors (Year)	Type of Study	Aim of the Study	Materials	Results
Gada Nimeri et al. (2019) [36].	A clinical trial	Evaluate the capabilities of photobiomodulation associated with orthodontic movements with measurements using CBCT.	The device used was a laser with a wavelength of 850 nm and an intensity of 60 nW/cm continuous light emission. Morphological changes were measured with CBCT before treatment and after the alignment phase.	Photobiomodulation caused resorption similar to treatments without therapy.
Gaetano Isola et al. (2019) [37].	A randomized clinical trial	The use of LLLT enhanced the levels of IL-1 in gingival crevicular fluid and sped up orthodontic tooth movement when combined with light orthodontic force.	After the first few superior premolars were removed, the test side was treated with a laser diode that was focused on the palatal region on three points per side until the space was closed. The time required to finish the livelihood and closing of the space, as measured on a studio cast, was the first requirement. The secondary procedure used was the evaluation of pain thresholds related to tooth traction.	The use of LLLT has been successful in promoting tooth movement and reducing pain levels associated with OTM.
Ghizlane Genc et al. (2013) [38].	RCT	Evaluate the effects of LLLT on the speed of orthodontic dental movement and the levels of nitric oxide in the genito-crevice fluid (GCF) during orthodontic treatment.	The camp was made up of 20 soldiers; among them were the first maxilla premolars and distalized canines. When the lateral mascellar incisor retractions were anticipated, a diode laser was used. The studio group was made up of the left-side lateral maxillaries, while the right-side lateral maxillaries served as the control.	There have not been statistically significant changes in the levels of nitric oxide in the genito-crevice fluid during orthodontic treatment, although the use of LLLT has significantly accelerated the movement of orthodontic teeth.
Gianluigi Caccianiga et al. (2017) [39].	RCT	Analyze if LLLT improves the effectiveness of dental or orthodontic alignment.	Thirty-six subjects were included in this pilot interventional study and were assigned to receive treatment with hand-held devices and LLLT (test group) or only hand-held devices (control group). Utilizing a diode laser, a single manual LLT administration was performed for an intraoral route.	In comparison to the control group (284.1 days), the test group's treatment time for allineation was significantly shorter (p 0.001).
Guido A. Marañón-Vásquez et al. (2019) [40].	A clinical study	Evaluating the impact of PBM on the stability and positioning of MI's that are being treated.	IMs were assigned according to the intervention. PBM therapy was used immediately after implantation and at the following appointments every 48–72 h for two weeks.	PBM made it possible to decrease the risk of loss of stability of MIs.

Table 2. *Cont.*

Authors (Year)	Type of Study	Aim of the Study	Materials	Results
Gunet Guram et al. (2018) [41].	RCT	Evaluate the impact of the LLLT on the length of the orthodontic dental movement (OTM) and pain perception.	Twenty orthodontic patients that require bilateral canine retraction. The amount of time required for canine LLLT retraction relative to the control region on the same patient (Group A) was calculated together with the patient's pain level using the scale of facial pain.	LLLT can reduce OTM's fixed times and the pain experience.
Jacek Matys et al. (2020) [42].	A split-mouth study	Evaluate the effect of photobiomodulation (PBM) on orthodontic MIs	MIs were inserted into the maxillary upper jaw in the laser group. Irradiation was performed buccally and palatally relative to the maxillary crest with 808 nm diode lasers immediately at 3, 6, 9, 12, 15, and 30 days after MI insertion.	Laser reported no significant differences in pain but increased the secondary stability of MIs.
Junyi Zheng et al. (2021) [43].	Clinical research	Investigate the effects on orthodontic movement and its relationship to interleukin-1 (IL-1) levels.	Twelve patients undergoing tooth extractions were exposed to radiation treatments on one side using a diode laser. After tracing the canine retraction forces, the laser treatment was applied at various times. The GCF concentrations of IL-1 were examined. Each patient's upper arch has been examined using an intraoral scanner to assess the movement of their teeth.	With the adjustments made to the parameters used in this study, LLLT could, in a certain sense, lead to changes in osseous metabolism that might speed up the movement of orthodontic teeth.
Lo Giudice A et al. (2019) [44].	RCT	Efficacy of LLLT associated with orthodontic forces and dental crowding.	Three groups of patients, LLLT, placebo, and untreated, were evaluated by assessing pain with a numerical scale from 1 to 10 at time intervals.	In the treated groups, values were much lower than in the placebo and untreated groups, with no differences according to the degree of crowding.
Luminița Lazar et al. (2022) [45].	RCT	Evaluate the analgesic and antimicrobial effect of randomized laser therapy for each patient on the right and left hemiarchate. Single-trial with placebo control.	Laser therapy was performed with a diode laser with power 1 W in a pulsed system and 980 nm wave for 20 s.	LLLT significantly reduced gingival inflammation in the treated hemiarchate while also reducing bacterial presence.
M Artes-Ribas et al. (2012) [46].	Clinical study	Evaluation of the analgesic effect of LLLT in patients with elastic separators and placebo group with pain assessment by VAS.	Elastic radiopaque separators irradiated with an 830 nm diode laser were applied to the treated and placebo groups and evaluated with controlled time periods.	The results showed that the treated groups benefited from the analgesic treatment of LLLT.

Table 2. *Cont.*

Authors (Year)	Type of Study	Aim of the Study	Materials	Results
Manoel Heitor Brito et al. (2022) [47].	Clinical study	Clinical evaluation of the analgesic efficacy of LLLT after orthodontic wire application in the first hours of application.	One group was treated with gallium-aluminum arsenide infrared laser, and one group had no treatment. Pain assessment with VAS and comparison of pain perception between groups with nonparametric Mann–Whitney.	The treated group at 6 and 48 h greatly reduced pain perception compared with the untreated group.
Merve Goymen et al. (2019) [48].	RCT	Effect of LLLT between groups treated with photobiomodulation and placebo group.	In the laser group, a force was applied on the tipping premolar of 150 gr. with GaAlAsda 810 nm laser at 8 J/cm at 0, 3, 7, 14, 21, 28 days; the second group with 850 nm laser and 20 mW/cm with 10 min per day and the third group with placebo for a total of 28 days.	At the end of the study, root resorption was lower in the laser group than in the control group.
Mohammad Khursheed Alam (2023) [49].	RCT	The primary goal of this research was to examine the effects of LLLT in cases of orthodontic malocclusion treated with fixed appliances by evaluating osseous changes with 3DCBCT before and after treatment.	Patients with malocclusions who often visited the orthodontic clinic were treated with fixed orthodontic appliances and exposed to CBCT before and after the procedure. These patients were divided into two groups: group A (LLLT) and group B (non-LLLT). The 3DCBCT-based osseous interradicular changes have been used as test parameters.	Differences across groups have been noted for the least significant parameters.
Mohammad Khursheed Alam et al. (2022) [50].	RCT	Analyze the contribution of low-level laser emission/photobiomodulation (LE/P) to root resorption measures that are quantitative (QRR).	Following fixed orthodontic treatment (FOT) of the upper arch with ectopic eye tooth/teeth [EET], LE/P was applied after each orthodontic activation with four different types of treatment interventions (TI) on the RR. Thirty-two orthodontic patients with FOT appointments were chosen and divided into four groups: LE/P + Self-ligating bracket (SLB), LE/P + Conventional bracket (CB), Non-Photobiomodulation (non-LE/P) + SLB, and non-LE/P + CB.	Further research is necessary to study the particular explanations for the increased quantity of QRR identified in EET patients following FOT treatment with the CB, non-LE/P, and non-LE/P + CB systems.

Table 2. *Cont.*

Authors (Year)	Type of Study	Aim of the Study	Materials	Results
Mohammad Moaffak A AlSayed Hasan et al. (2017) [51].	RCT	Assess the efficiency of LLLT in quickening the movement of crowded maxillary incisors during orthodontics.	Twenty-six patients with abnormalities of the superior incisive maxillary were subjected to the removal of the first two premolars. The patients were casually assigned to either the laser or control group. The laser group patients immediately received a dosage of LLL from a laser device after the first arch was inserted.	LLLT is a method that works well to speed up the orthodontic dental movement.
Mohammad Moaffak A. AlSayed Hasan et al. (2020) [52].	RCT	Evaluation of the effectiveness of LLLT in the use of orthodontic forces.	Application of randomization between the treated group and placebo group with VAS assessment of pain.	No major differences were found. Vas (18.84–13.44) mm for the LLLT group and (38.15–27.06) mm for the placebo.
Nida Nayyer et al. (2021) [53].	RCT	Comparison of patients undergoing phobiomodulation and patients not undergoing LLLT.	Forces applied to dental elements that would be extracted and irradiated with InGaAs lasers with 980 nm 100 mW at programmed time.	Results were positive, with a reduction in root resorption in the group with LLLT therapy.
Rafał Flieger et al. (2020) [54].	RCT split-mouth	Evaluate the influence of a diode laser on the stability of orthodontic MIs (mini-implants) and the level of pain after treatment.	On the right and left sides, MIs were positioned 2 mm below the mucogingival junction in the adhering gingiva between the upper first and second molars. A diode laser was used to irradiate each implant on the right side of the maxilla, while the implants on the left side served as the control group.	The stability of MIs after laser application revealed significantly greater stability than non-irradiated MIs after 3 days. No significant difference was found in the level of pain measured on both maxillary sides.
Sagar J Jivrajani et al. (2020) [55].	RCT	Understanding how LILT affects the speed at which teeth move as well as the expression of MMP-9, a well-known factor in osseous absorption in GCF.	Ten patients who required removal of the first premolar maxillary for orthodontic treatment were eliminated. It was carried out LLLT at a higher part of the maxilla for the dog's consecutive withdrawal on days one, three, five, seven, fourteen, and fifteen.	LILT speeds up the movement of the teeth. LILT also has a biostimulating effect, as seen by the rise in MMP-9 concentrations in GCF.
Tae Kim et al. (2013) [56].	RCT	Test the effect of LLLT after applying orthodontic separators with continuous frequency. Three groups were selected: treated, placebo, and untreated.	The laser used was an ALGaInP diode, wavelength 635 nm, energy 10 mJ, and output power 6 mW portable and for home use after appropriate training.	No major differences were found between the laser, placebo, and control groups. Only after the first day of force application did the laser group show a lower level of pain than placebo and control.

Table 2. *Cont.*

Authors (Year)	Type of Study	Aim of the Study	Materials	Results
W Limpanichkul et al. (2006) [57].	Double-blind, RCT	Confirm the hypothesis that mechanical forces coupled with LLLT stimulate dental and orthodontic movement speed.	Investigate the effectiveness of LLLT on 12 young adult patients. This study was designed as a double-blind, randomized clinical trial.	The energy density of LLLT at the surface level in this study was likely too low to express a stimulating or inhibiting effect on the range of motion of orthodontic teeth.
Yaman Guray et al. (2022) [58].	RCT	Assess the impact of light-based phototherapy (LPT) on canine distalization threshold.	Thirty patients in whom there was extractive space of the right and left upper first premolars were recruited (15 in the group with LPT and 15 in the control group).	Laser allowed the orthodontic movement to be accelerated by 33%.

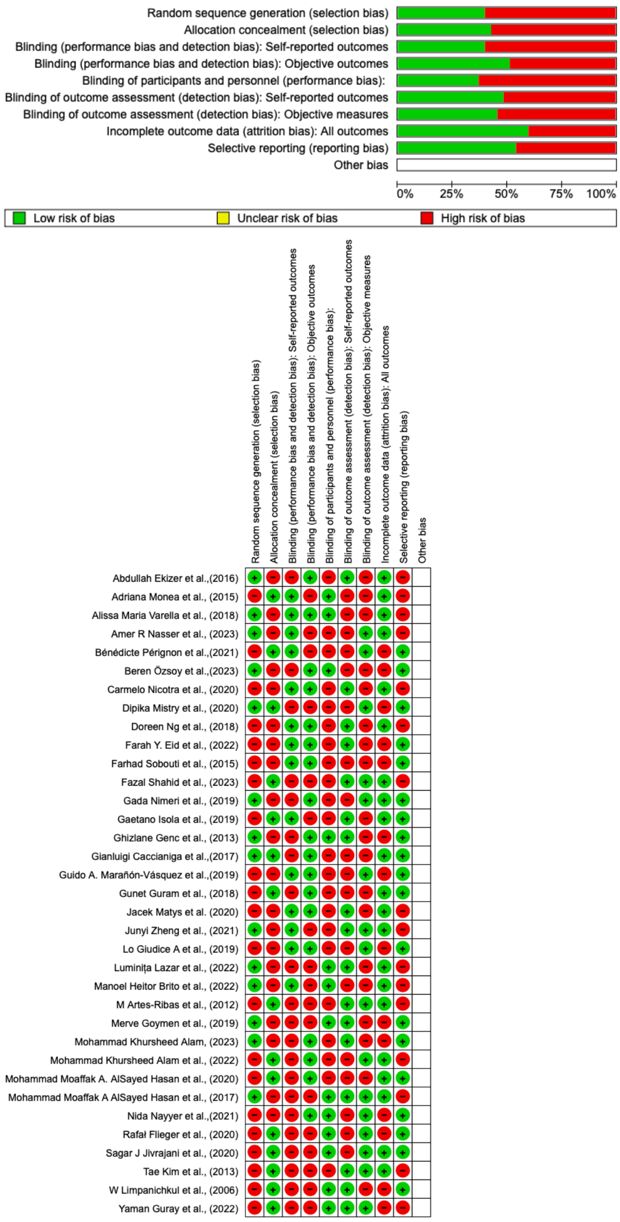

Figure 2. Risk of bias: red indicates high risk, and green indicates low risk.

4. Discussion

4.1. LLLT and Pain

The pain caused by the use of orthodontic force originates from the biological response generated by Prostaglandin E2 and Interleukin-1b acting in the gingival crevicular fluid 1 h after the application of force [44,46]. Through LLLT, an attempt is made to modulate pain without the use of drugs that can cause tissue reactions, side effects, and inhibition of root movements [44]. LLLT is performed with lasers at about 800 nm and with minimum doses of 6 joules and no more than 10 joules [47]. A high dose should be avoided because it reduces the anti-inflammatory and analgesic effects and increases the heat of the locoregional mucosal tissues [31]. The visual analog scale (VAS) is used to assess pain, which is a subjective method but the most reliable way of assessing it [46].

Analyzing the VAS values, pain increases in the first few hours and peaks within 24 h and then decreases towards day seven [45]. Hypotheses made about the action potential of LLLT are that it modulates inflammation by reducing cytokines and mRNA and COX-2 levels, alters the conduction of peripheral nerve action potentials, reduces endogenous endorphins, and has anti-nociceptive properties [45,46]. Studies can be performed between experimental and placebo groups [45]. It should be borne in mind that the perception of pain is variable and subjective. This bias occurs when the difference is compared between groups [34,52]. Environmental, anatomical, sociocultural, and genetic factors can influence studies. For this, it would be suitable to apply a split-mouth assessment method [56]. In one study, pain intensity was assessed by comparing a laser-treated hemi-arch and the contralateral hemi-arch without laser treatment. The resulting VAS reported lower pain values for the LLLT-treated hemi-arch [45].

Therefore, further investigations are needed to assess whether LLLT offers any real benefits in pain relief [59].

4.2. LLLT and Root Resorption

Root resorption (RR) can occur thanks to many factors, such as root morphology, tooth anatomy, genetic factors, therapeutic procedures, and malocclusion [35]. Several studies have shown that through LLLT, RR is reduced due to its biostimulatory and bioinhibitory benefits [12]. LLLT has an effect on the mitochondria of leucocytes and fibroblasts, increasing the production of ATP, growth factors, and reactive oxygen species (ROS) and promoting cell migration. An important role is played by RANKL and osteoprotegrins (OPG) that interact in hard tissue remodeling [48]. Morphological changes are assessed with CBCT [36]. Studies performed with high-reliability micro-CT have not shown a great difference between the groups with and without LLLT [53]. Mini-implants were used in research on intrusive movement, and LLLT verified that the groups treated with LLLT reduced both volumetric and linear root resorption by 10 to 12% [60].

4.3. LLLT and Miniscrew Stability

In a randomized clinical trial by Rafał Flieger et al. in 2020 and in a follow-up study by Jacek Matys et al. in 2020, low-level light therapy was used to assess the impact of photobiomodulation (PBM) on the stability and potential loss of mini-implants (MIs), while also assessing patients' post-treatment pain experiences. At 60 days after the end of treatment, there was significantly greater stability in the laser group than in the control groups but no significant difference in pain sensation over time [54].

The MIs were placed 2 mm below the mucogingival junction on both sides of the maxilla at the region of adherent gingiva between the second premolar and the first molar. While the implants on the left side were in the control group and therefore not exposed to laser irradiation, the MIs on the right side of the maxilla were exposed to a 635 nm diode laser with a dosage of 10 J and exposure periods of 100 s per spot [54]. Light therapy was performed at different periods during orthodontic treatment: immediately and in different periods. MI stability was also measured at the same time periods. The secondary stability was found to be much higher in the right MIs compared with the left control group. There were no appreciable differences, however, in the level of pain measured on both sides of the jaw. Therefore, it could be concluded that 635 nm diode laser irradiation increases the secondary stability of orthodontic MIs by maintaining their total stability for as long as two months of treatment [42,54].

Also, Abdullah Ekizer et al., in an RCT performed in 2016, studied the effects of light-emitting diode (LPT)-mediated photobiomodulation therapy on the stability of MI, as well as the rate of tooth movement during orthodontic treatment in cases of upper first premolar extraction, in which it was necessary, therefore, to retract the upper canines (Figure 3) [32,40,58].

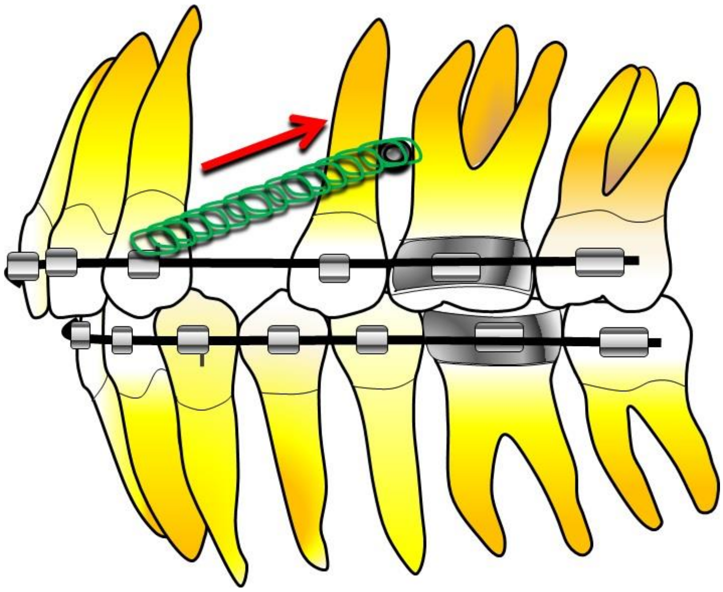

Figure 3. Stability case of MI in orthodontic treatment with extraction of the upper first premolar [40].

The primary outcome of this study was to evaluate the effect of LPT on the rate of orthodontic tooth movement. The secondary outcome was the measurement of MI stability and interleukin-1β levels in gingival and peri-implant crevicular fluid after LPT [30,40].

With a large increase in tooth movement following LPT, MI stability was dramatically increased in the LPT group in the second and third months. In conclusion, LPT might hasten tooth movement during orthodontic treatment and improve MI stability [40].

In the 2019 clinical study by Guido A. Marañón-Vásquez et al., the effect of photobiomodulation (PBM) on the stability and displacement of orthodontic MIs subjected to loading was evaluated. Cone beam computed tomography images were viewed to determine the extent of MIs' head displacement. MIs in PBM groups showed less loss of stability [58].

MIs can lose stability and be moved during loading in the various phases of orthodontic treatment, debunking the beliefs that were held until a few years ago, thinking that MIs remained stable throughout the loading period. It has been established that physiological repair processes and a consequent decrease in bone density around MIs could promote their instability over time.

The bone around the MIs may increase its density significantly only 3 months after implantation. For this reason, some authors suggest that several weeks of repair time is needed before applying loading to MIs. Although immediate loading protocols are widely recommended in clinical practice, the literature on this topic still remains unclear. It has been shown that the stability of MIs is subject to change during the repair process and that, after an initial decrease, stability values remain stable only after the fourth week. It has been suggested that photobiomodulation (PBM) can increase the stability of MIs. Non-ionizing light sources in the near-infrared and visible range are used in this therapy to encourage nonthermal biological activities on tissues [40,58].

The PBM light emissions have the potential to permeate into tissues and promote wound healing. PBM enhances the process of bone healing by promoting an increase in vascularization, control of inflammatory processes, proliferation of fibroblasts, keratinocytes, chondrocytes, and osteoblasts, as well as the production of cytokines that trigger matrix formation. As a result, this treatment has been employed to repair the midpalatal suture following fast maxillary growth and to enhance osseointegration following the installation of dental implants. The MIs' heads were exposed to laser emissions. The MI was placed, and then the diode laser was applied. The MIs' heads were exposed to laser emissions. The diode laser was used immediately after the MIs were inserted and then every 48–72 h for two weeks. The distance between the light source and the tissues was standardized with a small spacer applied to the laser tip (Figure 4) [40].

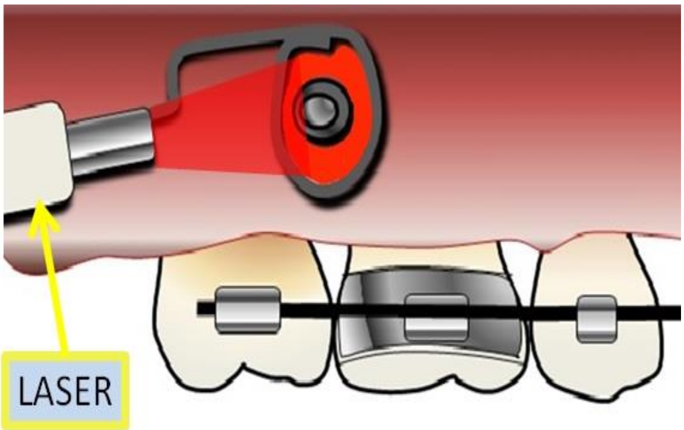

Figure 4. Laser irradiation by device adapted to laser equipment.

It has been demonstrated that LLLT inhibits mitosis during in vivo cellular division, leading to an accumulation of collagen and nucleic acids. Further research on the LLLT has been conducted in order to improve the repair and safeguarding of fractured tissues as well as the nerve revitalization processes.

The amount of energy used and the length of the laser's beam are what determine the PBM's effects at the cellular level. Some studies have examined the effects of PBM on osteoblast differentiation [42]. After a month or two, the stability of the MI has improved thanks to the use of a laser with an 808 nm wavelength on peri-implant materials. The use of a diode laser has not had any appreciable effects on the pain point. The PBM appears to have a beneficial impact on osseous implant healing.

Therefore, clinically, LLLT could be helpful to provide an adequate level of stability of the MI that serves as a scheletric restraining system in complex orthodontic treatment.

4.4. LLLT and Tooth Movement

The primary goal of orthodontic patients is to improve their dental and facial aesthetics as quickly as possible. Typically, patients anticipate a treatment period lasting no more than one year and a half. It is frequently believed that the prolonged duration of orthodontic treatments poses a risk of treatment interruption or results in the patient's unwillingness to cooperate. Long-term orthodontic treatment entails an increase in the risk of developing cancer, gingivitis, and caries [29]. Additionally, a lengthy course of treatment may have a detrimental impact on the effectiveness of the national health system as well as private research studies. Therefore, a shorter treatment duration by acceleration of dental movement has long been a source of concern for both orthodontists and patients [38,61].

The movement of the teeth during orthodontic treatment, or Orthodontic Tooth Movement (OTM), is a biological response to interference with the dentofacial structure's physiological balance as determined by an external force. When mechanical forces are applied during OTM, there is periodontal remodeling that is followed by an osseous remodeling that is classified as a biological mechanism that causes an immediate inflammatory response and an improvement in the patient's perception of pain. This might result in a significantly reduced rate of OTM and related phenomena, such as gingivitis, tooth abscesses, and radicular absorption [37,41].

It is crucial to ease tooth movement, which accelerates osseo-remodeling, in order to shorten the duration of orthodontic treatment [38,61]. To reduce the length of orthodontic therapy, minimally invasive alternative therapies and methods have been developed. Mechanical vibration, corticotomy, piezocision, as well as other pharmaceutical adjuvants have all been proposed as potential methods to speed up OTM. However, despite the fact that the majority of them were effective, their use might not be clinically justified due to their intrusive nature or potential side effects [37].

Recent studies have shown that LLLT is effective in triggering remodeling processes in oral tissues that are hydrophilic and durative by virtue of its photobiostimulatory effects. The use of LLLT during OTM has been demonstrated to be helpful and effective in speeding up dental movement. In addition, it has been shown that LLLT could prevent the release of pain-related analgesic mediators and increase cellular activity during wound healing, including an increase in collagen and elastin production. The laser's biostimulating effect is most noticeable during the cellular proliferation phase [37,41,49].

Most studies that have evaluated the impact of LLLT on the speed of dental movement have come to the conclusion that LLLT causes an increase in dental movement [49].

The biostimulating effects of LLLT on oral tissues also result from the tissue's cellular absorption of the laser's light, which triggers the activation of intracellular signal cascades that increase cellular metabolism and alter the anti-inflammatory properties of soft and hard oral tissues. It has been demonstrated that this procedure promotes, over time, a better dental movement and the formation of osteoclasts on the compression side during the experimental dental movement, determining and improving the OTM time [37,41].

Tooth crowding is believed to be the most common type of malocclusion [43,51]. The leveling and lining up of such cases may take up to 8 months. In general, one of the main reasons why patients hesitate to continue their treatment is the duration of orthodontic treatment [43].

A study by Beren Zsoy and colleagues was launched in 2023 to examine the impact of LLLT on tooth mobility during orthodontic treatment maxillary molar distalization in a 12-week period. A total of 16 different points on the first and second molars have had laser therapy applied for 10 s at a time to an arbitrary molar area (Figure 5). When compared to the contralateral control group, the amount of movement of the subjects' teeth on the applied side by the laser was much greater. In comparison to moles on the other side, those treated with the laser grew 1.22 times more in 12 weeks [30].

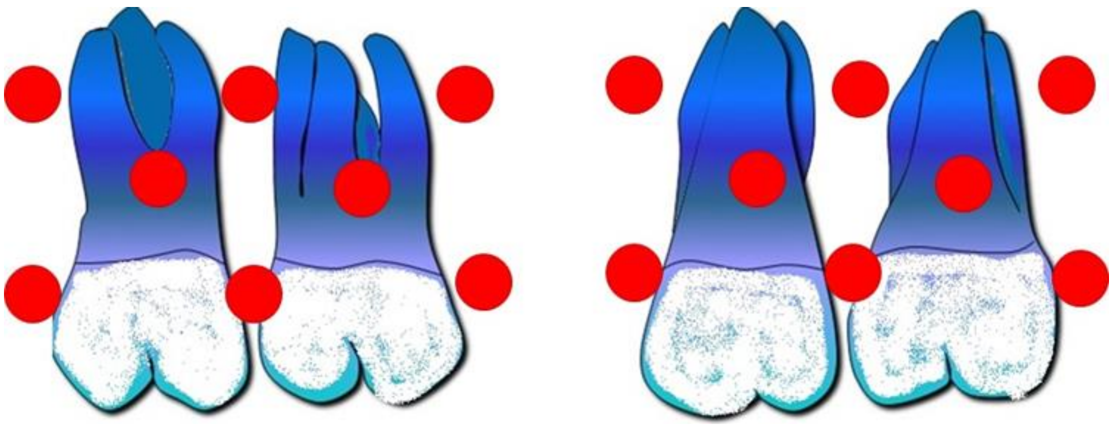

Figure 5. Laser application points on the first and second molars from the vestibular and palatal views.

Sixteen application points were used on the vestibule and palate [30].

The application of LLLT in orthodontics:

- Could accelerate orthodontic tooth movement [43];

- Could significantly increase treatment efficiency during tooth alignment [39];
- Could provide some efficacy in pain reduction during treatment [28,43,55]

Some studies show that the PBM does not affect the amount of tooth radicular inflammatory response during orthodontic treatment, regardless of whether different laser application protocols increase or decrease its presence [33,62].

LLLT significantly decreases treatment times by accelerating orthodontic alignment and gap closure by an average of 30% [63–65].

Despite the fact that the LLLT was statistically significant in terms of accelerating oral movement during orthodontic treatment, its clinical impact was not significant [30,57].

Therefore, more research is required to determine the impact of LLLT on tooth movement while paying close attention to the laser's parameters [49].

5. Conclusions

In the context of modern, minimally invasive dentistry, LLLT fits in perfectly and, thanks to its intrinsic characteristics, helps the clinician in his or her daily routine. The goal of dentistry in general, and therefore also of orthodontics, is indeed to achieve the best possible result with the best means available, but at the same time, it is also important to do so while reducing chair time and minimizing patient discomfort.

Unfortunately, some orthodontic procedures—separator placement, banding of fixed orthodontic appliances, removable or orthodontic dental braces—can also be associated in a good number of patients with discomfort and/or pain that can not only reduce patient compliance and thus confidence in the practitioner, but also in some cases, discourage them from starting or continuing with a given treatment. In this regard, LLLT has been found to be useful in modulating pain perception, although there is an underlying subjectivity inherent in the individual, as well as possible bias due to the placebo effect. It also seems to be able to minimize root resorption in a good percentage of studies, although again, factors such as the degree of initial crowding and/or long follow-up must be taken into account. PMB can help in stabilizing MIs in terms of osseointegration, just as it can be a very valuable resource in accelerating OTM.

LLLT, despite its innumerable advantages, still has some limitations, but the current literature is in agreement as to the usefulness and safety of the indications for the use of LLLT, provided that the clinician is properly trained and practiced in the use of this type of light, but it is equally certain that further randomized controlled clinical trials with a larger sample size are needed to increase the strength of the evidence on the beneficial effects of the use of low-intensity light therapy in orthodontics.

Author Contributions: Conceptualization, A.M.I., A.P., G.L., G.D.V. and G.D.; methodology L.F., G.L., A.D.I. and A.P.; software, A.M.I., G.L., F.I., I.T. and L.F.; validation, G.L., F.I., G.D.V. and A.M.I.; formal analysis, A.M.I., I.T., A.D.I., F.I. and A.P.; investigation, G.L., A.M.I. and A.P.; resources, A.D.I., A.M.I., G.L, I.T., L.F. and A.P.; data curation, G.D.V., A.D.I., G.D., G.L. and A.P.; writing—original draft preparation, A.M.I., A.D.I., I.T. and A.P.; writing—review and editing, G.L., G.D., F.I. and A.P.; visualization, G.D.V. and F.I.; supervision, A.M.I., I.T., L.F. and F.I.; project administration, G.L., G.D., L.F. and A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to acknowledge Luis Eduardo Almeida, native English speaker and associate professor at the Department of Surgical Sciences, School of Dentistry, Marquette University, Milwaukee, Wisconsin, USA, for reviewing and correcting the scientific English of the article.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

LLLT	Low-level light therapy
ATP	Adenosine triphosphate
RR	Root resorption
MI	Mini-implants
LTP	Photobiomodulation mediated by light-emitting diodes
PBM	Photobiomodulation
OTM	Orthodontic tooth movement
IL-1	Interleukin-1
VAS	Visual analogue scale
CBCT	Cone beam computed tomography
LE/P	Laser emission/photobiomodulation
RCT	Randomized clinical trial

References

1. Khumaidi, M.A.; Paturusi, I.; Nusdwinuringtyas, N.; Islam, A.A.; Gunawan, W.B.; Nurkolis, F.; Taslim, N.A. Is Low-Level Laser Therapy Effective for Patients with Knee Joint Osteoarthritis? Implications and Strategies to Promote Laser Therapy Usage. *Front. Bioeng. Biotechnol.* **2022**, *10*, 1089035. [CrossRef]
2. Chung, H.; Dai, T.; Sharma, S.K.; Huang, Y.-Y.; Carroll, J.D.; Hamblin, M.R. The Nuts and Bolts of Low-Level Laser (Light) Therapy. *Ann. Biomed. Eng.* **2012**, *40*, 516–533. [CrossRef]
3. Adina, S.; Dipalma, G.; Bordea, I.R.; Lucaciu, O.; Feurdean, C.; Inchingolo, A.D.; Septimiu, R.; Malcangi, G.; Cantore, S.; Martin, D.; et al. Orthopedic Joint Stability Influences Growth and Maxillary Development: Clinical Aspects. *J. Biol. Regul. Homeost. Agents* **2020**, *34*, 747–756. [PubMed]
4. Karu, T. Is It Time to Consider Photobiomodulation as a Drug Equivalent? *Photomed. Laser Surg.* **2013**, *31*, 189–191. [CrossRef] [PubMed]
5. Minervini, G.; Franco, R.; Marrapodi, M.M.; Crimi, S.; Badnjević, A.; Cervino, G.; Bianchi, A.; Cicciù, M. Correlation between Temporomandibular Disorders (TMD) and Posture Evaluated Trough the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD): A Systematic Review with Meta-Analysis. *J. Clin. Med.* **2023**, *12*, 2652. [CrossRef] [PubMed]
6. Smith, K.C. The Photobiological Basis of Low Level Laser Radiation Therapy. *Laser Ther.* **1991**, *3*, 19–24. [CrossRef]
7. Yu, W.; Naim, J.O.; McGowan, M.; Ippolito, K.; Lanzafame, R.J. Photomodulation of Oxidative Metabolism and Electron Chain Enzymes in Rat Liver Mitochondria. *Photochem. Photobiol.* **1997**, *66*, 866–871. [CrossRef] [PubMed]
8. Do Nascimento, P.M.; Pinheiro AL, B.; Ângelo Castilho Salgado, M.; Pedreira Ramalho, L.M. A Preliminary Report on the Effect of Laser Therapy on the Healing of Cutaneous Surgical Wounds as a Consequence of an Inversely Proportional Relationship between Wavelength and Intensity: Histological Study in Rats. *Photomed. Laser Ther.* **2004**, *22*, 513–518. [CrossRef]
9. Malcangi, G.; Patano, A.; Trilli, I.; Piras, F.; Ciocia, A.M.; Inchingolo, A.D.; Mancini, A.; Hazballa, D.; Di Venere, D.; Inchingolo, F.; et al. Therapeutic and Adverse Effects of Lasers in Dentistry: A Systematic Review. *Photonics* **2023**, *10*, 650. [CrossRef]
10. Sun, G.; Tunér, J. Low-Level Laser Therapy in Dentistry. *Dent. Clin. N. Am.* **2004**, *48*, 1061–1076. [CrossRef]
11. Cruz, D.R.; Kohara, E.K.; Ribeiro, M.S.; Wetter, N.U. Effects of Low-Intensity Laser Therapy on the Orthodontic Movement Velocity of Human Teeth: A Preliminary Study. *Lasers Surg. Med.* **2004**, *35*, 117–120. [CrossRef]
12. Ng, D.; Chan, A.K.; Papadopoulou, A.K.; Dalci, O.; Petocz, P.; Darendeliler, M.A. The Effect of Low-Level Laser Therapy on Orthodontically Induced Root Resorption: A Pilot Double Blind Randomized Controlled Trial. *Eur. J. Orthod.* **2018**, *40*, 317–325. [CrossRef] [PubMed]
13. Minervini, G.; Franco, R.; Marrapodi, M.M.; Fiorillo, L.; Cervino, G.; Cicciù, M. Prevalence of Temporomandibular Disorders (TMD) in Pregnancy: A Systematic Review with Meta-analysis. *J. Oral Rehabil.* **2023**, *50*, 627–634. [CrossRef] [PubMed]
14. Marrelli, M.; Tatullo, M.; Dipalma, G.; Inchingolo, F. Oral Infection by Staphylococcus Aureus in Patients Affected by White Sponge Nevus: A Description of Two Cases Occurred in the Same Family. *Int. J. Med. Sci.* **2012**, *9*, 47–50. [CrossRef] [PubMed]
15. Minervini, G.; Franco, R.; Marrapodi, M.M.; Ronsivalle, V.; Shapira, I.; Cicciù, M. Prevalence of Temporomandibular Disorders in Subjects Affected by Parkinson Disease: A Systematic Review and Metanalysis. *J. Oral Rehabil.* **2023**, *50*, 877–885. [CrossRef] [PubMed]
16. Reyad, A.A.; Mishriky, R.; Girgis, E. Pharmacological and Non-Pharmacological Management of Burning Mouth Syndrome: A Systematic Review. *Dent. Med. Probl.* **2020**, *57*, 295–304. [CrossRef]
17. Doshi-Mehta, G.; Bhad-Patil, W.A. Efficacy of Low-Intensity Laser Therapy in Reducing Treatment Time and Orthodontic Pain: A Clinical Investigation. *Am. J. Orthod. Dentofac. Orthop.* **2012**, *141*, 289–297. [CrossRef] [PubMed]
18. Vermesan, D.; Inchingolo, F.; Patrascu, J.M.; Trocan, I.; Prejbeanu, R.; Florescu, S.; Damian, G.; Benagiano, V.; Abbinante, A.; Caprio, M.; et al. Anterior Cruciate Ligament Reconstruction and Determination of Tunnel Size and Graft Obliquity. *Eur Rev Med Pharmacol Sci* **2015**, *19*, 357–364.
19. Ngan, P.; Kess, B.; Wilson, S. Perception of Discomfort by Patients Undergoing Orthodontic Treatment. *Am. J. Orthod. Dentofac. Orthop.* **1989**, *96*, 47–53. [CrossRef]

20. Sergl, H.G.; Klages, U.; Zentner, A. Functional and Social Discomfort during Orthodontic Treatment–Effects on Compliance and Prediction of Patients' Adaptation by Personality Variables. *Eur. J. Orthod.* **2000**, *22*, 307–315. [CrossRef]
21. Rapone, B.; Ferrara, E.; Santacroce, L.; Topi, S.; Gnoni, A.; Dipalma, G.; Mancini, A.; Di Domenico, M.; Tartaglia, G.M.; Scarano, A.; et al. The Gaseous Ozone Therapy as a Promising Antiseptic Adjuvant of Periodontal Treatment: A Randomized Controlled Clinical Trial. *Int. J. Environ. Res. Public Health* **2022**, *19*, 985. [CrossRef] [PubMed]
22. Inchingolo, A.D.; Ceci, S.; Patano, A.; Inchingolo, A.M.; Montenegro, V.; Di Pede, C.; Malcangi, G.; Marinelli, G.; Coloccia, G.; Garibaldi, M.; et al. Elastodontic Therapy of Hyperdivergent Class II Patients Using AMCOP® Devices: A Retrospective Study. *Appl. Sci.* **2022**, *12*, 3259. [CrossRef]
23. Dima, R.; Tieppo Francio, V.; Towery, C.; Davani, S. Review of Literature on Low-Level Laser Therapy Benefits for Nonpharmacological Pain Control in Chronic Pain and Osteoarthritis. *Altern. Ther. Health Med.* **2018**, *24*, 8–10.
24. Grassi, F.R.; Ciccolella, F.; D'Apolito, G.; Papa, F.; Iuso, A.; Salzo, A.E.; Trentadue, R.; Nardi, G.M.; Scivetti, M.; De Matteo, M.; et al. Effect of Low-Level Laser Irradiation on Osteoblast Proliferation and Bone Formation. *J Biol Regul Homeost Agents* **2011**, *25*, 603–614. [PubMed]
25. Liberati, A.; Altman, D.G.; Tetzlaff, J.; Mulrow, C.; Gøtzsche, P.C.; Ioannidis, J.P.A.; Clarke, M.; Devereaux, P.J.; Kleijnen, J.; Moher, D. The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions: Explanation and Elaboration. *J. Clin. Epidemiol.* **2009**, *62*, e1–e34. [CrossRef]
26. Ekizer, A.; Türker, G.; Uysal, T.; Güray, E.; Taşdemir, Z. Light Emitting Diode Mediated Photobiomodulation Therapy Improves Orthodontic Tooth Movement and Miniscrew Stability: A Randomized Controlled Clinical Trial. *Lasers Surg. Med.* **2016**, *48*, 936–943. [CrossRef]
27. Monea, A.; Monea, M.; Pop, D.; Bereşescu, G. The Effect of Low Level Laser Therapy on Orthodontic Tooth Movement. *Optoelectron. Adv. Mater.* **2015**, *9*, 286–289.
28. Varella, A.M.; Revankar, A.V.; Patil, A.K. Low-Level Laser Therapy Increases Interleukin-1β in Gingival Crevicular Fluid and Enhances the Rate of Orthodontic Tooth Movement. *Am. J. Orthod. Dentofac. Orthop.* **2018**, *154*, 535–544.e5. [CrossRef] [PubMed]
29. Pérignon, B.; Bandiaky, O.N.; Fromont-Colson, C.; Renaudin, S.; Peré, M.; Badran, Z.; Cuny-Houchmand, M.; Soueidan, A. Effect of 970 nm Low-Level Laser Therapy on Orthodontic Tooth Movement during Class II Intermaxillary Elastics Treatment: A RCT. *Sci. Rep.* **2021**, *11*, 23226. [CrossRef]
30. Özsoy, B.; Güldüren, K.; Kamiloğlu, B. Effect of Low-Level Laser Therapy on Orthodontic Tooth Movement during Miniscrew-Supported Maxillary Molar Distalization in Humans: A Single-Blind, Randomized Controlled Clinical Trial. *Lasers Med. Sci.* **2023**, *38*, 76. [CrossRef] [PubMed]
31. Nicotra, C.; Polizzi, A.; Zappalà, G.; Leonida, A.; Indelicato, F.; Caccianiga, G. A Comparative Assessment of Pain Caused by the Placement of Banded Orthodontic Appliances with and without Low-Level Laser Therapy: A Randomized Controlled Prospective Study. *Dent. J.* **2020**, *8*, 24. [CrossRef]
32. Mistry, D.; Dalci, O.; Papageorgiou, S.N.; Darendeliler, M.A.; Papadopoulou, A.K. The Effects of a Clinically Feasible Application of Low-Level Laser Therapy on the Rate of Orthodontic Tooth Movement: A Triple-Blind, Split-Mouth, Randomized Controlled Trial. *Am. J. Orthod. Dentofac. Orthop.* **2020**, *157*, 444–453. [CrossRef] [PubMed]
33. Eid, F.; El-Kenany, W.; Mowafy, M.; Elkalza, A. The Influence of Two Photobiomodulation Protocols on Orthodontically Induced Inflammatory Root Resorption (a Randomized Controlled Clinical Trial). *BMC Oral Health* **2022**, *22*, 221. [CrossRef] [PubMed]
34. Farias, R.D.; Closs, L.Q.; Miguens, S.A.Q. Evaluation of the Use of Low-Level Laser Therapy in Pain Control in Orthodontic Patients: A Randomized Split-Mouth Clinical Trial. *Angle Orthod.* **2016**, *86*, 193–198. [CrossRef] [PubMed]
35. Shahid, F.; Nowrin, S.A.; Alam, M.K.; Khamis, M.F.; Husein, A.; Rahman, N.A. Effects of Low-Level Laser Therapy and Bracket Systems on Root Resorption during Orthodontic Treatment: A Randomized Clinical Trial. *Healthcare* **2023**, *11*, 864. [CrossRef]
36. Nimeri, G.; Kau, C.H.; Corona, R.; Shelly, J. The Effect of Photobiomodulation on Root Resorption during Orthodontic Treatment. *Clin. Cosmet. Investig. Dent.* **2014**, *6*, 1–8. [CrossRef]
37. Isola, G.; Matarese, M.; Briguglio, F.; Grassia, V.; Picciolo, G.; Fiorillo, L.; Matarese, G. Effectiveness of Low-Level Laser Therapy during Tooth Movement: A Randomized Clinical Trial. *Materials* **2019**, *12*, 2187. [CrossRef]
38. Genc, G.; Kocadereli, I.; Tasar, F.; Kilinc, K.; El, S.; Sarkarati, B. Effect of Low-Level Laser Therapy (LLLT) on Orthodontic Tooth Movement. *Lasers Med. Sci.* **2013**, *28*, 41–47. [CrossRef]
39. Caccianiga, G.; Paiusco, A.; Perillo, L.; Nucera, R.; Pinsino, A.; Maddalone, M.; Cordasco, G.; Lo Giudice, A. Does Low-Level Laser Therapy Enhance the Efficiency of Orthodontic Dental Alignment? Results from a Randomized Pilot Study. *Photomed. Laser Surg.* **2017**, *35*, 421–426. [CrossRef]
40. Marañón-Vásquez, G.A.; Lagravère, M.O.; Borsatto, M.C.; de Souza, S.S.; Watanabe, P.C.A.; Matsumoto, M.A.N.; Saraiva, M.d.C.P.; Romano, F.L. Effect of Photobiomodulation on the Stability and Displacement of Orthodontic Mini-Implants Submitted to Immediate and Delayed Loading: A Clinical Study. *Lasers Med. Sci.* **2019**, *34*, 1705–1715. [CrossRef]
41. Guram, G.; Reddy, R.K.; Dharamsi, A.M.; Syed Ismail, P.M.; Mishra, S.; Prakashkumar, M.D. Evaluation of Low-Level Laser Therapy on Orthodontic Tooth Movement: A Randomized Control Study. *Contemp. Clin. Dent.* **2018**, *9*, 105–109. [CrossRef]
42. Matys, J.; Flieger, R.; Gedrange, T.; Janowicz, K.; Kempisty, B.; Grzech-Leśniak, K.; Dominiak, M. Effect of 808 nm Semiconductor Laser on the Stability of Orthodontic Micro-Implants: A Split-Mouth Study. *Materials* **2020**, *13*, 2265. [CrossRef]
43. Zheng, J.; Yang, K. Clinical Research: Low-Level Laser Therapy in Accelerating Orthodontic Tooth Movement. *BMC Oral Health* **2021**, *21*, 324. [CrossRef]

44. Lo Giudice, A.; Nucera, R.; Perillo, L.; Paiusco, A.; Caccianiga, G. Is Low-Level Laser Therapy an Effective Method to Alleviate Pain Induced by Active Orthodontic Alignment Archwire? A Randomized Clinical Trial. *J. Evid. Based Dent. Pract.* **2019**, *19*, 71–78. [CrossRef]
45. Lazăr, A.-P.; Dakó, T.; Bud, A.; Vlasa, A.; Ormenișan, A.; Mârțu, M.-A.; Păcurar, M.; Lazăr, L. The Effects of Periodontal Laser Therapy on Pain in Adult Patients with Orthodontic Treatment: A Randomized Clinical Trial. *Appl. Sci.* **2022**, *12*, 3601. [CrossRef]
46. Artés-Ribas, M.; Arnabat-Dominguez, J.; Puigdollers, A. Analgesic Effect of a Low-Level Laser Therapy (830 nm) in Early Orthodontic Treatment. *Lasers Med. Sci.* **2013**, *28*, 335–341. [CrossRef] [PubMed]
47. Brito, M.H.; Nogueira, C.Q.; Cotrin, P.; Fialho, T.; Oliveira, R.C.; Oliveira, R.G.; Salmeron, S.; Valarelli, F.P.; Freitas, K.M.S.; Cançado, R.H. Efficacy of Low-Level Laser Therapy in Reducing Pain in the Initial Stages of Orthodontic Treatment. *Int. J. Dent.* **2022**, *2022*, 3934900. [CrossRef]
48. Goymen, M.; Gulec, A. Effect of Photobiomodulation Therapies on the Root Resorption Associated with Orthodontic Forces: A Pilot Study Using Micro Computed Tomography. *Clin. Oral Investig.* **2020**, *24*, 1431–1438. [CrossRef] [PubMed]
49. Alam, M.K. Effects of Low-Level Laser Therapy on Orthodontic Tooth Movement: Evaluation of Bony Changes via 3DCBCT. *Children* **2023**, *10*, 384. [CrossRef] [PubMed]
50. Alam, M.K.; Ganji, K.K.; Alfawzan, A.A.; Manay, S.M.; Srivastava, K.C.; Chaudhari, P.K.; Hosni, H.A.; Alswairki, H.J.; Alansari, R.A. Ectopic Eye Tooth Management: Photobiomodulation/Low-Level Laser Emission Role in Root Resorption after Fixed Orthodontic Treatment. *Healthcare* **2022**, *10*, 610. [CrossRef]
51. AlSayed Hasan, M.M.A.; Sultan, K.; Hamadah, O. Low-Level Laser Therapy Effectiveness in Accelerating Orthodontic Tooth Movement: A Randomized Controlled Clinical Trial. *Angle Orthod.* **2017**, *87*, 499–504. [CrossRef]
52. AlSayed Hasan, M.M.A.; Sultan, K.; Ajaj, M.; Voborná, I.; Hamadah, O. Low-Level Laser Therapy Effectiveness in Reducing Initial Orthodontic Archwire Placement Pain in Premolars Extraction Cases: A Single-Blind, Placebo-Controlled, Randomized Clinical Trial. *BMC Oral Health* **2020**, *20*, 209. [CrossRef]
53. Nayyer, N.; Tripathi, T.; Rai, P.; Kanase, A. Effect of Photobiomodulation on External Root Resorption during Orthodontic Tooth Movement-a Randomized Controlled Trial. *Int. Orthod.* **2021**, *19*, 197–206. [CrossRef]
54. Flieger, R.; Gedrange, T.; Grzech-Leśniak, K.; Dominiak, M.; Matys, J. Low-Level Laser Therapy with a 635 nm Diode Laser Affects Orthodontic Mini-Implants Stability: A Randomized Clinical Split-Mouth Trial. *J. Clin. Med.* **2019**, *9*, 112. [CrossRef] [PubMed]
55. Jivrajani, S.J.; Bhad Patil, W.A. Effect of Low Intensity Laser Therapy (LILT) on MMP-9 Expression in Gingival Crevicular Fluid and Rate of Orthodontic Tooth Movement in Patients Undergoing Canine Retraction: A Randomized Controlled Trial. *Int. Orthod.* **2020**, *18*, 330–339. [CrossRef] [PubMed]
56. Kim, W.T.; Bayome, M.; Park, J.-B.; Park, J.H.; Baek, S.-H.; Kook, Y.-A. Effect of Frequent Laser Irradiation on Orthodontic Pain. A Single-Blind Randomized Clinical Trial. *Angle Orthod.* **2013**, *83*, 611–616. [CrossRef]
57. Limpanichkul, W.; Godfrey, K.; Srisuk, N.; Rattanayatikul, C. Effects of Low-Level Laser Therapy on the Rate of Orthodontic Tooth Movement. *Orthod. Craniofac. Res.* **2006**, *9*, 38–43. [CrossRef]
58. Güray, Y.; Yüksel, A.S. Effect of Light-Emitting Photobiomodulation Therapy on the Rate of Orthodontic Tooth Movement: A Randomized Controlled Clinical Trial. *J. Orofac. Orthop.* 2022. [CrossRef] [PubMed]
59. Minervini, G.; Franco, R.; Marrapodi, M.M.; Fiorillo, L.; Cervino, G.; Cicciù, M. Economic Inequalities and Temporomandibular Disorders: A Systematic Review with Meta-analysis. *J. Oral Rehabil.* **2023**, *50*, 715–723. [CrossRef]
60. Nasser, A.R.; Sultan, K.; Hajeer, M.Y.; Hamadah, O. Investigating the Effectiveness of Low-Level Laser in Reducing Root Resorption of the Upper Incisors during Intrusion Movement Using Mini-Implants in Adult Patients with Deep Overbite: A Randomized Controlled Clinical Trial. *Cureus* **2023**, *15*, e35381. [CrossRef]
61. Dohan Ehrenfest, D.M.; Del Corso, M.; Inchingolo, F.; Sammartino, G.; Charrier, J.-B. Platelet-Rich Plasma (PRP) and Platelet-Rich Fibrin (PRF) in Human Cell Cultures: Growth Factor Release and Contradictory Results. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endodontology* **2010**, *110*, 418–421. [CrossRef] [PubMed]
62. Qamar, Z.; Alghamdi, A.M.S.; Haydarah, N.K.B.; Balateef, A.A.; Alamoudi, A.A.; Abumismar, M.A.; Shivakumar, S.; Cicciù, M.; Minervini, G. Impact of Temporomandibular Disorders on Oral Health-related Quality of Life: A Systematic Review and Meta-analysis. *J. Oral Rehabil.* **2023**, *50*, 706–714. [CrossRef] [PubMed]
63. Youssef, M.; Ashkar, S.; Hamade, E.; Gutknecht, N.; Lampert, F.; Mir, M. The Effect of Low-Level Laser Therapy during Orthodontic Movement: A Preliminary Study. *Lasers Med. Sci.* **2008**, *23*, 27–33. [CrossRef]
64. Sousa, M.V.d.S.; Scanavini, M.A.; Sannomiya, E.K.; Velasco, L.G.; Angelieri, F. Influence of Low-Level Laser on the Speed of Orthodontic Movement. *Photomed. Laser Surg.* **2011**, *29*, 191–196. [CrossRef] [PubMed]
65. Kreisner, P.-E.; Blaya, D.-S.; Gaião, L.; Maciel-Santos, M.-E.-S.; Etges, A.; Santana-Filho, M.; de Oliveira, M.-G. Histological Evaluation of the Effect of Low-Level Laser on Distraction Osteogenesis in Rabbit Mandibles. *Med. Oral Patol. Oral Cir. Bucal* **2010**, *15*, e616–e618. [CrossRef] [PubMed]